LANDSCAPE METRICS ASSOCIATED WITH HABITAT USE BY OCELOTS IN SOUTH TEXAS

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Abstract: Ocelots (*Leopardus pardalis*) are listed as endangered federally and by the state of Texas. Preference for closed canopy habitat has been shown in previous studies, but preference for patch size has not been reported. Geographic Information Systems (GIS) and satellite imagery were used to compare areas in south Texas used by radio-collared ocelots to areas with no known use. We hypothesized that ocelots would prefer large patches of closed canopy habitat and avoid large patches of unsuitable habitat. Areas used by ocelots had a greater degree of fragmentation (i.e., larger number of patches, smaller size, and more edge) than did those not used. Further investigation revealed that ocelots preferred patches of closed canopy over other types of land cover and that this land cover type exhibited a greater degree of fragmentation. Results of this study were used to designate areas for conservation of ocelot habitat and can be applied to the management of other threatened or endangered wildlife.

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In the United States, ocelots once were found as far north as Arkansas and Arizona but are currently limited to the southern tip of Texas where population estimates are no greater than 120 individuals (Tewes and Everett 1986). The species is listed as endangered federally and by the state of Texas (Texas Parks and Wildlife Department 1977, U.S. Fish and Wildlife Service 1982). Over 95% of the native chaparral and riparian forests of the Lower Rio Grande Valley, the primary habitat for ocelots in south Texas, have been modified by human use (Purdy 1983). Loss of habitat and reduction of corridors between known populations are major threats to the potential recovery and ongoing viability of populations of ocelots in the United States.

Clearing of thorn scrub vegetation, prime habitat for ocelots, for agriculture has occurred at a rapid pace in recent years. Using satellite images from 1991 and 2000, Jackson (2002) determined that the apparent loss of closed canopy land cover and its change to open canopy in the study area was dramatic. Nearly 45,800 ha of closed canopy was converted to open canopy during this 9-yr period. Patches (i.e., homogenous parcels of habitat of various sizes) result from human disturbance (e.g., clearcutting, development) and natural processes such as change in climate, soils, and slope. Increased distance between patches and loss of connectivity result in fragmentation. Results of fragmentation on interior habitat specialists with large home ranges may include increases in isolation and extinction rates and decreases in dispersal (Forman 1995).

Although the importance of large, contiguous patches of native thorn scrub to ocelots has been well documented (Tewes 1986, Laack 1991, Shindle 1995), effects of fragmentation on the species has not been quantified nor have minimum patch size, shape of patches, and other landscape metrics associated with ocelot habitat use. The goal of this research was to examine ocelot habitat availability in south Texas to understand how fragmentation can affect resource selection. Results of this study will allow wildlife managers to make informed management decisions regarding the maintenance of current populations and reintroduction of new populations. Methodologies explored in this research, such as using GIS and remote sensing technologies, can also be applied to any species in need of conservation management.

STUDY AREA

Our study area included Cameron and Willacy counties, Texas (Fig. 1). Our study concentrated on habitat available to a known population of approximately 40 ocelots near Laguna Atascosa National Wildlife Refuge (LANWR), located in the northeastern portion of Cameron County and extending into southern Willacy County.

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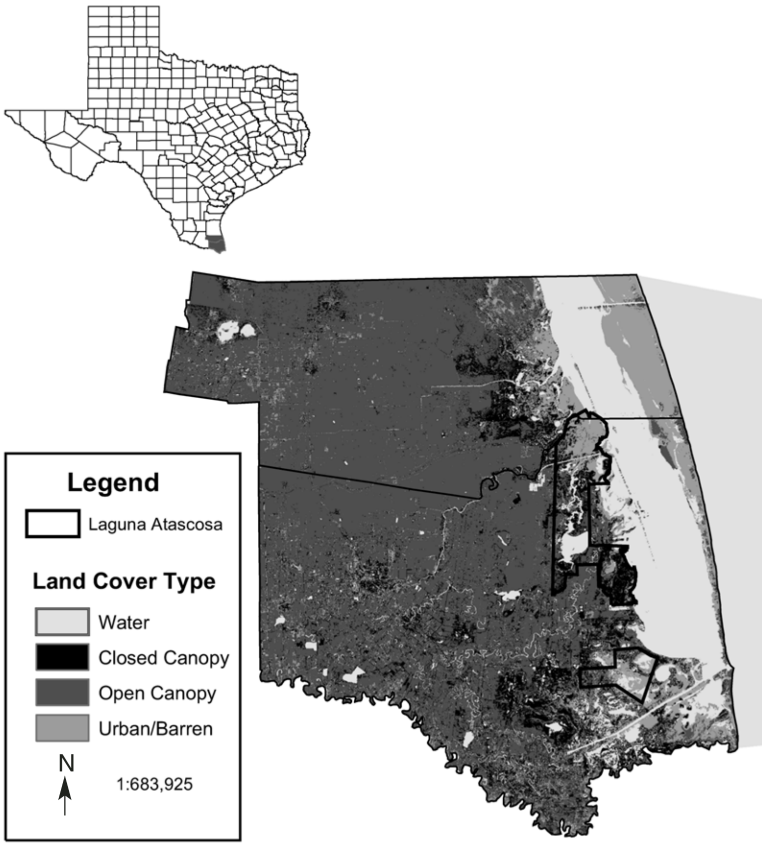

Fig. 1. Study site used to quantify the effects of fragmentation on ocelot habitat use in 1991 in Willacy and Cameron counties, Texas, USA.

Laguna Atascosa National Wildlife Refuge was bordered to the north, south, and west by privately owned land used primarily for agriculture and on the east by the Laguna Madre of the Gulf of Mexico. The refuge consisted of coastal prairies, salt flats, estuaries, and thorn forest. Small tracts of native vegetation existed in the surrounding landscape and were linked by vegetated resacas (old river channels), drainages, and fencerows (Laack 1991). Thorn scrub was the principal habitat used by ocelots and comprised approximately 1,200 ha (6.6%) of LANWR.

METHODS

Classification of Imagery

We used August 1991 Landsat Thematic Mapper (TM) imagery to create a land cover map. We assigned land cover classes to the image using a combination of supervised and unsupervised classification techniques in ERDAS IMAGINE 8.4 (ERDAS 1997). A hybrid approach that uses both methods of classification can help increase accuracy by teasing apart land cover types with similar reflectance patterns. TM data were classified into 4 categories: open canopy, closed canopy, urban/barren, and water. Open canopy areas were comprised mostly of agriculture and pasture lands. Thorn scrub, riparian corridors, and other forms of closed canopy vegetation were classified as closed canopy. Urban/barren land cover included urban areas and mud flats. We conducted an accuracy assessment using a stratified sampling design with ground reference data and aerial photography from Texas Natural Resource Information Service (TNRIS). A minimum of 204 reference points should be assessed when the expected accuracy is 85% at an allowable error of 5% (Jensen 1996). Congalton (1991) suggested the collection of at least 50 reference points per land cover class when calculating an error matrix. A stratified random sampling technique was employed to locate reference points in each land cover class proportionate to area covered (open canopy $n = 90$, closed canopy $n = 51$, urban/barren $n = 50$, and water $n = 61$). We determined land cover from aerial photos and/or digital orthophoto quadrangles (DOQs) for each of these random points and entered this into the accuracy assessment function of IMAGINE 8.4. The minimum level of accuracy acceptable for land use and land cover classification is 85% (Anderson et al. 1976). An overall accuracy of 88.10% was deemed acceptable.

Radiotelemetry

Telemetry data were recorded by volunteers working at LANWR from January through December 1991, in the form of permanent station locations and respective bearings. Volunteers drove to pre-determined stations and used a 4-element yagi antenna to discern the bearing from that station to an ocelot. Ocelots were tracked predominantly during the day. Locations of 11 ocelots (7 males and 4 females) were estimated using LOAS 1.4.0.1 (Location of a Signal, Ecological Software Solutions) software to convert bearings to point locations using best biangulation method. All data with at least 2 bearings could be used to estimate ocelot locations, and whenever more than 2 bearings were available, those that produced the smallest error ellipse were chosen. We calculated error ellipses for each location estimate. Estimated locations were eliminated if error ellipses were greater than the 95% confidence interval (3,800 m^2). We used a total of 760 estimated locations.

Landscape Metrics

Our landscape metrics were: number of patches, mean patch size, shape, edge, and mean nearest neighbor. We chose these metrics because they represent the degree of fragmentation occurring in the landscape. Shape complexity was calculated using the following formula: MSI = sum of each patch perimeter divided by the square root of patch area. MSI will equal 1 if patches are circular or square, with deviations from 1 indicating a greater degree of complexity in shape (Rempel and Carr, 2003). Mean nearest neighbor is a measure of patch isolation that measures the shortest distance between patches of similar class values. We used Patch Analyst, an extension for ArcView 3.2 (Environmental Systems Research Institute 1995), to assess metrics at the landscape (Willacy and Cameron counties, Texas) and class (per land cover type) scales (Rempel and Carr 2003). We did this by using the land cover thematic map overlaid with a theme of 100-ha hexagons. We used hexagons because they are the closest packing shape to a circle, thus decreasing the effects of artificial edge. We assessed landscape metrics for each hexagon, and each hexagon was tested for use by ocelots (at least 5 locations) or no known use (no locations). Any hexagon that had fewer than 5 locations was eliminated from statistical analysis. An area-based approach was used to understand the landscape metrics surrounding each estimated location. This, combined with the elimination of hexagons with less than 5 locations, decreased the affects of classification, telemetry, and triangulation error. We used Mann-Whitney U tests to determine whether a significant difference existed for each landscape metric between hexagons with known use by ocelots (n = 30) and an equal number of randomly selected unused hexagons (n = 30). Logistic regression was used to identify landscape metrics that could be used to accurately predict use or no known use by ocelots for each hexagon.

Proportional Use of Patches

Methodologies outlined in Otis (1997) were used to assess utilization and relationships between patch size and use within cover types. If disproportionate use is supported, careful examination of results may help to define minimum patch size and habitat requirements and help explain the nature of functional relationships between patch size and use (Otis 1997). We divided patches of each land cover class into 3 categories: (1) first quartile (small), (2) second and third quartiles (medium), and (3) fourth quartile of patch areas (large). Small patches were ≤28 ha; medium patches ranged from 29 to 2,461 ha; and large patches ranged from 4,930 to 10,614 ha. We calculated use of each of these patch size by ocelots, and we used log-likelihood goodness-of-fit tests to determine whether patches of habitats were selected for disproportionately to availability. We determined availability of patch size by assessing 1,000 random points located throughout the study site for land cover type. The proportion of locations expected was calculated from the proportion of these random points in each habitat type. Patches used more often than would be expected were defined as preferred, and those patches used less often than expected were defined as avoided. We determined patch selection regardless of land cover type, as well as for each class of land cover.

RESULTS

We reported landscape metrics for the landscape (across the study site) and class (per land cover type) scale (Table 1). Urban/barren land cover was the most fragmented class with the largest number of patches (3,847) and the smallest mean patch size of 0.71 ha. Closed canopy was the second most fragmented land cover type with 3,309 patches and a mean patch size of 2.9 ha. Mean shape index was similar for all land cover types ranging from 1.28 to 1.36. Water had the largest mean nearest neighbor distance at 116.3 m, and the other 3 land cover types ranged from 42.52 m (open canopy) to 56.9 m (urban/barren).

Significant differences existed between hexagons with known use by ocelots and hexagons

Table 1. Landscape metrics associated with habitat used by ocelots in south Texas, USA, throughout 1991 at landscape and class scales.

Class	Number of patches	Mean patch size (ha)	Total edge (km)	Mean shape index	Mean nearest neighbor (m)
All	10,557	3.62	4,194	1.32	54.9
Water	761	6.08	696	1.31	116.33
Closed canopy	3,309	2.90	2,904	1.36	48.32
Open canopy	2,640	8.06	3,104	1.31	42.52
Urban/Barren	3,847	0.71	1,580	1.28	56.9

Table 2. Descriptive statistics for landscape metrics measured in hexagons that contained no ocelot locations (NO) and hexagons that contained at least 5 locations (OP) in Willacy and Cameron counties, Texas in 1991. All metrics were significantly different between hexagons (Mann-Whitney U test, $P < 0.001$).

Landscape metric		Minimum	Maximum	Mean	SD
Number of patches	OP	6	24	11.97	4.4
	NO	1	19	5.63	5.4
Mean patch size (ha)	OP	3.63	17.24	9.2	3.7
	NO	3.9	108.68	46.87	41.1
Total edge (km)	OP	8	25	15	4.1
	NO	4	20	9	5.2
Mean shape index	OP	6.79	23.5	12.2	4.33
	NO	1.07	21.93	6.06	5.55
Mean nearest neighbor (m)	OP	0	75.34	24.27	19.8
	NO	0	100.94	7.99	20.3

with no known use for every landscape metric tested (Mann-Whitney U test, $P < 0.001$). Ocelots used hexagons with a greater number of smaller patches with more edge (Table 2). For instance, patch sizes used by ocelots ranged from 3.63 to 17.24 ha with a mean of 9.2 ha, and those not used ranged from 3.9 to 108.7 ha with a mean of 46.87 ha. This resulted in longer edge lengths in patches used by ocelots (8 to 25 km, mean = 15 km) than for those patches not used (4 to 20 km, mean = 9 km). Mean shape index and mean nearest neighbor distance were larger in hexagons with known use by ocelots (Table 2). These results indicate a greater degree of fragmentation with more patch edge associated with hexagons that ocelots most often used.

The second step of a forward stepwise logistic regression model yielded an equation that accurately predicted ocelot presence 90% of the time (Table 3). This model was significantly better (likelihood ratio, $P = 0.001$) than chance alone at predicting ocelot presence. These results indicate that, out of all landscape metrics tested, only mean patch size contributed significantly to the model.

Table 3. Variables in the equation for predicting presence–absence of ocelots in south Texas, USA, during 1991, based on logistic regression. Beta coefficients, Wald statistics, and significance of each parameter are reported.

Variables	B	Wald	Sig.
Mean patch size	–0.249	4.398	0.036
Total edge	0.0001	0.494	0.482
Constant	4.826	2.261	0.133

Selection by ocelots occurred for patches of particular sizes (log-likelihood goodness-of-fit tests, $P < 0.001$). When all habitat types were pooled, ocelots preferred small patches and avoided medium and large-sized patches (Table 4). Ocelots preferred small and avoided medium and large patches of water (Table 4). Ocelots preferred medium-sized patches of closed canopy and avoided small patches of this habitat type (Table 4). No patches in the large category were associated with 1,000 random points for closed canopy, which indicates the rarity of this size class. However, 1 ocelot location occurred in a large patch of closed canopy. Ocelots avoided large patches of open canopy but were found in small and medium-sized patches.

DISCUSSION

Landscape metrics such as number, size, shape, and edge can reflect the degree of fragmentation in the landscape. In south Texas, one of the last areas in the United States where ocelots are known to occur, available habitat for this species is highly fragmented with greater edge in areas used by these animals. The study area was located west of the Laguna Madre of the Gulf of Mexico and included the Laguna Atascosa, both large bodies of water. Open canopy areas included agricultural crops and open rangeland and, by definition, were large tracts of continuous vegetation but not typical of habitat for ocelots. Water and open canopy land cover types were less fragmented than the landscape as a whole or for closed canopy and urban/barren areas. The coastal nature of this area also affected the fragmentation of closed canopy and urban/barren land cover types. Mudflats, inundated areas, and vegetation growing in these areas formed a complex pattern depending on tide depth and season. Ocelots inhabiting this coastal area are utilizing the highly fragmented landscape available to them.

Hexagons with ocelot use exhibited a greater degree of fragmentation than did hexagons with no known use. These results indicated that ocelots were choosing areas of greater fragmentation that were smaller, less contiguous patches with greater amounts of edge. However, these relationships may be misleading without understanding the species' preference for closed canopy. Ocelots utilized the largest patches of closed canopy available to them, but the mean patch size of this land cover was only 2.9 ha. No large patches of closed canopy were found associated with 1,000 random points; however, 1 ocelot location occurred in a large patch. This is further evidence of the rarity of large patches of this preferred land cover type.

Logistic regression indicated that the most important landscape metric for predicting ocelot habitat use in this area was mean patch size. However, because this was severely restricted due to the rarity of large patches of preferred habitat (closed canopy), these results may be misleading. It would be expected that, if large tracts of closed canopy were available to ocelots, the mean patch size would increase accordingly.

Further research is needed to understand how patch size affects distribution of ocelots when larger patches of optimal habitat are available. Research conducted on populations of ocelots in South America may corroborate the assumption that ocelots choose the largest patches available to them. However, ocelots may still utilize edge for hunting and travel. Shindle (1995) speculated that the lower temperature within dense cover and the increased ability for concealment among dark shadows increase ocelots' use of interior areas. Emmons et al. (1989) found that ocelots avoided exposed trails while hunting on bright moonlit nights. We used primarily diurnal telemetry locations. A study linking edge use to time of day may indicate that ocelots use more open areas during the coolest, darkest nights, while restricting use during the heat of the day to areas with closed canopy. Increasing the number of telemetry locations during crepuscular and nocturnal activity may provide a clearer picture of how ocelots are utilizing the patches available to them.

MANAGEMENT IMPLICATIONS

Characterization of the landscape through patch metrics and determining the degree of fragmentation can aid in conservation decisions that usually focus on choosing areas best supporting a given species or have the largest tract of intact habitat. Wildlife biologists can use this research as further support for the necessity of conserving large tracts of ocelots' preferred habitat, native thorn scrub. Our research suggests that ocelots prefer medium to large-sized patches and avoid small patches of closed canopy (<28.9 ha). Most research on resource utilization by ocelots in south Texas has focused on type of land cover preferred not on the landscape metrics associated with these land cover types. In this highly fragmented landscape, management decisions must be influenced by size, shape, and amount of edge for each patch of suitable habitat. The paucity of large-sized patches may force managers to consider protecting areas consisting of smaller patches. Considering the arrangement of these patches in the landscape is critical to predicting habitat suitability. Use of landscape metrics, in conjunction with presence of thorn scrub, can aid in the decision to include a particular area for protection.

Table 4. Selection of patch size for all habitat types combined, water, closed canopy, open canopy, and barren/urban land cover by ocelots in south Texas, USA, during 1991. Small patches ranged from 0 to 28 ha, medium patches ranged from 29 to 2,461 ha, and large patches ranged from 4,930 to 10,614 ha.

	Size category	Selection	*P*-value
All habitats	small	P	<0.001
	medium	A	
	large	A	
Water	small	P	<0.001
	medium	A	
	large	0	
Closed canopy	small	A	<0.001
	medium	P	
	large	a	
Open canopy	small	P	<0.001
	medium	P	
	large	A	
Urban/barren	small	A	<0.001
	medium	P	
	large	0	

A = avoidance, P = preference, NS = no selection ($p > 0.05$), and 0 = no locations within this patch size.
a. No randomly located points were found in large patches of closed canopy; however, 1 ocelot location was within a large patch of closed canopy.

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