FLORIDA KEY DEER SCREWWORM

FINAL REPORT

(PHASE I)

Prepared for:

National Key Deer Refuge

South Florida Ecological Services Field Office

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Executive Summary

The Florida Key deer (*Odocoileus virginianus clavium*) are an endangered subspecies of white-tailed deer endemic to the Lower Florida Keys. The U.S. Fish and Wildlife Service (USFWS) is tasked with managing the extant population and moving towards recovery. In July 2016, Key deer were reported to have lesions consistent with New World screwworm (*Cochliomyia hominivorax*) infestation. Entomologists subsequently confirmed the presence of New World screwworm (hereafter screwworm) in recent months. Screwworm is a threat to U.S. agricultural interests and ecological health prompting an immediate and large response. Local, state, and federal agencies mobilized efforts to stop any further expansion of screwworm in North America and to eradicate the current infestation in the Lower Florida Keys. The USFWS, U.S. Department of Agriculture (USDA), Florida Fish and Wildlife Conservation Commission (FWC), Florida Department of Agriculture and Consumer Services, Monroe County, Texas A&M Institute of Renewable Natural Resources (IRNR), and local community members have partnered to address the screwworm infestation. This multi-agency response consists of three distinct but related actions: (1) elimination of screwworm flies, (2) treatment of impacted animals and implementation of preventative strategies, (3) determination of Key deer population status and recovery strategies. These efforts are ongoing. The focus of this report is to determine Key deer population status and future recovery strategies. Synthesis of historic and newly collected data on Key deer distribution, population density, demographics, and screwworm-caused mortalities provided insight into screwworm impacts. Some key findings and recommendations from the assessment are outlined below:

<u>Key Findings</u>:

- Approximately 15% of the Key deer population were euthanized and/or died due to screwworm infections (*n*=127 deer mortalities) between July-October 2016.
- Adult males were disproportionately impacted by screwworm infestations (91%), which is attributed to injuries sustained during the breeding season increasing risk of screwworm infection.
- Screwworm mortalities have decreased (-92%) in last month following aggressive sterile fly efforts by USDA and USFWS.
- Key deer sex and age structure shifted with adult male mortalities; sex ratios (females:adult males) are slightly higher (4.12:1 current) compared to the historic average (3.76:1).
- An estimated 678 Key deer occupy Big Pine and No Name keys (core population) post-screwworm incident. An updated estimate throughout its range (all islands to include Big Pine and No Name keys) is not currently available but estimated to be approximately 844 deer based on a compilation of the most recent survey estimates.
- Population estimates suggest more than enough males are available (>4 times the number needed) within the core range and/or most adult females are likely already bred, suggesting a shortage of males is not an issue to complete the 2016 breeding season.

Management Strategies:

- Continued use of sterile flies and doramectin treatments are recommended.
- A tiered-approach in Key deer management responding to a continued screwworm infestation or acceleration is recommended. Management activities by tiers are as follows:
  - Tier I (Big Pine and No Name) – intensive screwworm monitoring/sterile fly releases, monthly road surveys, continued doramectin treatments, and preparation of emergency holding facilities. Activities for each of 4 management levels based on population density "triggers" are outlined.
  - Tier II (Sugarloaf, Cudjoe, Little Pine, and Big Torch) – intensive screwworm monitoring/sterile fly releases, camera-based surveys, and translocations (when appropriate).
  - Tier III (remaing islands in deer range) – intensive screwworm monitoring/sterile fly releases and targeted camera-based surveys for select islands.
- A shift in screwworm infestations to adult females and fawns (e.g., vaginal discharge, umbilicus) would likely have a significant population impact on the Key deer population. Close monitoring of adult females via radio telemetry may be considered as an early screwworm detection strategy prior to fawning.
- Future recovery efforts should consider supplemental translocations as a tool to accelerate Key deer recovery following screwworm eradication and control.

Citation:
Lopez, R. R., I. D. Parker, N. J. Silvy, B. L. Pierce, J. T. Beaver, A. A. Lund. 2016. Florida Key deer screwworm final report (Phase I). Texas A&M Natural Resources Institute. College Station, Texas. 52 pages.

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List of Acronyms

CDFA	California Department of Food and Agriculture
FWC	Florida Fish and Wildlife Conservation Commission
IRNR	Texas A&M Institute of Renewable Natural Resources
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service

INTRODUCTION

Background

Screwworms are the larvae of the New World screwworm fly (*Cochliomyia hominivorax*) and result in major economic and ecological impacts in the Western Hemisphere. Adult screwworm fly females lay 100–300 eggs on the dry edges of a single open wound, orifice, or newborn umbilicus (Drees 2016) and up to 2,800 eggs during its 10–30-day lifespan (CDFA 2016). The larvae emerge within 24 hours to feed upon live and dead tissue within the wound (obligatory myiasis), potentially causing large amounts of tissue loss, secondary infections or toxicity resulting in death within 7–14 days.

Until recent confirmation of a sustained presence in the Lower Florida Keys, the screwworm had largely been eradicated in the United States with periodic reintroductions through imported animals. The screwworm is primarily found in South American and Caribbean countries (CDFA 2016) and strict reporting and quarantine guidelines are followed in the United States to minimize the risk of reintroduction. The U.S. Department of Agriculture (USDA) has estimated that widespread reintroduction of screwworm into the United States would result in $750 million in annual losses to livestock operations alone. Ecological and monetary losses would likely have much greater economic impacts.

In July 2016, screwworm was detected in the Lower Florida Keys centered on Big Pine and No Name keys. These infestations were observed in Florida Key deer (*Odocoileus virginianus clavium*), an endangered subspecies of white-tailed deer endemic to the Lower Florida Keys. Key deer are a relatively healthy herd with few population-impacting diseases or genetic issues. Occasional cranial abscesses result from pedicel wounds sustained when males spar with each other during the breeding season. Additionally, recent disease research has found Johne's Disease (*Mycobacterium avium ss. Paratuberculosis*) in the southern portion of Big Pine Key; however, there is little evidence that either Johne's Disease or cranial abscesses have impacted Florida Key deer at the population level. The primary cause of non-natural mortality continues to be deer-vehicle collisions (Lopez 2001, Lopez et al. 2003), particularly on US 1 on Big Pine Key (Parker et al. 2008*a*, *b*). Previous population density estimates range from 600–800 total Key deer with 60–75% of the population residing on Big Pine and No Name keys (Lopez 2001, Lopez et al. 2004, Roberts 2005).

Key deer have a very limited range, relatively small extant population, and are particularly vulnerable to screwworm infestations due to wounds sustained by males during the breeding period and female and fawn susceptibility during the fawning period. Fortunately, for detection and response efforts, Key deer are highly visible and routinely observed by U.S. Fish and Wildlife Service (USFWS) biologists and the local community. Additionally, Key deer have an extensive monitoring and research history to draw upon during the incident response phase.

Response

In response to the threat to agricultural and ecological health, the USFWS, USDA, Florida Fish and Wildlife Conservation Commission (FWC), Florida Department of Agriculture and Consumer Services, Monroe County, Texas A&M University Institute of Renewable Natural Resources (IRNR), and local community members have partnered to address the screwworm infestation. This multi-agency response consists of three distinct but related actions: (1) elimination of screwworm flies, (2) treatment of impacted animals and implementation of preventative strategies, and (3) determination of Key deer population status and recovery strategies. Although, this report focuses on the work performed by Texas A&M University to assess the Key deer population status and recommended recovery strategies, other response efforts are briefly described below.

Biological Control

Elimination of screwworm fly efforts, spearheaded by USDA in close cooperation with other agencies, involves biological control called the sterile insect technique (USDA 2016). Infertile male flies are released in infested areas where they then mate with female flies. Because female flies only mate once, if they mate with an infertile male, this reduces the number of fly offspring over multiple generations, thereby reducing the viability of the screwworm fly population over time. This technique was used as a primary tool in the United States, as well as in other countries, during previous screwworm fly elimination strategies. Over the last several months, the USDA and USFWS have worked closely to release millions of sterilized males onto islands known to have screwworm flies. Results appear very promising in reducing the number of screwworm occurrences in Key deer.

Treatments

Biologists and veterinarians with USDA, FWC, and USFWS have collaborated to determine appropriate treatment options for Key deer on both individual and population levels. Close observation of Key deer through official monitoring and community involvement have allowed rapid reporting and treatment of infested individuals. Wildlife veterinarians determined the appropriate chemical treatment (i.e., doramectin) to reduce or prevent screwworm infestation in individuals. A process to diagnose, treat or euthanize infested individuals was established via close collaboration between wildlife veterinarians and biologists, citizens, governmental monitoring, and on-call veterinarian consultations of sick deer. The evaluation, treatment decision, and capture process was decided on a case-by-case basis. This collaboration extended to population efforts to reduce screwworm infestation via broad preventative treatments to deer, but with reduced non-target applications. Finally, the comprehensive training and involvement of concerned local citizens has dramatically increased reporting and treatment efforts.

Study Objectives

The objectives of this study were to provide USFWS with a status assessment of the Key deer population and determine observed impacts of the screwworm infestation. Appropriate short- and long-term management strategies also were provided for further consideration in future recovery actions. The specific report objectives are as follows:

1. Summarize Key deer mortalities attributed to screwworm infestations.
2. Estimate the current population density on Big Pine and No Name keys (core population areas).
3. Evaluate screwworm impacts on the Key deer population via a deer model.
4. Provide management strategies to aid in the recovery of the Key deer population in response to the screwworm incident.

PROJECT AREA

General Description

The Florida Keys extend 200 km from the southern tip of peninsular Florida. 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 buttonwood (*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). Big Pine Key (2,548 ha) and No Name Key (461 ha) support the core Key deer population (≈ 75%, Lopez 2001, Lopez et al. 2004) and have long-term population survey data available (Silvy 1975, Lopez et al. 2004). However, outer islands also support Key deer populations, but at much lower abundance and density (Watts et al. 2008, Parker et al. 2008*a*).

Climate

Climate is subtropical marine with mean January temperatures of 21°C, mean July temperatures of 29°C, and average annual rainfall of 98.8 cm (National Oceanic and Atmospheric Administration data, 2006). Rainfall is highly seasonal, generally consisting of a 5-month wet season from late May to October, and a long dry season from November through May. Scattered thunderstorms and tropical storms are responsible for wet season precipitation.

Vegetation

Vegetation is principally West Indian in origin (Dickson 1955) and is greatly influenced by elevation (Folk 1991, Lopez 2001). Vegetative communities near sea level are primarily comprised of mangroves and other halophytes, which are successively replaced by buttonwood, hammock, and pineland communities with increasing elevation. Outer islands typically exhibit dense vegetation which considerably impedes visibility and movement in these areas. Lopez (2001) reported Key deer used upland vegetation types (i.e., pineland and hammock) and avoided lowland vegetation types (i.e., buttonwood and tidal areas). However, lowland vegetation types occur at comparatively higher proportions on outer islands and Key deer on these islands frequently use buttonwood and tidal areas (Watts 2006, Watts et al. 2008). Florida Key deer habitat was defined as pineland, hammock, buttonwood forest, and developed areas (i.e., excluded non-tidal areas).

DATA DESCRIPTION

Multiple data sets were used in report preparation. A brief description of each data set is provided and referenced when used as part of the analysis. Many of these data sets have been collected for many decades, which provides for long-term trends in understanding Key deer population dynamics.

Deer Mortality

USFWS refuge staff have recorded Key deer mortalities since 1966. Direct sightings, citizen reports, or observation of turkey vultures have located most dead animals. Key deer collected have been examined, and sex, age, body weight, location, and cause of death recorded in a database (Nettles et al. 2002, Quist et al. 2002). The management of the Key deer population is unique in having this comprehensive and long-term mortality dataset. During the screwworm incident, these deer mortalities continued to be recorded, and in many cases, cause of death was listed as euthanasia though presence of screwworm infection was noted.

Road Surveys

Road surveys were conducted from January 1969–March 2001 on Big Pine and No Name keys along a standardized route (Silvy 1975, Lopez 2001, Lopez et al. 2004). These surveys were designed to provide an index (i.e., average number of deer seen/km) to the population size and structure of Key deer (i.e., number, sex, and age). There also were road surveys designed to estimate deer density (i.e., number of deer/ha) using mark-resight and distance sampling methods (Silvy 1975, Lopez 2001, Roberts 2005). In 2004, Roberts (2005) compared distance sampling (Buckland et al. 1993, Corn and Conroy 1998, Tomas et al. 2001, Forcardi et al. 2002, Koenen et al. 2002, Swann et al. 2002, Ransom and Pinchak 2003), strip-transect (Burnham and Anderson 1984, Johnson and Rutledge 1985, Hiby and Krishna 2001), and mark-resight methodologies to evaluate the usefulness of these methods in future monitoring efforts. Distance sampling was calibrated and validated by concurrent mark-resight efforts (Roberts 2005), and was applied in obtaining a current population estimate as part of this study.

Radiotelemetry

Key deer were radio-collared as part of 2 separate research time periods in December 1968–June 1972 and January 1998–December 2001. All telemetry data were collected primarily on Big Pine and No Name keys though some telemetry work was done on other islands. Deer were captured throughout the study using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998), and marked in a variety of ways depending on sex and age. A battery-powered radio transmitter was attached to collar material. In addition, each animal captured received an ear tattoo, which served as a permanent marker (Silvy 1975). Radio-collared deer were monitored 6–7 times per week at random intervals (24-hour period was divided into 6 equal 4-hour segments; one 4-hour segment was randomly selected and during that time all deer were located, Silvy 1975). Deer locations were determined via homing and triangulation, and telemetry locations were entered into a database.

STUDY FINDINGS

Screwworm Deer Mortality

Methods

Descriptive statistics of Key deer mortality due to screwworm were summarized from the previously described USFWS mortality database. Mortality summarizes are presented in the following tables and figures.

Results

As of 1 November 2016, approximately 15% of the Key deer population were euthanized and/or died due to screwworm infections (*n*=127 deer mortalities). The vast majority of these infected deer were found on Big Pine Key (*n*=121); however, mortalities also were found on No Name and Middle Torch keys (Table 1). Mortalities increased significantly from the initial screwworm detection in July (*n*=4) to the end of October (*n*=96, Table 2). The fall season is the breeding period (rut) for male Key deer where they often spar and receive minor injuries (Nettles et al. 2002, Quist et al. 2002), increasing the risk of screwworm infection. As a result, a large majority of infected deer were older adult males (>3 years of age) subject to increased sparring and associated injuries (Figures 1-2). In contrast, the age-distribution of infected females were much more evenly distributed (Figure 3) as females are often injured due to general environmental factors rather than intraspecies conflict. The decline in screwworm infestations in the last 2 weeks of October and first 2 weeks of November suggests the impact of doramectin treatments, application of sterile flies, and decline in rutting behavior is likely resulting in a decline in the screwworm infestation for the Key deer population (Figure 4).

Table 1. Key deer screwworm mortalities by island, October 2016.

Island	*n*
Big Pine Key	121
No Name Key	5
Middle Torch Key	1
Total	127

Table 2. Key deer screwworm mortalities by month, October 2016.

Month	*n*
July	4
August	7
September	20
October	96
Total	127

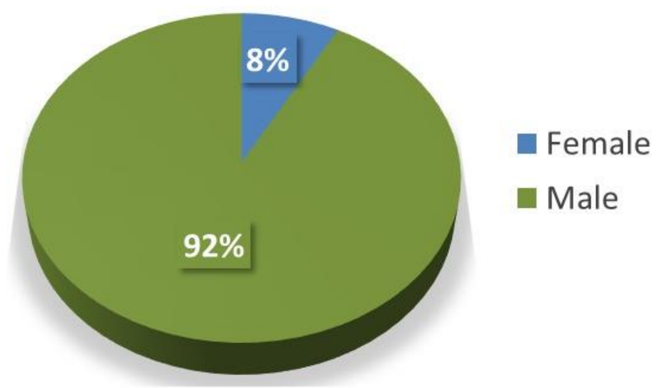


Figure 1. Key deer screwworm mortalities (%, *n*=127) by gender, October 2016.

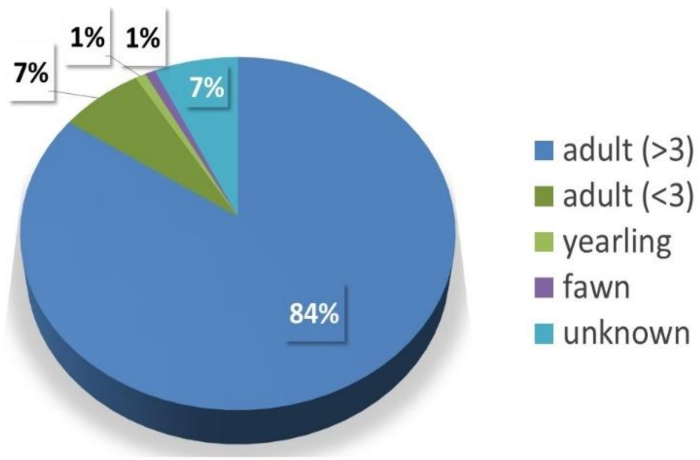


Figure 2. Male Key deer screwworm mortalities (%, *n*=117) by age class, October 2016.

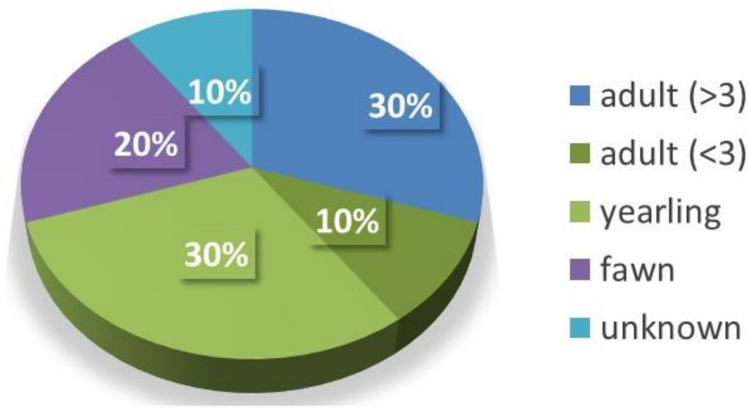


Figure 3. Female Key deer screwworm mortalities (%, *n*=10) by age class, October 2016.

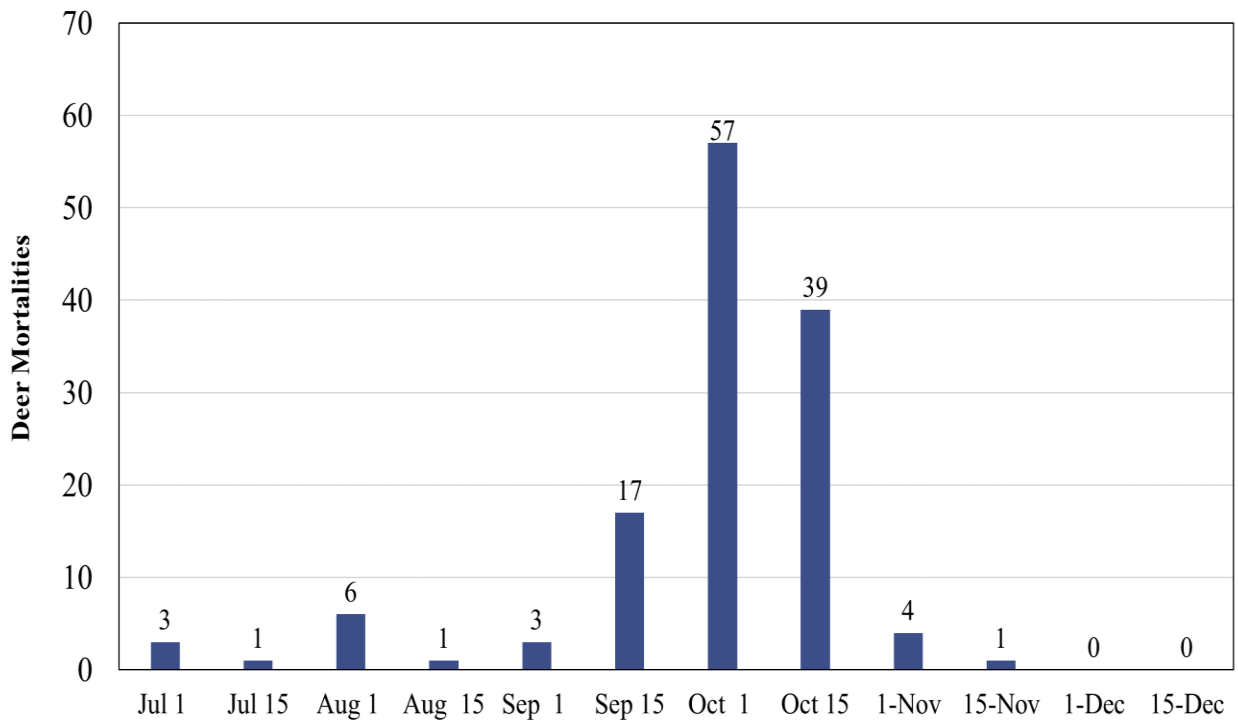


Figure 4. Key deer screwworm mortalities in 2-week intervals, July–December 2016.

Deer Screwworm Mortality Locations

Methods

Radio telemetry data were collected between January 1998–December 2001 within the core habitat of Big Pine and No Name keys (Lopez 2001, Lopez et al. 2004). These deer locations were used to construct 75% range probability maps (Worton 1989, Seaman et al. 1998, Seaman et al. 1999) for both male and female Key deer by month. For months where screwworm infestation data were available, a “heat map” was generated and overlaid with male and female ranges for comparison. Future range maps can be used by refuge staff for identifying areas of likely screwworm infestations and areas to target for preventative strategies.

Results

The distribution and density of males was related to occurrence of screwworm hotspots (Figures 5-7). This was particularly acute in the mid-region of Big Pine Key area along Watson Blvd (near Tropical Bay subdivision) with additional high screwworm mortality in the far northern section in Port Pine Heights and Eden Pines subdivisions. Additionally, a screwworm hotspot was observed along the US 1 underpass zone, a known Key deer crossing area and particularly important for males crossing south (Harveson et al. 2004, 2006).

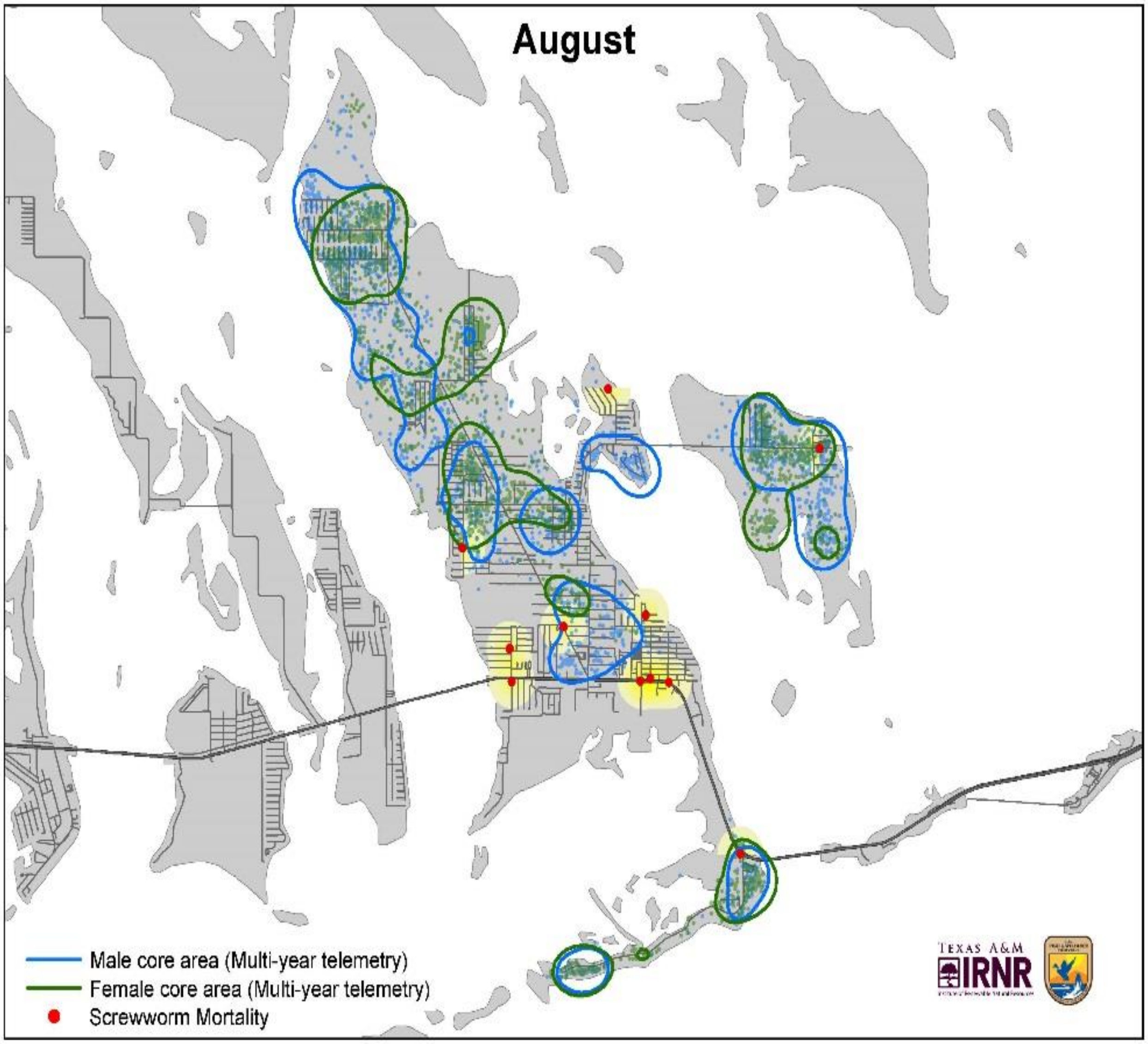


Figure 5. Male and female telemetry locations (1998-2001) and screwworm mortalities, August 2016.

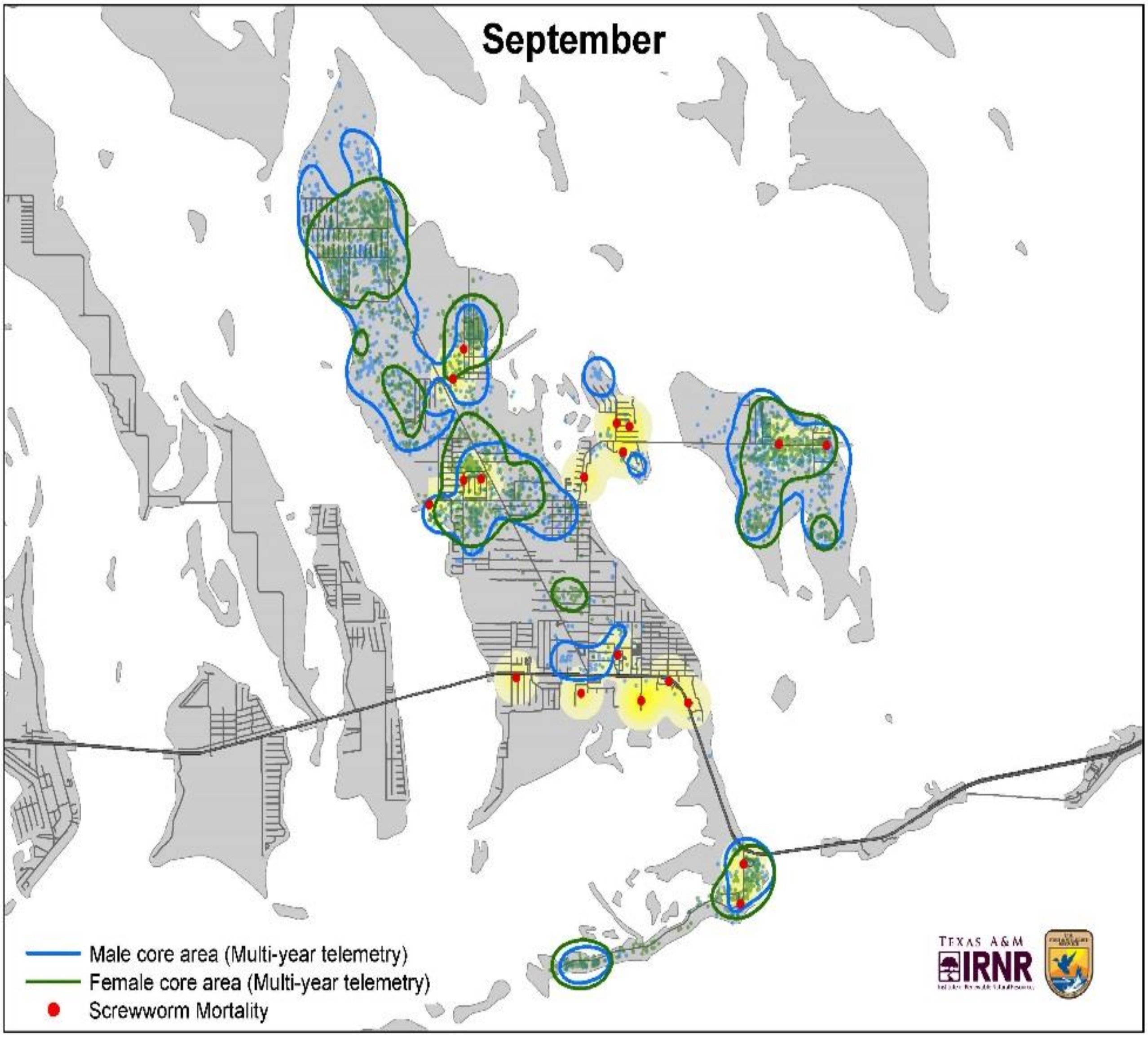


Figure 6. Male and female telemetry locations (1998-2001) and screwworm mortalities, September 2016.

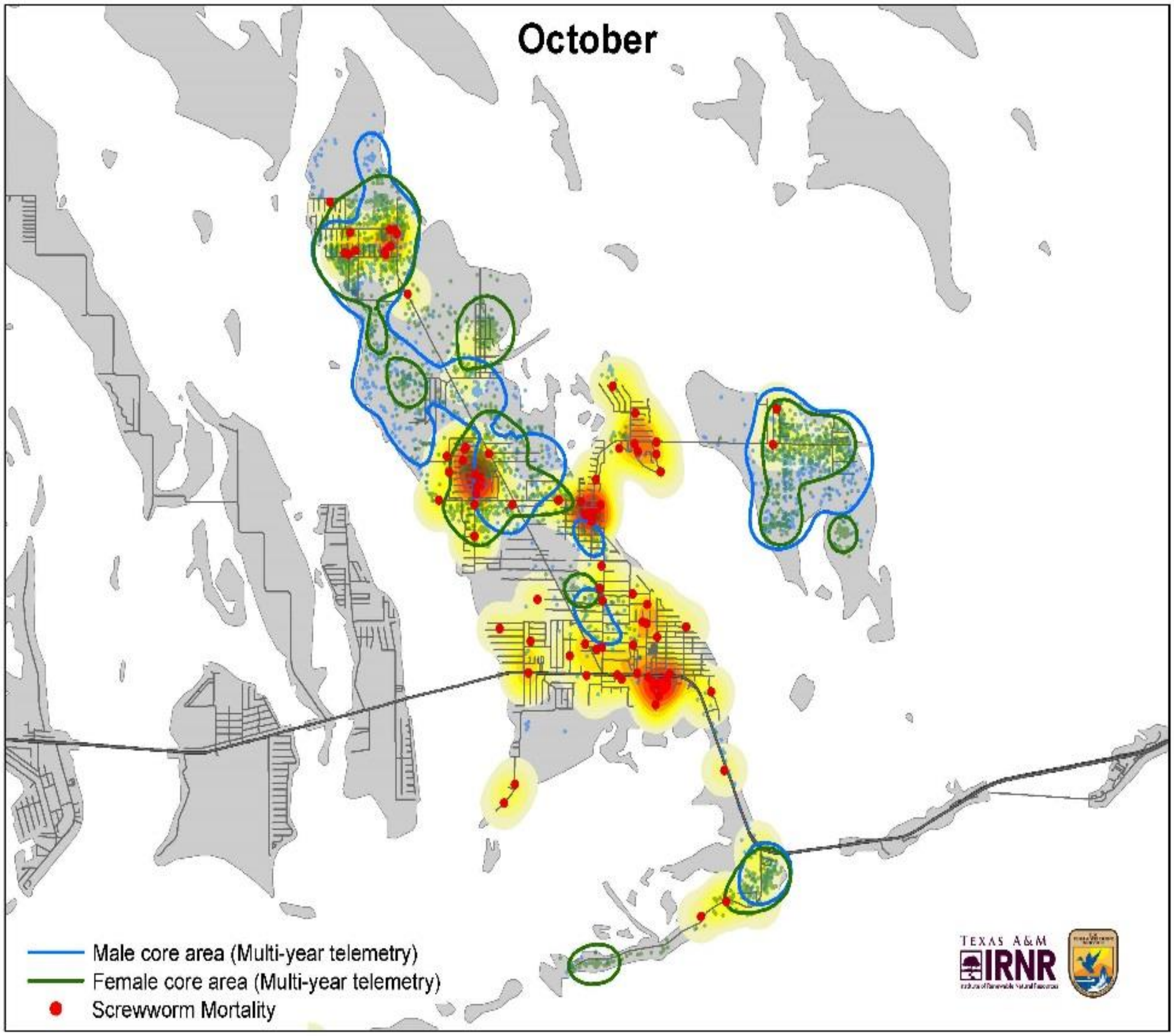


Figure 7. Male and female telemetry locations (1998-2001) and screwworm mortalities, October 2016.

Population Density and Structure

Methods

Road surveys were conducted in 27 October–3 November 2016 on Big Pine, No Name, Cudjoe, and Sugarloaf keys using methods described by Roberts (2005). Sunrise and sunset surveys were conducted via 2 observers traveling along the survey route (average travel speed 25–40 km/hr) and recording the number of deer observed, distance, location, sex, and age (fawn, yearling, adult). Perpendicular distance estimates were obtained using a laser rangefinder from the centerline of the survey route. These data provided a current baseline relative abundance estimate, as well as the information necessary to generate a current density estimate (Buckland et al. 1993, Corn and Conroy 1998, Tomas et al. 2001).

We used Program DISTANCE to estimate density and population size for both islands by month, with stratified detection, density, cluster size, and encounter rates. Previous research has found distance sampling is positively-biased in estimating Key deer density compared to mark-resight methods (Roberts 2005). For these reasons, we use 2 approaches in our distance sampling to generate population estimates:

1. *Population Viability Analyses (PVA) and Current Deer Density Estimates*.—we attempted to remove this positive-bias through data truncation (left<22 m [effective strip-width]; right 100 m), and best fit model selection (Kolmogorov-Smirnov Test) and AIC. The analysis selected a Half-Normal model with 2 cosine adjustment terms. Density estimates from this model were used for PVA modeling and Key deer density estimates.
2. *Population Monitoring Estimates*.—For future Key deer population monitoring, we recommend right data truncation only (100 m) to improve model precision (i.e., 26.8% CV for approach above versus 7.9% CV for this approach). Population monitoring estimates are not reported here but instead in future monitoring reports.

Other density estimates relied upon a compilation of previous studies, most of which relied on camera-based surveys (Watts 2006, Watts et al. 2008). Long-term USFWS road survey data and mortality data also were used in evaluating long-term population trends. These data were used in validating density estimates as well as comparing population sex and age structure estimates.

Results

Distribution and Population Growth.—Key deer historically have been widely distributed throughout the Lower Florida Keys; however, most of the population continues to occupy Big Pine and No Name keys (Figure 8). Updated density estimates, served to validate the importance of these 2 islands to the overall population's viability. Approximately 75% of the deer population reside on Big Pine and No Name keys. Review of long-term survey and mortality data suggests the Key deer population has been increasing at 3.5% annually for the last 30+ years (Figure 9).

Deer Density.—Previous density methodologies used by Roberts (2005) were conducted on Big Pine and No Name keys. We attempted to expand those methods to Cudjoe and Sugarloaf with recent survey efforts, which proved to be inefficient due to low deer density observed. Thus, results presented in this report focused primarily on the core population of Big Pine and No Name keys. Key deer estimates using either mark-resight or distance sampling methodologies have been conducted since the late 1960s. During the rapid response period, we conducted road surveys on 16 routes over a 7-day period on Big Pine and No Name keys, yielding a post-screwworm incident population estimate of 678 Key deer (95% CI 401–1147, n=160, k=16, L=289 km; Figure 10). In adding the 127 Key deer screwworm mortalities to this estimate, it suggests the Key deer population was likely 804 deer prior to the infestation (Figure 10). We attempted to further validate the point estimate using 2 separate approaches via linear regression. First, assuming an annual population growth of 3.5%, we projected the population growth starting with an initial abundance estimated by Lopez (2001; n=482 deer) and Roberts (2005; n=587 deer) to obtain ending population sizes of 806 and 857, respectively, for an average of 831 (Figure 11, green bar). The projected population size (831 deer, Figure 11) is comparable to the current estimated size (804 deer, Figure 10, screwworm mortalities added).

Similarly, we also attempted to validate our current density estimate by comparing density estimates between 1971–2016. We estimated the annual rate of growth for all density estimates between 1971–2016, and compared that rate of growth to the annual rate obtained from mortality and annual USFWS road survey data (Figure 9). We found annual rates of growth to density estimates (3.1%, Figure 12) and long-term trend data (3.5%, Figure 9) to be similar.

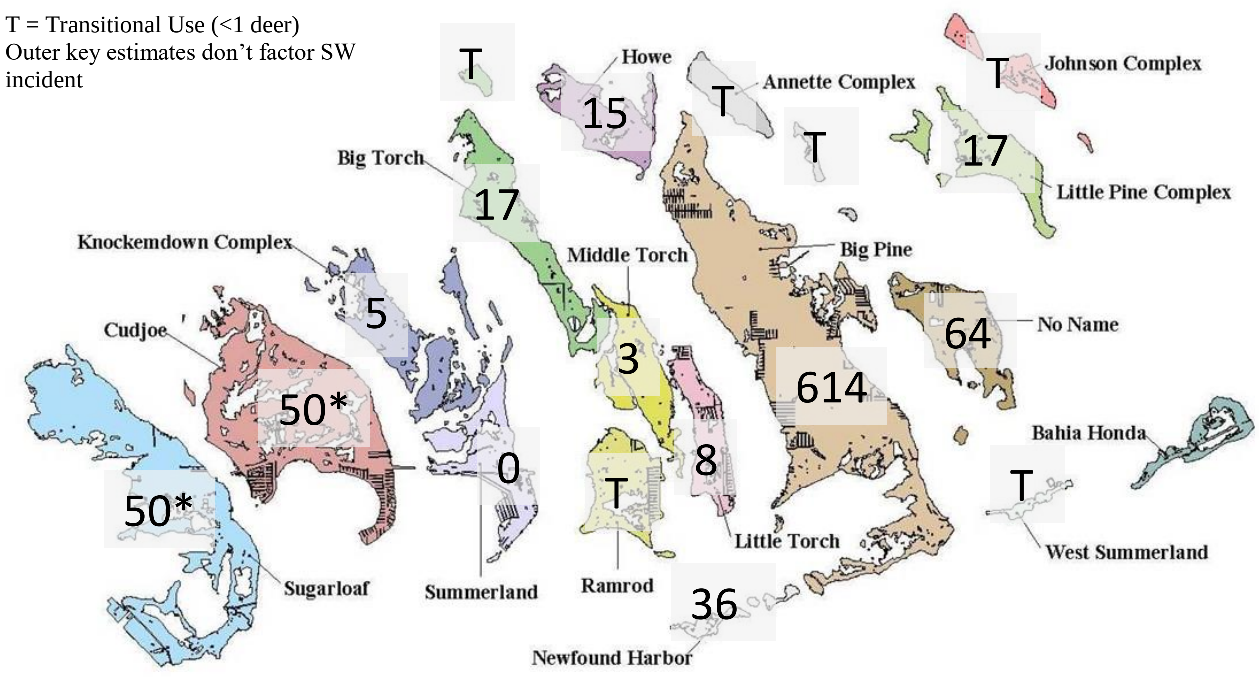


Figure 8. Current Florida Key deer distribution, November 2016.

Table 3. Estimated abundance of Key deer throughout their range derived from various sources (numbers correspond with Figure 8), November 2016.

Island complex	Area (ha)	Density Estimate (low)	Density Estimate (high)	Source
Big Pine	2,522	614	614	A
No Name	459	64	64	A
Annette	222	<1	<1	B
Cudjoe	1,319	42	50	C
Howe	373	12	15	B
Johnson	154	<1	<1	B
Knockemdown	582	4	5	B
Little Pine	381	14	17	B
Newfound Harbor	76	30	36	B
Ramrod	374	<1	<1	B
Sugarloaf	1,399	42	50	C
Summerland	436	<1	<1	B
Big Torch	626	14	17	B
Little Torch	305	6	8	B
Middle Torch	410	2	3	B
Total		844	879	

A = estimates obtained in this report
B = estimates reported by Watts, D. E., I. D. Parker, R. R. Lopez, N. J. Silvy, and D. S. Davis. 2008. Distribution and abundance of endangered Florida Key deer on outer islands. Journal of Wildlife Management 72:360-366.
C = estimates obtained by Kate Watts, Key deer biologist in November 2015 (personnel communication)

Population estimates from both B and C are pre-screwworm incident and are likely overestimated (Table 3). Assuming a 15% population impact (% observed on Big Pine and No Name keys), a low population estimate was calculated for outer keys. Estimate for Big Pine and No Name keys already adjusted (Table 3).

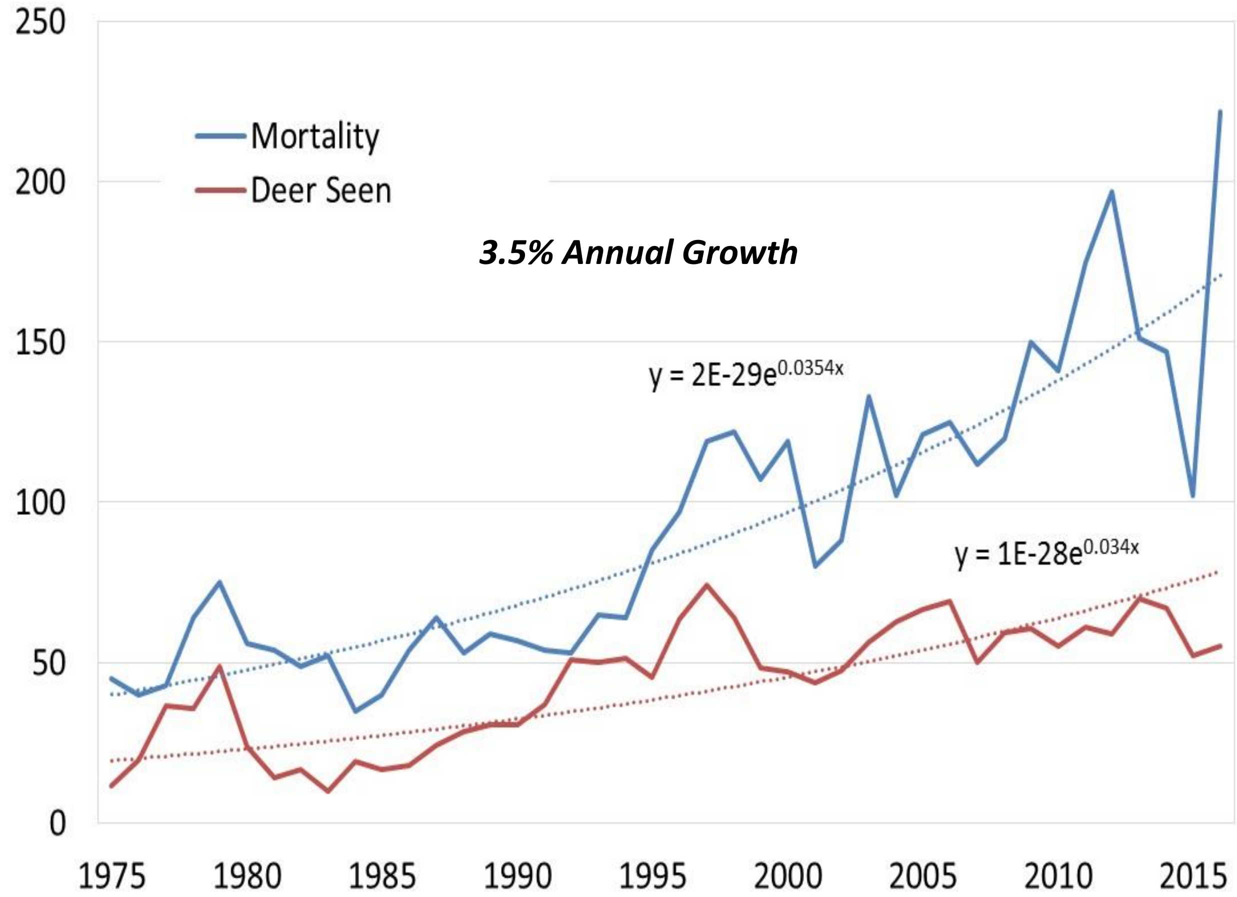
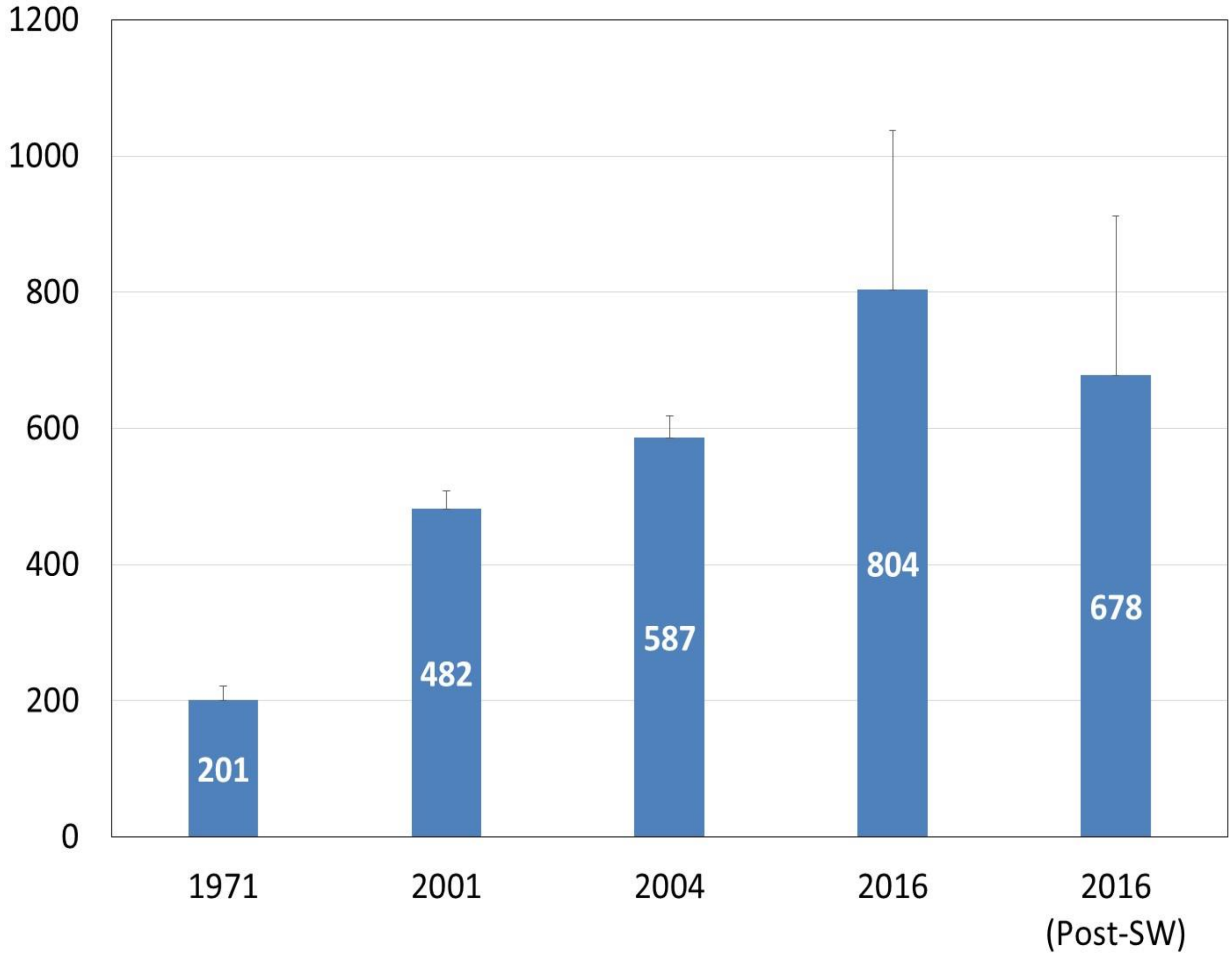


Figure 9. Annual Key deer mortality and monthly road surveys (average deer seen), 1975–2016.



**2016 includes both a pre-screwworm (SW) and post-screwworm incident estimate.*

Figure 10. Key deer population density on Big Pine and No Name keys, 1971–2016.

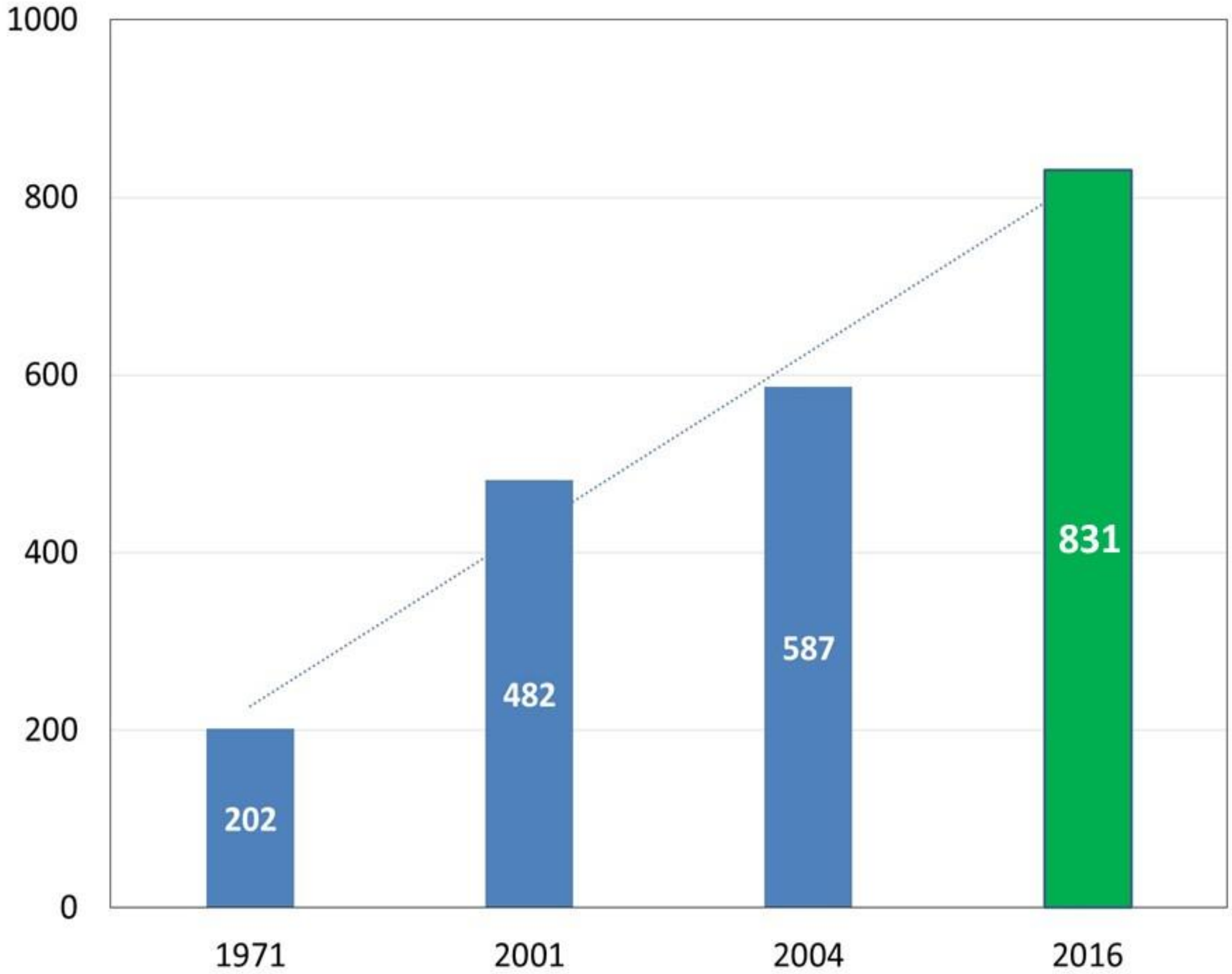
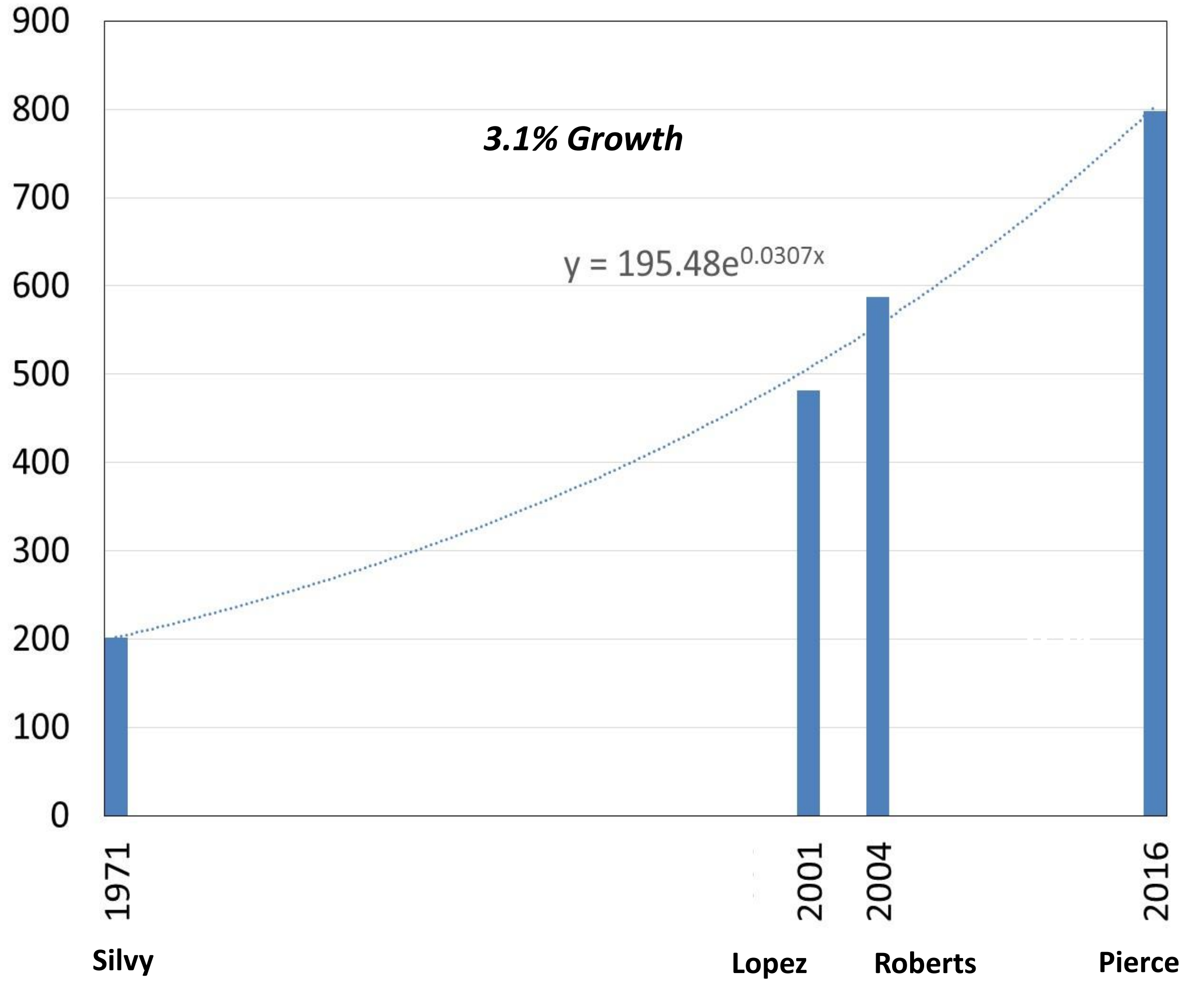


Figure 11. Key deer population density on Big Pine and No Name keys, 1971–2016.



**Estimated growth based on fitted regression line of historic population density estimates.*

Figure 12. Projected Key deer annual population growth on Big Pine and No Name keys, 1971–2016.

Population Sex Ratios.—Screwworm impacted males disproportionately likely due to rutting behavior as previously mentioned. This impact was observed in male:female ratios (Table 4, Figure 13). Previous studies have reported the Key deer population on Big Pine and No Name keys are bias towards females, largely due to road kills which are bias toward males (Lopez et al. 2004). The average annual female:male ratio was 2.55–3.76:1 (Table 4, Figure 13). During the breeding season, sex ratios were closer to 2:1 as expected (more males are moving). Following the peak screwworm incident (i.e., Period I), the female:male ratio shifted with a strong bias toward females, particularly the female:adult male ratio (4.12:1, Table 4, Figure 13). As previously mentioned, adult male Key deer were particularly impacted by screwworms and survey results suggest a shift in both sex and age structure within population, with a reduction in adult males.

Table 4. Key deer sex ratios before, during, and after screwworm incident, October 2016.

	Annual Estimates (Pre-screwworm)	Screwworm Period I (Jul-Oct 2016)	Screwworm Period II (Nov 2016)
All Females:All Males	2.55	1.23	1.89
All Females:Adult Males	3.76	1.80	4.12

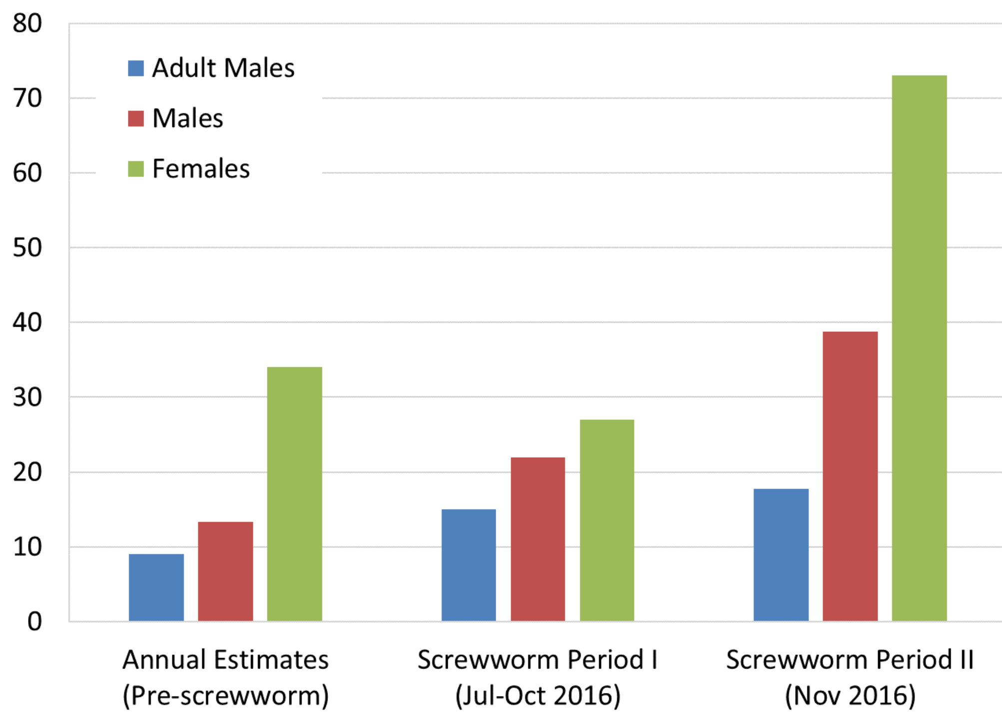


Figure 13. Average Key deer seen on road surveys by age clas and period, 2016.

Population Viability Analyses

Methods

A Population Viability Analyses (PVA) is a method used to evaluate the viability of threatened or endangered species using computer simulation models (Boyce 1992, Burgman et al. 1993). Species viability is often expressed as the risk or probability of extinction, population decline, expected time to extinction, or expected chance of recovery (Akçakaya 1991, Akçakaya and Sjogren-Gulve 2000). PVA models attempt to predict such measures based on demographic and habitat data. In this section of the report, we assess the status of the Key deer population using 2 approaches with a focus on the core deer population (i.e., Big Pine and No Name keys). First, we determined whether there were enough males to maintain a successful breeding season in 2016–2017 given the high mortality observed due to the screwworm infestation. We relied on survey data and current sex and age structure estimates in that assessment. Here, we asked the question "what is the number of males needed in the population?".

Second, we updated a Key deer population model used in 1998 in the development of a Habitat Conservation Plan (HCP) for Big Pine and No Name keys. A detailed description of the Key deer HCP model can be found in Lopez (2004). If the screwworm infestation was to continue, we attempted to identify key "trigger points" for USFWS decision-makers. Because the female segment of the population is the principle driver to overall viability with a polygamous reproductive strategy (DeYoung et al. 2006) and to avoid underestimating risk (Brook et al. 2000), only female Key deer were modeled in our assessment. An assumption was made that enough males would exist for breeding under all scenarios, which was cross-referenced from project initial abundances (Tables 6-7). Five scenarios were modeled for Big Pine and No Name keys. Each scenario assumed a reduction in the Key deer population in 20% increments assuming the continued infestation of screwworm (Tables 6-7). To assist decision-makers in determining acceptable levels of risk, several tables and figures were constructed to summarize levels of risk for different scenarios and metapopulation thresholds (25 and 50 individuals) over a simulation timeline of 100 years. This approach asks the question "what is the minimum number of females needed".

Results

Number of Males Needed.—White-tailed deer are polygamous breeders where adult males may breed with multiple females during a single breeding season (Verme 1983). Recent research has disproven the notion that dominant adult males do most of the breeding (DeYoung et al. 2006, Hewitt 2011), where recent studies reporting that a large proportion of males of all ages participate during the breeding season (DeYoung et al. 2006). Though the maximum number of females that can be bred by a single male in free-ranging deer populations is poorly understood, an estimate of 8–10 females per male can be considered a reasonable estimate (DeYoung et al. 2006). Based on that assumption and current population estimate/sex ratio on Big Pine and No Name keys, an estimated minimum of 38 deer are required for completing the 2016-2017 breeding season (Table 5). Population estimates suggest approximately >4X that requirement (179 vs. 38) within the core deer range (Table 5, Figure 14).

Table 5. Estimated number of males needed to breed Florida Key deer females, 2016.

	Number of Breeding Females	Estimated Needed Males
Big Pine Key	342	34
No Name Key	36	4

Note: AM=Adult Male, AF=Adult Female, YM=Yearling Male, YF=Yearling Female, FM=Fawn Male, FF=Female Fawn.

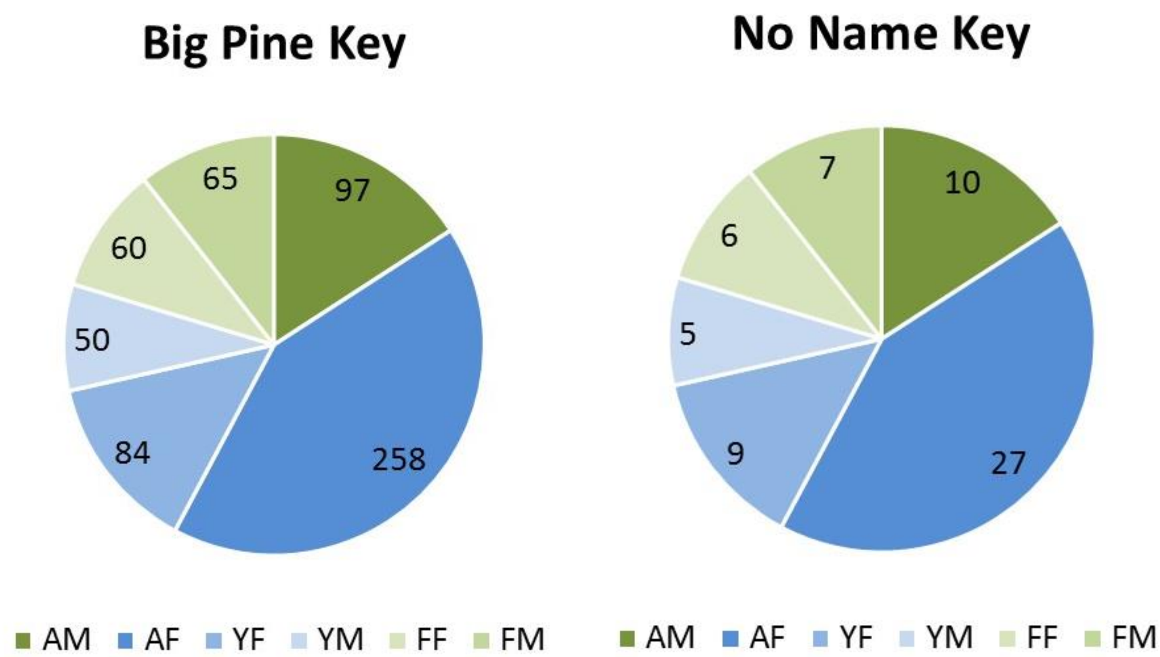


Figure 14. Estimated number of Key deer by sex and age, November 2016.

In addition, most adult females most likely have already been bred. Thus, if the screwworm infestation is controlled, the current number of males on Big Pine and No Name keys appears to be adequate to complete the 2016–2017 breeding season.

Minimum Number of Females—We modeled 5 scenarios for our core population: (1) current baseline estimate, (2) 80% reduction of baseline, (3) 60% reduction of baseline, (4) 40% reduction of baseline, and (5) 20% reduction of baseline (Tables 5–6). As previously mentioned only females were modeled, however, male abundances are presented to provide the likely number of available males at a given population threshold.

Table 6. Estimated initial abundances by sex, age, island, and model scenario, 2016.

Scenario	Island[2]	Sex and Age[3]						Total
		AM	AF	YM	YF	FM	FF	
Base[1]	BPK	97	258	50	84	65	60	614
	NNK	10	27	5	9	7	6	64
	Total	*108*	*284*	*55*	*93*	*72*	*66*	*678*
80% Base	BPK	78	206	40	67	52	48	491
	NNK	8	21	4	7	5	5	51
	Total	*86*	*228*	*44*	*74*	*58*	*53*	*542*
60% Base	BPK	58	155	30	50	39	36	368
	NNK	6	16	3	5	4	4	38
	Total	*65*	*171*	*33*	*56*	*43*	*40*	*407*
40% Base	BPK	39	103	20	34	26	24	246
	NNK	4	11	2	4	3	2	26
	Total	*43*	*114*	*22*	*37*	*29*	*26*	*271*
20% Base	BPK	19	52	10	17	13	12	123
	NNK	2	5	1	2	1	1	13
	Total	*22*	*57*	*11*	*19*	*14*	*13*	*136*

[1]Base=current baseline estimate, 80%Base=20% reduction of baseline, 60%Base=40% reduction of baseline, 40%Base=60% reduction of baseline, 20%Base=80% reduction of baseline
[2]BPK=Big Pine Key, NNK=No Name Key
[3]AM=Adult Male, AF=Adult Female, YM=Yearling Male, YF=Yearling Female, FM=Fawn Male, FF=Female Fawn.

Table 7. Estimated total females, breeding females (AF, YF), and breeding males (AM, YM) by model scenario, 2016.

	Total Females	Breeding Females	Breeding Males
Base	443	377	163
80% Base	354	302	130
60% Base	266	226	98
40% Base	177	151	65
20% Base	89	75	33

As expected, extinction probabilities decreased with a reduction in initial abundances for all model scenarios (Table 8, Figures 15–18). Assuming a 25 quasi-extinction threshold, a 40–60% population reduction suggests managers should take added measures in addressing a prolonged screwworm infestation. We suggest use of (1) 25 quasi-extinction threshold based on earliest Key deer estimates (Dickson 1955, estimated 25 Key deer) and (2) 40% base due to initial abundance comprable to contemporary estimates were population has recovered (Silvy 1975, estimated 201 Key deer) (Table 8). This combination of scenarios suggests a *P*=0.049 over the 100 simulation time period (Table 8). A management framework based on this risk assessment in presented in the final section of the report.

Table 8. Population Viability Analyses (PVA) summaries by model scenario, initial abundances, extinction probabilities, and upper 95% confidence intervals (UCI), 2016.

Scenario	Initial Abundances	Terminal Extinction[1]	95% UCI	25 Quasi-Extinction[2]	95% UCI	50 Quasi-Extinction[3]	95% UCI
Base	443	0.004	0.032	0.033	0.061	0.152	0.18
80% Base	354	0.006	0.034	0.036	0.064	0.164	0.192
60% Base	266	0.008	0.036	0.040	0.068	0.185	0.213
40% Base	177	0.011	0.041	0.049	0.077	0.227	0.295
20% Base	89	0.017	0.045	0.091	0.119	0.304	0.332

[1]Risk of extinction in 100 years
[2]Risk of population falling below 25 individuals in 100 years.
[3]Risk of population falling below 50 individuals in 100 years.

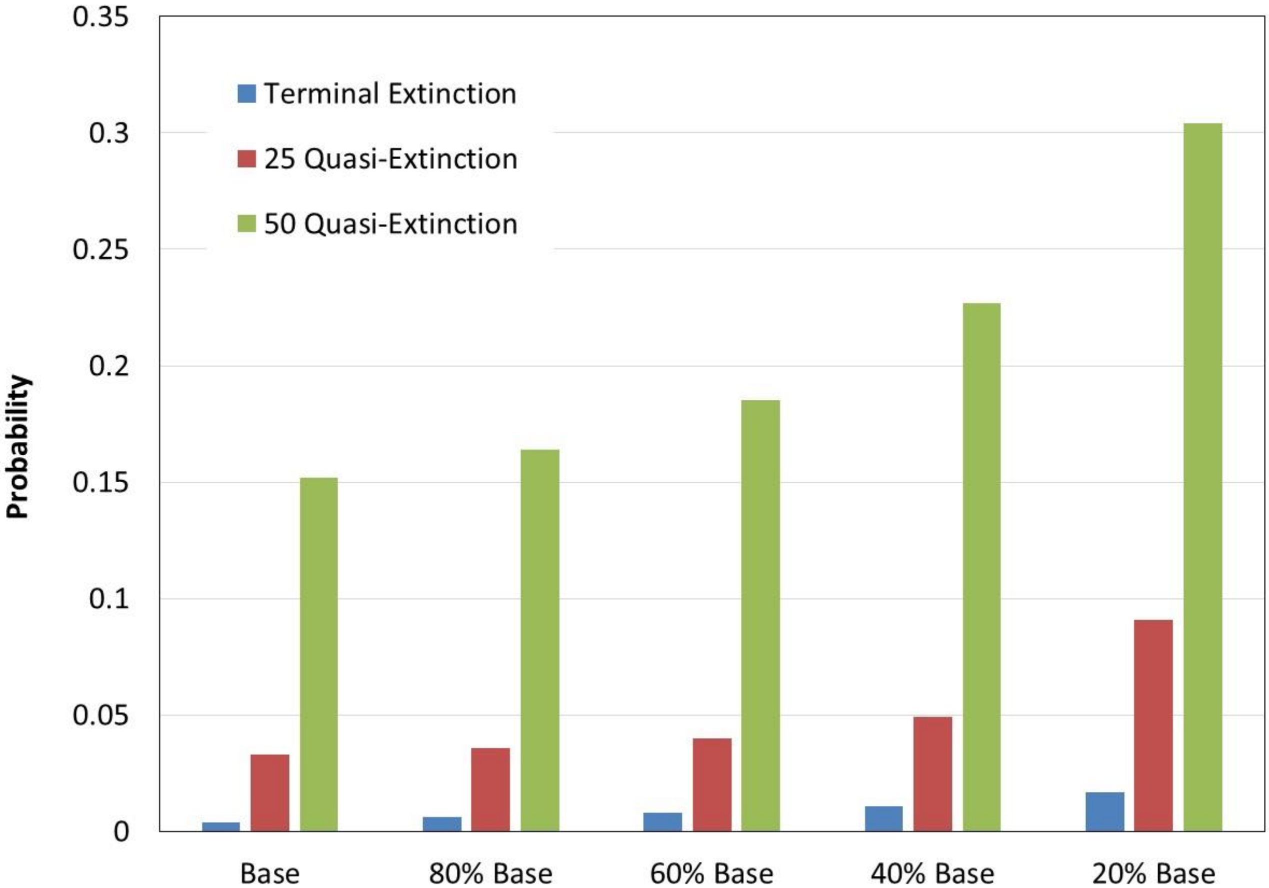


Figure 15. Ending extinction probabilities by population scenario and thresholds, Big Pine and No Name keys.

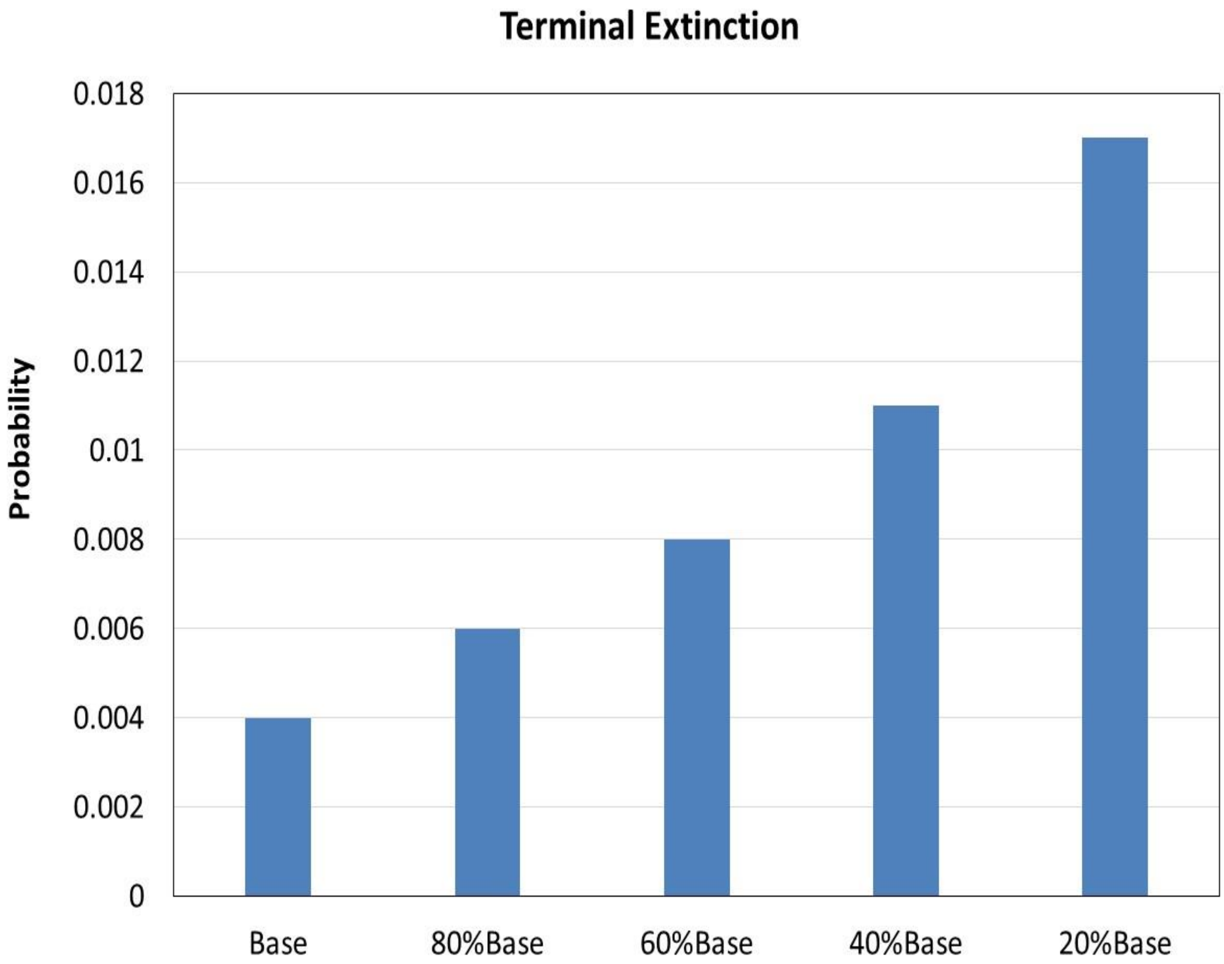


Figure 16. Terminal extinction probabilities by population scenario for 100-year simulation period, Big Pine and No Name keys.

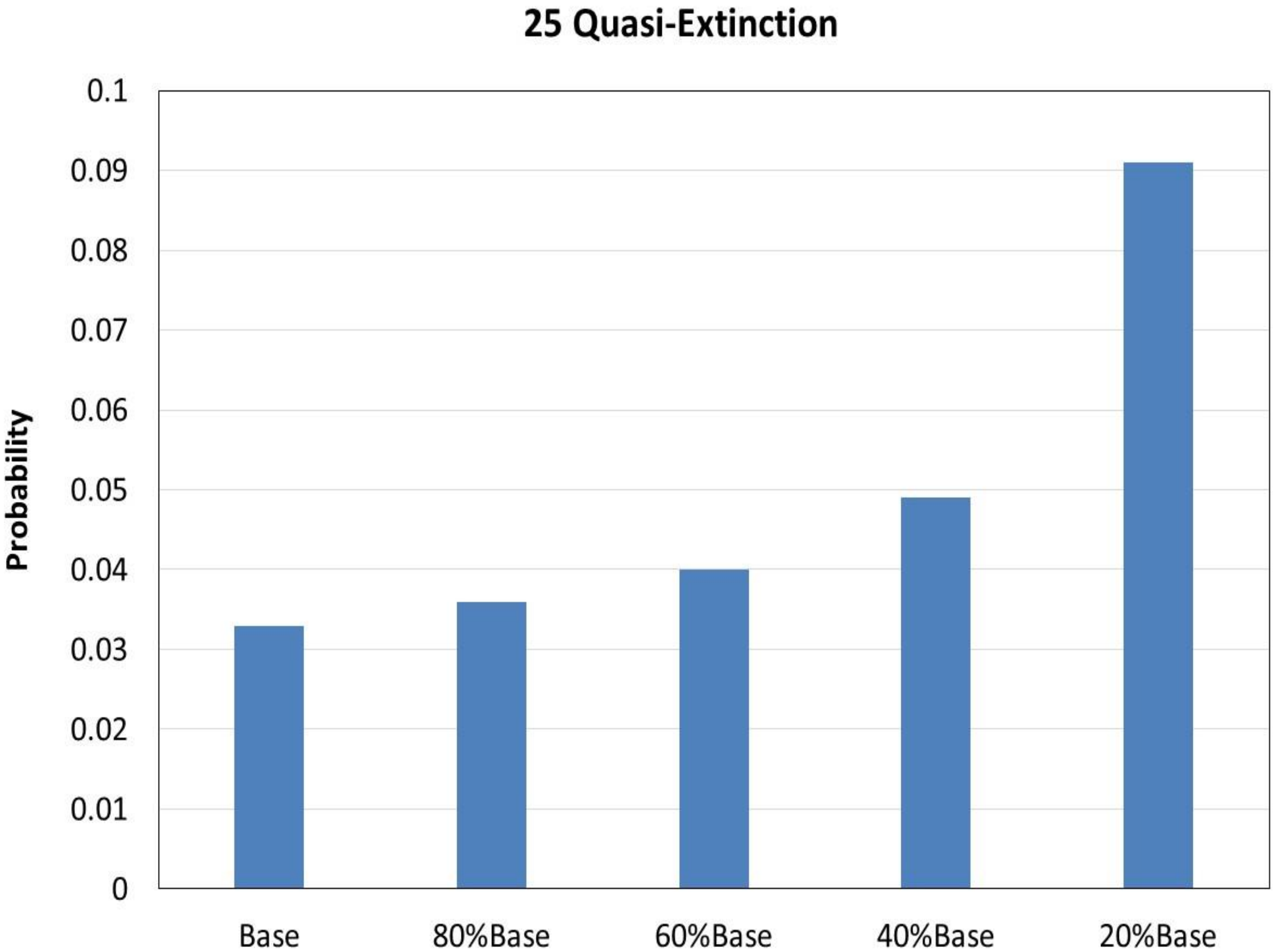


Figure 17. Quasi-extinction probabilities (25 deer threshold) by population scenario for 100-year simulation period, Big Pine and No Name keys.

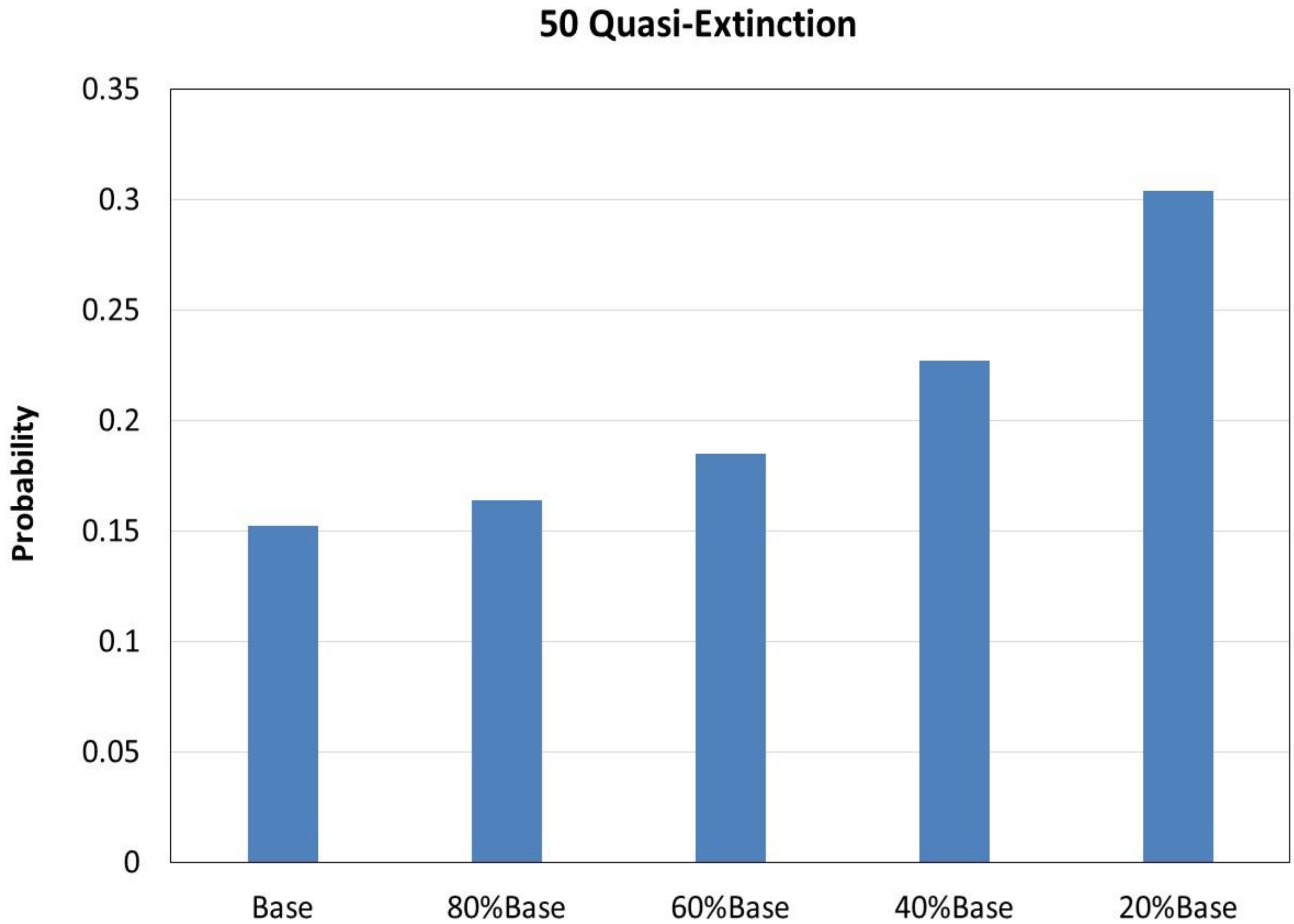


Figure 18. Quasi-extinction probabilities (50 deer threshold) by population scenario for 100-year simulation period, Big Pine and No Name keys.

Management Strategies

Efforts by USDA, USFWS, and other key agencies suggest are having a positive impact in the deceleration of screwworm mortalities in Key deer. Continued use of sterile flies and doramectin treatments are recommended. In the event that the screwworm infestation were to reoccur on certain islands or within core Key deer habitat, a general management strategy based on probable population density threshold and respective management actions is provided for consideration. We suggest a tiered-approach to the management of Key deer based on habitat characteristics and overall deer density, which ultimately influences long-term Key deer population viability. Below is a conceptual classification scheme based on 3 tiers:

Tier I.—Includes Big Pine and No Name keys. Islands provide critical core habitat for Key deer in terms of pinelands (79% in), water resources (48%), and overall deer density (77%) (Table 9, Figure 19). Previous research has found that upland habitat, particularly rock pinelands, are important to Key deer in meeting their overall habitat requirements year-round (Lopez et al. 2004). Furthermore, islands with these upland habitats (particularly pinelands), typically have freshwater resources available, a necessary requirment for Key deer (Lopez et al. 2003, Lopez et al. 2004). Deer density and ultimately population viability are correlated with the proportion of upland habitat and amount of water resources (Lopez et al. 2004). From a metapopulation perspective, Big Pine and No Name keys can be considered a source populations (Dias 1996, Harveson et al. 2004, 2006). Management activities within Tier I islands would include intensive screwworm monitoring/sterile fly releases, monthly road surveys, continued doramectin treatments, and preparation of emergency holding facilities (assuming continued outbreaks).

Within Tier I islands, we propose 4 management levels based on population density "trigger points" for various screwworm infestations modeled in our PVA. Each model scenario results in a different set of suggested management actions (Table 8). Currently, USFWS is constructing 100+ acre holding facility on Big Pine to intensively manage Key deer (doramectin treatment, intense health monitoring, etc.) if screwworm infestations were to accelerate. Based on PVA extinction probabilities, we suggest use of the holding pen when a 60% reduction in the deer population is observed. It is recommended that initially the number of deer placed in the holding pen approximately < ½ carrying capacity (4:1 female:male, 2–3 acres/deer) (Table 8). The primary purpose of initiating the holding pen 60% population is to finalize the capture and handling logistics within the facility prior to moving to full capacity. Other recommendations are outlined in Table 8.

Tier II.—Includes Sugarloaf, Cudjoe, Little Pine, and Big Torch keys. Islands provide important habitat for Key deer in terms of pinelands (21%), water resources (23%), and overall deer density (15%) (Table 9, Figure 19). From a metapopulation perspective, these islands can be considered a source populations though active management such as translocations are likely necessary (Parker et al. 2008*a*). Previous translocation efforts were conducted on Sugarloaf, Cudjoe, and Little Pine (Parker et al. 2008*a*) to bolster current population numbers. Management activities within Tier II islands would include intensive screwworm monitoring/sterile fly releases, camera-based surveys, and translocations (when appropriate). Camera-based surveys are recommended should be done monthly/quarterly as part of a monitoring plan. Trapping and collaring of deer on these islands for monitoring purposes is not recommended due to the likely level of resources required and return on investment in terms of amount of information to be gained from such efforts.

Tier III.— Includes 11 islands/complexes: West Summerland, Newfound Harbor, Bahia Honda, Johnson Complex, Annette Complex, Little Torch, Howe, Ramrod, Middle Torch, Summerland, Knockemdown Complex (Table 9, Figure 19). Islands provide moderate or transitional habitat for Key deer in terms of pinelands (0%), water resources (29%), and overall deer density (7%) (Table 9). From a metapopulation perspective, these islands can be considered primarily sink populations though active management such as translocations are likely (Harveson et al. 2004, 2006, Parker et al. 2008*a*). Management activities within Tier III islands would include intensive screwworm monitoring/sterile fly releases and targeted camera-based surveys for select islands. The primary focus would include ensuring a reservoir screwworm fly population not survive on these islands. Camera-based surveys are recommended should be done monthly/quarterly as part of a monitoring plan. Trapping and collaring of deer on these islands for monitoring purposes is not recommended due to the likely level of resources required and return on investment in terms of amount of information to be gained from such efforts.

Table 8. A conceptual tiered-approach to Key deer management in response to screwworm infestation, 2016.

Tier	Islands	Deer Population (*n*, %)	Freshwater Sources (*n*, %)	Pinelands (acres, %)	Uplands (Pineland + Hammock) (acres, %)
I	Big Pine No Name	678 (77%)	142 (48%)	Big Pine (580 ac) No Name (46 ac) (79%)	Big Pine (807 ac) No Name (202 ac) (46%)
II	Sugarloaf Cudjoe Little Pine Big Torch	134 (15%)	68 (23%)	Sugarloaf (28 ac) Cudjoe (92 ac) Little Pine (50 ac) Big Torch (0 ac) (21%)	Sugarloaf (294 ac) Cudjoe (198 ac) Little Pine (107 ac) Big Torch (106 ac) (32%)
III	Others*	63 (7%)	84 (29%)	Other (0 ac) (0%)	Other (568 ac) (26%)
Total	17	875	294	*n* = 796	*n* = 2,203

*West Summerland, Newfound Harbor, Bahia Honda, Johnson Complex, Annette Complex, Little Torch, Howe, Ramrod, Middle Torch, Summerland, Knockemdown Complex (see Figure 19).

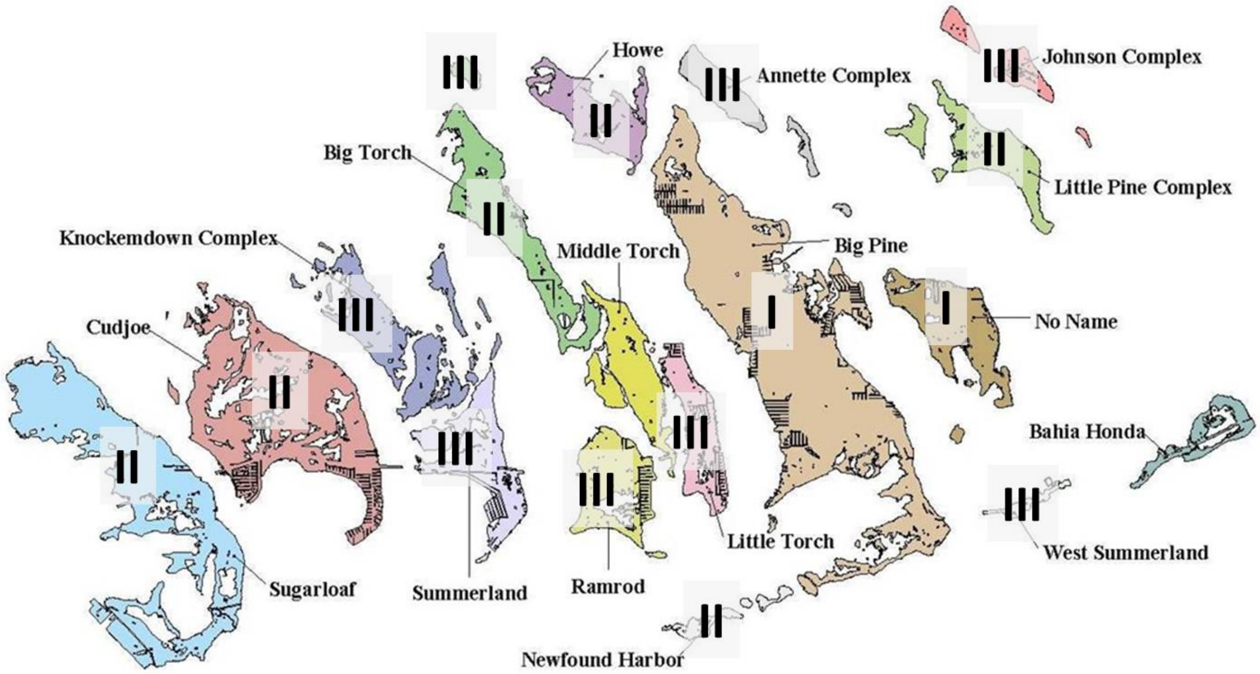


Figure 19. Range map of conceptual tiered-approach to Key deer management in response to screwworm infestation, 2016.

Closing Thoughts.—The rapid application of sterile flies appears to have been a critical management strategy in the deceleration of screwworm infestation Key deer. In addition, doramectin preventative treatments are also likely to have been helpful in reducing screwworm infections. Continuing to focus on eradicating the screwworm should be the primary focus, particularly with the upcoming fawning season. A shift in screwworm infestation to adult females and fawns (e.g., vaginal discharge, umbilicus) would likely have a significant population impact on the Key deer population. Close monitoring of adult females via radio telemetry may be considered as management strategy and early screwworm detections. In the event construction of secondary holding pens are considered, facility placement on Sugarloaf and Cudjoe Keys can serve a dual purpose role as well for supplemental translocations in the near future. Future recovery efforts should consider supplemental translocations as a tool to accelerate Key deer recovery following screwworm eradication and control.

Table 9. Conceptual Key deer response strategy for Tier I islands by suggested management actions (Levels I–IV), 2016.

Scenarios	Population Estimates	Level I	Level II	Level III	Level IV
Base	678 (443)	▪ Monthly surveys ▪ Sterile fly releases ▪ Doramectin treatments			
80% Base	542 (354)	▪ Base (Level I activities) ▪ Prepare holding pens (fencing, feeders, etc.)			
60% Base	407 (266)		▪ Base (Level I activities) ▪ Mobilize primary holding pen at ½ carrying capacity ▪ Finalize captive holding protocol and logistics		
40% Base	271 (177)			▪ Base (Level I activities) ▪ Mobilize primary holding pen at full carrying capacity ▪ Maintain and implement final protocols for captive holding procedures and logistics ▪ Prepare secondary holding pen for deer captivity	
20% Base	136 (89)				▪ Base (Level I activities) ▪ Mobilize all holding pens at full carrying capacity ▪ Translocate and quarantine deer to zoos?

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APPENDIX

December 2016 – Monitoring Density Report

DENSITY ESTIMATES

Road surveys were conducted from November 2016–present on Big Pine and No Name keys along a standardized route (Silvy 1975, Lopez 2001, Lopez et al. 2004). These surveys were designed to provide an index (i.e., average number of deer seen/km) to population size, population structure (i.e., sex, age), and deer density (i.e., number of deer/ha) using mark-resight and distance sampling methods (Silvy 1975, Lopez 2001, Roberts 2005). For the latter, distance sampling was calibrated and validated by concurrent mark-resight efforts (Buckland et al. 1993, Roberts 2005) in 2005. Survey methods applied in obtaining a population estimate as part of this study are outlined by Roberts (2005).

Following collection of road survey data, we used Program DISTANCE to estimate density and population size for both islands by month, with stratified detection, density, cluster size, and encounter rates. Data were right truncated at 100 m, and best fit model was selected by model fit (Kolmogorov-Smirnov Test) and AIC (Lopez et al. 2016). The analysis selected a half-normal model with 2 cosine adjustment terms for both months. While the data for both months was spiked near distance zero, this analysis clarifies differences between periods due to weather, deer perturbations, surveyors, survey effort, and changes in population estimates. Sampling effort summaries and statistical outputs are provided (see Appendix).

Mean encounter rates may serve as good index to detecting Key deer population changes, particularly as related to recommended PVA thresholds (Lopez et al. 2016). Encounter rates between November surveys (1.116) were slightly lower compared to December (1.445) (Figure 1) though not different ($P>0.05$) between periods and islands (see Appendix). We attribute these differences to weather events during the November survey period and adjustments in survey routes made for December intended to increase deer observations.

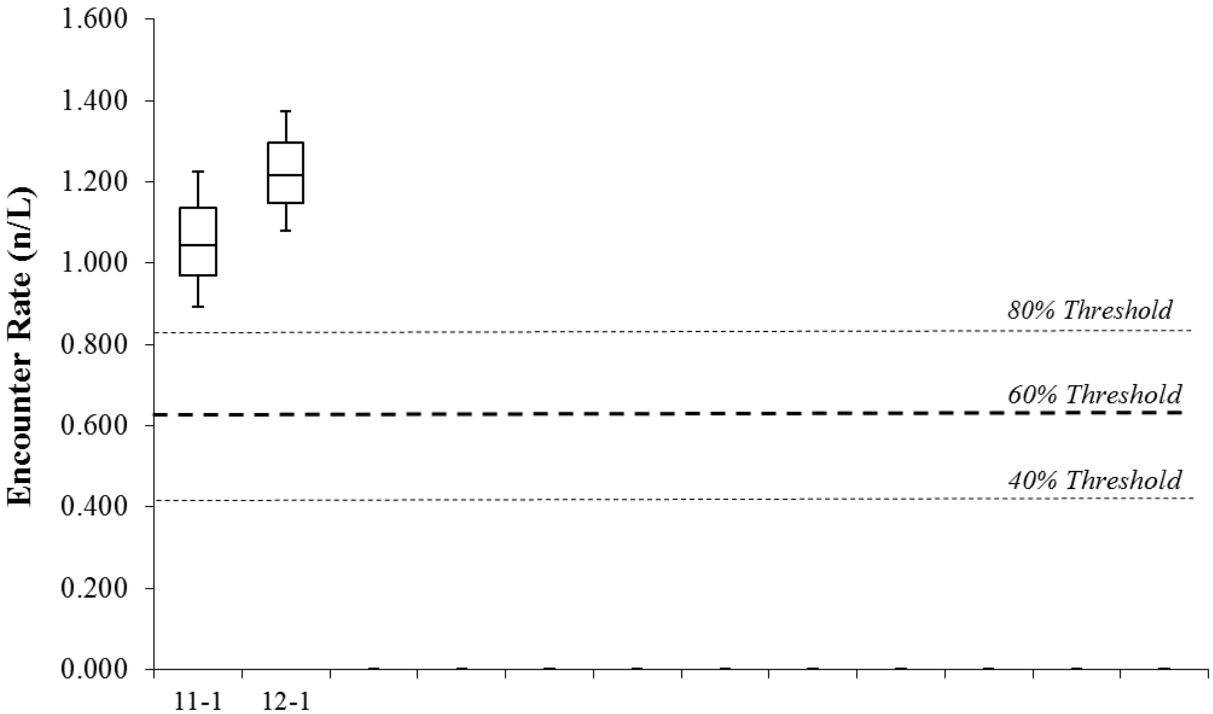

Figure 1. Key deer mean encounter rate (n/L) for Big Pine and No Name keys from distance sampling via road surveys, November 2016-present.

Note: Dash lines represent recommended PVA thresholds (Lopez et al. 2016). Estimated thresholds have been adjusted to account for positive-bias in density model to allow direct comparison to PVA results.

Key deer density on Big Pine and No Name keys for November (k=30, D=890, CI 749-1056) were comparable to December (k=8, D=1010, CI 877-1163) though the latter were higher (Figure 2, see Appendix).

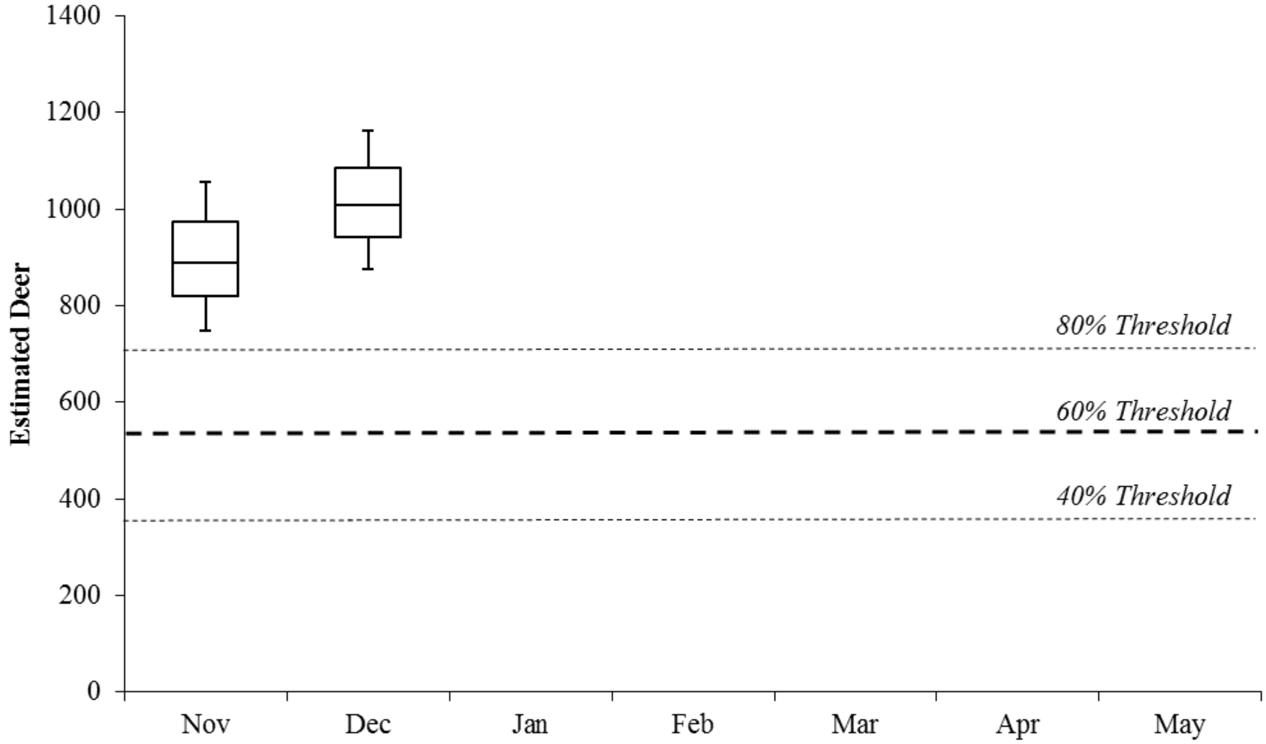

Figure 2. Key deer abundance estimates for Big Pine and No Name keys from distance sampling via road surveys, November 2016-present.

Note: Dash lines represent recommended PVA thresholds (Lopez et al. 2016). Estimated thresholds have been adjusted to account for positive-bias in density model to allow direct comparison to PVA results.

Screwworm Mortalities

USFWS refuge staff have recorded Key deer mortalities since 1966. Direct sightings, citizen reports, or observation of turkey vultures have located most dead animals. Key deer collected are typically are examined, and sex, age, body weight, location, and cause of death recorded in a database (Nettles et al. 2002, Quist et al. 2002). The management of the Key deer population is unique in having this long-term mortality dataset. During the screwworm incident, these deer mortalities continued to be recorded, and in many cases, cause of death was listed as euthanasia though presence of screwworm infection was noted. The decline in screwworm infestations post-November suggests the impact of doramectin treatments, application of sterile flies, and decline in rutting behavior is likely resulting in a decline in the screwworm infestation for the Key deer population (Figure 3).

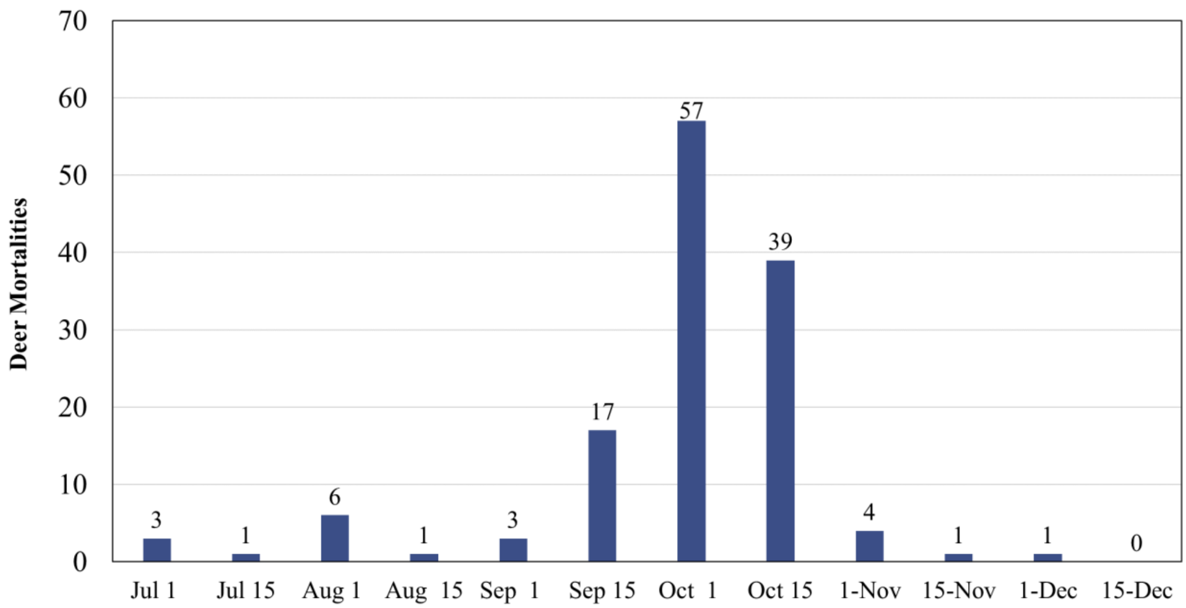

Figure 3. Screwworm mortalities in Key deer by 2-week intervals, July 2016-present.

POPULATION STATUS

Population metrics presented as potential indicators of Key deer population status suggests the Key deer population is stable and above PVA management thresholds. These indicators include mean encounter rate (Figure 1), monthly deer density (Figure 2), and screwworm mortalities (Figure 3), and allow comparison of population trends to PVA thresholds described in response plan (Lopez et al. 2016).

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GLOSSARY OF TERMS

Data items:

n - number of observed objects (single or clusters of animals)
L - total length of transect line(s)
k - number of samples
K - point transect effort, typically K=k
T - length of time searched in cue counting
ER - encounter rate (n/L or n/K or n/T)
W - width of line transect or radius of point transect
x(i) - distance to i-th observation
s(i) - cluster size of i-th observation
r-p - probability for regression test chi-p- probability for chi-square goodness-of-fit test

Parameters or functions of parameters:

m - number of parameters in the model
A(I) - i-th parameter in the estimated probability density function(pdf)
f(0) - 1/u = value of pdf at zero for line transects
u - W*p = ESW, effective detection area for line transects
h(0) - 2*PI/v
v - PI*W*W*p, is the effective detection area for point transects
p - probability of observing an object in defined area
ESW - for line transects, effective strip width = W*p
EDR - for point transects, effective detection radius = W*sqrt(p)
rho - for cue counts, the cue rate
DS - estimate of density of clusters
E(S) - estimate of expected value of cluster size
D - estimate of density of animals
N - estimate of number of animals in specified area Detection Fct/Global/Model Fitting

NOVEMBER 2016

```
 Effort        :    542.2499
 # samples     :    30
 Width         :    100.0000
 # observations:    567

Model  1
    Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
       Results:
       Convergence was achieved with    8 function evaluations.
       Final Ln(likelihood) value =  -2258.2750
       Akaike information criterion =   4518.5498
       Bayesian information criterion =   4522.8906
       AICc =   4518.5566
       Final parameter values:   26.000554
Model  2
    Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
    Cosine adjustments of order(s) :  2
       Results:
       Convergence was achieved with   14 function evaluations.
       Final Ln(likelihood) value =  -2212.2518
       Akaike information criterion =   4428.5034
       Bayesian information criterion =   4437.1841
       AICc =   4428.5249
       Final parameter values:   32.005360     0.63834050
      Detection Fct/Global/Parameter Estimates


Estimation Summary - Encounter rates

                         Estimate      %CV     df     95% Confidence Interval
                        -----------------------------------------------------
-
 Stratum: 1. BPK
                n       489.00
                k       15.000
                L       477.75
                n/L     1.0235        8.81    14.00 0.84756       1.2361
                Left    0.0000
                Width   100.00
 Stratum: 2. NNK
                n       78.000
                k       15.000
                L       64.500
                n/L     1.2093       14.32    14.00 0.89094       1.6414
                Left    0.0000
                Width   100.00
```

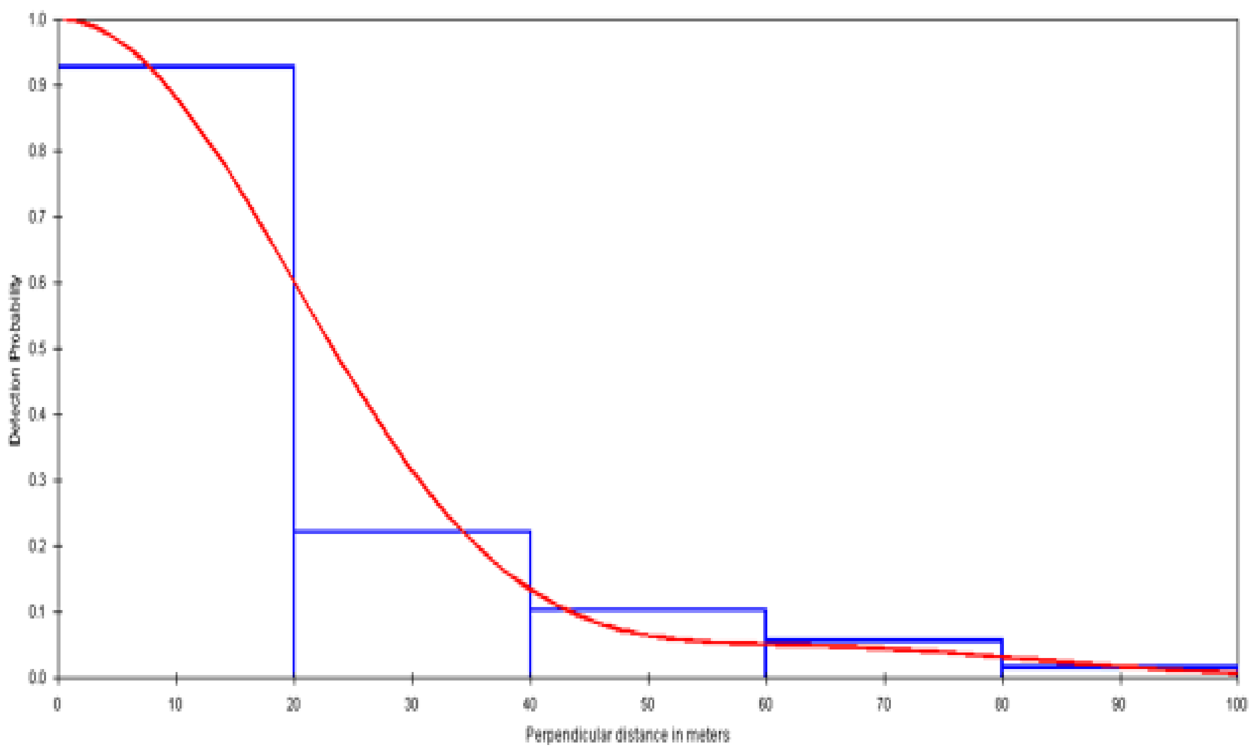
Estimation Summary - Density&Abundance

		Estimate	%CV	df	95% Confidence Interval	
Stratum: 1. BPK						
Half-normal/Cosine						
	DS	0.19321	9.17	16.43	0.15919	0.23449
	D	0.28162	9.42	18.24	0.23121	0.34302
	N	726.00	9.42	18.24	596.00	884.00
Stratum: 2. NNK						
Half-normal/Cosine						
	DS	0.22827	14.54	14.90	0.16768	0.31077
	D	0.33273	14.70	15.54	0.24389	0.45394
	N	164.00	14.70	15.54	120.00	224.00

Estimation Summary - Density&Abundance

Pooled Estimates:

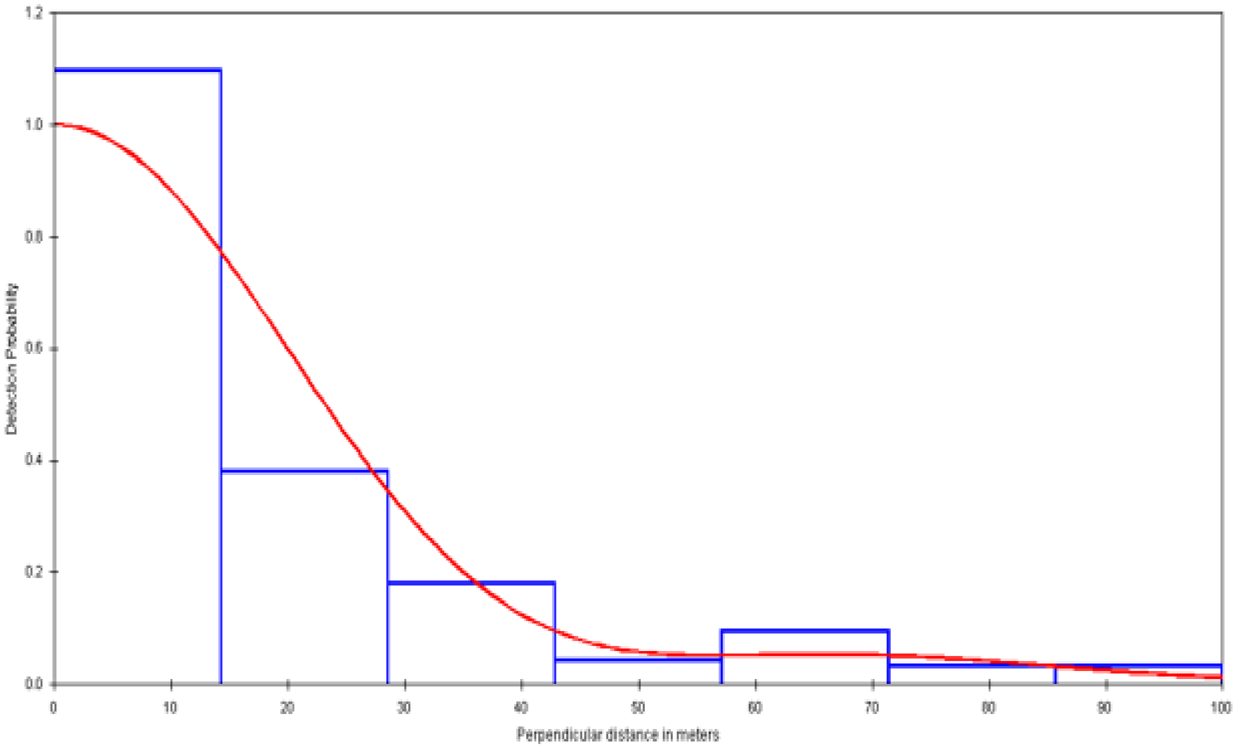
	Estimate	%CV	df	95% Confidence Interval	
DS	0.19884	8.07	21.83	0.16823	0.23502
D	0.28983	8.35	24.96	0.24413	0.34408
N	890.00	8.35			



DECEMBER 2016

```
Effort        :    144.6000
# samples     :      8
Width         :    100.0000
# observations:   176

Model  1
   Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
      Results:
      Convergence was achieved with    4 function evaluations.
      Final Ln(likelihood) value =  -710.38600
      Akaike information criterion =   1422.7720
      Bayesian information criterion =   1425.9425
      AICc =   1422.7949
      Final parameter values:   27.458410

Model  2
   Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))
   Simple polynomial adjustments of order(s) :  4
      Results:
      Convergence was achieved with   19 function evaluations.
      Final Ln(likelihood) value =  -705.63942
      Akaike information criterion =   1415.2788
      Bayesian information criterion =   1421.6198
      AICc =   1415.3481
      Final parameter values:   23.746187      9.6639173
     Detection Fct/Global/Model Fitting


Estimation Summary - Encounter rates

                         Estimate      %CV     df     95% Confidence Interval
                        -----------------------------------------------------
-
 Stratum: 1. BPK
                n       146.00
                k       4.0000
                L       127.40
                n/L     1.1460        3.95     3.00  1.0105       1.2996
                Left    0.0000
                Width   100.00
 Stratum: 2. NNK
                n       30.000
                k       4.0000
                L       17.200
                n/L     1.7442        8.61     3.00  1.3270       2.2926
                Left    0.0000
                Width   100.00
```

```
Estimation Summary - Density&Abundance

                        Estimate      %CV     df     95% Confidence Interval
                        ----------------------------------------------------
-
 Stratum: 1. BPK
 Half-normal/Cosine
                 DS      0.21634        6.18    17.29 0.18995       0.24641
                 D       0.30356        7.26    32.38 0.26191       0.35182
                 N        782.00        7.26    32.38  675.00        907.00
 Stratum: 2. NNK
 Half-normal/Cosine
                 DS      0.32927        9.83     5.10 0.25627       0.42307
                 D       0.46201       10.54     6.73 0.35961       0.59356
                 N        228.00       10.54     6.73  177.00        293.00

Estimation Summary - Density&Abundance

 Pooled Estimates:
                        Estimate      %CV     df     95% Confidence Interval
                        ----------------------------------------------------
-
                 DS      0.23448        5.98    34.50 0.20770       0.26471
                 D       0.32900        7.08    65.92 0.28566       0.37891
                 N        1010.0        7.08    65.92  877.00        1163.0
```



Detection Probability
Perpendicular distance in meters