Effects of Hurricane Irma on the Endangered Lower Keys Marsh Rabbit

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Abstract - *Sylvilagus palustris hefneri* (Lower Keys Marsh Rabbit [LKMR]) is an endangered subspecies of marsh rabbit found only in the Lower Florida Keys. In September 2017, Hurricane Irma was measured as a Category 4 storm when it passed through the center of the LKMR range causing significant damage to human infrastructure and natural habitats. To assess the impact of Hurricane Irma to LKMR and its habitat, we compared pre- and post-hurricane monitoring data. Overall, 82% of LKMR habitat patches were abandoned, the average number of pellets per sampling plot decreased 94%, and average patch pellet density decreased by 84% following Hurricane Irma. Generally, pellets were found in plots with greater open cover, an intermediate amount of herbaceous and woody cover, and areas with more standing water post-Hurricane Irma. We also observed a slight decrease in signs of *Procyon lotor* (Raccoon) and *Didelphis virginiana* (Virginia Opossum). The decrease in rabbit pellets detected after Hurricane Irma is likely attributed to both direct mortality from the storm and flooding, as well as indirect mortality from the loss of critical, salt-sensitive herbaceous cover. Because climate-change models suggest increases in future flooding and hurricane frequency, we recommend that wildlife managers continue to closely monitor the recovery of LKMR populations and their habitat to determine if more active management actions (e.g., habitat remediation, translocations, or captive breeding) are necessary.

Introduction

Sylvilagus palustris hefneri Lazell (Lower Keys Marsh Rabbit [LKMR]) is a subspecies of *S. palustris* (Bachman) (Marsh Rabbit) that was listed as endangered by the US Fish and Wildlife Service (USFWS) in 1990 under the Endangered Species Act (USFWS 1990). LKMR populations have decreased substantially over the past 50 years due to habitat loss and fragmentation, vehicle collisions, predation by feral *Felis catus* L. (Domestic Cat) and *Procyon lotor* (L.) (Raccoon), fire suppression, and severe weather events (Eaton et al. 2014; USFWS 1990, 1999, 2007). As a result, LKMR are now found only in small, fragmented populations across 4 large keys (Boca Chica, Saddlebunch, Sugarloaf, and Big Pine keys), and several smaller (outer) adjacent islands (de Pourtales 1877, Faulhaber et al. 2007).

On 10 September 2017, the eye of Category 4 Hurricane Irma passed through the center of the LKMR's range (Fig. 1). On Big Pine Key, maximum sustained winds

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were measured at 193 kph, storm surge measured 1.5–6 m above the mean high water line, and wave wash marks were as high as 6 m above the mean high water line causing extensive damage to humans, animals, property, and natural resources (NOAA 2019). Because elevation in the Lower Keys is mostly <2 m, these islands and their associated flora and fauna are highly vulnerable to storm surges (Lopez et al. 2003, Ross et al. 1992). As a result, we predicted there would be a difference in rabbit patch occupancy and associated vegetative structure before and after the landing of Hurricane Irma. The goal of our study was to describe the impact of Hurricane Irma on LKMR and their habitat. Specifically, our objectives were to describe changes in relative densities, habitat condition, and patch occupancy via pellet density and vegetative-cover measurements in LKMR habitat following the landing of Hurricane Irma.

Field-Site Description

We performed this study within the range of the LKMR from Big Pine Key south to Boca Chica Key (Fig. 2). Local vegetative communities are strongly influenced by elevation broadly transitioning from mangroves, to saltmarsh/*Conocarpus erectus* L. (Buttonwood) transition zones, and ultimately upland areas of hammocks and pinelands (Faulhaber 2003). Mangroves are dense forests dominated by *Rhizophora mangle* L. (Red Mangrove), *Avicennia germinans* (L.) L. (Black Mangrove), and *Laguncularia racemose* (L.) C.F. Gaertn. (White Mangrove), with Buttonwoods occurring at slightly higher elevations. Saltmarsh/Buttonwood transition zones are more open or grass-dominated areas with herbaceous species such as *Sporobolus virginicus* (L.) Kunth (Seashore Dropseed), *Borrichia frutescens* (L.) DC (Sea

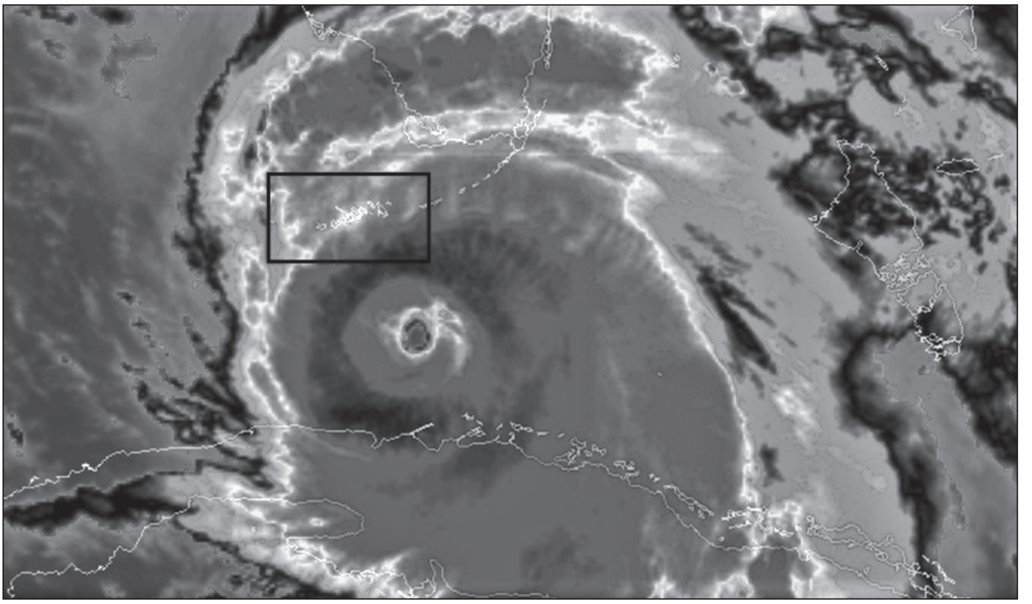

Figure 1. Hurricane Irma prior to arrival in the Lower Florida Keys (black box), September 2017.

Oxeye Daisy), *Spartina spartinae* (Trin.) Merr. ex Hitchc. (Gulf Cord Grass), and *Spartina patens* (Aiton) Muhl. (Saltmeadow Cordgrass). Hammocks and pinelands consist of primarily broadleaf, evergreen, or semi-evergreen tree species including *Metopium toxiferum* (L.) Krug & Urb. (Poisonwood), *Bursera simaruba* (L.) Sarg. (Gumbo Limbo), *Pinus elliottii* Engelm. (Slash Pine), and *Piscidia piscipula* (L.) Sarg. (Jamaican Dogwood). Although detrimental to LKMR habitat through loss and degradation, invasive exotic species such as *Schinus terebinthifolius* Raddi (Brazilian Peppertree) and *Leucaena leucocephala* (Lam.) de Wit (Lead Tree) also are found scattered through LKMR habitat patches (Faulhaber 2003, Schmidt et al. 2010). LKMR can occupy a variety of habitat communities with sufficient herbaceous cover. Specifically, preferred habitat LKMR occurs in patches of vegetation with low canopy cover, high bunchgrass density, high forb presence, and tall vegetation (Perry 2006).

The Florida Keys has a notably mild, subtropical marine climate, with mean January temperatures of 21 °C and mean July temperatures of 29 °C (NOAA 2016). Averaging 95 cm of rainfall a year, thunderstorms and showers generally occur during the wet season from late June through October, whereas the dry season, from December to April, accounts for less than 25% of the annual precipitation (NOAA NWS 2010).

Methods

Following the landing of Hurricane Irma (10 September 2017), we conducted a rapid occupancy assessment during 7–11 December 2017 for LKMR in USFWS patches which contained pellets during any of the previous 3 annual monitoring surveys (i.e., 2014, 2015, and 2017 pre-hurricane [no survey was performed in

Figure 2. Patches sampled on Sugarloaf, Cudjoe, Big Torch, Middle Torch, Little Torch, Big Pine, No Name, and Little Pine keys in Florida.

2016]; USFWS, Vero Beach, FL, unpubl. data). These past USFWS surveys were performed in the spring dry season as time and personnel were available. It was assumed that there was no difference in pellet degradation or loss during post-Hurricane Irma surveys in December because of the limited changes between seasonal climate and because surveys were timed to avoid periods of rain and flooding. This assumption was supported by the presence of many dry, old pellets observed during post-Hurricane Irma surveys. Pellet counts were used for all surveys because they are relatively quick, inexpensive, and an efficient method of monitoring patch-occupancy rates and population trends since LKMR density estimates are strongly correlated with LKMR fecal pellets per square meter (Anderson 2001, Krebs et al. 1987, Murray et al. 2002, Schmidt et al. 2011). In total, we sampled 128 circular plots (12-m diameter) within 30 patches across Big Pine, Little Pine, No Name, Sugarloaf, Cudjoe, Little Torch, Middle Torch, and Big Torch keys (Fig. 2). Patches varied in size from 0.1 to 27.0 ha (mean = 10.3 ha) and contained between 2 and 9 plots (mean = 4.3 plots) based on patch size according to the following rules: patches <6 ha = 2 plots; number of plots in patches 6–20 ha = patch size divided by 2.5 and rounded to the nearest whole number; and number of plots in patches >20 ha = patch size divided by 3.0 and rounded to the nearest whole number. Plots were dispersed ≥ 20 m apart within areas of known LKMR habitat. We used a combination of satellite imagery and researcher site experience as it is a more effective method of determining LKMR distribution and abundance (NASKW 1994). At each plot, we collected the same data that was previously collected pre-Hurricane Irma including information on patch occupation, cover and vegetation, and predator occurrence. All participants in this survey were experienced in LKMR monitoring and the methods used in this study.

Patch occupation

At each plot, we counted the number of pellets and classified them by age class and condition. We classified pellets with a diameter of 6.7 mm or larger as "adult" and smaller pellet diameters as "juvenile" (Forys 1995, Forys and Humphrey 1997). We classified pellets as "fresh" when they were shiny, consolidated, and dark brown in coloration; "old" when they were a dull and light brown in coloration; and "indeterminable" when decomposition made aging and condition classification unreliable. Finally, we also recorded incidental LKMR pellet sightings between plots. Pellets between plots were recorded as present or absent. These data were intended as a means of confirming LKMR patch occupancy, especially in patches where low pellet density might result in an occupied patch containing only plots without pellets.

Cover and vegetation

We visually estimated cover for open substrate (e.g., bare ground, organic matter, marl, muck, debris, fill), herbaceous species (e.g., Seashore Dropseed, *Andropogon glomeratus* (Walter) Britton, Sterns & Poggenb. [Bushy Bluestem], *Typha* spp. [cattails], *Salicornia* spp. [glassworts], Sea Oxeye Daisy, *Serenoa repens* (W. Bartram) Small [Saw Palmetto]), and woody species (e.g., Buttonwood, mangrove, *Pinus* spp. [pines]) within the plot to the nearest 5% (Schmidt et al. 2011). Independent of the cover estimates, we also estimated percent standing water within the plot to the nearest 5%.

Predators

We noted tracks, scat, or direct sightings of established or presumed predators including Raccoons, *Didelphis virginiana* Kerr (Virginia Opossum), and *Solenopsis invicta* Buren (Red Imported Fire Ant) both within plots and between plots. We used these data to monitor predator patch occupancy, which can be a significant limiting factor for LKMR populations (Forys and Humphrey 1999, Schmidt et al. 2010).

Data analysis

We averaged pellet and vegetation data and compared it specifically to data collected by USFWS in spring 2017 (e.g., the data collected most immediately pre-Hurricane Irma). We calculated 3 pellet statistics for each patch: patch pellet count (total of all pellets counted in a patch's plots), plot pellet mean (the patch pellet count divided by the number of plots within the patch), and patch pellet density (the patch pellet count divided by the total area of a patch's plots [pellets/m^2]) (Table 1). Finally, we used *t*-tests to statistically compare the average patch pellet count, plot pellet mean, and patch pellet density before ($n = 17$ sampled patches) and after the hurricane ($n = 30$ sampled patches) using JMP 15.0 (SAS Institute Inc., Cary, NC).

Results

Patch occupation

In our post-Hurricane Irma surveys, pellets (fresh, old, and indeterminable) were only observed on Big Pine Key within the plots of 11 of the 30 surveys patches. Patch pellet counts varied from 6 to 552 pellets/patch including 13 juvenile pellets, which we found in 2 of the 30 surveyed patches (7%). We encountered incidental adult pellets between plots within patches 2906 and 3612, the latter of which had no pellets detected within its plots. Considering both pellets within and between plots, we observed signs of rabbit occupancy in 40% ($n = 12$) of the 30 surveyed patches. Looking at all patch data ($n = 47$ surveys over the 3 years; Table 1) the number of juvenile pellets decreased 98% (741 pellets to 13 pellets). The post-Hurricane Irma patch pellet count averaged 47.80 pellets/patch (SE = 54.86) representing a decrease of 89% (422.06 pellets/patch pre-Hurricane Irma, SE = 86.15). The post-Hurricane Irma plot pellet mean averaged 8.60 pellets/plot (SE = 21.05) representing a decrease of 94% (143.91 pellets/plot pre-Hurricane Irma, SE = 27.96). The post-Hurricane Irma patch pellet density averaged 0.08 pellets/m^2 (SE = 0.08) representing a decreased of 84% (0.50 pellets/m^2 pre-Hurricane Irma, SE = 0.11). Statistical analyses showed that average patch pellet count ($t = 3.471$, $P < 0.001$, df = 45), average plot pellet mean ($t = 3.866$, $P < 0.001$, df = 45) and average patch pellet density ($t = 3.164$, $P = 0.001$, df = 45) were all significantly lower post-Hurricane Irma. Considering only patches with data from both before and after the hurricane ($n = 17$ patches), 82% of patches were abandoned post Hurricane-Irma (Table 1).

Table 1. Patches sampled and their locations (key), area (ha), number of sampling plots (n), past monitoring survey detections of pellets, pellet counts (pre- and post-hurricane), juvenile pellet counts (pre- and post-hurricane), mean number of pellets per plot (pre- and post-hurricane), and pellet density (pellets/m^2; pre- and post-hurricane). * indicates missing data. † indicates incidental pellets.

				Past detections			2017 Pellet counts		2017 Juvenile pellets		2017 Pellet means		2017 Pellet density	
Patch	Key	Area	n	2014	2015	2017	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1200	Big Pine	4.3	2			X	40	0	0	0	20.0	0.0	0.09	0.00
2002	Big Pine	19.6	6	X	X	X	1661	96	151	0	277.0	16.0	0.41	0.14
2003	Big Pine	15.6	6	X	X		*	195	*	0	*	32.5	*	0.29
2004	Big Pine	7.8	3			X	1878	66	78	0	626.0	22.0	1.85	0.19
2005	Big Pine	10.6	4	X	X		*	216	*	0	*	54.0	*	0.48
2011	Big Pine	6.0	3	X			*	38	*	0	*	12.7	*	0.11
2108	Big Pine	0.3	2			X	858	0	280	0	429.0	0.0	1.90	0.00
2109	Big Pine	18.7	8	X	X		*	32	*	0	*	4.0	*	0.04
2110	Big Pine	18.5	8	X	X		*	552	*	0	*	69.0	*	0.61
2113	Big Pine	17.8	5	X	X	X	23	0	0	0	4.6	0.0	0.01	0.00
2906	Big Pine	12.0	5	X			*	134†	*	9	*	26.8	*	0.24
3102	Big Pine	27.0	9	X	X		*	0	*	0	*	0.0	*	0.00
3103	Big Pine	20.0	7			X	255	0	0	0	36.4	0.0	0.05	0.00
3105	Big Pine	22.7	8	X	X		*	0	*	0	*	0.0	*	0.00
3501	Big Pine	13.6	4	X		X	28	0	0	0	7	0.0	0.02	0.00
3607	Big Pine	15.2	6	X	X		*	85	*	4	*	14.2	*	0.13
3610	Big Pine	10.4	3	X	X	X	223	14	7	0	74.3	4.7	0.22	0.04
3612	Big Pine	0.5	2	X	X		*	0†	*	0	*	0.0	*	0.00
3613	Big Pine	1.0	2	X	X		*	0	*	0	*	0.0	*	0.00
3614	Big Pine	7.5	3	X			*	6	*	0	*	2.0	*	0.02
3615	Big Pine	0.1	2			X	135	0	0	0	67.5	0.0	0.30	0.00
3704	Big Pine	0.1	2			X	46	0	7	0	23.0	0.0	0.10	0.00
5200	No Name	0.8	2			X	658	0	202	0	329.0	0.0	1.46	0.00
13108	Little Pine	25.3	8	X		X	199	0	16	0	24.9	0.0	0.03	0.00
13109	Little Pine	6.5	3			X	97	0	0	0	32.3	0.0	0.10	0.00
31211	Middle Torch	8.8	3			X	249	0	0	0	83.0	0.0	0.24	0.00
33403	Little Torch	0.2	2			X	10	0	0	0	5.0	0.0	0.02	0.00
34402	Big Torch	0.3	2			X	15	0	0	0	7.5	0.0	0.03	0.00
44530	Cudjoe	0.9	2			X	800	0	0	0	400.0	0.0	1.77	0.00
57402	Sugarloaf	16.4	6	X			*	0	*	0	*	0.0	*	0.00

Cover and vegetation

Overall, Hurricane Irma visibly damaged vegetative cover, with many plots showing debris, mud, and evidence of herbaceous LKMR habitat replaced with bare ground (Fig. 3). Post-Hurricane Irma, plots across the sampling range most frequently showed 5–25% open cover, 5–25% herbaceous cover, 25–50% woody cover, and 0% standing water. When comparing all plots with pellets sampled before (n = 41) and after Hurricane Irma (n = 24), our data show that after Hurricane Irma, pellets tended to occur within plots with less overall cover, intermediate herbaceous cover and woody cover, and areas with a slightly greater standing water (Fig. 4).

Predators

Post-Hurricane Irma, 9 patches had evidence of Raccoon occupancy, 2 patches had evidence of Virginia Opossum occupancy, and 1 patch had evidence of Red Imported Fire Ants. When compared to pre-hurricane surveys, our post-hurricane data indicated a slight decrease in Raccoon signs (-1 patch) and evidence of Virginia

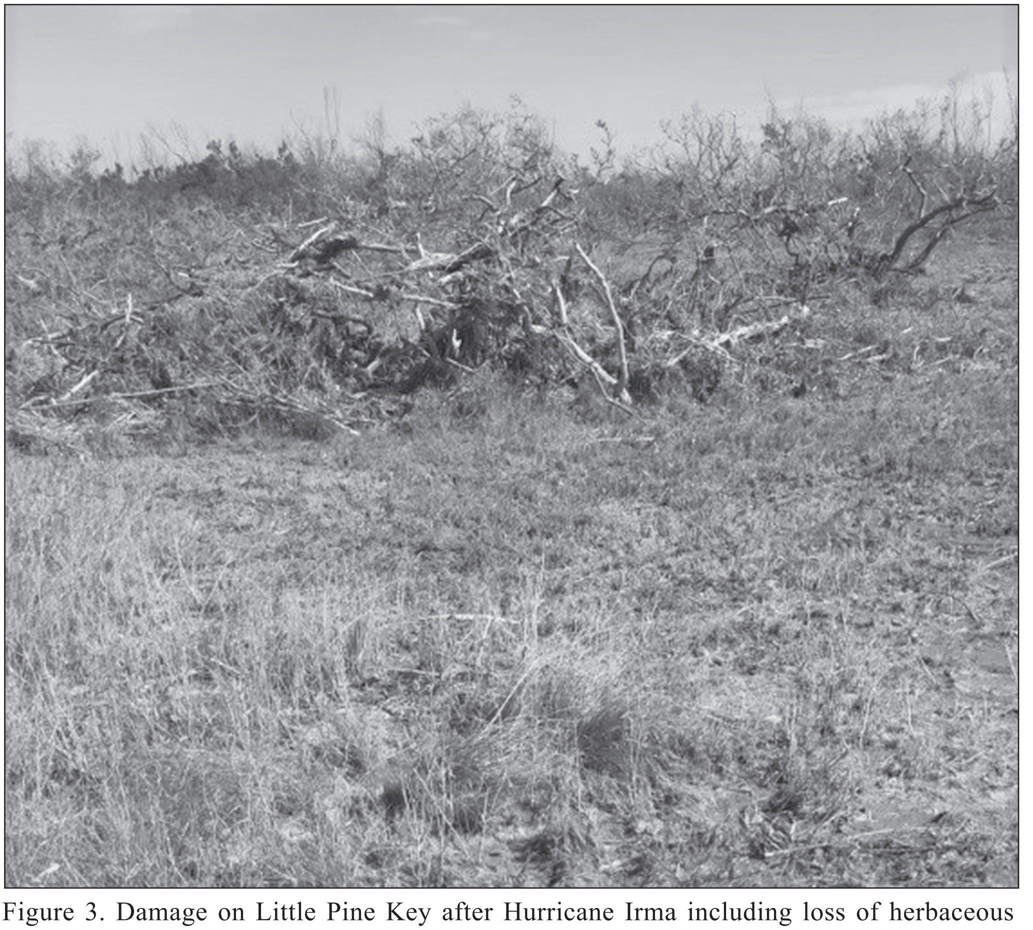

Figure 3. Damage on Little Pine Key after Hurricane Irma including loss of herbaceous cover (foreground) and accumulation of woody debris (background).

Opossum in 2 patches compared to no sign of opossum in pre-hurricane patches. Red Imported Fire Ants were seen in a single patch both before and after Hurricane Irma (Table 2).

Discussion

Overall, our results indicate substantial LKMR patch abandonment following Hurricane Irma. The decrease in rabbit pellet detection after Hurricane Irma is likely attributed to both direct mortality from the storm and flooding, as well as indirect mortality from the loss of critical, salt-sensitive herbaceous cover (Ross et al. 2009). Surviving individuals were found to use habitat with less herbaceous, more open cover, and patches with comparable numbers of predators. Though this study only describes the effects of a single hurricane, Schmidt et al. (2011) found 38% patch abandonment 6 months after landfall of Hurricane Wilma (Category 1), with concurrent research calculating 71% mortality of radio-collared rabbits (N.D. Perry, Bureau of Land Management, Farminton, NM, unpubl. data). We suspect mortality after this Category 4 Hurricane Irma was even larger given the greater winds, as well as wave wash marks measured at 6 m above mean high water line (NOAA 2019).

It is possible rabbits moved to patches not sampled, non-traditional habitat, or habitat that has not been delineated. Some patches without pre-Hurricane data (i.e., 2003, 2005, 2110) did have post-Hurricane Irma pellet densities that were similar to counts detected in the patches surveyed prior to Hurricane Irma (Table 1), but

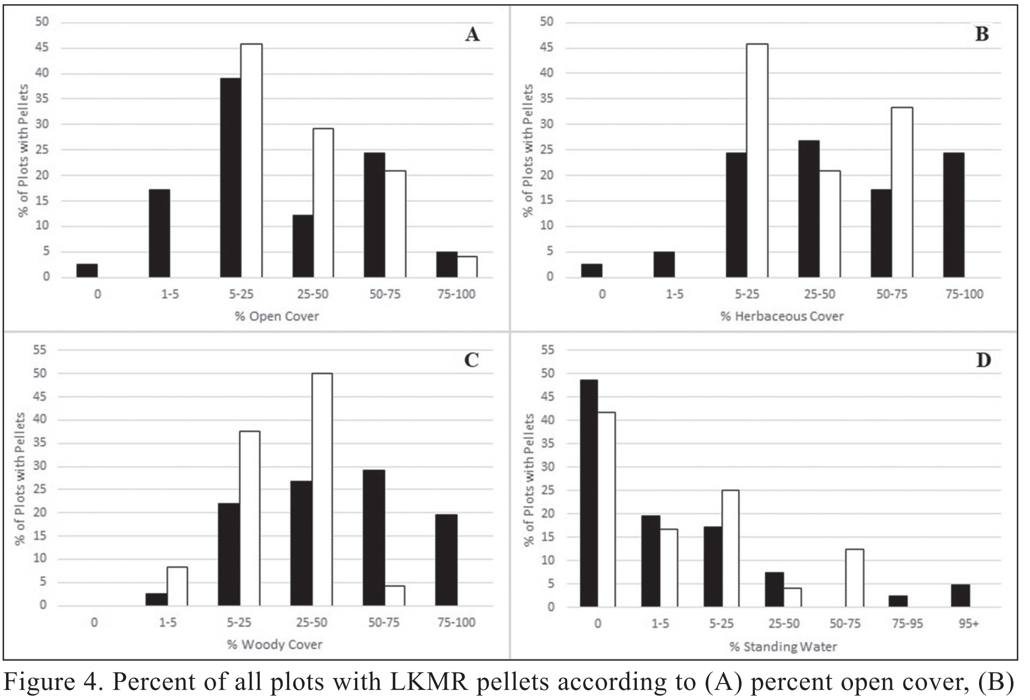

Figure 4. Percent of all plots with LKMR pellets according to (A) percent open cover, (B) percent herbaceous cover, (C) percent woody cover, and (D) percent standing water both before (black bars; n = 41) and after (white bars; n = 24) Hurricane Irma.

without pre-hurricane data we cannot definitively say this represents any change in rabbit density, including by emigration or immigration. Additionally, this study was intended as a rapid occupancy assessment. Habitat delineation last occurred more than 15 years ago (Faulhaber 2003), and LKMR management would benefit from a range-wide delineation of potential habitat patches and occupancy survey.

Climate-change models predict future increases in flooding and hurricane frequency, suggesting severe weather events will be a growing risk to LKMR survival (Hoyos et al. 2006, Ross et al. 2009). We recommend that USFWS continue to monitor the status of LKMR populations to determine changes in patch occupancy post-hurricanes. Specifically, we recommend continued annual fecal pellet counts as an index of distribution and presence or absence. This will allow biologists to monitor LKMR population and habitat recovery and better plan and evaluate the need for more aggressive management activities (e.g., translocations, habitat remediation, captive breeding).

Table 2. Patches sampled and the associated detection of predators (R = Raccoon, O = Virginia opossum, F = Red Imported Fire Ants, and M = missing data) both pre- and post-Hurricane Irma.

	2017 Predators	
Patch	Pre-hurricane	Post-hurricane
2002	R	
2003	M	
2004		
2005	M	
2011	M	
2108		
2109	M	R
2110	M	
2113		O
2906	M	
3102	M	
3103		
3105	M	R
3501	R	F, R
3607	M	R
3610		O, R
3612	M	
3613	M	
3614	M	
3615	R	
3704		
5200		
13108	F, R	R
13109	R	
31211	R	R
33403		
34402		
44530		R
57402	M	R

Predation on LKMR by native and exotic mammals, primarily Raccoons as well as free-ranging Domestic Cats, is a significant factor limiting LKMR populations (Forys and Humphrey 1999, Schmidt et. al. 2010). Forys and Humphrey (1999) noted in their study that Domestic Cat predation attributed to 53% of all LKMR mortality, killing an equal number of both adult and juvenile Marsh Rabbits. Raccoons are a significant predator of both adult and juvenile LKMR but particularly threaten nesting and neonatal rabbits (USFWS 2007). Due to the lethal relationship between predator species and LKMR, we recommend continued monitoring, and when necessary, removal of free-roaming Domestic Cats and Raccoons, in particular. This is vital as predators represent an avoidable risk to LKMR survival and removal, particularly of non-native predators, is an actionable means of supporting long-term patch occupancy. Control efforts should be coordinated to target large patches with high LKMR occupancy levels and those within LKMR dispersal ranges (Schmidt 2009). LKMR function as a metapopulation (Forys 1995; Forys and Humphries 1996, 1999), so support of large, high-occupancy patches therefore supports source populations that in turn support sink populations and their patch occupancy.

Finally, we also recommend maintenance of vegetation structure in habitat patches including supplemental replanting of native grass species and hardwood and exotic species control (Faulhaber et al. 2007). In addition to the damage caused by hurricanes, local habitats were historically maintained by periodic wildfires. Fire has been suppressed in the area since the 1950s, thereafter facilitating successional replacement of herbaceous rabbit habitat with closed-canopy woody vegetation (Harley et al. 2013, Schmidt et al. 2010). The goal of this management action should be to closely mimic the preferred habitat described by Perry (2006), which includes low canopy cover, high bunchgrass density, high forb presence, and tall vegetation.

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