Department of Physics, Chemistry and Biology

Bachelor´s Thesis

Jaguar (*Panthera onca*) activity on the beach of Tortuguero National Park, Costa Rica

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Sammanfattning
Abstract:

The jaguars (*Panthera onca*) of Tortuguero National Park, Costa Rica, sometimes kills and eats green sea turtles (*Chelonia mydas*), they also, though less often, kill and eat leatherback sea turtles (*Dermochelys coriacea*). The three species are considered endangered and are listed in CITES. It was the aim of this study to find out more about the jaguars behaviour in the area. To discern any patterns of jaguar and turtle activity on the beach the number of tracks per eighth of a mile was recorded on a daily basis for 26 days and then analyzed. It was also considered to be of interest to determine how many jaguars could be responsible for the predation of sea turtles. In addition to this average beach width was measured for each eighth of a mile. There was a noticeable difference in jaguar activity on the beach between days of recording. Analysis found that the beach width could possibly have a small positive effect on jaguar activity. No correlation was found between jaguar and turtle activity. It is believed that the reason that there was no correlation between jaguar activity and turtle activity was due to most of the tracks used to estimate turtle activity had originated from leatherback turtles, which are not as often predated by jaguars as the green turtle. An estimation of five or six jaguars was made using photographs of pugmarks and a method of track discrimination together with information from personnel from the Jalova station.

Nyckelord
Keyword:

Activity, *Chelonia mydas*, *Dermochelys coriacea*, Identification, *Panthera onca*, Predation

Table of Contents

1. Abstract
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Keywords: Activity, *Chelonia mydas*, *Dermochelys coriacea*, Identification, *Panthera onca*, Predation,

2. Introduction
Every year the beach of Tortuguero National Park, Costa Rica, is visited by green sea turtles (*Chelonia mydas*) and leatherback sea turtles (*Dermochelys coriacea*) that come to nest. During the peak of the green turtle season 2009, over 2000 turtles came up to nest during one night (Atkinson et al., 2009). Some of the turtles are killed by jaguars (*Panthera onca*) while attempting to nest on the beach. Four turtles were recorded as killed by jaguars during 1997 (Troëng, 2000) but the number has since then risen and during the period between 3rd January and 31st July 2010, 38 turtles were reported as having been predated, 33 of which were green sea turtles, three were leatherback turtles and the last two were hawksbill turtles (*Eretmochelys imbricata*)(Atkinson et al., 2011). Jaguars are generally described as being opportunistic hunters (Sunquist et al., 2002), although some studies show that they may have prey preferences (Weckel et al., 2006). Jaguars have been known to predate on smaller turtles by crushing the carapace with their jaws (Sunquist et al., 2002) and on larger river turtles by biting open the neck and scooping out the insides with their paws (Sunquist et al., 2002). Previous studies have considered jaguars to kill sea turtles by biting the turtle in the neck and then consume the neck (Troëng, 2000). The jaguar is listed in appendix I of CITES (Sunquist et al., 2002). Very few studies have been done on the jaguars of Tortuguero (Troëng, 2000) and most research being done in the area is focused on sea turtles (pers. comm. GVI personnel). However studies on jaguars have been done elsewhere in Costa Rica. One recent study in Corcovado National Park, Costa Rica, showed a lower than expected density of jaguars (Salom-Pérez et al., 2007).

A method to discriminate between prints from different jaguars has been developed by Isasi-Catalá et al., (2008). The method uses linear, areal and angular measurements to discriminate between tracks. Similar methods have been developed and tested for tigers (*Panthera tigris*) (Riordan, 1998; Sharma et al., 2005), mountain lions (*Puma concolor*) (Grigione et al., 1999; Lewison et al., 2001) and snow leopard (*Uncia uncia*) (Riordan, 1998).

Few studies have been done on the predation of sea turtles by jaguars and which factors influence the jaguars' nightly patrols of the beach, and it was therefore the aim of this study to examine possible factors that could influence the jaguars' behavior. It was also considered to be of interest to estimate how many jaguars that could be responsible for the predation of sea turtles.

3. Material & Method

3.1. Study Area

This study was conducted in Tortuguero National Park, Costa Rica, between 10th April 2011 and 5th May 2011. Tortuguero National Park was founded in 1975 to protect 35 kilometers of turtle nesting beach and almost 190 square kilometers of the surrounding forest (Jacobson et al. 1994).

Each mile of the beach had previously been marked with poles at each eighth of a mile, called mile markers, to assist turtle conservation work being done in the area (pers. comm. GVI personnel). The area surveyed was a three mile stretch of the beach, starting at mile marker number 18 and ending at mile marker number 15 (Fig. 1). Between mile markers 17 6/8 and 17 there is coconut plantation with a patch of forest between 17 1/8 and 17. There is rainforest between mile markers 18 and 17 6/8 and between mile markers 17 and 15.

A path runs roughly parallel to the beach through the forest and coconut plantation, about 30 to 40 meters inland from the vegetation edge. At mile markers 16 4/8, 16, 15 4/8 and 15 trails runs out to the beach from this path. At mile 17 another path connects to the first path, this path leads deeper into the forest roughly perpendicular to the first path. A research station (Jalova station) was located by the 17 5/8 mile marker and there is a private residence located close to it. This private residence houses a man responsible for looking after the coconut plantation and several cows that graze in the coconut plantation during the day and that are locked up during the night.

During the study period the survey area was patrolled during roughly three to four hours each night because of turtle conservation work being done in the area.

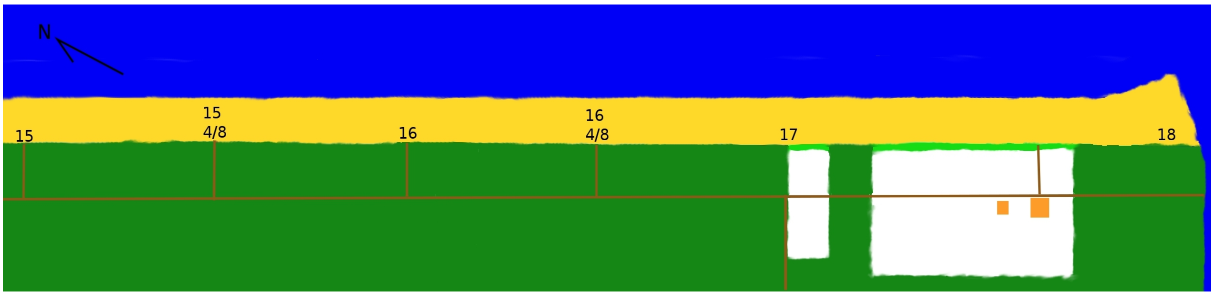

Figure 1: Rough sketch of survey area. Green: Forest, Blue: Water, Yellow: Beach, Brown: Paths, White: Coconut plantation, Orange: Jalova station and private residence. Only mile markers 15, 15 4/8, 16, 16 4/8 17 and 18 has been marked on the sketch.

3.2 Jaguar and turtle activity

Information on jaguar and turtle tracks were collected and used as indicators of activity of each species. Beach width was recorded to determine if it had any effect on jaguar activity.

3.2.1 Track counting

Using the pre-existing mile markers the beach was split into 24 sections labeled after the northern mile marker. Distance from the station was determined as number of sections from section 17 5/8, with section 17 5/8 being 0.

Every morning the survey area was patrolled and for every section of the beach the number of jaguar track series that ran for further than half the one eighth of a mile was recorded as a point of jaguar activity (also referred to as a jaguar activity point or jaguar activity). Jaguar activity points were only counted if the tracks were from the previous night and thus no more than 24 hours old, to avoid double counting.

The number of spots where jaguar tracks enter and exit the beach were counted for each one eighth of a mile.

Sea turtle tracks were counted for each one eighth of a mile. Turtle tracks were separated by species, green sea turtle and leatherback turtle, and by half-moon or full track. A half-moon is a track that ran up half the width of the beach and a full track is a track that runs up past half the width of the beach. If a turtle had nested that was counted as a full track.

Anything that was considered out of the ordinary, such as dead turtles, was recorded as comments for the appropriate section.

3.2.2 Beach width measurements

The width of the beach was measured at nine points in each section except 17 5/8 which was excluded since the proximity to the station was suspected to affect jaguar presence. The points of measurement were determined by taking 20 steps down the beach (roughly southwards) from the previous point, first point of measurement being 20 steps down from the northern mile marker. Measurements were made to the closest whole meter. Measurements were taken from the start of the vegetation to the high tide line. Most beach width measurements were taken on separate days during the study period.

3.2.3 Statistics

Graphs of jaguar activity as a function of turtle activity and beach width were rendered using Open Office Calc v3.1.0 (http://www.openoffice.org/), to aid in visually identify outliers. Sections 17 4/8 to 17 7/8 were identified as obvious outliers for jaguar activity and 17 3/8 was suspected to be an outlier. 17 7/8 was identified as an outlier for beach width. Therefore 17 4/8 to 17 7/8 was excluded from all analysis of jaguar tracks and 17 7/8 from all analysis involving beach width (unless otherwise specified).

A graph of the sums of jaguar activity points for all sections as a function of date was created using Open Office Calc to help discern if there was any change as a function of time.

Linear regression was performed to determine if there was any correlation between turtle activity, jaguar activity and beach width. Linear regression analysis was performed using all data from all sections for turtle activity and jaguar activity as functions of distance to the station. Two tailed partial correlation tests were done between jaguar activity and beach width controlling for turtle activity and between jaguar activity and turtle activity controlling for beach width.

Since 17 4/8 to 17 7/8 were considered to be outliers concerning jaguar activity they were excluded from analysis of entry and exit points. Two tailed bi-variate correlation analysis was used to determine if there was any correlation between the sum of entry and exit points and the sum of jaguar tracks per section. Linear regression analysis was done to determine if there the number of entry and exit points per section could be influenced by the the sum of turtle tracks and/or beach width.

All statistical analyses were done using IBM(C) SPSS(C) Statistics 19.0 (SPSS Inc.).

3.3 Estimating the number of jaguars

3.3.1 Track photography

When a track series was encountered during track counting it was photographed if there were at least four prints which were considered clear enough to be used. Then a ruler with centimeter markings was placed on the side of the track as a scale and the nearest northern mile marker, set number and print number of the set was written on a note placed by the print or written in the sand. The camera was placed so that the area between the two middle toes and the heel pad was in the center of the picture. The camera was also placed as close as possible to the print while still allowing the scale and note to fit into the picture. A minimum of four and a maximum of six different prints were photographed per track series to create a track set. This number was chosen since similar studies had shown that four

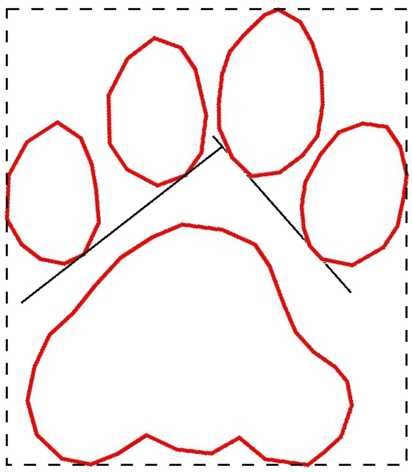

Figure 2: Track outline (red), baselined, rotated and with support lines. The baseline is the black dotted line at the bottom; the other black lines are support lines to aid in measuring.

photographs were enough to reach a classification accuracy of roughly 90 % (Sharma et al., 2005). Photographs were only taken once per length of track. Photographs were only taken of tracks that were identified as being produced by the back left paw, identified as such by being narrower and slightly smaller than the front paw and the placement of the print (pers. comm. GVI personnel). This was due to back paws being considered better than front paws at discriminating between tracks in sand (Isasi-Catalá et al., 2008). Tests using track sets with known identities using this method has shown that the method is able to correctly estimate the number of individuals 87.7 % of the time (Isasi-Catalá et al., 2008) when using the prints of the back paws in sand.

All photographs were taken using digital cameras. Outlines of tracks were drawn using the photographs. Outlines were then rotated and baselined and support lines were drawn to aid measuring (DeAngelo et al., 2010)(Fig. 2). All image editing was done on a computer using GIMP 2.6.10 (http://www.gimp.org/).

Photographs and sets were evaluated to determine if they were viable to be used. Photographs would be considered viable if an outline could be drawn using the photograph and the outlines drawn did not differ visibly from other outlines within the set. A set would be considered viable to be used if at least four usable outlines could be drawn using the photographs of the set and the outlines did not differ visibly within the set.

Following Isasi-Catalá et al. (2008) 13 measurements were measured to be used for statistical analysis: area of toe 1 (A1), area of toe 2 (A2), area of toe 3 (A3), area of toe 4 (A4), area of heel pad (AHP), total length of print (TPL), total width of print (TPW), heel pad length (HPL), heel pad width (HPW), length of toe 2 (L2), width of toe 2 (W2), length between toe 2 and heel pad (L 2-HP) and angle between toe pairs (Angle). Measurements were taken from the outlines using ImageJ 1.44p (http://rsweb.nih.gov/ij/). Following Isasi-Catalá et al. (2008) three ratios were calculated using some of the measurements taken: TLP/TWP, TWP/HPW and AHP/A2.

3.3.2 Statistics

Following Isasi-Catalá et al. (2008) three principal component analysis was done on 12 of the 13 variables, one on A1, A2, A3, A4 and AHP, the second on TPL, HPL, L 2-HP, and L2, the third on TPW, HPW and W2. The components were evaluated based on eigenvalues and the first component of each was then used together with the three ratios and Angle as variables during statistical analysis.

To estimate from how many different individuals the prints may have originated from, discriminant function analysis was performed (Grigione et al., 1999, Sharma et al., 2005, Isasi-Catalá et al., 2008) using SPSS(C) Statistics 19.0. A graph of 95 % confidence interval ellipsoids around the set centroids (Grigione et al., 1999) was created using Open Office Calc and Gimp. If two ellipsoids intersect the tracks in the sets can be considered to originate from the same individual (Grigione et al., 1999).

When using SPSS(C) Statistics 19.0 to do a discriminant function analysis of all the sets, a classification matrix (Lewison et al., 2001) and a table stating predicted set membership and the squared Mahalanobis distance to the two closest set centroids for each outline (Lewison et al., 2001) was created to aid in estimating the number of jaguars.

4. Results

Three green turtle tracks, two green turtle half-moons, 24 leatherback tracks and 11 leatherback half-moons were recorded for the entire length of the survey area. 419 points of jaguar activity (Fig. 3), 35 points of entry and 39 points of exit were recorded for the entire length of the survey area. A summary of the data collected per section is presented in Table 1.

Points of interest that were noted include two dead leatherback turtles and deer tracks. The first dead turtle was discovered in section 15 4/8 by the water's edge on 2nd May. The second one was discovered on the beach in section 16 3/8 on the morning of 4th May. Presence of fresh deer tracks was recorded on three separate surveys but this was not enough to include them in any of the analyses.

Table 1: Summary of the data collected in each section

Section	Total number of jaguar activity points	Total number of turtle tracks	Total number of entries and exits	Average beach width in meters
17 7/8	3	0	0	76.22
17 6/8	4	2	1	28.78
17 5/8	3	0	0	
17 4/8	3	0	1	26.67
17 3/8	11	0	2	22
17 2/8	16	1	3	24.44
17 1/8	20	3	0	34.78
17	25	5	2	31.89
16 7/8	23	1	5	32.78
16 6/8	22	2	2	27
16 5/8	22	0	2	28.56
16 4/8	26	3	3	31.22
16 3/8	25	0	6	29.56
16 2/8	23	1	5	26.78
16 1/8	24	3	0	32.33
16	20	3	3	32.33
15 7/8	16	1	3	25.56
15 6/8	22	2	6	31.56
15 5/8	23	5	6	30.11
15 4/8	14	1	9	28.78
15 3/8	17	2	4	28.33
15 2/8	17	1	5	24.67
15 1/8	21	1	2	21.56
15	19	3	4	23.44

4.1 Correlations

4.1.1 Jaguar and turtle activity

Linear regression analysis showed a significant correlation between jaguar activity and beach width ($R^2 = 0.317$; $p = 0.010$)(Fig. 4). Linear regression analysis showed no significant correlation between jaguar activity and turtle activity but it was close to being significant ($p = 0.066$) (Table 2).

Partial correlation test between jaguar activity and beach width and controlling for the effect of turtle activity ($R^2 = 0.205$; $p = 0.051$) and between jaguar activity and turtle activity controlling for the effect of average beach width ($R^2 = 0.042$; $p = 0.400$), were done excluding sections 17 4/8 to 17 7/8.

The data showed that there was a great deal of difference in the total jaguar activity in the survey area between days, ranging from 0 to 50 jaguar activity points, with an average of 16.11 and a standard deviation of 15.78.

4.1.2 Distance to the station

Linear regression analysis showed no significant correlation between turtle activity and distance to base (Table 2). A clear effect of distance to base could be seen for jaguar activity, which seems to dissipate after section 17 3/8 (Fig. 3).

4.1.3 Entry and exit points

Linear regression analysis showed no correlation between the sum of entry and exit points and turtle activity (Table 2). Linear regression analysis showed no correlation between the sum of entry and exit points and average beach width (Table 2). Two tailed bi-variate correlation analysis was performed for jaguar tracks and total number of entry and exit points ($R^2 = 0.015$ $p = 0.609$).

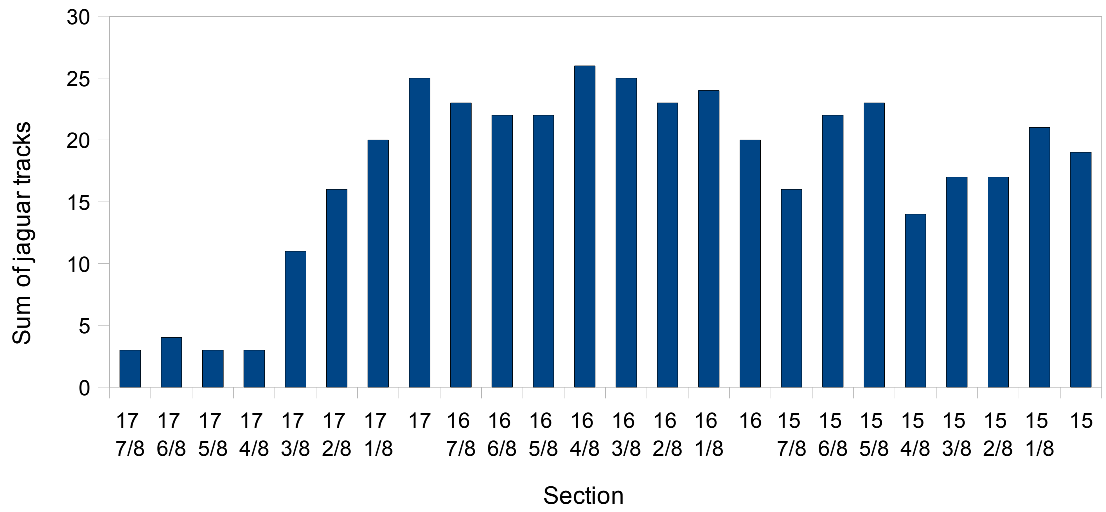

Figure 3: Sum of jaguar activity per section for the entire study period

Table 2: R2 from linear regression analysis for different section intervals. 17 5/8 was excluded all analyses involving average beach width. Bold numbers indicate significant correlation (p < 0.05).

Dependent – Independented	15 – 17 2/8	15 – 17 3/8	15 – 17 6/8	15 – 17 7/8
Jaguar activity – Turtle activity	0.102	0.176		
Jaguar activity – Average beach width	**0.205**	**0.317**		
Turtle activity – Average beach width			**0,238**	
Jaguar activity – Distance to base				**0.240**
Turtle activity – Distance to base				0.077
Entries and Exits – Turtle activity		0.030		
Entries and Exits – Average beach width		0.002		

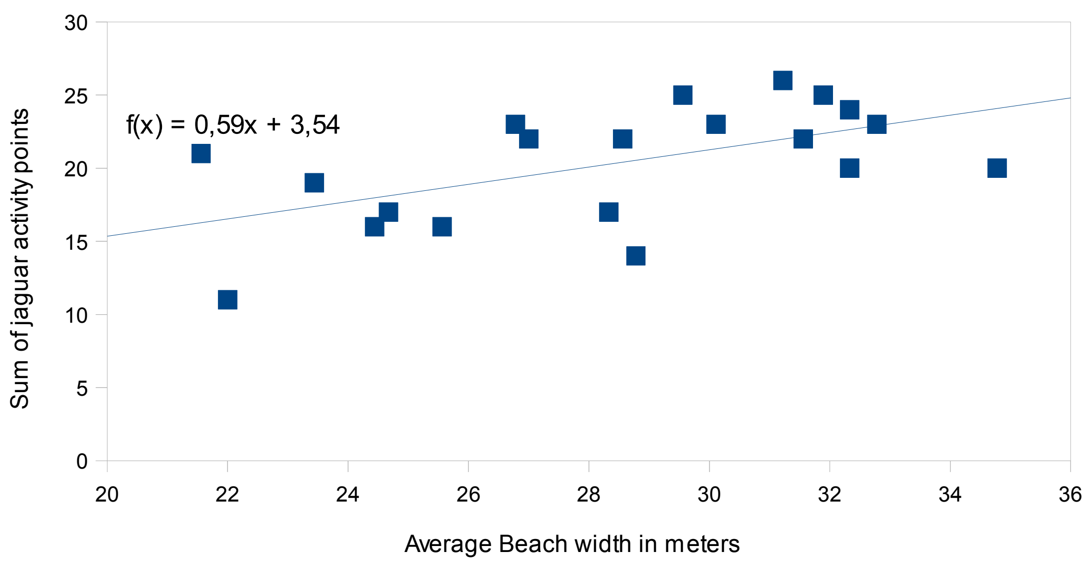

Figure 4: Sums of jaguar activity points for each section plotted as a function of that sections average beach width. Without sections 17 4/8 to 17 7/8.

4.2 Estimating the number of jaguars

A total of 20 sets, composed of a total of 113 photographs, were collected.

14 sets composed of 72 photographs were considered viable to be used for statistical analysis.

4.2.1 Principal Component analysis

PCArea, PCLength and PCWidth represent 84.97 %, 79.48 % and 89.08 % of the variance from the original variables respectively.

4.2.2 Discriminant function analysis

Outlines were indexed by set number, running from 1 to 14 and a discriminant function analysis was done using PCArea, PCLength, PCWidth, Angle, TLP/TWP, TWP/HPW and AHP/A2 as variables for all outlines (Table 4). Confidence interval ellipsoids were drawn around each set centroid and are presented in a graph and six aggregations of ellipses can be seen (Fig. 5). However sets 3, 5 and 11 are close to each other. Further examination was dine using predicted set memberships for the outlines (Table 4) and set membership probabilities for each outline . These showed that it was unlikely that sets 3, 5 and 11 came from the same jaguar.

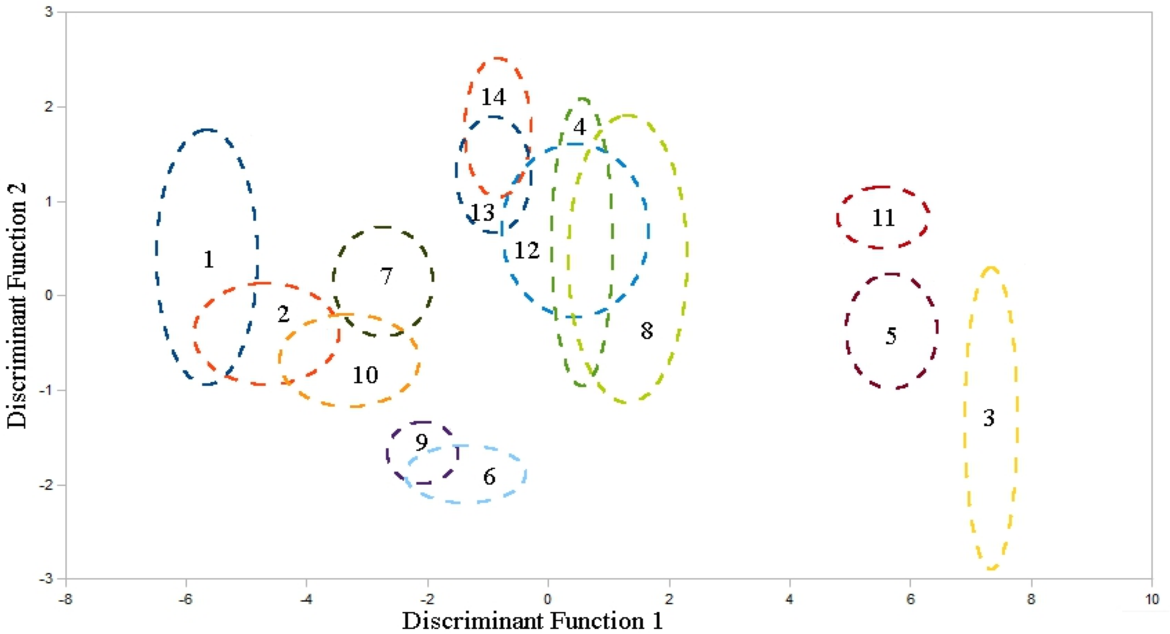

Figure 5: Results from the analysis of pugmarks. 95 % confidence interval ellipsoids of the first two discriminant functions for each set. The numbers in the ellipses is the set number, placement of number does not indicate set centroid.

Table 3: Centroid values of the first four discriminant functions (F1-F4) for each set, total number of outlines used per set and in which section and on which day the set was recorded. On the bottom the eigenvalues for each of the discriminant functions and the relative percent variance for each function

	F1	F2	F3	F4	N	Section	Date
Set 1	-5.65	0.41	1.54	0,67	4	17 7/8	10/04
Set 2	-4.68	-0.39	0.32	-0.30	5	17 4/8	10/04
Set 3	7.33	-1.32	0.76	0.68	5	16 1/8	10/04
Set 4	0.55	0.59	-0.32	1.77	4	16 1/8	10/04
Set 5	5.73	-0.38	1.17	-1.06	5	15 2/8	10/04
Set 6	-1.41	-1.88	-0.65	0.27	5	15 1/8	10/04
Set 7	-2.73	0.15	-1.02	-0.34	6	17 2/8	11/04
Set 8	1.31	0.40	0.61	-1.27	5	16 5/8	11/04
Set 9	-2.11	-1.67	0.12	0.55	5	16 3/8	11/04
Set 10	-3.29	-0.69	-0.79	-0.89	6	17 2/8	17/04
Set 11	5.54	0.80	-1.67	0.09	6	17 2/8	20/04
Set 12	0.43	0.71	0.16	0.25	5	17 2/8	27/04
Set 13	-0.88	1.28	0.56	0.38	5	15 6/8	03/05
Set 14	-0.89	1.78	0.12	-0.08	6	15 6/8	03/05
Eigenvalue	17.5	1.4	0.91	0.68			
% of Variance	82.3	6.6	4.2	3.2			
Cumulative %	82.3	88.9	93.2	96.4			

Table 4: The number of outlines that were correctly classified using squared Mahalanobis distances for each set and to which set the wrongfully identified outlines was predicted to belong to

	Predicted set													
Actual Set	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4													
2	1	3							1					
3			4								1			
4				4										
5					5									
6						4			1					
7		1					3		1	1				
8				1				3						1
9						1			4					
10		1					1			4				
11					1						5			
12									1			4		
13							1						3	1
14													1	5

5. Discussion

5.1 Jaguar activity

There was no discernible pattern in jaguar activity as a function of time. However the great variation in jaguar activity indicates that there is something affecting when, how much and probably which, jaguars move on the beach. It is possible that it could be weather, levels of moon-light and/or human activity that affect the jaguars. Further studies should be conducted to explore these and other possible factors.

R^2 values for jaguar activity as a function of beach width is slightly higher than that for jaguar activity as a function of turtle activity, whether 17 3/8 is included or not. Also any correlation between jaguar activity and turtle activity disappeared in the partial correlation test. It seems therefore that average beach width affect jaguar activity more than turtle activity, with jaguars being more active on wider beaches. However further studies on jaguar activity during periods of a greater green turtle activity, June to November (pers. comm. GVI personnel), and of periods of no turtle activity should be done to further help explain the slight correlation between beach width and jaguar activity. It is also possible that the jaguars are more likely to walk below the high tide line at the narrower segments and so their tracks are washed away before they get counted (pers. comm. David White). It should be noted that beach width has a very small effect on jaguar activity and further studies should be done to try and identify other more significant factors.

A possible explanation to beach width having a bigger effect on jaguar activity than turtle activity could be that most of the turtle tracks measured came from leatherback turtles and a majority of the turtles reported to have been killed by jaguars in this and other areas has been green sea turtles (Atkinson et al., 2009, Atkinson et al., 2011, Troëng et al., 2007).

Also since the p value of the correlation between jaguar activity and turtle activity is so close to being significant it could be possible that the limited sampling of beach width and turtle tracks have skewed the results. Repeating the study during times of greater turtle activity and measuring each beach section more than once could determine if this is the case.

It is possible that the dead turtles found could have skewed the results, especially the turtle found in section 16 3/8 since that section had five jaguar activity points out of a total of six recorded the day of the discovery.

The correlation between jaguar activity and proximity to base is entirely due to the first four sections (17 7/8 to 17 4/8) and partially 17 3/8 although not as clearly. However any visible effect of proximity to the base disappears after section 17 3/8. This indicates that although proximity to the base has an effect it is limited to a small area. It is deemed to be likely that the base and the human presence has a deterring effect on the jaguars. However further studies should be done to determine if this is true and if there are other factors which play a part.

There was no correlation between entry and exit points and turtle activity or between entry and exit points and average beach width which would signify that where the jaguars enter and exit the beach is determined by other factors. Earlier studies have determined that jaguars prefer to travel using man-made paths and tapir trails (Weckel et al., 2006), however the trail in the study area is used almost daily to perform biological surveys in the area (pers. comm. GVI personnel) which could have a deterring effect. Since the specific spot of an entry or exit points was not recorded, effects of the man-made trails that go through the forest was hard to estimate. It was also made more difficult by the openings being located at or very close to the mile markers themselves and the sections ending and starting at the specific mile markers meant that the entries or exits through these man-made trails could have been split up on two sections. It would therefore be interesting to study the specific nature of each beach entry and exit points to determine if the jaguars prefer to use the man-made trails and also to do this study on trails with different levels of human activity on the trails but also on the beach.

5.2 Estimating the number of jaguars

From the examination of the confidence ellipsoid graph and set membership probabilities as well as information from GVI personnel at the Jalova station, it was estimated that the collected track sets originated from a maximum of six and a minimum of five jaguars. GVI personnel at the Jalova station has so far been able to identify five individual jaguars using camera traps (pers. comm. GVI personnel). If this is the number of jaguars responsible for turtle predation it is unlikely that jaguar predation will have a significant impact on the nesting turtle population of Tortuguero. However it should be noted that the method used has been shown to be accurate in 87.7 % of trials and is more prone to underestimate than to overestimate the number of individuals (Isasi-Catalá et al., 2008).

The confidence interval ellipsoids of sets 13 and 14 have a very clear overlap, but the sets were collected on the same day from two track series running parallel to each other and it was considered likely that they came from two different individuals. It has been reported that a pair of jaguars in the area have been travelling together and even feeding together (pers. comm. GVI personnel). Previous studies have found presumed mother-daughter jaguar pairs that have associated closely (Schaller et al., 1980). Thus it is possible for these tracks to have come from two very closely related individuals. A similar method to the one used in this study, but developed to discriminate between tracks from mountain lions, has been shown to be able to discriminate between tracks from individuals that were assumed to be closely related (Grigione et al., 1999). It would however be interesting to do a validation study of this method using prints from known related individuals to see if the method could discriminate between these. Another interesting future study would be to device a method to ascertain the gender of an individual from the print, similar to the one for tigers (Sharma et al., 2003).

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