Calf Depredation by the Florida panther in Southwest Florida

Final Report to the USFWS

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Martin B. Main, PhD
Associate Dean and Program Leader for Natural Resources Extension
Professor, Department of Wildlife Ecology and Conservation
University of Florida IFAS
Gainesville, FL 32611

Caitlin Jacobs, M.S. Candidate
Department of Wildlife Ecology and Conservation
University of Florida IFAS
Gainesville, FL 32611

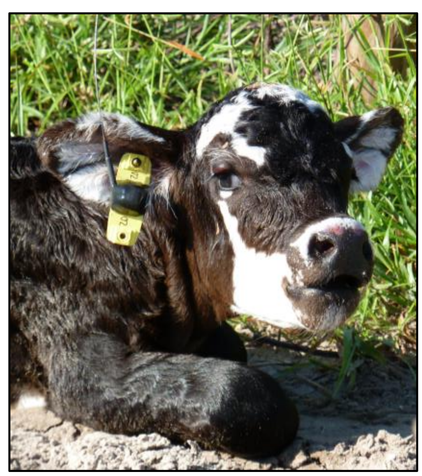

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY……………………………………………………………………………4

INTRODUCTION……………………………………………………………………………………9

STUDY AREA………………………………………………………………………………………10

CALF DEPREDATION

Methods……………………………………………………………………………………12

Results……………………………………………………………………………………13

LANDSCAPE VARIABLES, PANTHER HUNTING HABITAT, AND PREDATOR RISK

Methods……………………………………………………………………………………16

Results……………………………………………………………………………………23

DISCUSSION

Calf Depredation……………………………………………………………………28

Florida Panther Hunting Habitat Model……………………………………30

Management Implications…………………………………………………………32

LITERATURE CITED………………………………………………………………………………35

APPENDICES

Appendix I. Land cover reclassification used to calculate edge around kill sites and compare land cover characteristics of the two study areas………………………………41

Appendix II. Detailed explanation and evaluation of the species distribution model MaxEnt………………………………………………………………………………………………42

Appendix III. Landcover reclassification for MaxEnt Analysis on private lands within the Florida panther primary zone, excluding landcover classes that represented less than 1% of the study area……………………………………………………………………45

EXECUTIVE SUMMARY

Livestock depredation is an issue of growing concern in south Florida and of potential future concern in areas where breeding panther populations may eventually become established. Florida cattle ranches play a critical role in providing habitat that is needed for the conservation and recovery of the Florida panther. Approximately 53% of the northern portion of occupied panther habitat is privately owned, most of which is represented by cattle ranches. Addressing the issue of calf depredation, therefore, is important both for ranchers and for panther conservation efforts. The objectives of this study were to (1) quantify calf depredation by the Florida panther and other predators on two ranches in southwest Florida, and (2) to identify predictor variables associated with increased risks of calf depredation by the Florida panther.

Calf Depredation

We monitored 409 calves (~100 calves/ranch/yr.) equipped with VHF ear tag transmitters during September-April 2011-12 and 2012-13 on the JB Ranch and Immokalee Ranch(IM), both of which are located in the primary zone of panther habitat in southwest Florida. Calf mortalities were evaluated for cause of death and all panther depredations were verified by the Florida Fish and Wildlife Conservation Commission (FWC). We used trail cameras at panther depredation sites to identify and confirm the predator responsible.

On JB Ranch, panthers killed four tagged calves during the first study season and six in the second study season, for an average calf loss to panthers of 5.3%/yr. On IM Ranch, one tagged calf was killed by a panther in the first study season and no tagged calves were killed by panthers in the second study season for an average calf loss to panthers of 0.5%/yr. An additional tagged calf was killed on IM Ranch by an unidentified predator we believe was a panther or a bear which, if it was a panther, would have increased the average loss to ~1.0%/yr. It is also important to note that tagged calves on the IM Ranch were intermingled with calves that were not ear-tagged with transmitters, which spread the risk of predation among tagged and untagged individuals and may have influenced depredation rates in the study herd.

Panthers killed calves (tagged and untagged) ranging from four days old and 35 lbs. to 255 days old and 350 lbs. The average weight of all depredated calves we recorded during this study was 190 lbs. The average age of tagged calves killed by panthers was 27.2 days (± 7.0). The majority of calves killed by panthers were between 0-3 months old and tagged calves killed by panthers were significantly younger than the average age of all available calves in the study herds.

In addition to panther depredation, both ranches lost one tagged calf (0.5%/yr.) over the two year study to black bears. No other predators were determined to have been responsible for calf depredations in the tagged study herds. We also recorded depredations of untagged calves found during the study on both ranches, but percent losses could not be calculated. On JB Ranch we documented seven panther depredations and one bear depredation of untagged calves in an adjacent herd. On IM Ranch we documented four coyote depredations of untagged calves. Vultures (black vultures and turkey vultures) were also suspected of killing newborn calves that were not tagged. The proportion of calves that died from non-predator sources of mortality was similar between ranches and averaged 2.5%.

Landscape Variables, Panther Hunting Habitat, and Predation Risk

We evaluated and interpreted differences in depredation rates and predation risk between ranches by quantifying and comparing landscape variables at four scales and developing a model to evaluate the quality of panther hunting habitat on private lands in areas of southwest Florida designated as the panther primary, secondary, and dispersal zones. We quantified and compared the area and distribution of landscape variables because landscape variables influence where cattle graze, where panthers hunt, and the probability of encounters between cattle and panthers. We developed a panther hunting habitat model as a tool for predicting the probability of panthers hunting in an area. We tested whether this model could predict the risk of livestock depredation by evaluating the predicted probability of panther presence at documented calf depredation locations.

The panther hunting habitat model correctly predicted documented panther locations with 99.9% accuracy. Results from the panther hunting habitat model suggest that panthers are most likely to use landscapes with low cattle densities, large forest patches, a high percentage of forest cover, small patches of improved pasture, and areas of upland forest. Panthers were more likely to use upland forests than other land cover classes. Small patches of improved pastures contained a high probability of panther presence as well, but panther use of improved pasture declines rapidly as the size of improved pasture increases, and panther GPS locations indicate most panthers are found within 90 m of cover.

Our evaluation of whether the panther hunting habitat model could predict livestock predation risk revealed that, although the model cannot predict exactly where calf depredations will occur, depredations did occur in areas where the model predicted the probability of panther presence was higher. The panther hunting habitat model, therefore, may be useful for evaluating the quality of panther hunting habitat and the corresponding risk of depredation to livestock across the landscape.

The locations of untagged calf depredations were biased towards more open areas where ranchers could find depredated carcasses, with 65% of the untagged depredations occurring in areas identified as open, low use environments. This is because untagged, depredated calves are unlikely to be found unless they are killed and left in relatively open areas. All tagged calves killed by panthers in this study were cached in cover, which suggests that there could be more calves being killed in high risk environments than are being found and reported by ranchers.

The untagged calves killed in areas that were not identified as high quality panther hunting habitat might be the result of panthers opportunistically encountering and killing calves as they travel through open areas. However, it is also possible that calf depredations are not always opportunistic and that some panthers may learn to actively hunt calves, even in open pastures. The multiple kills (4) made by the adult male with a notched ear (Table 2) suggests this may be the case for some individuals. If some panthers are targeting calves as prey, livestock depredation should be greatest during the calving season, which is consistent with our findings.

Management Implications

Management techniques recommended to reduce vulnerability of calves to predators include keeping livestock bunched at high stocking rates, moving livestock around the landscape, and shortening the calving season. Implementing high stocking rates and moving livestock around the landscape on large Florida cattle ranches would increase the logistical and financial challenges of commercial cattle production, such as more fencing, labor, and the creation of larger improved pastures to support higher densities of cattle. Whether these intensive management practices are a viable option for ranches in south Florida is beyond the scope of this study, but converting forest and other land cover to improved pasture to implement anti-predator management strategies would eliminate important habitat for panthers and their prey and would be detrimental to panther conservation and recovery efforts. Whether it is practical for a Florida cattle ranch to shorten its calving season is also beyond the scope of this study, but most large cattle operations in Florida aim for a calving season that ranges from 90-150 days. The length of calving seasons are dictated by the extensive management system and the cattle breeds adapted to the Florida climate, which tend to have a less synchronized breeding season than breeds adapted to northern climates.

Compensation programs for livestock depredation have proven challenging to implement successfully and many compensation programs for livestock loss require verification of depredations. This type of program will be problematic in Florida where ranch management practices, the landscape, and the prey caching behavior of panthers make it difficult if not impossible to verify depredation events.

Programs that do not involve verifying kills are more applicable to Florida, such as those that use a Payment for Ecosystem Services (PES) strategy. In a PES program, the landowner is compensated based on some performance criteria related to conservation goals. A conservation incentives program modeled using a PES design may provide a mechanism for compensating cattle operations for real or potential calf losses because it would not require verification of depredations and instead could be based on actions that contribute to conservation goals, such as the amount of panther habitat maintained and managed on a ranch. Our panther hunting habitat model provides two important measures; it quantifies high quality panther habitat and provides a measure of predation risk to calves. There are various ways that this sort of information could be incorporated into a PES program. For one, payments could be scaled based on the amount of high quality/risky habitat on a ranch, which would reward high quality habitat while compensating ranchers for the risk associated with maintaining that habitat. Additionally, hunting habitat and predation risk values could be used as a means of prioritizing or categorizing ranches for participation in compensation programs or eligibility for mitigation funds.

If panther conservation and recovery is dependent on maintaining suitable habitat on cattle ranches, strategies designed to compensate and incentivize landowners for managing landscapes conducive to panther conservation will promote conservation efforts. The panther hunting habitat model provides a means to evaluate the likelihood of panther presence on privately owned lands as well as a means of evaluating the risk of livestock depredation and as such may prove a useful tool for prioritizing and categorizing private lands for participation in a PES incentive payment program.

INTRODUCTION

The conflict between large carnivores and humans is a global issue that has become an important aspect of large carnivore conservation. Livestock depredation is often the principal reason for this conflict and is one of the driving forces behind the worldwide decline of large carnivores (Karanth & Chellam 2009; Nelson 2009; Ripple et al. 2014). While compensation and mitigation programs have been established around the world to address the issue of livestock depredation, some of the most common programs are highly criticized (Zabel & Holm- Muller 2008). It is therefore important to evaluate new approaches to compensation and mitigation programs in order to conserve and, where needed, recover large carnivore species.

Once found throughout the southeastern United States, the federally endangered Florida panther (*Puma concolor coryi*) is now restricted to less than 5% of its historic range in south Florida due to habitat loss, prey decline, and past attempts to eradicate panthers in the early 1900's (USFWS 2008). During the 1980's the panther population was thought to be as low as 20-30 adults, but due to recent recovery efforts the population is now believed to range from 100-180 panthers that are of breeding age (FWC 2014). Panther population growth has led to an increase of panthers on private lands, resulting in an increase of verified calf (*Bos taurus*) depredations by panthers on ranchlands in south Florida (Land et al. 2011).

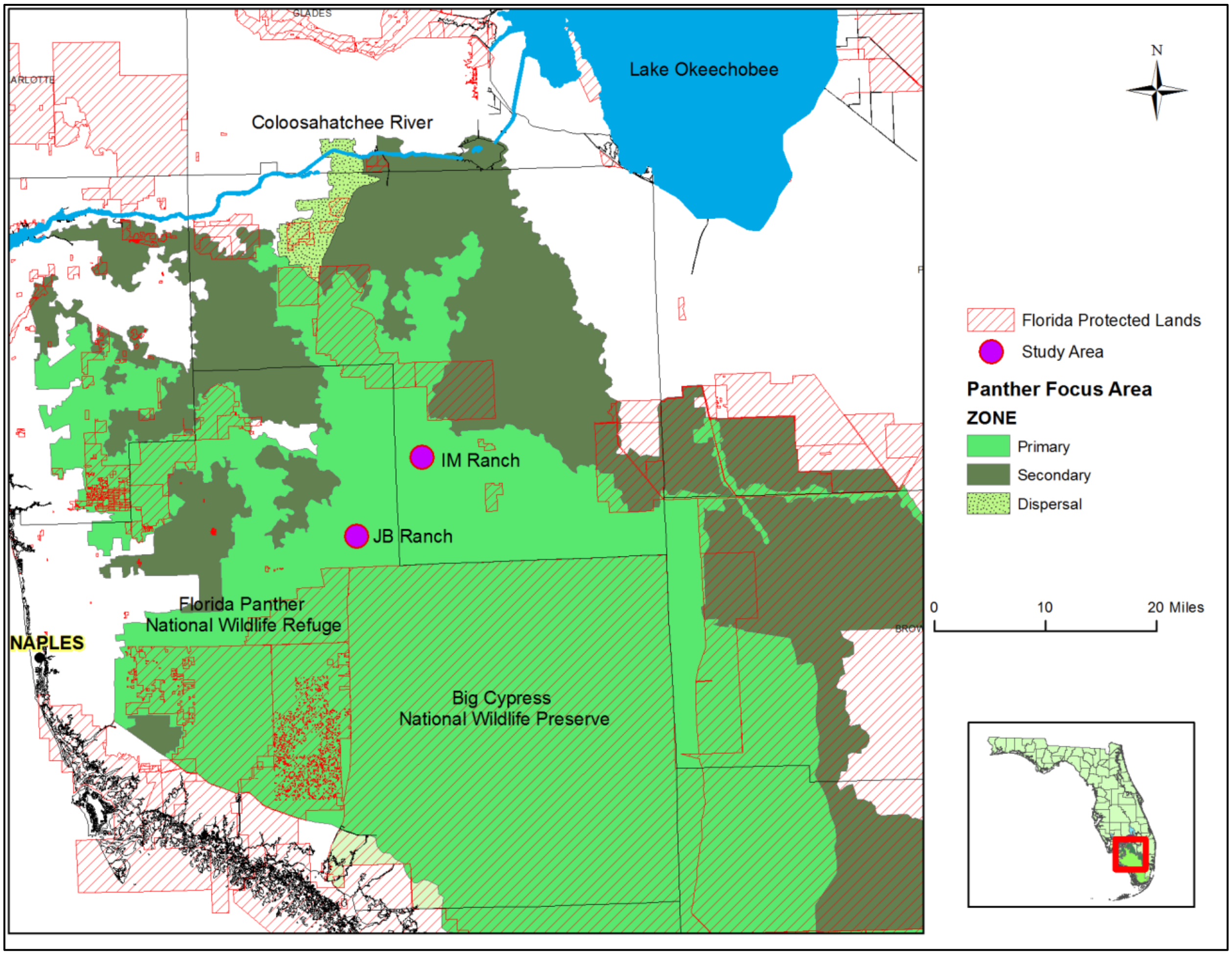
Calf depredation by Florida panthers was first documented in the late 1980's on ranches during a diet study conducted by the Florida Fish and Wildlife Conservation Commission (FWC) (Maehr et al. 1990). In 2010, FWC biologists began to verify calf depredations reported by cattle ranchers, but panthers hide their kills so many kills may go unreported. Livestock depredation is an issue of growing concern in south Florida and of potential future concern in areas where breeding panther populations may eventually become established. This is because the Florida cattle industry supports a vast network of businesses and is an important part of the state's cultural heritage (Florida Cattlemen's Association 2010). Wildlife agencies are also concerned about livestock depredations because cattle ranches and other privately-owned working landscapes and natural areas play a critical role in providing habitat that is needed for the conservation and recovery of the Florida panther. Privately owned land in south Florida encompasses approximately 27% and 60% of primary and secondary panther habitat, respectively, and the designated panther dispersal zone is almost entirely privately owned (Kautz et al. 2006; D. Land, FWC, personal communication).

Collectively, approximately 53% of occupied panther range is privately owned, most of which is represented by cattle ranches (Logan et al. 1993). Cattle ranches in south Florida are low-intensity land use operations and typically support a mosaic of different land cover types (forests, wetlands, grasslands) that provide habitat for the Florida panther and other wildlife. Consequently, cattle ranches provide essential habitat to the Florida panther and panther recovery efforts would suffer if calf depredation dissuaded ranchers from maintaining natural areas or resulted in land conversion to higher intensity agricultural production. Addressing the issue of calf depredation is, therefore, important to both ranchers and to the successful conservation and recovery of the Florida panther. To understand the potential impact of panthers on the ranching industry and help inform potential mitigation strategies, the objectives of this study were to (1) quantify calf depredation by the Florida panther and other predators on two ranches in southwest Florida, and (2) to identify predictor variables associated with increased risks of calf depredation by the Florida panther.

STUDY AREA

We monitored calves on two large commercial beef ranches, the JB Ranch (JB) and the Immokalee Ranch (IM), both of which are located within the primary zone of panther habitat (Kautz et al. 2006) in southwest Florida (Fig. 1).

Figure 1. Location of the JB Ranch (JB) and Immokalee Ranch (IM) study areas in the Florida panther habitat Primary Zone (high quality panther habitat) in southwest Florida.



Both study ranches are primarily engaged in raising cattle and support a mosaic of land uses including improved and unimproved pastures, hardwood hammocks, various wetland communities, and row crops. The JB Ranch covers 3,652 ha (9,000 ac) and contains 3,013 ha (7,445 ac) of cattle grazing land and 467 ha (1,154 ac) of farmland leased for growing tomatoes (R. Priddy, JB Ranch, personal communication). The IM Ranch encompasses 24,281 ha (60,000 ac) and contains 20,639 ha (51,000 ac) of cattle grazing land and 3,642 ha (9,000 ac) of farmland leased for growing tomatoes (B. Stoner, IM Ranch, personal communication). Study herds were associated with specific study areas on each ranch and these differed in size between ranches (JB: 268 ha, [661 ac]; IM: 913 ha, [2,257 ac]). White-tailed deer (*Odocoileus virginianus*) and other prey species of the Florida panther occurred on both ranches. In addition to the Florida panther, predator species found on the ranches included black bears (*Ursus americanus*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and alligators (*Alligator mississippiensis*). Black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*), both of which are reported to contribute to calf loss, occurred on both ranches.

CALF DEPREDATION

Methods

To quantify calf depredation we monitored 409 calves (n = ~100/ranch/yr.) during September-April 2011-12 and 2012-13 on the JB and IM ranches. All calves were ear-tagged within a few days of birth with 20 g VHF radio transmitters containing a mortality switch (Advanced Telemetry Systems, Isanti, Minnesota, USA). We obtained visual records of each tagged calf every other day until calves were rounded up in March-April for branding and marking, during which time ear tags were removed. Calf mortalities were evaluated for cause of death and the ages and estimated weights of calves that died were recorded. All panther depredations were verified by the FWC and calves that died of unknown causes were necropsied by the Bronson Animal Disease Diagnostic Laboratory in Kissimmee, Florida. We placed at least two trail cameras (Bushnell Trophy Cam) at each panther depredation site to identify and confirm the predator responsible.

The number and timing of calves tagged, the percentage and age structure of tagged calves in each study herd, and total monitoring effort differed between ranches due to differences in study herd sizes and ranch management practices. On JB Ranch, we tagged 100% of the calves in the study herd during each field season (n = 190 calves total). Calves were born and tagged over a period of approximately five months from September-February, which resulted in a study herd of tagged calves of different ages and weights as the field season progressed. Calves in the JB study herd were monitored for 31 weeks each field season during September-April 2011-12 and 2012-13.

The IM Ranch study herd was larger and we tagged approximately 30% of the total number of calves present in the study herd during each field season (n = 219 calves total). All calves tagged on IM Ranch were born during November-December, which resulted in a study herd of tagged calves of similar ages and weights as the field season progressed. The IM study herd was monitored for 23 weeks during November 2011-April 2012 and 16 weeks during November 2012-March 2013.

Results

The numbers and percentages of tagged calves that died due to depredation by panthers, other predators, and non-predation mortalities over the entirety of the study are summarized for both ranches in Table 1.

Table 1. Total number of calf mortalities, causes of death, and average values (%) documented for radio-tagged domestic calves on the JB Ranch and IM Ranch study areas in southwest Florida over two study seasons during September-April 2011-12 and 2012-13.

Study Site	Number of Tagged Calves	Number and Percentage (%) of Calves that Died	Cause of Death			
			Florida Panther	Black Bear	Unknown Predator	Non-Predation
JB	190	19 (10%)	10 (5.3%)	1 (0.5%)	0 (0.0%)	8 (4.2%)
IM	219	8 (3.7%)	1 (0.5%)	1 (0.5%)	1 (0.5%)	5 (2.3%)

On JB Ranch, panthers killed four tagged calves during the first study season and six in the second study season. This represented an average calf loss to panthers of 5.3%/yr. and accounted for 53% of total calf mortality and 90% of all predation events in the study herd over the two years on JB Ranch. On IM Ranch, one tagged calf was killed by a panther in the first study season and no tagged calves were confirmed as killed by panthers in the second study season. This represented an average calf loss to panthers of 0.5%/yr. and accounted for 13.5% of total calf mortality and 33% of all predation events in the tagged study herds over the two years on IM Ranch. One additional tagged calf was killed on IM Ranch by an unidentified predator that we believe was either a panther or a bear based on the size of the calf that was killed, but the predator responsible could not conclusively be determined because vultures destroyed the carcass before the calf could be evaluated. If the depredation was a panther, this would increase the panther depredation rate to ~1.0%/yr. on IM Ranch.

Calf loss to panthers over both years was significantly higher ($X^2_1 = 8.981$, $p = 0.003$) on JB Ranch than IM Ranch. However, it is important to note that tagged calves on the IM Ranch were intermingled with calves without ear-tag transmitters, which spread the risk of predation among tagged and untagged individuals and may have influenced depredation rates in the study herd. In addition to panther depredation, both ranches lost one tagged calf (0.5%/yr.) over the two year study to black bears. No other predators were responsible for calf depredations in the tagged study herds.

We also recorded depredations of untagged calves found during the study on both ranches, but percent losses of untagged calves could not be calculated because depredations may also have occurred among untagged calves that went undetected. On JB Ranch we documented seven panther depredations and one bear depredation of untagged calves that were located in a herd adjacent to our study herd. On IM Ranch we documented four coyote depredations of untagged calves located within the study area. Vultures (black and turkey vultures) were suspected of killing newborn calves that were not tagged, but it was not possible to determine whether calves had been killed by the vultures or if they were simply being scavenged.

Predators killed calves of different ages and weights (Tables 2 & 3). Panthers killed tagged calves ranging from four days old and 35 lbs., to 72 days old and 180 lbs. (avg. = 94 lbs.). Untagged calves killed by panthers ranged from 10 days old and 80 lbs. to 255 days old and 350 lbs. (avg. = 210 lbs.). Combining tagged and untagged panther depredations, the average weight of depredated calves was 190 lbs. The average age of tagged calves killed by panthers was 27.2 ± 7.0 days (range 4-72). Tagged calves killed by panthers were significantly younger ($z = -2.293$, $p = 0.023$) than the average age of all available calves (68.2 ± 2.2 days; range 1 – 199) in the study herds. The majority of calves (100% of tagged and 88% of total) killed by panthers were between 0-3 months old. The majority (82%) of all panther depredations on JB Ranch occurred between September and February, which corresponds to the calving season on that ranch. Considering just the tagged calves, 90% of all panther depredations occurred between September and February.

Table 2. Calf and predator information documented for calf depredations (both tagged and untagged calves) that occurred on the JB Ranch during September 2011-April 2013.

Study Season	Tagged (Y/N)	Date	Calf Age (days)	Estimated Weight of Calf (lbs.)	Predator (Details)
1	Y	Oct. 22, 2011	20	60-80	Panther (Male-sized tracks)
1	Y	Dec. 12, 2011	25	70-80	Panther (Notched-ear male)
1	Y	Dec. 20, 2011	46	110+	Panther (Adult and juvenile females)
1	Y	Jan. 6, 2012	92	95	Panther (Notched-ear male)
2	Y	Sept. 30, 2012	5	50	Panther (Young male)
2	Y	Oct. 4, 2012	4	35	Panther (Young male)
2	Y	Nov. 30, 2012	32	90	Panther (Young male)
2	Y	Jan 1, 2013	49	180	Panther (Young male)
2	Y	Feb. 3, 2013	19	90	Panther (Notched-ear male)
2	Y	April 1, 2013	72	180	Panther
2	Y	Jan 30, 2013	72	200	Bear
1	N	July 7, 2012	255	350	Panther
1	N*	June 11, 2012	255	325	Panther
2	N	Dec. 10, 2012	72	180	Panther
2	N	Dec. 14, 2012	7	60	Bear
2	N	Dec. 27, 2012	90	200	Panther
2	N	Jan. 22, 2013	53	180	Panther
2	N	Feb. 17, 2013	<2	80	Panther (Notched-ear male)
2	N	Feb. 24, 2013	87	160	Panther

* Tags came off in April, but ear slit indicated that calf had originally been part of study herd.

Table 3. Calf and predator information documented for calf depredations (both tagged and untagged calves) that occurred on the IM Ranch during September 2011-March 2013.

Study Season	Tagged (Y/N)	Date	Calf Age (days)	Estimated Weight of Calf (lbs.)	Predator (Details)
1	Y	Nov. 23, 2011	6	50-60	Panther (Male)
1	Y	Jan. 30, 2012	80	195	Bear
1	Y	Feb. 5, 2012	68-73	180	Panther or Bear
1	N	Nov. 21, 2011	2	60	Coyote
1	N	Nov. 25, 2011	2	60	Coyote
1	N	Feb. 20, 2012	< 7	70	Coyote
2	N	Dec 4th 2012	<14	70-80	Coyote

Calf losses on the two ranches also occurred due to causes other than predators, such as health issues and abandonment. The proportion of calves that died from all non-predator sources of mortality was similar between ranches. On JB Ranch, total tagged calf loss from non-predation sources was four calves each year, with an average loss of 4.2%/yr. However, three of these deaths were either thought or known to be influenced by this study (two abandonments and one newborn struck by vehicle). Excluding these three calf mortalities, the total loss from non-predation sources among tagged calves was 2.6%/yr. On IM Ranch, total loss among tagged calves from non-predation sources was four calves in the first year and one calf in the second year, with an average loss of 2.3%/yr. Total tagged calf loss from all sources over both years was 10% on JB Ranch and 3.7% on IM Ranch, and was significantly higher ($X^2_1 = 6.647$, $p = 0.010$) on JB Ranch.

LANDSCAPE VARIABLES, PANTHER HUNTING HABITAT, AND PREDATION RISK

Methods

We evaluated and interpreted differences in depredation rates and predation risk between ranches by quantifying and comparing landscape variables at four scales and developing a model that evaluated the quality of panther hunting habitat on private lands in areas designated as the primary, secondary, and dispersal zones

(Kautz et al. 2006) in southwest Florida. We quantified and compared the area and distribution of landscape variables because landscape variables influence where cattle graze, where panthers hunt, and the probability of encounters between cattle and panthers. We developed a panther hunting habitat model as a tool to predict the probability of panthers hunting in an area. We tested whether this model could predict the risk of livestock depredation by evaluating the predicted probability of panther presence at documented calf depredation locations.

We used ArcGIS 10.2 (ESRI, Redlands, CA) and Fragstats (McGarigal & Marks 1995) to quantify and compare landscape variables on each ranch (Table 4). We quantified and compared percent cover and mean patch size for six land cover types (upland forest, wetland forest, non-forested wetlands, shrub-brush-prairie, improved pasture, agriculture) that were created by combining appropriate land cover types from the South Florida Water Management District (SFWMD) Land Cover Landuse map 2009 (Appendix I). A seventh land cover type described as poor-stalking habitat (PSH) was also created and defined as improved pasture >90 m from forest or shrub cover based on findings that 72% of Florida panther locations occur <90 m from forest cover (Onorato et al. 2011). We also compared three landscape configuration variables (edge density, upland forest patch density, and connectivity between upland forest patches; Table 4). We chose to evaluate edge habitat because studies indicate that edge is important for ambush predators such as panthers (Laundré & Hernández 2003; Laundré & Loxterman 2007; Onorato et al. 2011). We defined edge as the boundary between areas of cover (forest and shrub/brush) and open areas (pasture and prairie). Upland forest patch density was a count of forest patches ≥0.5 ha per 100 ha. Connectivity was measured as the mean distance between upland forest patches ≥0.5 ha in size, which we measured using the Euclidean Distance Nearest Neighbor (ENN) metric in Fragstats (McGarigal & Marks 1995). We focused on upland forest in our analyses of patch density and connectivity because the Florida panther is reported to use upland forests more than other land cover types during nighttime hours, which is the primary time when panthers hunt (Beier et al. 1995; Comisky et al. 2002; Onorato et al. 2011).

Table 4. Comparison of landscape variables between the JB Ranch and IM Ranch at three scales. The Study Area scale refers to the rangeland used by the two study herds (JB = 268 ha; IM = 913 ha). The 5- and 10-km Buffer Zones refer to the size of the radii of a circle (buffer zone) surrounding each study area. Landscape cover metrics include percent cover and mean patch size (MPS). Poor Stalking Habitat was created as a separate variable and defined as improved pasture >90 m from the edge of forest or other cover. Edge was defined as the boundary between cover and open areas. Upland forest patch density quantifies the number of upland forest patches >0.5 ha/100 ha and upland forest patch connectivity provides the average (mean) distance between the center of those forest patches.

Landscape Variable	**Study Area**				**5-km Buffer Zone**				**10-km Buffer Zone**			
	JB Ranch		IM Ranch		JB Ranch		IM Ranch		JB Ranch		IM Ranch	
Landscape Cover and Configuration Variables	Cover (%)	MPS (ha)	Cover (%)	MPS (ha)	Cover (%)	MPS (ha)	Cover (%)	MPS (ha)	Cover (%)	MPS (ha)	Cover (%)	MPS (ha)
Upland Forest	20	6	14	32	10	21	8	14	9	19	10	17
Wetland Forest	5	3	12	4	32	21	20	8	34	25	21	9
Non-Forested Wetland	6	3	9	2	13	31	11	76	10	8	15	7
Shrub-Brush-Prairie	4	5	10	19	6.11	16	13	33	7	19	9	26
Improved Pasture	64	21	55	64	11	51	21	118	10	57	25	139
Agriculture	n/a	n/a	n/a	n/a	25	219	26	113	27	311	20	155
Poor Stalking Habitat	15	5	29	33	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Edge Density (m/ha)	61 m/ha		45 m/ha		29 m /ha		37 m /ha		35 m /ha		48 m/ha	
Upland Forest Patch Density (#/100 ha)	3.4/100 ha		0.4/100 ha		0.9/100 ha		1.8/100 ha		0.6/100 ha		0.9/100 ha	
Mean Upland Forest Patch Connectivity (Std. Dev.)	138 m (57)		1100 m (1627)		n/a		n/a		n/a		n/a	

Landscape variable scales included the kill site, study area, and 5- and 10-km buffer zones around the study area. The kill site was defined as a circle with a 100-m radius around the location where the depredated calf was found (cache site). This was because we could not identify the actual kill site and therefore assumed the original attack occurred within 100 m of the cache site because pumas are reported to stalk within 1-5 m of their prey for a successful attack and then drag and cache prey 0-80 m from the kill site (Beier et al. 1995; Ruth & Murphy 2009). The only landscape variable that was significant at the kill-site scale was total edge. To determine whether there was a greater amount of edge around kill sites than around random locations, we used a Wilcoxen signed rank test to compare total edge around 18 panther cache sites on JB Ranch and IM Ranch to total edge around control sites located in a random direction at a distance of 500 m from each cache site (Kunkle & Pletcher 2000).

The study area on each ranch was defined as the area within which the study herd was confined by fencing (JB = 268 ha, IM = 913 ha). The 5- and 10-km buffer zones were circular areas with 5- and 10-km radii around each study area. We analyzed the same landscape variables for the study area and buffer zones, except PSH and mean distance between forest patches were not measured at the 5- and 10-km buffer zone scales (Table 4). We used descriptive statistics to compare percent land cover type and PSH, upland forest patch density, and edge density. We compared mean patch size of different land cover types with Mann-Whitney U-tests and used the ENN metric in Fragstats to compare the mean distance and standard deviation between upland forest patches on each ranch.

To model panther hunting habitat and the probability of panther presence, we used the species distribution model MaxEnt (Phillips et al. 2006), which compares environmental variables at species location sites to the same variables at 10,000 random locations (Elith et al. 2011). Using MaxEnt we evaluated percent contribution of each variable to the model, assessed how each variable individually influenced the model, determined the variables with the highest probability of presence, and mapped the probability of presence across the landscape (see Appendix II for a detailed explanation of MaxEnt).

We defined panther hunting habitat as the habitat used by panthers between 7:00 pm-7:00 am (nocturnal habitat use) because this is when panthers are the most active and the primary time when they hunt (Beier et al. 1995; Comisky et al. 2002). We determined nocturnal habitat use by panthers in the area of interest using location data recorded from 10 GPS-collared panthers (7 males, 3 females) during 2005-2009 (FWC, unpublished data). For our model, we selected a random subset of 100 nocturnal location records per individual panther to eliminate bias from panthers that had greater numbers of location records. We excluded all points that occurred within the Okaloacoochee Slough State Forest and Corkscrew Regional Ecosystem Watershed because these conservation areas are dominated by wetlands and land cover at these locations differs substantially from private lands. To eliminate sample selection bias, we constructed minimum convex polygons around the GPS locations from each panther and selected 10,000 random points throughout this region (Phillips et al. 2009; Webber et al. 2011). Finally, we projected the panther hunting habitat map onto our area of interest, i.e., private lands within the primary, secondary, and dispersal habitat zones in southwest Florida (Kautz et al. 2006).

We used eight landscape variables in our hunting habitat model, two of which (distance from edge and land cover) had multiple subcategories (Table 5). All variables except cattle density were generated from the Cooperative Land Cover (CLC) v.2.3 Florida Natural Areas Inventory (FNAI) database and were prepared as raster maps in ArcGIS using a cell size of 10 m. We reclassified the CLC land cover categories into similar land cover classes, designated each as either cover or open environments and forested or non-forested, and excluded all land cover classes that represented <1% of the study area such as mines, urban areas, and water bodies (Appendix III). The final land cover layer included eight classes designated as upland forest, wetland forest, non-forested wetlands, shrub-brush-prairie, unimproved pasture, improved pasture, row crops, and groves (Table 5). We used a scale of 4.5 km^2 to calculate edge density, percent forest cover, and dominant land cover, because 4.5 km^2 represents the average area used by an individual panther over a 24-hour period based on location data collected every hour from 13 GPS-collared Florida panthers (3 females, 10 males) during February 2005-December 2011 (FWC, unpublished data). Cattle density data was generated by Robinson et al. (2014) who used a combination of subnational and national cattle estimates as well as predictor variables (vegetation, climate, topography, and demography) to create regional cattle density estimates in a GIS format. All variables were assessed for correlation using principal components analysis and variables were retained in the model if correlations were <0.55.

Table 5. Variables included in the panther hunting habitat model using the program MaxEnt on private lands in the panther habitat zones in southwest Florida.

Variable	Description	Hypothesis
Cattle density	# of cattle / km2	Areas of low cattle density will contain a high probability of panther presence
Distance from edge (m)	Distance in both directions from the edge between closed and open environments (forest and shrub cover = closed environment; improved pasture and prairie = open environment). Edge categories: • 10 m into closed environment • 0 m (the edge border) • 10 m into open environment • 20 m into open environment • 30 m into open environment • 40 m into open environment • 50 m into open environment • ≥60 m into open environment	Panthers use edge as a hunting environment so the probability of presence will be higher close to edge environments.
Forest edge density (km/4.5 km^2)	Forest edge defined as the line between forest polygons (upland and wetland forests) and any land cover polygon forming a natural edge with the forest (excludes urban, crops, mines). Forest edge density measured within 4.5km^2. *	Surrogate for prey abundance / availability as primary prey species (white tailed deer and hog) are considered edge species.

Forest patch size (ha)	Patch size (ha) of wetland and upland forests.	Panthers select for the smallest (0.1-1.0 ha), intermediate (5.1-10.0 ha) and largest (>1000 ha) classes of forest patch size (Onorato et al. 2011). Probability of presence will be higher in these patch sizes.
Percent forest cover	The percent of upland and wetland forests within 4.5km^2. *	Panthers select for upland and wetland forests and panthers use upland forests more than other habitat classes during nighttime hours (Onorato et al. 2011): Probability of presence will be greater in areas of high % forest cover.
Improved pasture patch size	Patch size (ha) of improved pastures.	Small patches of improved pasture that lie within a heterogeneous landscape create hunting edge for panthers and will have higher probability of presence. Large patches create areas of PSH that will have lower predation risk.
Land cover	Land cover classes reclassified from the FNAI Cooperative Land Cover database (v.2.3) • Upland forest • Wetland forest • Shrub Brush Prairie • Non-forested Wetlands • Unimproved pasture • Improved pasture • Row crops • Citrus groves	Panthers select for upland and wetland forest (Onorato et al. 2011). Predation risk will be highest in these land cover classes.
Dominant land cover	Land cover class that occurs most often within 4.5 km^2.*	Panthers on private lands may use areas that contain a high amount of human-altered landscapes.

* Scale based on average area used by panthers during a 24-hr period.

To evaluate whether our panther hunting habitat model could accurately predict nocturnal panther locations, we used the methods of Raes & ter Steege (2007) to test whether the model performed statistically better than what would be expected by chance (Appendix II). We used the logistic output of MaxEnt, which provides an estimate of the probability of presence based on the environmental variables included in the model. It is recommended that probability of presence be interpreted as an index of habitat suitability, rather than a literal interpretation of percent probability (Elith et al. 2011; Merow et al. 2013). For example, a cell with a value of 0.6 should be interpreted as having a greater chance of species occupancy than a cell of value 0.5, and not as the literal interpretation of having a 60% probability of the species occurring at the site.

To assess whether the panther hunting habitat model could be used to predict predation risk to livestock, we examined the mean probability of presence around 28 documented calf depredation (cache site) locations collected during our study and by the FWC during 2010-2014 (FWC, unpublished data). In each case, we assumed the kill took place within 100 m of each cache site (Beier et al. 1995), created circular buffers (radius = 100 m) around each cache site, and used the panther hunting habitat model to calculate the mean probability of panther presence within this area. We compared the probability of presence between tagged and untagged calf depredations using a two-sample t-test. We used a Mann-Whitney U-test to compare the probability of presence between the study areas and calculated the percent of each study area that contained greater than 50% probability of panther presence.

Results

Analyses at the kill site scale revealed that total edge habitat around kill sites ($\bar{x}$ = 274 m) was greater than the total edge habitat around paired random sites ($\bar{x}$ = 118 m) ($z = 3.196$, $p = 0.001$). Analysis of landscape variables at the study area scale indicated that the JB Ranch study area contained greater edge density, a greater percentage and patch density of upland forest, and more concentrated and evenly distributed patches of upland forest compared to the IM Ranch study area (Table 4). The JB Ranch study area also contained a greater percentage of improved pasture, but patches of improved pasture on the JB Ranch were significantly ($U = 10.0$, $z = 2.310$, $p = 0.021$) smaller than on the IM Ranch study area. Patches of improved pasture on the IM Ranch were on average three times larger than those on JB Ranch, which created significantly larger patches of PSH ($U = 10.0$, $z = -2.310$, $p = 0.021$). Mean PSH patch size on the IM Ranch study area was roughly six times larger than mean PSH patch size on the JB Ranch study area (Table 4). In addition to having larger patches of PSH, a greater percentage of the total IM Ranch study area contained PSH (29%) compared to JB Ranch (15%). At both the 5- and 10-km scales, JB Ranch contained a greater percentage of forest cover and the IM Ranch contained higher edge density and both a greater percentage and larger patches of improved pasture (Table 4).

Variables that contributed most to the panther hunting habitat model (Table 6), did so in both positive and negative ways (Fig. 2). Positive influences on panther presence included the size of forest patches and the percentage of forest cover. Forest edge density also had a positive influence until edge densities approached 3,000 m/km^2 (13 km/4.5 km^2), after which the probability of panther presence began to decline. In terms of landscape cover, panthers were most likely to use upland forest, wetland forest, and unimproved pasture, as well as areas where unimproved pastures and wetland forests were the dominant land cover class.

Negative influences on the probability of panther presence included cattle density, increasing size of improved pasture, and distance from edge habitat. As cattle density increases, the probability of panther presence decreases rapidly, especially as cattle densities exceed 30 $cows/km^2$ (~1 cow/8 ac). Likewise, as the size of improved pasture patch size increases, the probability of panther presence declines rapidly. The probability of panther presence also decreases as the distance from edge (from cover) increases, and the probability of presence decreases substantially at distances of ~40 m outside of a cover environment. The negative influences of cattle densities, increasing size of improved pasture, and distance from edge are all related because higher cattle densities require larger improved pastures, which represents poor hunting habitat as the distance from edge habitat into improved pasture increases. Conversely, small open patches near edge environments provide good hunting habitat, which is why small patches of improved pasture have a high probability of panther presence (Fig. 2).

Table 6. Percent contribution of the eight environmental variables included in the final panther hunting habitat model.

Variable	**% Contribution**
Cattle density	23.2
Forest patch size	19.5
Distance from edge	16.4
Land cover	11.8
Percent of forest	9.1
Forest edge density	8.4
Dominant land cover	8.4
Improved pasture patch size	3

The panther hunting habitat model indicated that the JB Ranch study area had a higher probability of panther presence (0.50 ± 0.16) than the IM Ranch study area (0.29 ± 0.14), and that these differences were significant ($U = 463{,}780{,}767$; $p < 0.05$) (Fig. 3). To place this in perspective, nearly half (47%) of the JB Ranch study area had a probability of >0.50 of panther presence, whereas only 3% of the IM Ranch study area had a probability of >0.50 of panther presence.

We found that the mean probability of panther presence associated with the kill site (100 m radius around cache site) differed between tagged and untagged calves. The probability of panther presence was 0.60 around tagged calves (n = 11), 0.42 around untagged locations (n = 17), and 0.50 around all locations (n = 28) (Fig.4). Depredation sites of tagged calves (0.60 ± 0.06) had a significantly greater ($t_{22} = 4.08$, p= <0.05) probability of panther presence than depredation sites of untagged calves (0.42 ± 0.16).

Figure 2. Probability of panther presence (y-axis) associated with changes in environmental variables (x-axis) as predicted by the panther hunting habitat model. UF = Upland Forest, WF = Wetland Forest, SBP = Shrub-Brush-Prairie, NFW = Non-Forested Wetland, UP = Unimproved pasture, IP = Improved Pasture, RC = Row Crops, CG = Citrus Groves.

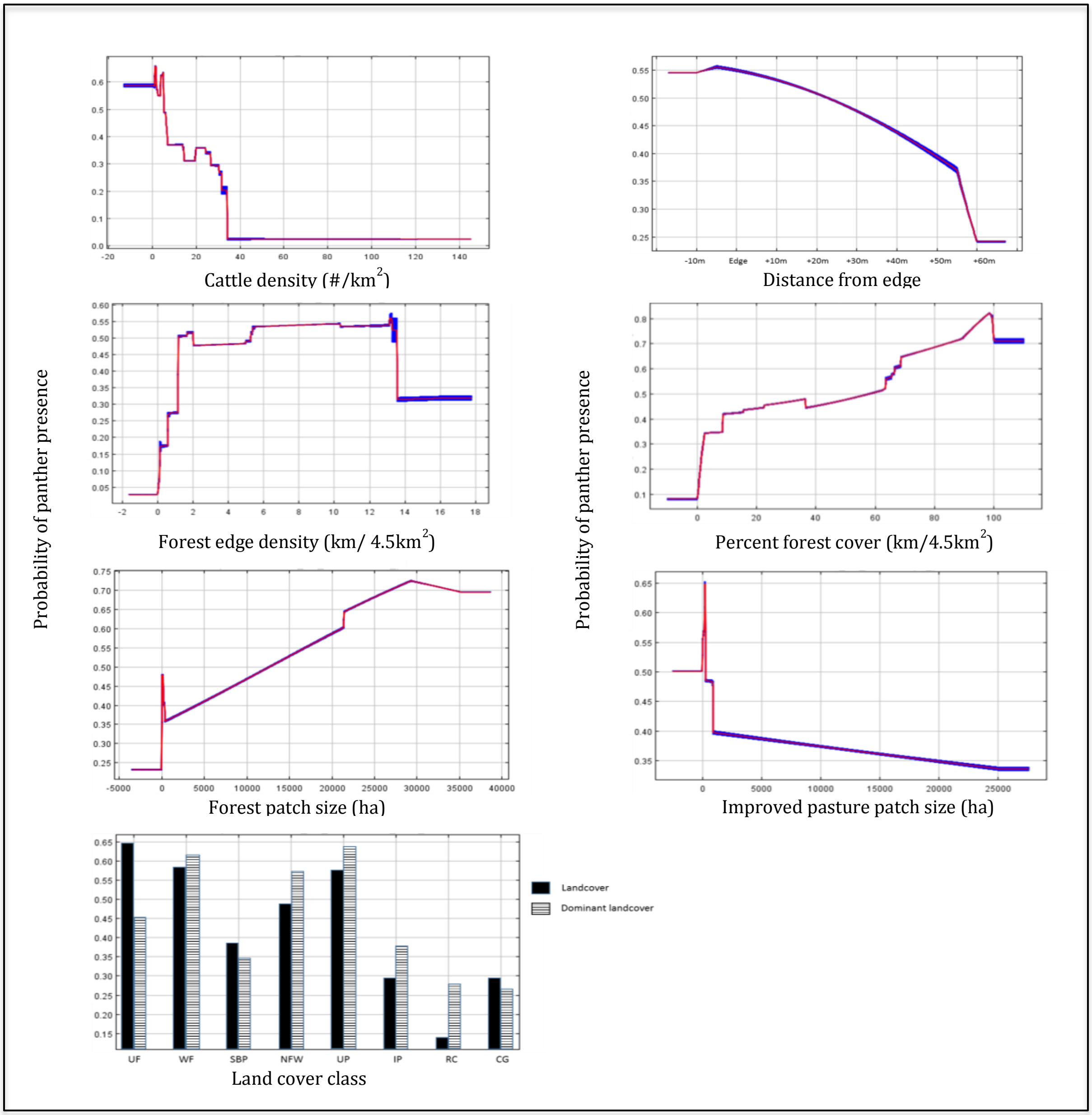


Figure 3. Florida panther hunting habitat model created with MaxEnt, showing the probability of panther presence at night on private lands within the primary, secondary, and dispersal habitat zones in southwest Florida. Inset maps display JB Ranch and IM Ranch study areas with calf depredation sites (ranch maps not to scale).

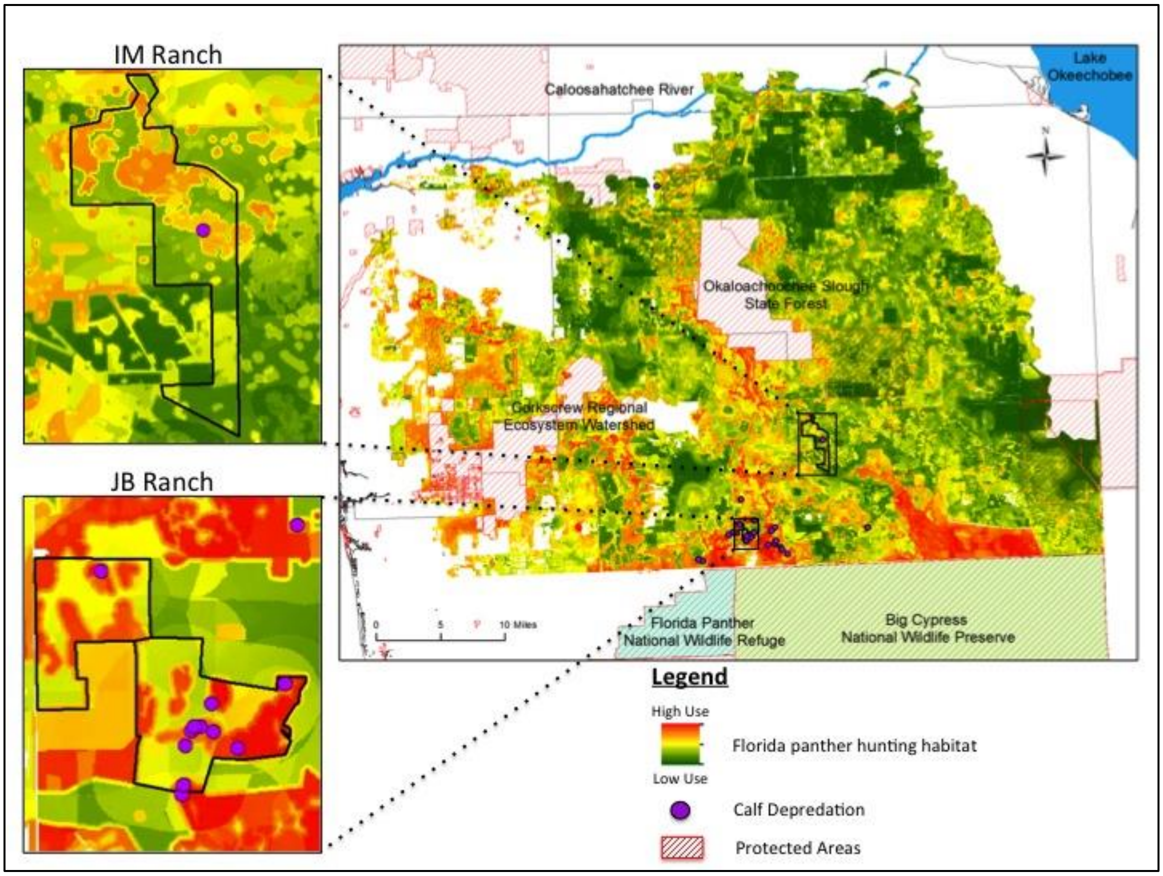
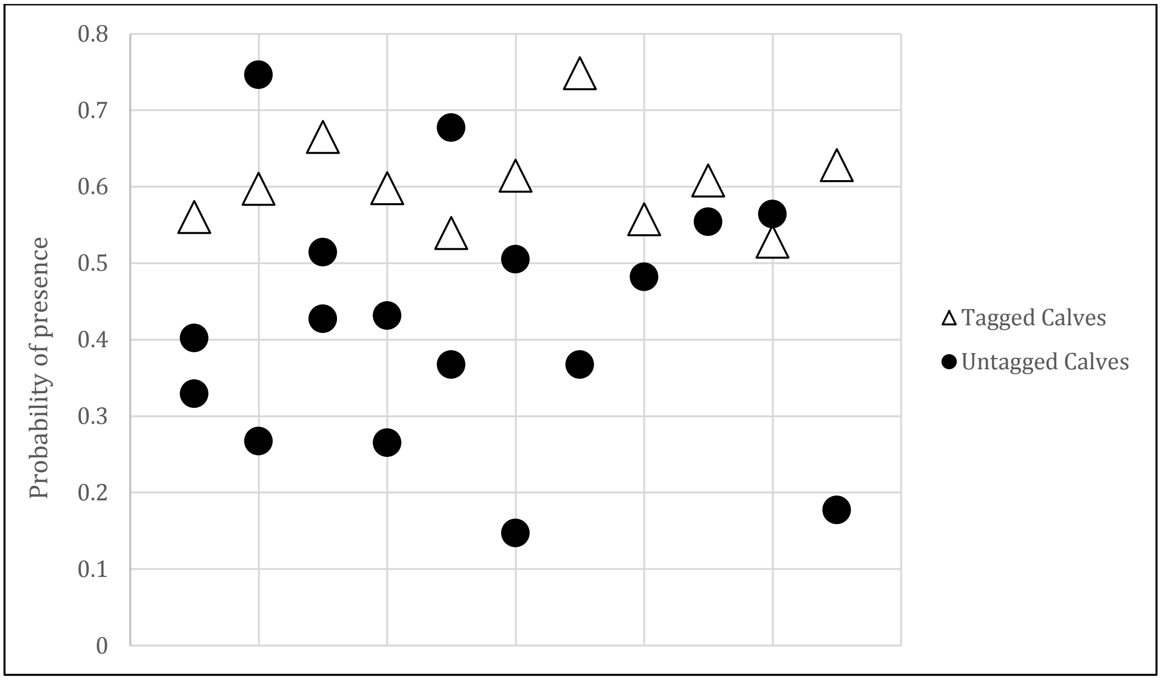


Figure 4. Probability of panther presence predicted by the panther hunting habitat model at locations of tagged and untagged calf depredations documented in southwest Florida. Points are arbitrarily distributed along the x-axis for illustrative purposes (to prevent overlapping points) and do not reflect a time series.



DISCUSSION

Calf Depredation

Florida panthers of different sexes and age classes killed calves and one adult male panther that could be identified by a notched ear was documented as being responsible for multiple depredations. Several calves were killed by young males, which may have been the same or separate individuals. An adult female accompanied by a juvenile female also killed a calf. Calves, therefore, are at risk of depredation from adult and sub-adult male and female panthers.

Calf depredation events were not evenly distributed throughout the year, among calf age and weight classes, or between ranches. The majority (82%) of all calf depredation events (tagged and untagged) documented on JB Ranch occurred during the calving season (September-February). These results are consistent with

JB Ranch records that indicate calves are rarely lost between April and July (R. Priddy, JB Ranch, personal communication). And, although panthers killed calves ranging from <1 week old and <50 lbs. to >8 months old and ~350 lbs., our data indicated panthers selected for smaller calves. The majority (88%) of calves killed were <200 lbs., which approximates the average size of adult feral hogs (*Sus scrofa*; <200 lbs.) and white-tailed deer (95-125 lbs.) in south Florida, which are reported to be the preferred prey of the Florida panther (Maehr et al. 1990; Garrison & Gedir 2006; Giuliano 2010).

Depredation rates varied between the two ranches. Both landscape comparisons and the panther hunting habitat model indicated that JB Ranch provided a more optimal hunting environment for panthers, which was consistent with the higher rates of calf depredation documented on the JB Ranch study area. For example, the JB Ranch study area contained greater edge density and greater percentage of upland forest. Edge environments have been reported to be important stalking habitat for pumas (Laundré & Hernández 2003; Laundré & Loxterman 2007) and Onorato et al. 2011 reported that Florida panthers selected for upland forest at night, which is when panthers are most actively hunting (Beier et al. 1995; Comisky et al. 2002). The JB Ranch study area also contained smaller patches of improved pasture, which increased the probability of panther presence according to the panther hunting habitat model. This makes intuitive sense because small improved pastures contain less PSH and more edge environment, which provides feeding habitat for white-tailed deer and feral hogs (Waller & Alverson 1997; Gabor, Hellgren, & Silvy 2001) as well as stalking habitat for panthers (Laundré & Hernández 2003; Laundré & Loxterman 2007).

The differences we documented in depredation rates between ranches may also have been influenced by differences in the percentage of tagged calves and the age distributions of tagged calves in the two study herds. Whereas all (100%) of the calves were tagged within the JB Ranch study area, only 30% of the calves were tagged within the IM Ranch study area because of the larger herd. Additionally, because we tagged the first 100 calves born in the IM Ranch study herd, untagged calves born later would have been smaller and more vulnerable as suggested by our depredation data. Consequently, the possibility exists that panthers killed untagged calves on the IM Ranch study area that went undocumented and our findings may have underestimated the actual depredation rates that occurred within the combined herd of tagged and untagged calves on IM Ranch. Whether depredation rates on IM Ranch approached those documented on JB Ranch is unknown, but average mortality within the tagged study herds from sources other than predators (and direct effects of the study) were similar between ranches (JB = 2.6%/yr.; IM = 2.3%/yr.). Total mortality from all causes reported by the ranches was 19% for the JB Ranch study herd (R. Priddy, JB Ranch, personal communication) and 15.5% from the IM Ranch combined herd (tagged and untagged calves) (B. Stoner, IM Ranch, personal communication). The difference in total calf mortality (3.5%) between JB and IM ranches was slightly less than the total difference in calf depredation by panthers (4.8%) between the two ranches over the entire study period.

Florida Panther Hunting Habitat Model

Our panther hunting habitat model correctly predicted documented panther locations with 99.9% accuracy. Results from the model suggest that panthers are most likely to use landscapes with low cattle densities, large forest patches, a high percentage of forest cover, small patches of improved pasture, and areas of upland forest (Fig. 2). The response to cattle density is likely a function of land cover, with cattle densities being lower in areas with small improved pastures and more forest cover. Panthers were also more likely to use upland forests than other land cover classes, despite the fact that upland forests were not the dominant land cover (Fig. 2). This suggests that panthers select for upland forests at night, which is consistent with data reported by Onorato et al. (2011). Our model indicated that small patches of improved pastures contained a high probability of panther presence as well, likely due to the proximity of cover and the edge environment created by forest interspersed within these pastures. Although improved pastures are not traditionally viewed as ideal panther habitat, our results suggest that small patches of improved pasture with low percentages of PSH (i.e., low percentage of improved pasture >90 m from cover) should be assessed differently than large pastures when evaluating the quality of panther habitat on a landscape. Furthermore, while panthers do use open habitats, they tend to stay near cover (Onorato et al. 2011). Our model predictions were consistent with this information and indicated that use of open habitat by panthers declines rapidly as the distance from edge habitat increases.

Although the panther hunting habitat model cannot predict exactly where calf depredations will occur, depredations did occur in areas where the model predicted the probability of panther presence was higher. The panther hunting habitat model, therefore, may be useful for evaluating the quality of panther hunting habitat and the corresponding risk of depredation to livestock across the landscape.

Our model predicted the mean probability of panther presence was significantly higher around depredation sites of tagged calves than untagged calves. This difference was influenced by the fact that the locations of untagged calf depredations were biased towards more open areas where ranchers could find depredated carcasses, with 65% of the untagged panther depredations occurring in areas identified as open, low use environments (Fig. 4). Although panthers use edge and forested environments substantially more than open areas, Onorato et al. (2011) reported that 28.2% of panther GPS locations occurred >90 m from a forest patch and pumas have been reported to use a wide range of both open and cover environments (Franklin et al. 1999; Logan and Sweaner 2001; Dickson et al. 2005), especially in regions that support high prey biomass and that lack large terrestrial competitors such as wolves (*Canis lupus*) (Elbroch & Wittmer 2013).

The fact that most untagged calves that were killed by panthers were found in open areas has important implications. The first is that untagged, depredated calves are unlikely to be found unless they are killed and left in relatively open areas. Typically, pumas do not leave prey in the open and instead conceal their prey under brush and in dense cover to hide the carcass from scavengers (Beier et al. 1995). All tagged calves killed by panthers in this study were cached in cover whereas the majority of untagged calves were in the open, which suggests that there are probably many more calves being killed in high risk environments than are being found and reported by ranchers.

The untagged calves killed by panthers in areas that were not identified as high quality panther hunting habitat might have fallen prey to panthers opportunistically encountering and killing calves as they traveled through open areas. However, it is also possible that calf depredations by panthers are not always opportunistic and that some panthers may learn to actively hunt calves, even in open pastures. The four documented kills by the adult male with a notched ear (Table 2) suggests this may be the case for some individuals. Learned behavior among predators, including large felids, is well documented and is a function of exposure to the prey species and practice (Leyhausen 1979). Learned hunting behaviors have been documented for large felids and wild prey (Ross et al. 1997; Polisar et al. 2003; Elbroch & Wittmer 2013), and also with livestock. For example, Rosas & Rosas (2008) report that >90% of confirmed livestock depredations in Sonora, Mexico, were attributable to three jaguars. If some panthers are targeting calves as prey, livestock depredation may be correlated with the calving season, which is consistent with our data and which has also been reported for jaguars and pumas in Venezuela (Michalski et al. 2006).

<u>Management Implications</u>

The extent to which calf depredation occurs by predators is influenced by calf availability and vulnerability, and calf depredation will decrease if you can limit these factors (T. Kaminski, Mountain Livestock Cooperative, personal communication). Management techniques recommended to reduce availability and vulnerability of calves include keeping livestock bunched at high stocking rates, moving livestock around the landscape, and shortening the calving season (Barnes 2013). When livestock are bunched at high stocking rates and moved around the landscape, the availability and vulnerability of calves decreases by reducing encounter rates and by disrupting a predator's ability to learn the location of available prey. It also decreases the vulnerability of livestock by allowing them to benefit from group anti-predator strategies such as improved vigilance, predator confusion, and communal defense. In addition, anti-predator techniques such as the use of livestock guarding dogs are only effective when cattle are not widely dispersed.

Management techniques recommended to reduce livestock depredation rates, such as keeping livestock bunched at high stocking rates and moving livestock around the landscape require intensive management (Barnes 2013). Due to the generally low productivity of the land, many Florida ranches are extensively rather than intensively managed, which means that cows are not monitored for long periods of time and are free to range over large pastures. This allows cows to become widely dispersed, which increases both their availability and vulnerability to panthers. Implementing intensive management practices on large Florida cattle ranches would increase the logistical and financial challenges of commercial cattle production, such as more fencing, labor, and the creation of larger improved pastures to support higher densities of cattle (B. Stoner, IM Ranch, personal communication). Whether these intensive management practices are a viable option for ranches in south Florida is beyond the scope of this study, but converting forest and other land cover to improved pasture to implement anti-predator management strategies would eliminate important habitat for panthers and their prey and would be detrimental to panther conservation and recovery efforts.

Shortening the calving season is another recommended technique to reduce calf losses to predators (Breck et al. 2011). Shortening the calving season can limit depredation by decreasing the amount of time that small vulnerable calves are available to predators and enabling calves to reach a size where they are less vulnerable (Estes 1976; Rutberg 1987; Testa 2002). Our results indicated panthers selected for smaller calves, suggesting that calf vulnerability decreases with age. The difference in calf depredation rates between the two ranches also suggests that shortening the calving season may decrease depredation, because tagged calves on the IM Ranch had a month long calving season and experienced a 0.5% annual calf loss to panthers compared to a five month long calving season and a 5.3% annual calf loss to panthers on the JB Ranch. Whether it is practical for a Florida cattle ranch to shorten its calving season is beyond the scope of this study, but most large cattle operations in Florida aim for a calving season that ranges from 90-150 days. The length of calving seasons in Florida are dictated by the extensive management system and the cattle breeds adapted to the Florida climate, which tend to have a less synchronized breeding season than breeds adapted to northern climates (G. C. Lamb, University of Florida IFAS, personal communication).

Our study provides evidence of livestock loss to panthers and provides information on the landscape and environmental variables that influence the risk of livestock depredation. The panther hunting habitat model we developed identified depredation locations of tagged calves as areas of high probability of panther presence. This model also identified areas of low probability of panther presence, which was strongly influenced by large improved pastures with poor stalking habitat (e.g., areas >90 m from cover), high cattle densities, and non-preferred land cover types. Panther conservation and recovery efforts will need to maintain suitable panther habitat on the landscape, but increased risk of calf depredation from panthers may prove to be a disincentive for private landowners to do so.

Compensation programs for livestock depredation have proven challenging to implement successfully (Main et al. 1999; Bulte & Rondeau 2005; Nyhus et al. 2005). While many compensation programs for livestock loss require verification of depredations, this sort of program will be problematic in Florida where livestock management practices, the landscape, and the behavior of the predator make it difficult if not impossible to verify depredation events. Programs that do not involve verifying kills are more applicable to Florida, such as those that use a Payment for Ecosystem Services (PES) strategy. In a PES program, the landowner is compensated based on some performance criteria related to conservation goals, such as the number of young produced, prey density, or the conservation and management of desired habitat (Nelson 2009; Zabel & Engel 2010; Dickman et al. 2011). A conservation incentives program using a PES design may provide a mechanism for compensating cattle operations for real or potential calf losses because it would not require verification of depredations and instead could be based on actions that contribute to conservation goals, such as the amount of panther habitat maintained and managed on a ranch. Our panther hunting habitat model provides two important measures; it quantifies high quality panther habitat and provides a measure of predation risk to calves. There are various ways that this sort of information could be incorporated into a PES program. For one, payments could be scaled based on the amount of high quality/risky habitat on a ranch, which would reward high quality habitat while compensating ranchers for the risk associated with maintaining that habitat. Additionally, hunting habitat and predation risk values could be used as a means of prioritizing or categorizing ranches for participation in compensation programs or eligibility for mitigation funds.

If panther conservation and recovery is dependent on maintaining suitable habitat on cattle ranches, strategies designed to compensate and incentivize landowners for managing landscapes conducive to panther conservation will promote conservation efforts. The panther hunting habitat model provides a means to evaluate the likelihood of panther presence on privately owned lands as well as a means of evaluating the risk of livestock depredation and as such may prove a useful tool for prioritizing and categorizing private lands for participation in a PES incentive payment program.

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APPENDICES

Appendix I. Land cover reclassification used to calculate edge around kill sites and compare land cover characteristics of the two study areas (JB Ranch and IM Ranch) in southwest Florida.

Reclassified Land Cover Class	Original Land Cover Class (SFWMD LCLU 2008-2009)	Cover/ Open	Forest/ Non-Forest
Upland Forests	Upland Coniferous	Cover	F
	Upland Hardwood	Cover	F
	Upland Mixed	Cover	F
	Coniferous and hardwood plantations	Cover	F
Wetland Forests	Wetland Hardwood Forests	Cover	F
	Wetland Coniferous Forests	Cover	F
	Wetland Forested Mixed	Cover	F
Non-Forested Wetlands	Vegetated Non-forested Wetland	Cover	NF
	Non-vegetated Wetland	Open	NF
Shrub / Brush / Prairie	Herbaceaous Dry Prairie	Open	NF
	Unimproved Pasture	Cover	NF
	Woodland Pasture	Cover	NF
	Abandoned Groves	Cover	NF
	Forest Regeneration	Open	NF
	Mixed Upland Non-Forested	Open	NF
	Upland Shrub and Brushland	Cover	NF
	Mixed Rangeland	Open	NF
Improved Pasture	Improved Pasture	Open	NF
Agriculture	Row Crops / Field Crops / Mixed Crops	Open	NF
	Citrus Groves / Other Groves	Open	NF
	Feeding Operations	Open	NF
	Nurseries and Vineyards	Open	NF
	Specialty Farms	Open	NF
Other	Urban	Open	NF
	Water	Open	NF
	Transportation	Open	NF
	Barren	Open	NF

Appendix II. Detailed explanation and evaluation of the species distribution model MaxEnt.

MaxEnt is a program based on machine learning that was designed to model species distribution using presence only species records by comparing both continuous and categorical environmental variables at occurrence sites to the same variables at 10,000 random locations (Elith et al. 2011). MaxEnt is similar to Resource Selection Function (RSF) models in that they both statistically compare presence locations to random available locations in order to understand what resources are selected for by a species (McLouglin et al. 2010). While Maxent is commonly used with occupancy data and RSF's commonly used with individual location data, mathematically there is no reason why MaxEnt cannot be used with location data as well (Lele et al. 2013). In species distribution modeling, studies indicate that MaxEnt consistently outperforms other methods of modeling distribution (Elith et al. 2006; Hernandez et al. 2006; Phillips et al. 2006; Baldwin et al. 2009)

MaxEnt presents output data in raw, cumulative, and logistic formats (Phillips & Dudik 2008). We used the logistic format as it provides estimates of the probability of presence based on the environmental variables included in the model and is the most easily interpreted (Baldwin et al. 2009). However, it is important to note that the ability of Maxent to predict a probability of presence has been criticized (Royle et al. 2012; Merow et al. 2013). For example, a cell with a value of 0.6 should not be interpreted as a 60% probability of the species occurring at the site. Instead, MaxEnt predictions should be interpreted as indices of habitat suitability, in that a cell with a value of 0.6 has a greater chance of species occupancy than a cell of value 0.5 (Merow et al. 2013).

We assessed which variables had the greatest influence on the model through percent contribution, which is determined by the increase in gain in the model provided by each variable (Phillips et al. 2006). We evaluated how each variable individually influenced the probability of presence through response curves. The response curves represent a MaxEnt model created through use of only one variable and illustrate the probability of presence (defined by a logistic output) as a function of the variable (Phillips 2006). We mapped the probability of presence across the landscape, with cells ranging from values of 1 (highest probability of presence) to values of 0 (lowest probability of presence) within the study area,

We evaluated model performance using the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve, which is a plot of sensitivity and specificity, with sensitivity evaluating how well data correctly predicts presence, and specificity a measure of correctly predicted absences (Fielding & Bell 1997). The AUC value measures model performance and quantifies the significance of the ROC curve, with values close to 0.5 indicating that the fit is no better than that expected by random, and values of 1.0 indicating a perfect fit (Baldwin et al. 2009). To test the significance of the model we compared our AUC value against a null distribution of expected AUC values based on random points (Raes and Steege 2007). We generated our null model following the methods of Raes and Steege (2007). To do so, we created 1000 random points within the same area used to generate our panther presence model. We used 1000 random points because we used 1000 panther locations in our model. We repeated this 999 times so that each random set of points (set 1- set 1000) consisted of 999 locations. We then ran these points through the MaxEnt using the same environmental variables used in the panther presence model. MaxEnt output consisted of 1000 AUC values, each representing a different set of 999 random points. We compared the value of our panther presence model to the values of the null model to assess whether it fell into the top 5%, which would indicate that our model performed better than random at p= 0.05.

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Appendix III. Landcover reclassification for MaxEnt Analysis on private lands within the Florida panther primary zone, excluding landcover classes that represented less than 1% of the study area.

Reclassified Landcover Class	**Original Landcover Class (CLC v. 2.3)**	**Cover / Open**	**Forest / Non-Forest**
Upland Forest	Hardwood Forested Uplands	Cover	F
	Rockland Hammock	Cover	F
	Other High Pine	Cover	F
	Sandhill	Cover	F
	Mesic Flatwoods	Cover	F
	Mixed Hardwood Coniferous	Cover	F
	Maritime Hammock	Cover	F
	Tree Plantations	Cover	F
	Exotic Plants - Austrailian Pine	Cover	F
	Exotic Plants - Melaleuca	Cover	F
	Rural Lands - Rural Open Forested	Cover	F
	Rural Lands - Oak-Cabbage Palm Forests	Cover	F
	Rural Lands - Rural Open Pine	Cover	F
Wetland Forest	Cypress / Tupleo	Cover	F
	Strand Swamp	Cover	F
	Other Coniferous Wetland	Cover	F
	Wet Flatwoods	Cover	F
	Mixed Wetland Hardwoods	Cover	F
	Hydric Hammock	Cover	F
	Other Wetland Forested Mixed	Cover	F
	Wet Coniferous Plantations	Cover	F
	Exotic Plants - Exotic Wetland Hardwoods	Cover	F
Non-Forested Wetlands	Freshwater Non-forested Wetlands	Open	NF
	Prairies and Bogs	Open	NF
	Wet Prairie	Open	NF
	Freshwater Marshes	Open	NF
	Floodplain Marsh	Open	NF
	Glades Marsh	Open	NF
	Non-vegetated Wetlands	Open	NF

Shrub-Brush-Prairie	Scrub	Cover	NF
	Scrubby Flatwoods	Cover	NF
	Dry Prairie	Open	NF
	Shrub and Brushland	Cover	NF
	Exotic Plants - Brazilian Pepper	Cover	NF
	Rural Lands - Rural Open	Cover	NF
Unimproved Pasture	Unimproved Pasture	Cover	NF
Improved Pasture	Improved Pasture	Open	NF
	Agriculture - Cropland / Pasture	Open	NF
Row Crops	Agriculture	Open	NF
	Agriculture - Row Crops	Open	NF
	Agriculture - Field Crops	Open	NF
	Agriculture - Sugarcane	Open	NF
	Agriculture - Fallow Cropland	Open	NF
	Agriculture - Vineyard & Nurseries	Open	NF
	Agriculture - Tree Nurseries	Open	NF
	Agriculture - Sod Farms	Open	NF
	Agriculture - Ornamentals	Open	NF
	Agriculture - Feeding Operations	Open	NF
	Agriculture - Specialty Farms	Open	NF
Citrus groves	Agriculture - Orchards / Groves	Cover	NF
	Agriculture - Citrus	Cover	NF
	Agriculture - Fallow Orchards	Cover	NF