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C O N F L U E N C E

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Characterization of Jaguar Utilization Distributions in the Brazilian Pantanal

Delaney Callahan

ABSTRACT

Jaguars (Panthera onca) have been eradicated from 50% of their historical range across Mexico, Central America, and South America. The Brazilian Pantanal in west-central Brazil represents a stronghold of core habitat for the species and is an important site for conservation. Habitat in the Pantanal is threatened largely due to expanding human activity causing habitat loss and fragmentation, making remaining habitat vitally significant. This study seeks to characterize the utilization distributions of jaguars in the area to better understand the habitat use and spatial ecology of a threatened species. GPS locations taken from 13 jaguars were used to calculate estimates of kernel homes ranges at the 50% (core range) and 95% (home range) isopleth levels. These ranges were used to quantify habitat use in relation to land cover types. Patterns of distribution heavily followed waterways, perhaps following that of their main prey, caimans (Caiman crocodilus yacare). Wetlands were the most heavily utilized among all jaguars at the 95% home range followed by grasslands. However, at the 50% core range level there was a shift in greater utilization of forest habitat over grassland. Additionally, females generally had smaller home ranges than that of males and exhibited less overlap between home ranges (27 km2) than between male home ranges (217 km2) – a key indicator of female spatial avoidance.

Introduction

When considering how to develop meaningful conservation programs, it is helpful to understand how a species uses its landscape. What habitats or resources is the animal utilizing? What is it avoiding? What does this animals' movement patterns suggest about how or why it uses different areas? Home ranges, also known as utilization distributions, are the primary means of defining and characterizing an animal's use of space.

The Brazilian Pantanal is the world's largest tropical wetland and serves as a pivotal stronghold for jaguars (Panthera onca). It sits at the heart of the species' historical range in west-central Brazil (Cavalcanti, 2008). Listed as near threatened on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, the Pantanal also serves as an important site for jaguar conservation. It is threatened by conflicts with ranching activities, habitat loss, and increasingly destructive fires that can all have effects on space use and habitat selection by jaguars (Panthera, n.d.; Cavalcanti, 2008).

This exploratory study seeks to characterize jaguar utilization distributions in the Brazilian Pantanal by quantifying habitat use and spatial patterns of distribution in relation to land cover types. By understanding the spatial and behavioral ecology of this elusive species, we can further develop and contribute to larger conservation planning efforts. While positing specific conservation measures is beyond the scope of this study, the findings herein can be leveraged to inform meaningful management decisions around conservation.

Methods

Data on jaguar relocations were obtained from Movebank, an online platform that works to serve as a global archive for animal movement and bio-logging data (Morato et al., 2021). The dataset used in this study is a subset of a larger jaguar movement database which contained relocations from all over Mexico, Central America, and South America. The dataset was compiled with the purpose to make animal tracking data more readily accessible to the conservation science community (Morato et al., 2018). To narrow the study, a subset was chosen of 13 individual jaguars that all inhabited the same general area in the northern part of the Pantanal from 2011 to 2016. Some basic reference information (sex, weight, life stage, etc.) for each of the cats were included in addition to GPS locations and timestamps. All data came in CSV format which were directly loaded into R for analysis. The 2015 land cover classification raster was obtained from the MapBiomas Project, "a multi-institutional initiative to generate annual land cover and land use maps from automatic classification processes applied to satellite images" (MapBiomas, n.d.).

Once in R, the package adehabitatHR (version 0.4.19) was installed and loaded. Created by Clement Calenge, it is a collection of tools made specifically for the estimation of animal home ranges and is popular in the movement ecology field. Some simple prep was needed to identify the name IDs and latitude/longitude fields for the program, as well as project the data. A kernel density estimate (KDE) was calculated using the reference (href) bandwidth and a bivariate normal kernel for all 13 jaguars in the study (Figure 1). The window size of the function is specified by the bandwidth selection, or smoothing parameter, and can have dramatic effects on the results. The href bandwidth is a common choice among ecologists/biologists, but does have a tendency to over-smooth results (Calenge, 2019). A least-squares cross-validation bandwidth was attempted, but there was no minimum convergence for any of

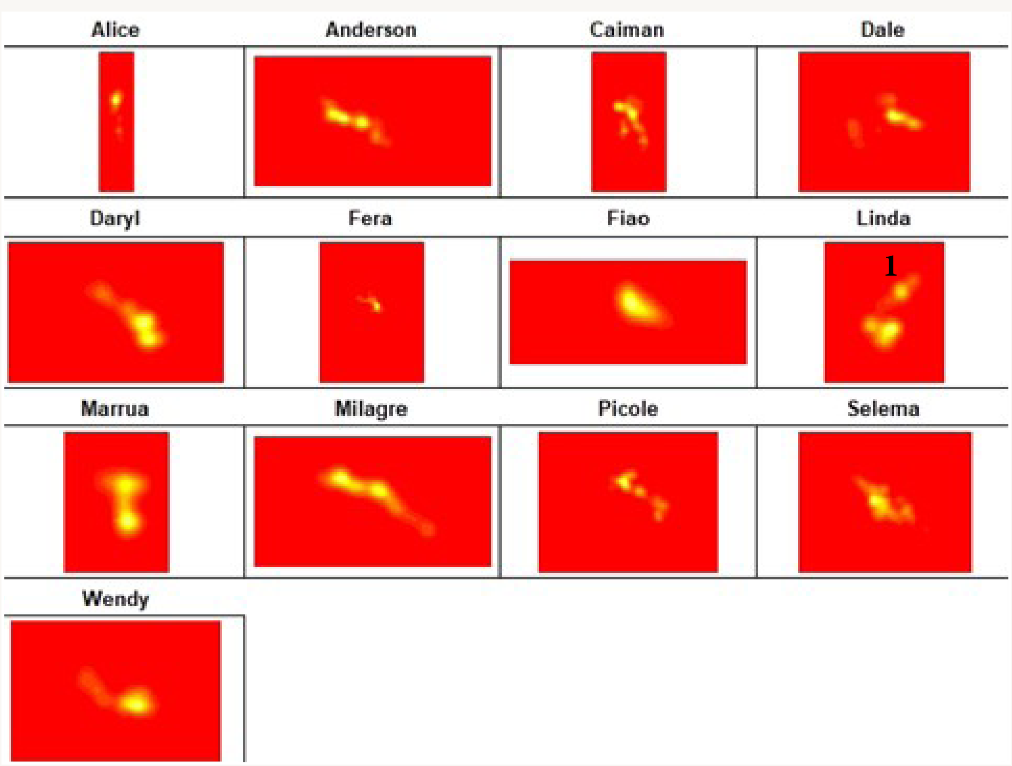

Figure 1. Raw KDE output for all cats using href bandwidth

the cats. In order to compute areas from a KDE with equal levels of presence, the raw KDE must be transformed using the function 'getvolumeUD'. The resulting rasters show from 0 to 99 the percentage of the distribution across the surface, creating home ranges (Figure 2). Effectively, a KDE done this way gives a raster with probabilities of presence for an animal at any given location. It also makes for a more intuitive visualization of probability levels. Next, the total area of each probability level (or home range, at this point) from 50 to 95 in intervals of five were calculated for each of the jaguars using the function 'kernel.area' (Appendix A). Lastly, contour lines were created for the 50% (considered the core area) and the 95% home range estimations using the 'getverticeshr' function. The 50% and 95% levels were selected following suit of other home range studies (Cavalcanti, 2008; Morato et al., 2016). All these outputs were exported as either shapefiles, GeoTiffs, or CSV files for further analysis in QGIS. A copy of the R script can be found in Appendix B.

Once in QGIS, data were loaded in to calculate the area of each land cover class within the 50% core range and 95% home range contours. This was done using the zonal histogram tool which produced a count of cells belonging to each unique land cover class within the contours. The cell count was multiplied by 900 (30m x 30m cell resolution) and divided by one million using the field calculator to get the area of each land cover class in square kilometers. In order to calculate the amount of overlap between males and females home ranges, a union was performed for all female home ranges (n=6) at the 95% level. Any part that overlapped other female home ranges were selected and a dissolve performed to obtain a single polygon representing the amount of overlap. The '$area' function of the field calculator was used and divided by one million to get the area in square kilometers. This process was repeated for all male jaguars (n=7).

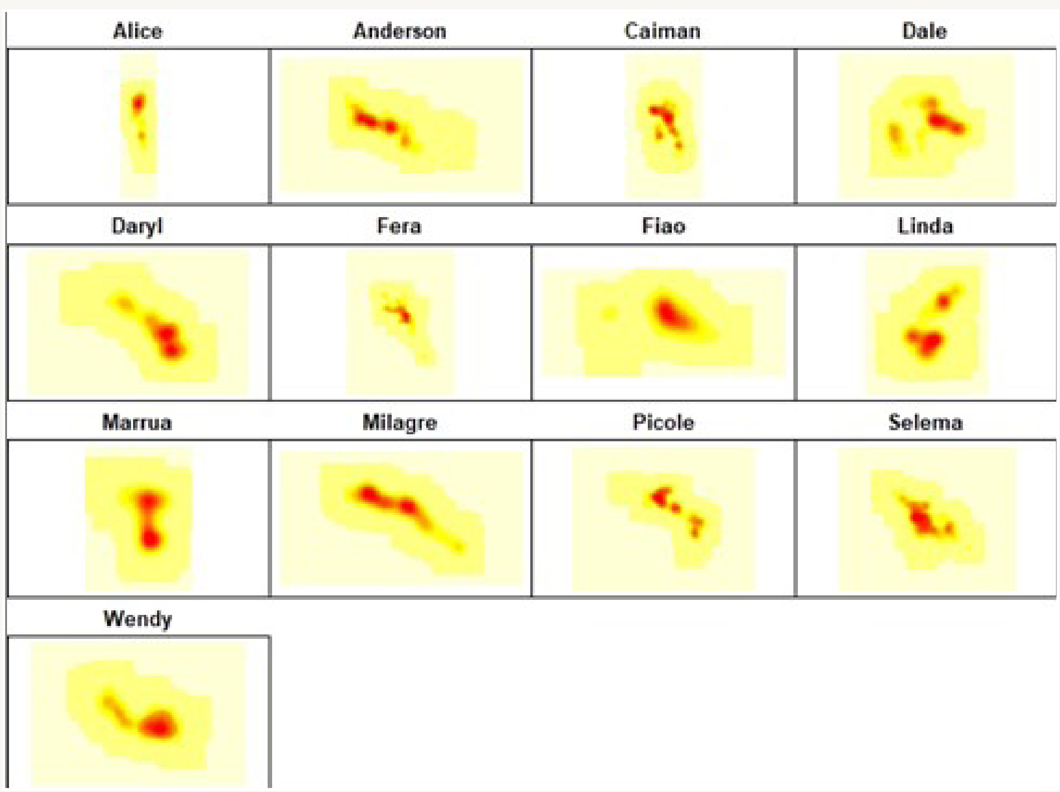

Figure 2. Output from the 'getvolume' function for all cats

Results

The characterization of jaguar utilization distributions encompasses six unique land cover types that all 13 jaguars utilized to various extents: wetlands, forest, savanna, grasslands, open water, and pasture (Figure 3). Wetlands were the most heavily utilized among all jaguars, ranging anywhere from 45% to 75% of the total 95% home range. Grasslands were generally the second highest, although there was a larger range of utilization among jaguars, anywhere from 7% to 40%. This was followed by forest and open water, with no more than 19% of the total home range. Savanna and pasture were the least utilized, all coming in at less than 3%. Figure 4 shows the average utilization of habitat type for all jaguars at the 95% home range level.

At the 50% core range level, there were similar patterns of habitat use, however there was a shift in greater utilization of forest habitat over grassland (Figure 5). I can speculate that grasslands must provide some sort of resource on the periphery of their core range that they frequent, such as for hunting, but ultimately it is forests where they spend more time. Forest cover is more secluded and protected, usually selected by jaguars as a place to consume their kill (Seymour, 1989). Figure 6 show the average utilization of habitat type at the 50% core range level – not that different than the 95% home range level overall.

Name	Sex	Weight (lbs.)	# of Locations	Total Area (km2)	% Wetlands	% Grassland	% Forest	% Water	% Savanna	% Pasture
Anderson	M	223	5,040	33.68	54.66	26.99	15.26	6.77	1.54	0.00
Caiman	M	243	2,331	86.03	74.08	12.46	8.94	8.87	0.76	0.05
Dale	M	176	4,709	62.06	57.40	14.79	18.74	11.97	2.26	0.02
Daryl	M	142	572	17.84	61.44	21.53	11.21	9.31	1.63	0.06
Fiao	M	225	78	35.89	52.21	25.63	12.31	13.32	1.64	0.06
Milagre	M	212	3,340	116.76	70.80	20.70	7.47	4.38	1.62	0.19
Picole	M	198	10,989	193.69	63.34	21.82	10.02	8.32	1.60	0.09
Alice	F	154	2,682	223.57	45.19	39.51	8.71	10.88	0.87	0.11
Fera	F	182	8,347	27.85	71.21	7.07	15.12	10.70	1.11	0.00
Linda	F	172	615	11.55	74.97	7.36	12.73	9.61	0.52	0.00
Marrua	F	154	93	29.72	63.97	23.72	8.34	6.97	1.82	0.27
Selema	F	154	2,820	29.07	52.98	28.80	14.97	6.50	1.86	0.03
Wendy	F	145	1,296	34.72	70.36	19.35	7.72	4.75	2.62	0.35

Figure 3. Total area calculations for the 95% home range level. Each land cover class is broken down into a percentage of the total area.

Patterns of distribution heavily followed waterways. This is likely consistent with caiman (Caiman crocodilus yacare) habitat, one of their main sources of prey (Cavalcanti, 2008). Jaguars are known to be some of the most aquatic big cats and are excellent swimmers who often hunt and play in water (Seymour, 1989). Figure 7 is a series of six maps showing the KDE and home range contours/land cover map outputs to better visualize patterns of distribution on the landscape for a three of the jaguars in the study.

There were notable differences in home ranges between male and female jaguars. Common among jaguars, the results indicated that males generally had larger home ranges than that of females (Cavalcanti, 2008), with the exception being Alice. Initially, I thought this could have been attributed to a higher number of locations due to a longer sampling period for this particular jaguar which resulted in a larger total area. However, a linear regression was performed to check for any associations between the two variables across all cats (Figure 8). There does not appear to be any relationship between the number of locations collected and total area of the home range (p-value=0.13, r2=0.11). Interestingly, Alice went on a one-month adventure south into habitat she had never used the previous three months of data collection, more than doubling her original three-month range, before contact was lost.

Lastly, there was much less overlap between female home ranges (27 km2) than between male home ranges (217 km2) when looking at the 95% home range level. This suggests that males did not retain exclusive home ranges the same way females did, who practiced avoidance of other female home ranges (Cavalcanti, 2008; Seymour, 1989).

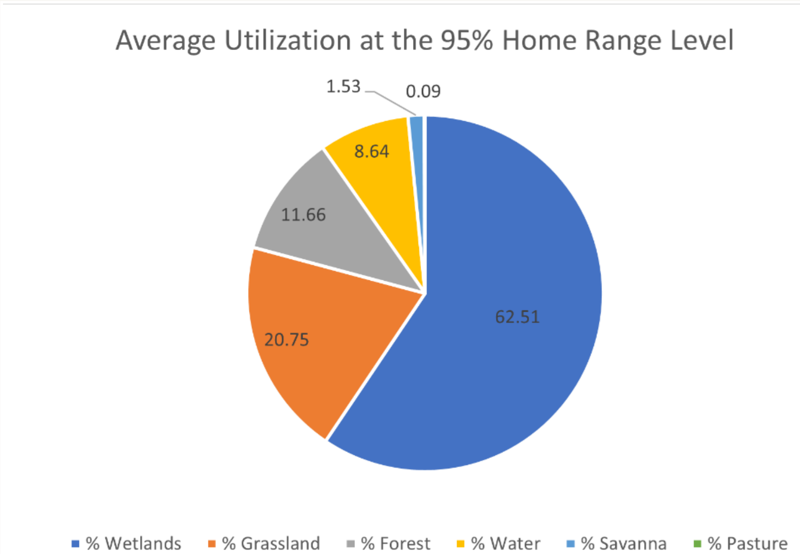

Figure 4. Average utilization of habitat type at the 95% home range level

Name	Sex	Weight (lbs.)	# of Locations	Total Area (km2)	% Wetlands	% Grassland	% Forest	% Water	% Savanna	% Pasture
Anderson	M	223	5,040	6.62	35.48	28.39	33.37	6.34	1.66	0.00
Caiman	M	243	2,331	20.95	69.61	10.03	12.65	11.94	0.95	0.00
Dale	M	176	4,709	10.86	59.75	4.97	23.01	15.74	1.75	0.00
Daryl	M	142	572	4.01	57.37	12.97	23.45	10.73	0.50	0.00
Fiao	M	225	78	6.29	53.61	15.75	21.95	12.89	0.95	0.00
Milagre	M	212	3,340	29.41	73.44	15.54	9.38	4.96	1.70	0.14
Picole	M	198	10,989	47.35	60.87	22.68	10.50	9.48	1.65	0.02
Alice	F	154	2,682	37.72	53.85	32.48	8.27	9.07	1.19	0.37
Fera	F	182	8,347	4.13	69.79	8.48	13.57	13.33	0.00	0.00
Linda	F	172	615	2.78	80.16	8.63	7.55	8.27	0.36	0.00
Marrua	F	154	93	7.93	55.61	23.58	15.01	8.07	2.90	0.13
Selema	F	154	2,820	7.55	57.99	19.06	19.20	7.94	0.93	0.00
Wendy	F	145	1,296	7.35	61.21	27.75	9.39	4.35	2.31	0.00

Figure 5. Total area calculations for the 50% core range level. Each land cover class is broken down into a percentage of the total area.

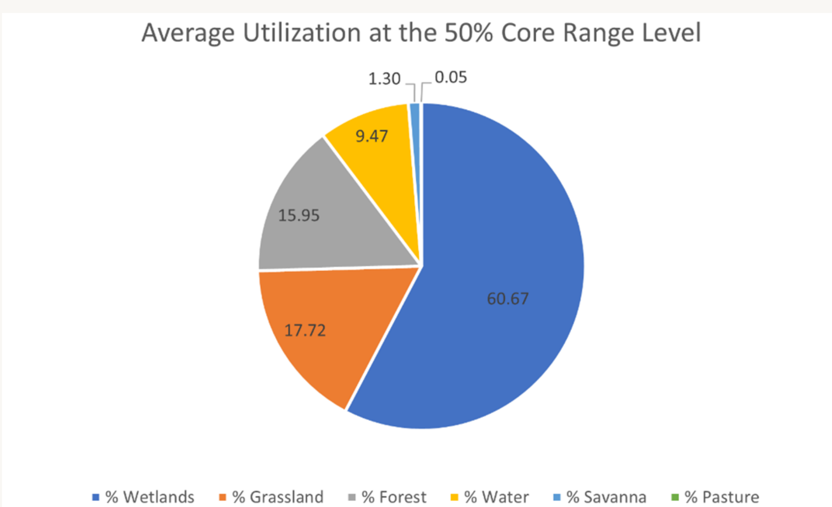

Figure 6. Average utilization of habitat type at the 50% core range level

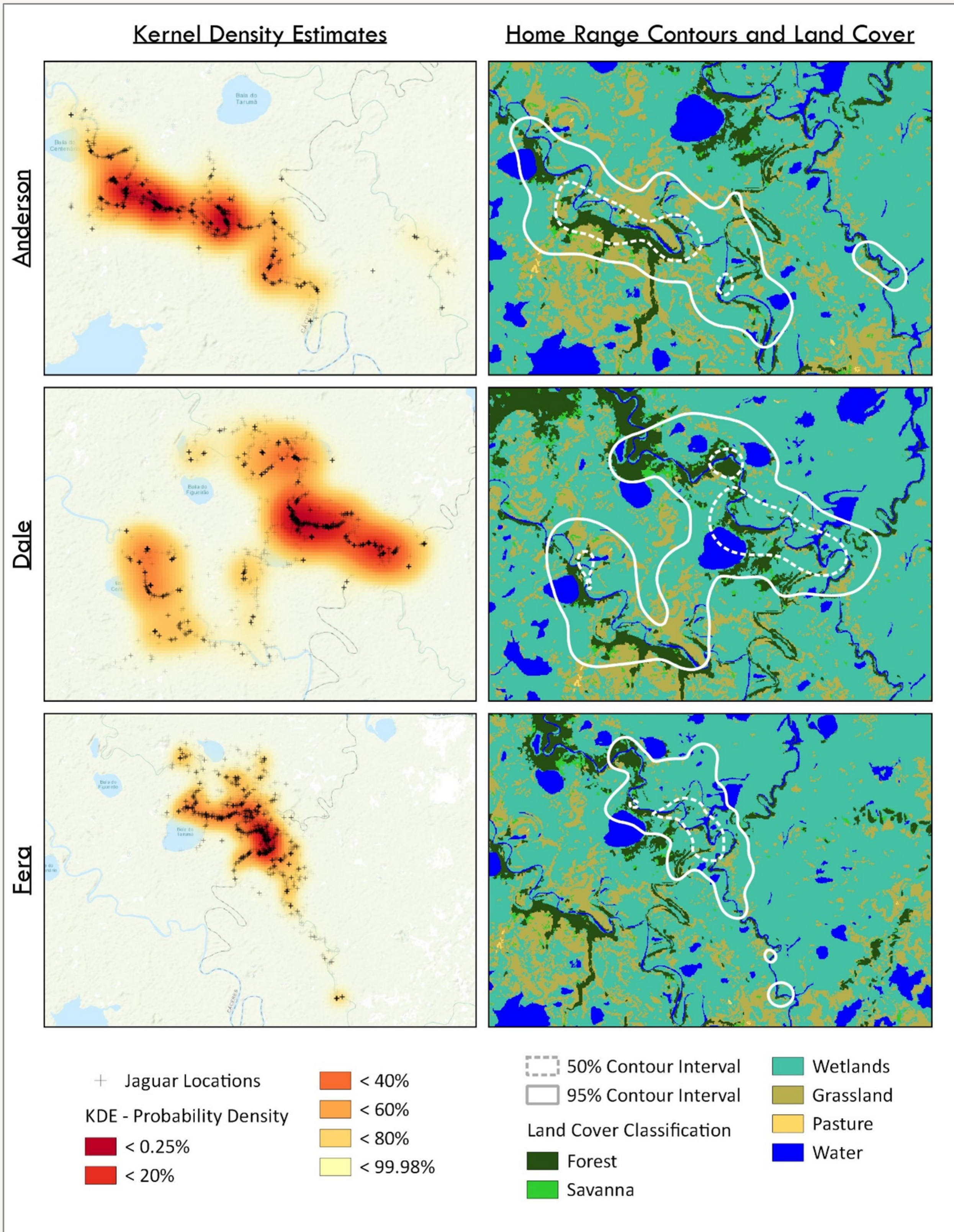

Figure 7. Series of maps showing the KDE and home range contours/land cover map outputs for three cats.

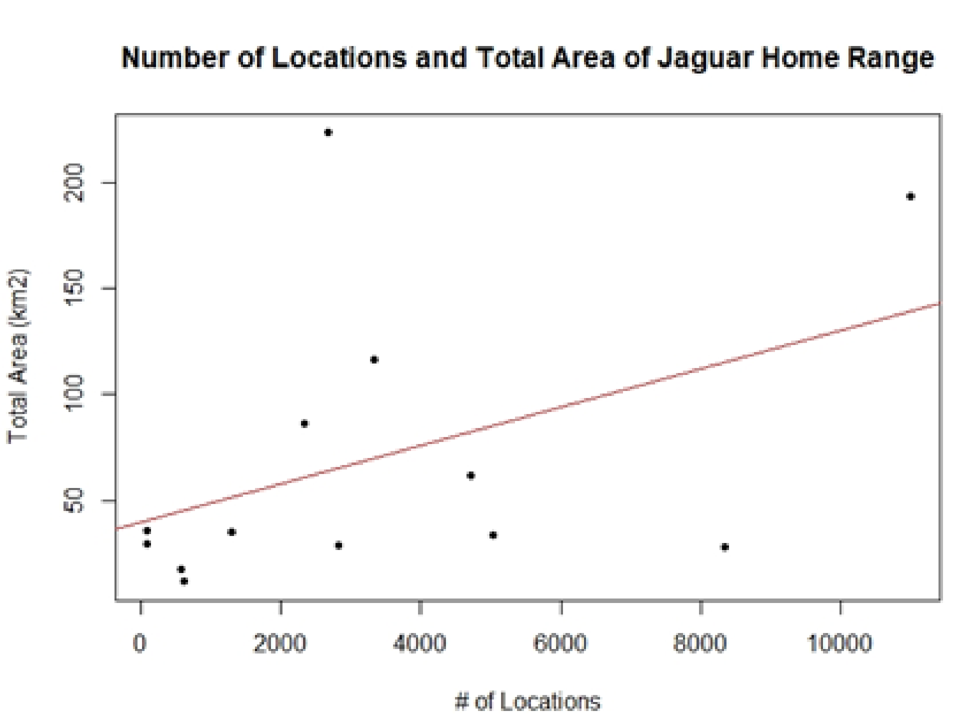

Figure 8. Linear regression analysis on the number of locations collected and total area of jaguar home range

Limitations

The KDE with href bandwidth method is considered a traditional first-generation home range estimator (Walter et al., 2015). It assumes that data are nonparametric (true) and independent (not true). More advanced methods that incorporate different data elements have been developed to try to curb this false assumption. Due to the high collection rates of GPS data, locations are often highly autocorrelated (i.e. dependent) which can affect the resulting home ranges. There are other KDE methods, such as autocorrelated KDE, that deal with this specifically and can reduce its effect (Fleming et al., 2015). Other estimators that incorporate time between each successive location, such as movement-based KDE or Brownian bridge movement models have also proven to further refine utilization distributions (Walter et al., 2015). This study did not account for the differences between the wet and dry season utilization distributions. Other behavioral ecology studies show that male and female jaguars can use their habitat differently according to the season (Crawshaw et al., 1991; Cavalcanti, 2008). The change of seasons in the Pantanal has extreme effects on environmental conditions where entire areas can become flooded, which likely effects which types of habitats are being used (Cavalcanti, 2008). Separating out the GPS locations to distinguish between seasons would result in more polished home ranges estimations, as well as provide insight into the seasonal social interactions among neighboring jaguars.

Lastly, there was a difference in sampling time frames and collection rates among the study sample size. Not all cats were monitoring during the same time period or season, for the same duration of time, or had the same rates of data collection (most locations were fixed every hour, but a couple were every six hours or every two hours). These variables can have influences on the results and conclusions drawn, such as directly effecting the selection of habitat types between the wet and dry seasons. Controlling for these variables would create more refined results.

Conclusion

Overall, the characterization of jaguar utilization distributions showed a preference for wetland habitat which comprised over half of the home ranges. Grasslands were generally the second highest utilized habitat, following by forest and water. Patterns of distribution heavily followed waterways, likely where their main source of prey is. There were also differences between male and female jaguar home ranges. Males almost always had a larger home range than females and females had considerably less home range overlap than that of male jaguars, suggesting a pattern of spatial avoidance among females.

Jaguars have been eradicated from 50% of their historical range largely due to expanding human activity causing habitat loss and fragmentation (Panthera, n.d.). We can expect that as human altered landscapes continue to grow, jaguars will shift their use of the environment accordingly. Understanding how a conservation-species-of-concern uses their habitat is pivotal to ensuring the genetic integrity and futurity of a species. Programs such as the Jaguar Corridor Initiative seek to protect jaguars across their entire six million km2 range by preserving core ranges and connectivity corridors, which can only be done by mapping jaguar presence and movement patterns (Panthera, n.d.). In the future, a cross-region comparison looking at utilization distributions of jaguars in other parts of Central or South America would contribute to larger studies on habitat connectivity. Furthermore, deploying other methods of home range estimation that incorporate a temporal component as well as barriers to movement would likely provide further insights.

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Delaney Callahan is an MA student in Applied Geography and Geospatial Science.

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Appendix

Area Calculations for Each Probability Level, Per Jaguar

Level	Alice	Anderson	Caiman	Dale	Daryl	Fera	Fiao	Linda	Marrua	Milagre	Picole	Selema	Wendy
50	37.99	6.66	20.99	11.00	4.03	4.19	6.28	2.78	7.93	29.39	47.40	7.55	7.46
55	45.87	7.79	24.49	13.13	4.71	5.05	7.28	3.21	9.05	33.92	54.98	8.72	8.96
60	54.92	9.09	28.43	15.54	5.48	6.01	8.38	3.71	10.28	38.91	63.23	9.98	10.57
65	65.77	10.58	32.83	18.33	6.34	7.18	9.67	4.26	11.64	44.63	72.54	11.38	12.33
70	79.21	12.24	37.69	21.70	7.33	8.64	11.20	4.90	13.20	51.31	83.10	12.92	14.27
75	96.01	14.23	43.19	25.86	8.48	10.51	13.10	5.66	15.00	59.18	95.57	14.72	16.48
80	116.16	16.61	49.65	31.07	9.84	12.91	15.60	6.56	17.15	68.64	110.44	16.85	19.07
85	140.33	19.76	57.72	38.00	11.54	16.11	19.25	7.69	19.87	79.75	128.87	19.51	22.32
90	171.73	24.57	68.52	47.58	13.87	20.49	25.17	9.20	23.59	94.15	153.33	23.14	26.87
95	222.77	33.59	85.92	61.94	17.85	27.78	35.86	11.54	29.70	116.52	193.06	29.02	34.69

*these are slighty different than the 95% home range and 50% core range because they were calculated on the raw KDE values