HURRICANE IMPACTS ON KEY DEER IN THE FLORIDA KEYS

ROEL R. LOPEZ,[1] Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA
NOVA J. SILVY, Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843, USA
RONALD F. LABISKY, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA
PHILIP A. FRANK, U.S. Fish and Wildlife Service, National Key Deer Refuge, Big Pine Key, FL 33043, USA

Abstract: The landing in the Florida Keys of Hurricanes Georges (Category 2) in 1998 and Irene (Category 1) in 1999, in combination with an ongoing radiotelemetry study of Florida Key deer (*Odocoileus virginanus clavium*), offered a unique opportunity to evaluate the impacts of natural disturbances on Key deer. We relocated 53 deer (female, $n = 29$; male, $n = 24$) during Hurricane Georges and 45 deer (female, $n = 27$; male, $n = 18$) during Hurricane Irene. One adult male drowned due to Hurricane Georges (<2% of radiomarked deer); no deaths were attributed to Hurricane Irene. A comparison of productivity estimates between years found a significant ($P < 0.001$) increase in fawn:doe estimates for post-hurricane years (1999–2000) as compared to pre-hurricane years (1995–1998). The mean fawn:doe ratio observed during 1995–1998 was 0.31. The mean fawn:doe ratio observed during 1999–2000 was 0.64. We found no significant difference in mean daily distances moved by deer between hurricane and non-hurricane years. However, we observed significantly larger ranges (95% probability area) and core areas (50% probability area) for both males and females following Hurricane Georges. Fifteen water holes were monitored monthly following Hurricane Georges, and due to the storm surge, 27% (4/15) of these water holes were found to be unsuitable for deer use (salinity > 15 ppt). In some cases, water-hole suitability did not improve until several weeks or months later. Our study suggests that mild to moderate hurricanes (Category 1–2) have little direct impact on the survival of Key deer; however, stronger storms (>Category 3) might have a greater impact due to stronger winds and greater storm surges (>3.5 m).

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The endangered Florida Key deer, the smallest subspecies of white-tailed deer in the United States, are endemic to the Florida Keys on the southern end of peninsular Florida, USA (Fig. 1; 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 estimated deer population on Big Pine Key (BPK) and No Name Key (NNK; Lopez 2001). Reports indicate that hurricanes or tropical storms might have a negative impact on the Key deer population (Klimstra et al. 1974, Silvy 1975, Seal and Lacy 1990), which currently numbers about 482 on BPK (406) and NNK (76; Lopez 2001). Hurricanes have been a major natural disturbance affecting coastal areas in the United States, particularly in the Caribbean islands (Boose et al. 1994, Ross et al. 2000). The role of hurricanes on the flora and fauna of the Florida Keys is of interest due to the relatively high frequency of tropical storm occurrences and the low land elevations (<3 m), that make these islands susceptible to storm surges (Folk 1991, Ross et al. 2000). At the landscape level, hurricanes have the potential to reshape shorelines, cause extensive damage to vegetation in forested areas, and change hydrological properties (Boose et al. 1994, Ross et al. 2000). Potential impacts of hurricanes on deer populations include direct mortality and/or a reduction in herd productivity (Folk 1991, Labisky et al. 1999). Additionally, storm impacts also include changes to vegetation communities (windthrown trees, broken branches,

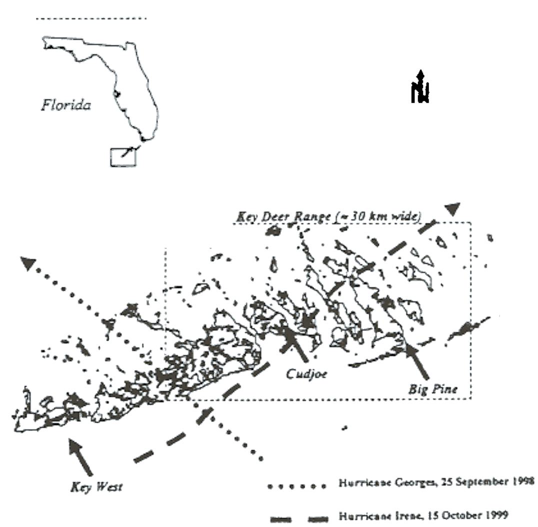

Fig. 1. Direction of passage of Hurricanes Georges and Irene in the Florida Keys, USA.

[1] E-mail: roel@tamu.edu

defoliation) and a decrease in freshwater availability. In the case of the latter, freshwater is a limiting factor for Key deer, and a significant storm surge might limit the amount of freshwater available in the form of natural water holes (Folk 1991).

Since 1968, researchers and biologists have studied the population ecology of the federally protected and endangered Key deer herd. Hurricanes, though a rather common occurrence in the Keys, have rarely passed through the narrow range (<30 km) of the Key deer population (Lopez 2001). The last significant storm that landed in the lower Keys was Hurricane Donna in 1960 (Category 2, Saffir-Simpson scale; Neumann 1991). In January 1998, a research project was initiated to evaluate the current status of the Key deer population. In September 1998, the center of Hurricane Georges (Category 2) passed through the lower Florida Keys within the Key deer range (Fig. 1; Guiney 1998, Lopez 2001). In October 1999, a less substantial storm, Hurricane Irene (Category 1), also landed directly within the Key deer range (Fig. 1; Avila 1999, Lopez 2001). The landing of these 2 hurricanes, in concert with the ongoing radiotelemetry study, offered a unique opportunity to evaluate the impacts of violent natural disturbances or catastrophes to an island deer population. An understanding of deer mortality and movements and impacts to natural resources such as vegetation and freshwater would aid in developing strategies to manage and recover this endangered deer population. Furthermore, such information also would be useful in the implementation of a Population Viability Analysis (PVA) being proposed for the Key deer (Boyce 1992, Akçakaya 2000, Lopez 2001). Our objectives were to (1) determine post-hurricane deer mortality immediately following the storm; (2) compare herd productivity in hurricane and non-hurricane years; (3) evaluate deer monthly ranges, core areas, and mean daily movements during hurricane and non-hurricane years; and (4) determine changes in freshwater availability due to the associated storm surge.

STUDY AREA

The Florida Keys are a chain of continuous small islands that stretch approximately 200 km southwest from peninsular Florida. Big Pine Key (2,548 ha) and NNK (461 ha) are within the boundaries of the NKDR, Monroe County, and 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 (*Rhisophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erecta*) forests. With increasing elevation, tidal areas transition into hardwood (e.g., Gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipulaa*]) and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) forests whose vegetation are intolerant of salt water (Dickson 1955). From 1960 to 2000, approximately 24% of native areas have been developed on BPK and NNK (Lopez 2001).

METHODS

Radiotelemetry

Key deer were radiomarked as part of a research project during January 1998–December 1999 on BPK and NNK. Key deer were captured and radiomarked using portable drive nets (Silvy et al. 1975), drop nets (Lopez et al. 1998), and hand capture (Silvy 1975, Lopez 2001). Captured deer were radiomarked using plastic neck collars (8-cm wide) for females, leather antler collars (0.25-cm wide) for yearling and adult males, and elastic expandable neck collars (3-cm wide) for fawns. A battery-powered, mortality-sensitive radiotransmitter (150–152 MHz, 100–110 g for plastic neck collars, 10–20 g for antler transmitters and elastic collars; Advanced Telemetry Systems, Isanti, Minnesota, USA) was attached to collar material. In addition, each captured animal received an ear tattoo that served as a permanent marker (Silvy 1975).

Key deer were monitored via radiotelemetry before and after Hurricanes Georges and Irene. Radiomarked deer were monitored 6–7 times/week at random intervals. Each 24-hr period was divided into 6 4-hr segments. During 1 randomly selected 4-hr segment, all deer were located (Silvy 1975). Deer locations were determined primarily via homing (≈98%) due to the high number of roads (≥155 km roads/2,500 ha; Lopez 2001). In most cases, deer locations were placed within a 1-ha block of habitat. Deer locations were then recorded on geo-referenced maps and transferred into a Geographical Information System (GIS) using ArcView (Version 3.2) and Microsoft Access (Version 97).

Productivity Estimates

U.S. Fish and Wildlife Service (USFWS) biologists conducted fall spotlight counts (5–8 surveys annually, first week of October, 1995–2000) along a standard route on BPK (56 km) and NNK (3 km) beginning at 2000–2100 hr (Humphrey and Bell 1986, Lopez 2001). These surveys provided the refuge with an index to population size and also served as the official survey route for NKDR (Humphrey and Bell 1986, USFWS 1999). With the aid of spotlights, 2 observers in a vehicle (average travel speed, 16–24 km/hr) recorded the number of deer observed along the route in addition to sex and age (fawn, yearling, adult) estimates (Humphrey and Bell 1986). The starting and ending points for the survey route were identical each time. A fawn:adult doe ratio was calculated from survey data. Data were pooled between islands due to the small contribution of observed animals on NNK (<5% of roads surveyed were on this island).

Water Availability

Freshwater has long been believed to be an important factor for Key deer survival (Folk 1991). Past studies report that Key deer can drink brackish water up to 15 ppt (Klimstra et al. 1974, Folk 1991). In January 1988–June 1990, Folk (1991) conducted a comprehensive study evaluating the distribution and quality of freshwater resources (i.e., natural water holes) throughout the Key deer range. Folk's (1991) data were used to identify suitable freshwater resources for Key deer and served as water-hole salinity benchmarks due to the absence of hurricanes during this period (1988–1990). The selection of water holes used in our study was based on (1) the availability of historic records (Folk 1991) from the NKDR, and (2) water holes that were suitable for Key deer (<15 ppt) based on these historic averages. First, we identified water holes with a minimum of 6 measurements during the period of interest (Sep–Feb). Because water salinity might be affected by many factors such as precipitation, water-hole characteristics (i.e., size, depth), and season (Folk 1991), we also attempted to identify water holes with long-term trend data that included natural fluctuations in water salinity throughout the year. From this review, we identified water holes that were considered suitable to Key deer (<15 ppt) during the sampling period. Fifteen water holes met our criteria, representing approximately 5% (15/276) of the total available water holes (Lopez 2001) and included the following islands: Big Pine ($n = 13$), Middle Torch ($n = 1$), and Big Torch ($n = 1$). Following the landing of Hurricane Georges, water-hole salinity for these 15 water holes was measured and recorded monthly using a Yellow Springs Instrument (YSI) conductivity/salinity meter (Model 33, YSI, Yellow Springs, Ohio, USA) until salinity returned to or below the historic average or the study ended. Water-hole salinity following Hurricane Irene was not measured due to the insignificant storm surge (<0.5 m) associated with that storm (Avila 1999).

Water-hole locations (upland vs. lowlands) were compared to determine water-hole susceptibility to a storm surge based on elevation. We categorized water-hole locations by general vegetation types based on elevations: (1) *lowlands*—maritime zones (≤1 m above mean sea level) comprised of mangrove and buttonwood forests, and (2) *uplands*—nontidal areas (>1 m above mean sea level) comprised of hammocks, pinelands, and freshwater wetlands (Lopez 2001).

Data Analysis

Mortality.—We determined percent direct mortality due to each hurricane from radiomarked deer by dividing the number of radiomarked deer that died in each storm (1 week post-storm) by the total number of radiomarked deer alive prior to the storm (1 week pre-storm). We excluded deer deaths that occurred during the 1-week post-storm period that were non-hurricane related (e.g., deer killed on highway) from the analysis.

Movements.—We calculated Key deer ranges (95% probability area) and core areas (50% probability area) using a fixed-kernel home-range estimator (Worton 1989; Seaman et al. 1998, 1999) with the animal movement extension in ArcView (Version 2.2; Hooge and Eichenlaub 1999). Calculation of the smoothing parameter (kernel width) as described by Silverman (1986) was used in generating kernel range estimates.

Ranges (ha), core areas (ha), and mean daily movements (m) were calculated by sex for a 3-week period following Hurricane Georges. We pooled Key deer movements by age-class due to small sample sizes (White and Garrott 1990). Hurricane Georges occurred on 25 September 1998; therefore, Key deer ranges, core areas, and mean daily distances moved were calculated from 26 September to 15 October 1998 and compared to 26 September–15 October 1999 (non-hurricane year). Movement data could not be extended beyond 15 October 1999 because of potential bias in overlap with Hurricane Irene. Ranges and movements for Hurricane Irene could not be compared due to the earlier occurrence of Hurricane Georges. Differences in Key deer ranges, core areas, and mean daily movements were tested using an ANOVA, and Tukey's Honestly Significantly Different (HSD) for multiple comparisons was used to separate means when F-values were significant ($P < 0.05$; Ott 1993).

Productivity.—Mean productivity, derived from fawn:adult doe ratio estimates in October, were determined by year 1995–2000. We defined productivity estimates between 1995–1998 as non-hurricane years and 1999–2000 as hurricane years. Impacts due to Hurricane Georges and Irene would not be measurable in the population until 1999–2000. Differences in productivity estimates among years were tested using an ANOVA, and Tukey's HSD for multiple comparisons was used to separate means when F-values were significant ($P < 0.05$; Ott 1993).

Water Availability.—Water salinity measurements following Hurricane Georges were compared to available historic salinity measurements (1988–1990, non-hurricane years; Folk 1991). For each unique water hole, observed average salinity post-Hurricane Georges was compared to historic averages using a 2-sample t-test (Folk 1991, Ott 1993). We defined water-hole unsuitability as an increase in average salinity above 15 ppt. We determined the percentage of fresh water holes that were unsuitable for deer (>15 ppt) due to the storm surge. Furthermore, water-hole locations (upland vs. lowlands) also were evaluated to determine water-hole susceptibility to a storm surge based on elevation.

RESULTS

Hurricanes

Hurricane Georges.—The center of Hurricane Georges made landfall on 25 September 1998 near Key West, Florida, with minimum central pressure of 981 mb and maximum sustained 2-min winds of 178 km/hr. Strongest recorded winds and storm damage occurred between Cudjoe Key and BPK (Fig. 1; Guiney 1998). The estimated storm surge on BPK was approximately 1.75 m. Rainfall associated with Georges was low; Key West recorded only 21 cm of rainfall (Guiney 1998).

Hurricane Irene.—The center of then Tropical Storm Irene crossed Havana, Cuba on 14 October 1999. Irene reached hurricane status over the Florida Straits, with the center of the storm moving northeast of Key West, Florida, on 15 October 1999. Hurricane Irene continued in a northeasterly track, crossing the northern half of BPK (Avila 1999). A minimum central pressure of 986 mb, maximum sustained 2-min winds of 127 km/hr, and a storm surge of approximately 0.5 m above normal were recorded for Hurricane Irene on BPK. Rainfall recorded in Key West was 22 cm (Avila 1999).

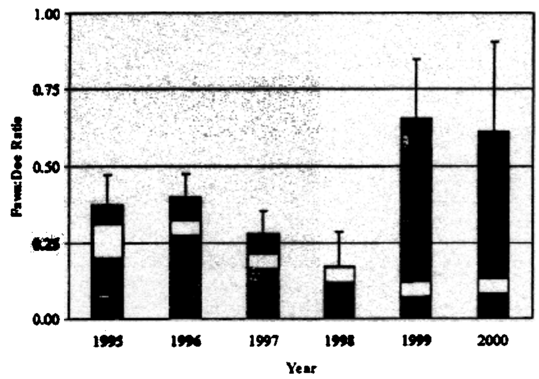

Fig. 2. Mean annual fawn:adult doe ratios from U.S. Fish and Wildlife Service October fall counts of Florida Key deer, 1995–2000 (Florida Keys, USA). Vertical lines represent standard deviation. Comparisons followed by the same letter are not significantly different ($P > 0.05$).

Mortality

We monitored 53 (female, $n = 29$; male, $n = 24$) radiomarked Key deer during Hurricane Georges and 45 (female, $n = 27$; male, $n = 18$) during Hurricane Irene. During Hurricane Georges, 1 adult male (2% of radiomarked sample) drowned due to the storm. No radiomarked deer died as a result of Hurricane Irene.

Productivity

We conducted 42 surveys during October 1995–2000, within a range of 5–8 surveys/year. A comparison of October productivity estimates among years revealed a significant ($P < 0.001$) increase in fawn:adult doe estimates during 1999–2000 (Fig. 2). The mean fawn:doe ratio observed for 1995–1998 was 0.31, whereas the mean fawn:doe ratio observed in post-hurricane years (1999–2000) was 0.64.

Movements

We used 100 (females, $n = 66$; males, $n = 34$) Key deer to calculate movements (ranges, core areas, daily distances) during Hurricane Georges (Table 1). The mean number of locations used to calculate ranges, core areas, and mean daily movements was 15 (SD = 3, range = 10–21). As expected, ranges, core areas, and daily distances differed ($P < 0.05$) between sexes for both storm events (Table 1). No significant difference ($P > 0.076$)

Table 1. Key deer mean daily distances (m), and 95% and 50% ranges (ha) for non-hurricane (NH) and hurricane (H) years in the Florida Keys, USA, 1998–1999.

	Sex	Year[b]	n	$\bar{x}$	SD	Tests[a] Sex	Tests[a] Year
Hurricane Georges							
Distance	Female	NH	24	268	99	A	A
	Male	NH	13	431	277	B	A
	Female	H	25	310	195	A	A
	Male	H	21	552	230	B	A
	$F_{1,2}$					21.94	2.73
	P					0.000	0.103
95% Area	Female	NH	24	30	26	A	B
	Male	NH	13	88	96	B	B
	Female	H	25	60	78	A	A
	Male	H	21	184	150	B	A
	$F_{1,2}$					19.77	6.88
	P					0.000	0.010
50% Area	Female	NH	24	6	6	A	B
	Male	NH	13	16	19	B	B
	Female	H	25	10	14	A	A
	Male	H	21	29	24	B	A
	$F_{1,2}$					16.83	4.53
	P					0.000	0.036

[a] Comparisons followed by the same letter are not significantly different ($P > 0.05$).
[b] Hurricane Georges occurred on 25 Sep 1998; therefore, deer movements were calculated 26 Sep–15 Octr 1998 (3 weeks, hurricane year) and compared to 26 Sep–15 Oct1999 (non-hurricane year).

was found in comparing mean daily distances before and after for both storm events. However, significantly ($P = 0.036$–0.010) larger ranges and core areas were observed for both males and females following Hurricane Georges (Table 1).

Water Availability

In reviewing historic water-hole salinity data, all 15 water holes, representing approximately 5% (15/276) of the total available water holes (Lopez 2001), were suitable (<15 ppt) for Key deer prior to Hurricane Georges (Table 2). Following Hurricane Georges, water salinity measurements for 27% (4/15) of water holes were unsuitable for deer use (Table 2). Many water holes were not only unsuitable immediately following the storm but also remained so several weeks or months later (Fig. 3). Fifty percent (3/6) of monitored water holes found within lowland areas were impacted by the storm surge, whereas 11% (1/9) of upland water holes were impacted. All water holes affected by the storm surge eventually returned to their historic average.

DISCUSSION

Mortality

Results from the study revealed that Key deer mortality due to hurricanes was low (<2%). Three major forces contribute to damage caused by a hurricane: winds, storm surge, and rain (Labisky et al. 1999). Winds and storm surges are of particular concern in the Keys due to the low elevation of these islands (highest point < 3 m), thus, storm surges can negatively impact flora and faunal communities. To illustrate, many areas occupied by Key deer were submerged due to the storm surge of Hurricane Georges for several hours (R. R. Lopez, personal observation). Many smaller islands that support small deer populations, such as Munson Island or Annette Key, were completely inundated. Previous studies have noted that Key deer are strong swimmers (Folk 1991), which suggests that Key deer might have been forced to tread water until the storm surge subsided. Few studies on the impacts of hurricanes on white-tailed deer populations exist; however, Labisky et al. (1999) reported 100% survival for radiomarked white-tailed deer in the Everglades during the aftermath of Hurricane Andrew (Category 4, 242 km/hr wind) in 1992. Results from our study suggest that mild to moderate hurricanes (Category 1–2) have little direct impact on the Key deer population, but we propose that stronger storms (>Category 3) would have a greater impact due to stronger winds and greater storm surge (>3.5 m; Neumann 1991). For example, a moderate Category 3 hurricane with a storm surge of 4 m would

Table 2. Water salinity (ppt) for 15 selected water holes within the Key deer range pre- and post-Hurricane Georges, Florida Keys, USA, 1988–1990 and 1998.

			Pre-storm[a]			Post-storm[a]			
Island	Hole no.	Elevation	n[b]	$\bar{x}$	SD	n[b]	$\bar{x}$	SD	P[c]
							24.00	6.91	0.000*
							11.88	6.94	0.090
							19.00	7.02	0.053*
							19.70	12.3	0.041*
							15.40	11.9	0.210*
							11.17	6.24	0.071
							5.37	1.60	0.007
							3.63	4.00	0.049
							3.00	2.45	0.210
							3.50	0.54	0.010
							7.57	3.41	0.092
							5.71	2.69	0.066
							9.17	1.47	0.940
							1.63	0.74	0.920
							7.57	2.64	0.002

[a] Pre-storm is defined as water salinity data from historical records (Folk 1991) collected in 1988–1990; post-storm data were collected following Hurricane Georges in 1998 and compared to historic averages.
[b] Number of water samples (monthly readings).
[c] Asterisk represents water holes that were suitable pre-storm (average salinity < 15 ppt) that became unsuitable (average salinity > 15 ppt) for Key deer following the storm. Pair-wise comparisons of average salinities for water holes 3 and 6 did not differ; however, some monthly readings during the 8-month post-storm period were unsuitable for Key deer.

result in the complete submersion of BPK and NNK. These 2 islands support most (approx. 75%) of the Key deer population and provide most (approx. 51%) of the freshwater sources (Lopez 2001). Greater deer mortality and impact to deer resources (e.g., vegetation and freshwater) would be expected with more severe storms.

Productivity

We found that Key deer productivity nearly doubled following Hurricane Georges on BPK and NNK. Most of the overstory component was reduced by approximately 50% due to strong winds and windthrown trees (R. R. Lopez, personal observation). This reduction in the overstory may have resulted in both an immediate and long-term effect in the amount of food available to Key deer. The reduction in the overstory may have caused (1) a short-term increase in the amount of forage available from windthrown trees and/or broken branches, and (2) a long-term increase in re-growth or sprouting that provided additional forage for Key deer. Other studies have reported an increase in understory vegetation following tropical storms or hurricanes (Ross et al. 1997, 1998; Wallace 1998). Perhaps the increase in herd productivity was due to an increase in the overall fitness of female Key deer resulting from higher food availability prior to the breeding season (Verme and Ullrey 1984).

Results from our study differed from Labisky et al. (1999), who reported a decrease in the productivity of Everglades white-tailed deer (*O. v. seminolus*) following Hurricane Andrew. A possible explanation for this difference might be that vegetation types in the Florida Everglades consist primarily of wet prairie with limited to no overstory (Miller 1993, Labisky et al. 1999). Conversely, dense hammocks and open pineland characterize upland vegetation types in the Florida Keys (Folk 1991, Lopez 2001). In the case of hardwood hammocks, strong winds opened the dense forest canopy, which in turn resulted in a flush of new understory growth (R. R. Lopez, personal observation). Such results would not be expected in the Everglades ecosystem due to the lack of a forest canopy.

Movements

Deer movements (ranges, core areas, daily distances) were compared by year and sex to determine effects of hurricanes on the Key deer population. As expected, differences in ranges, core areas, and daily distances were found between sexes. This difference is well documented (Marchinton and Hirth 1984, Beier and McCullough 1990, Demarais et al. 2000) and attributed to behavioral differences between sexes. In general, males have greater ranges and move greater distances. We found no significant difference in

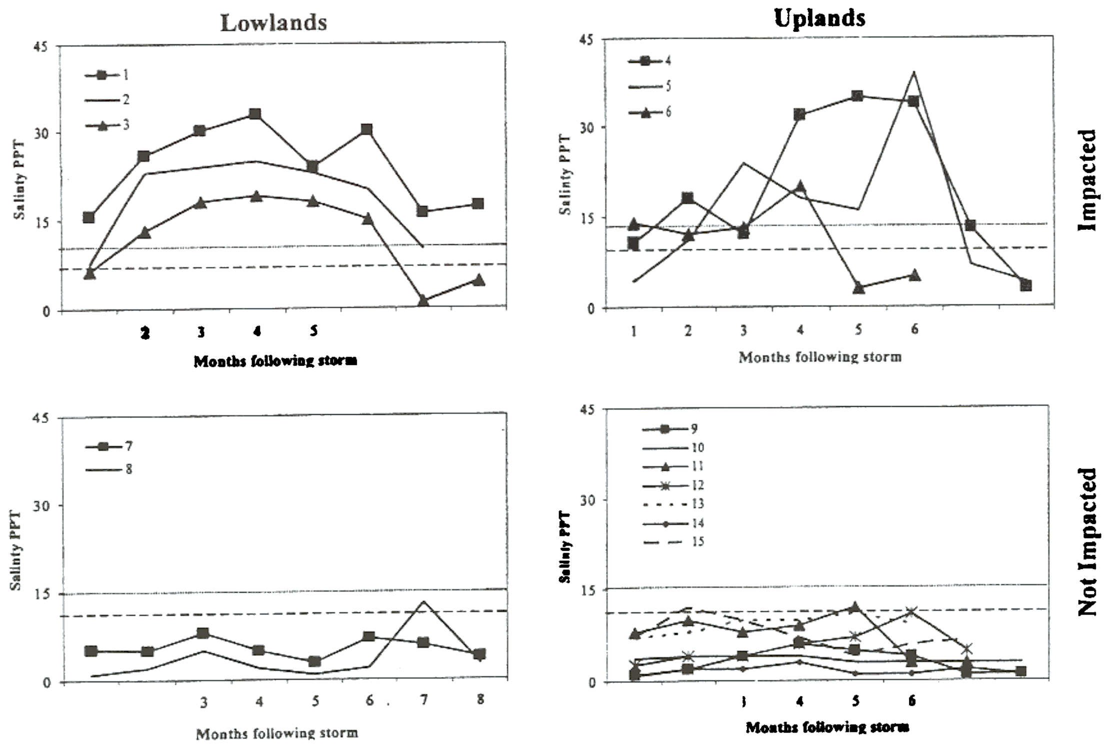

Fig. 3. Salinity measurements for water holes found in the lowlands (figures on left) and uplands (figures on right) that were impacted (top figures) and not impacted (bottom figures) by the storm surge during Hurricane Georges, Big Pine Key, USA, 25 September 1998. Horizontal lines represent maximum average salinity (long dashed line) and standard deviation (short dashed line) for water holes in a given figure from historic data (1988–1990). Water-hole suitability for Key deer use is 15 ppt (Folk 1991).

comparing mean daily distances among years for both storm events; however, significantly larger ranges and core areas were observed for both males and females following Hurricane Georges. Two reasons might explain the increase in ranges for both sexes. First, heavy machinery used to clean up following the aftermath of Hurricane Georges might have disrupted or disturbed normal movement patterns. Second, freshwater availability was reduced in lower elevations, forcing some deer to move greater distances to obtain needed freshwater. For example, freshwater in the southernmost area of BPK was scarce and likely caused Key deer to move greater distances than under non-storm circumstances (R. R. Lopez, personal observation). However, these results should be viewed with caution. Seaman et al. (1999) suggested that a minimum of 30 locations (>50 locations preferred) were needed for unbiased kernel estimates. Despite the potential sample size bias, we propose that this bias would be found in both hurricane and non-hurricane years, and differences in deer movements are relative.

Water Availability

Following the storm, water salinity measurements for 27% (4/15) of monitored water holes were found to be unsuitable for Key deer (>15 ppt). Interestingly, some water holes were suitable for Key deer immediately following the storm, becoming unsuitable several weeks or months later. Saltwater has a greater density than freshwater causing the latter to separate and form an upper lens (Folk 1991). We hypothesized that, following Hurricane Georges, rainfall quickly recharged the upper portion of water holes with freshwater. As the dry season approached several months later (Nov–Feb), however, evaporation may have increased water salinity. In some cases, water holes became hypersaline (>30 ppt, salinity of ocean water) beyond normal water-hole fluctuations with the added saltwater from the storm surge (Folk 1991). These results suggest that freshwater might not be limiting to Key deer until several weeks or months following a hurricane event.

Fifty percent (3/6) of monitored water holes found in lowlands were impacted due to the storm surge, which suggests that islands with low elevation, such as Cudjoe or Sugarloaf, might not sustain deer populations following a hurricane due to the limited availability of freshwater. If the latter supposition proves valid, it strengthens the point that larger islands such as Big Pine Key are critical to the Key deer due to the high number of fresh water holes in upland areas (Lopez 2001). Lopez (2001) reported that approximately 64% (91/142) of all permanent water holes on Big Pine, Big Torch, and Middle Torch keys were found in upland areas.

MANAGEMENT IMPLICATIONS

Key deer have survived in this island environment subject to frequent storm-related catastrophes for over 10,000 years (Hardin et al. 1984). Despite the small negative impacts to Key deer observed in our study, more severe storms (>Category 3) could be expected to have a greater impact to the deer population, as was reported by Labisky et al. (1999) following Hurricane Andrew in the Everglades in 1992. In our study, hurricanes may have actually benefited the deer population by rejuvenating plant growth.

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