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Distribución y densidad del conejo zacatuche (*Romerolagus diazi*) en el Área Natural Protegida Corredor Biológico Chichinautzin

Distribution and density of the zacatuche rabbit (*Romerolagus diazi*) at the Protected Natural Area "Corredor Biológico Chichinautzin"

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The Protected Natural Area (PNA) "Corredor Biológico Chichinautzin" contains a large area of bunchgrasses, a habitat that is necessary for the zacatuche rabbit to survive. As part of a monitoring program used to evaluate the status of the zacatuche rabbit's populations within this PNA, we estimated its distribution by using direct (sightings) and indirect methods (latrines) during visits performed to all the available habitats. Additionally, we estimated the annual density of the zacatuche rabbit using a line transect method, sampling eight, one-kilometer-long transects monthly during one year. Based on 101 latrine records and 48 sightings, a distribution map was prepared for the region using the convex polygon method in ArcView. Most of this distribution (166.43 km^2) represents an area that had not been previously reported in the literature for the zacatuche rabbit. Using the half-normal model that best fit the data, we estimated a density of 4.2 rabbits/ha. Our results suggest that the Corredor Biológico Chichinautzin meets the criteria necessary to be cataloged as a core distribution area for the zacatuche rabbit. Therefore, we suggest that both management and conservation of this habitat within the PNA should be made a priority.

El Área Natural Protegida (ANP) "Corredor Biológico Chichinautzin" contiene una extensa área de pastizales amacollados, un hábitat que es necesario para que el zacatuche sobreviva. Como parte de un programa de monitoreo para evaluar el estado de las poblaciones del conejo zacatuche en esta ANP, estimamos su distribución utilizando métodos directos (avistamientos) e indirectos (letrinas) durante visitas a todos los hábitats disponibles. Además, se estimó su densidad anual utilizando el método de transectos lineales, muestreando cada mes ocho transectos de un km de largo durante un año. Con base en los registros de 101 letrinas y 48 avistamientos, se elaboró un mapa de distribución para la región mediante el método del polígono convexo en ArcView. La mayor parte de esta distribución (166,43 km^2) representa un área que no habían sido previamente reportada en la literatura para el zacatuche. Usando el modelo half-normal que fue el mejor que se ajustó a los datos, se estimó una densidad de 4.2 conejos/ha. Nuestros resultados sugieren que el Corredor Biológico Chichinautzin cumple con los criterios necesarios para ser catalogado como un área núcleo de distribución para el zacatuche. Por lo tanto, sugerimos que el manejo y la conservación de este hábitat en el ANP deben ser una prioridad.

Key words: conservation, density, distribution, IUCN *Romerolagus diazi*.

Introduction

The zacatuche rabbit (*Romerolagus diazi*) is an endemic species to the Trans-Mexican Volcanic Belt. Previous studies have indicated that the zacatuche rabbit has a strong preference for subalpine habitats (2,800-4,200 m), with higher abundances found in open pine forests (*Pinus* spp.) that have abundant bunch grasses (*Festuca tolucensis*, *Muhlenbergia* spp., *Jarava ichu*) in their understory (Velázquez and Heil 1996; Rizo-Aguilar *et al.* 2015). Based on this, the zacatuche rabbit is considered a habitat specialist. Its habitat has been severely fragmented due to factors such as urbanization, agricultural conversion, illegal logging, and wildfires (Velázquez *et al.* 2011). As a result, the species is classified as endangered on the IUCN Red List (AMCELA *et al.* 2008), and as at risk of extinction by Mexican Legislation (SEMARNAT 2010).

Until the late 1980s the precise area of distribution of *R. diazi* was unknown. López-Forment and Cervantes (1979) estimated that its area covered a total of 150 km^2. In contrast, Hoth *et al.* (1987) only found zacatuche rabbits in three isolated areas in the central Trans-Mexican Volcanic Belt: the Sierra Nevada mountains, and the Tlaloc and Pelado volcanoes. The total area of distribution estimated by Hoth *et al.* (1987) was 280 km^2. Motivated by these contrasting findings, Velázquez *et al.* (1996) conducted a survey throughout the proposed geographic range of *R. diazi* to document its historical and current distribution. Based on collection records, sightings, traces (pellets) and interviews with farmers, they estimated a distribution area of 386 km^2. Within this, four core and 12 peripheral areas were recognized. This information was used to do the distributions maps for the zacatuche rabbit that are now available in the literature and on web pages (Velázquez *et al.* 1996; AMCELA *et al.* 2008).

Studies conducted on the Pelado Volcano, one of the four core areas of zacatuche rabbit, indicated that densities estimated using line transects ranged from 0.11 to 1.20 rabbits/ha according to habitat characteristics (Velázquez 1994). Other studies conducted on the Pelado, Tláloc and Iztaccíhuatl Volcanoes based on fecal pellet counts have shown that the abundance of this species is highly variable, ranging from 0.1 to 3.1 latrines/m^2 (Velázquez 1994; Velázquez and Heil 1996; Velázquez *et al.* 1996).

The Corredor Biológico Chichinautzin (hereafter COBIOCH) is a Protected Area located in the northern part of the state of Morelos (Figure 1). The area of the COBIOCH (657.2 km^2) includes Fractions I and II, covering the zone between Lagunas de Zempoala and El Tepozteco National Parks, and creating a biological corridor that ensures the continuity of ecological processes of the biota in the area. It contains on of the largest areas of grassland in centra Mexico (Cabrera-García *et al.* 2006), and likely acts as a corridor connecting the zacatuche rabbit populations of two core areas of its distribution, the Tláloc Volcano with those of the Pelado Volcano (Velázquez *et al.* 1996). Paradoxically, very little is known about the current status of *Romerolagus diazi* in the area, and there are only a few historical records dating from Velázquez *et al.* (1996).

In this paper we provide evidence of newly occupied areas by *R. diazi* as well as its annual density within the COBIOCH and its influence area. The outcomes are further discussed in the light of the relevance of this protected area for conservation of the endangered zacatuche rabbit.

Material and Methods

To document the distribution of the zacatuche rabbit, from June to November 2008, and from June to December 2011 we randomly selected 173 points (Appendix 1) from all habitats with bunchgrasses in the COBIOCH. Each point consisted of an area of 50 x 50 m within which exhaustive searches were conducted and latrines counted by at least 4 people. The zacatuche faeces are reliably distinguished from the ones of the other two lagomorphs *Sylvilagus floridanus*

and *S. cunicularius* due to their size and shape (Hoth *et al.* 1987). The latrine counting method has been used previously to document the abundance and distribution of the zacatuche rabbit (Fa *et al.* 1992; Velázquez 1994). In addition, we recorded all zacatuches sighted along the roads and in the grasslands while driving or walking between sampling sites. Each sampling point and rabbit sighting was recorded using the Universal Transverse Mercator (UTM) geographic coordinate system, and was uploaded to a Geographical Positioning System software using a Garmin GPS device (coordinate output to WGS84). With these records, we estimated the area of distribution for the species within the COBIOCH, and we compared it to the distribution area estimated using all of the records reported by Velázquez *et al.* (1996). In both cases, we first generated a buffer area of 100 m in radius around the location of each record, to determine the area where the species might be located. We then estimated its probable distribution area using the Minimum Convex Polygon method, and the Fixed Kernel Isopleths method, both at a 95 % confidence level (Harris *et al.* 1990; Worton 1995). The output models for each method were combined spatially (MCP + Kernel model), and were subsequently cut with contours above 2,800 m, the lower elevation limit recorded for the area; finally we intersected it with the polygon of the COBIOCH to measure the area that lies within the protected natural area. The process was performed using the "Animal Movement Analyst" for ArcView 3.2.

The annual density of the zacatuche rabbit was estimated using the line transect method (Buckland *et al.* 1993). For this, eight reasonably straight, permanent 1000-m-long walking line transects were established, at least 1 km apart, to cover different habitats. Monthly zacatuche rabbit surveys were conducted from March 2010 to February 2011. Two experienced observers

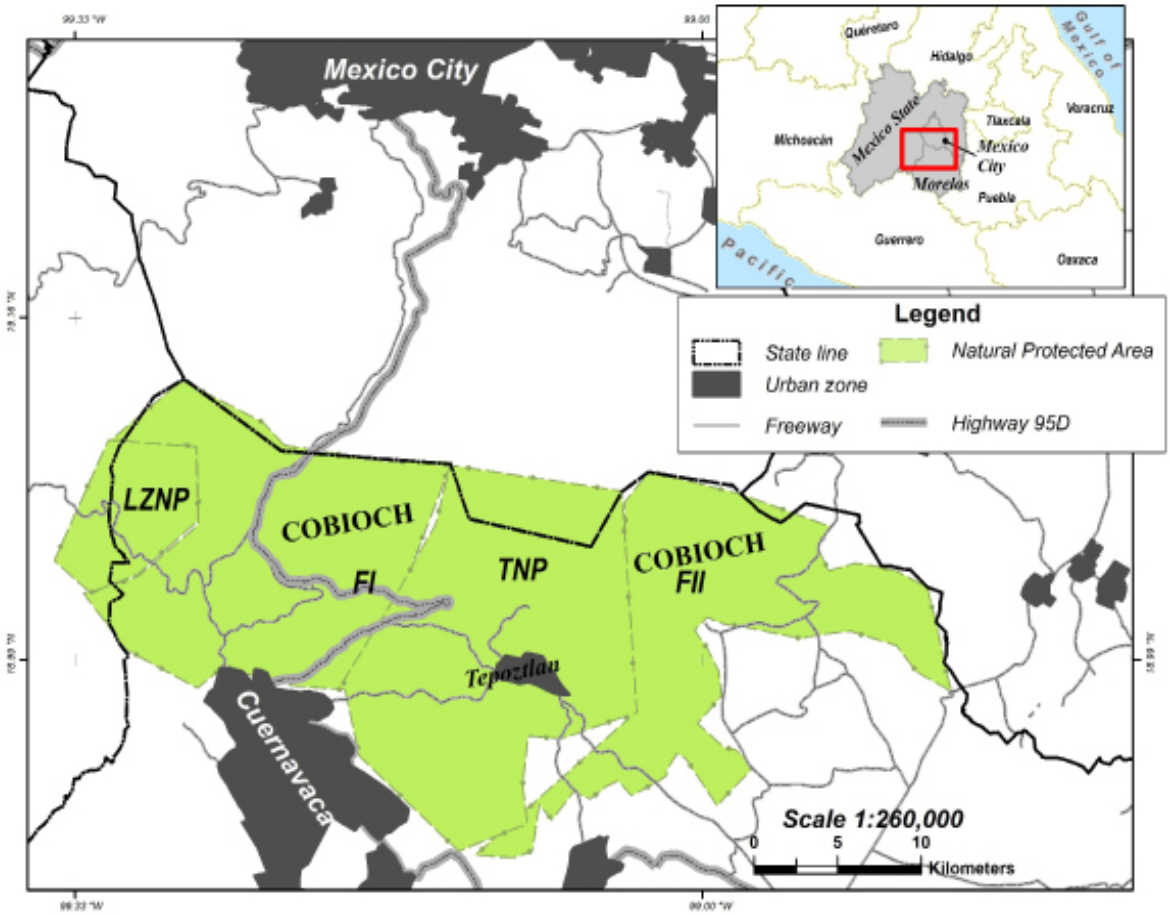

Figure 1. Location of the Corredor Biológico Chichinautzin Protected Area in Mexico. Lagunas de Zempoala National Park (LZNP).;Fraction I (FI) Fraction II (FII); El Tepozteco National Park (TNP).

conducted the survey, both searching ahead and to each side of the transect while walking at a relatively constant speed of 0.5 km/h. All surveys were conducted between 7:00 and 9:00 h, which is the time of the day when the zacatuche rabbit is most active (Solorio-Damián 2013). The position of rabbits observed on the center line of the transect was recorded as a distance of zero, and for those observed to either side of the transect the distance (m) was recorded perpendicularly from the rabbit to the center line (Buckland *et al.* 1993) using an electronic distance measuring tool, the Multi Measure Combo Pro (Sonin Inc.). The data were analyzed using the Distance 5.0 program (Thomas *et al.* 2010) to estimate rabbit density per hectare. To model the detection function of the perpendicular distances, data were pooled across all transects. Three models were considered for the detection function: half-normal, uniform and hazard rate. In each case, the need for cosine adjustment terms was assessed using likelihood ratio tests. In all analyses, 5 % of the longest distances were shortened to avoid bias introduced by outlier distance sightings. The final model was chosen based on a combination of a low value for Akaike's information criterion (AIC) and low variance.

Results

The presence of the zacatuche rabbit was documented at 149 points within the northernmost part of the COBIOCH. It was absent from 24 points with suitable habitat. The records include 48 sightings and 101 pellet counts. The estimated occupied area based on 49 historical records was 56.85 ha. Based on all our field records, the estimated area occupied by this species in the Protected Natural Area and the zone of influence was 166.43 km^2 (Table 1). Most of this estimated area (98 ha) is located within the polygon of the COBIOCH. Comparing this area with that estimated based on historical records (Figure 2), this one represents an increase of 109 ha of the occupied area previously known.

During the 12 months of the density survey, a total of 97 zacatuche rabbits were sighted along 96 km of transect. The analysis of this data using the Distance 5.0 software indicates that the half-normal + 1 cosine model provided the best fit to our distance data according to the AIC and variance values (Table 2). This model estimates a density of 4.2 individuals/ha.

Table 1. Estimated area occupied by *Romerolagus diazi* (km^2) based on historical and recent records for the Corredor Biológico Chichinautzin (COBIOCH) Protected Natural Area.

	Estimated area (km^2)	
	Historical records	**Recent records**
Fractions I and II	32.09	98.96
El Tepozteco	8.64	46.88
Lagunas de Zempoala	16.12	20.59
Total area	56.85	166.43

Discussion

Our results represent an increase of the knowledge related to the range of the distribution for *R. diazi* into the COBIOCH and its influence zone. Most of the recent estimated area was not included in the distribution map proposed by Velázquez *et al.* (1996), which is the basis for the IUCN map (IUCN 2012). Clearly, our findings do not represent an expansion of the zacatuche rabbit in the Sierra de Chihinautzin, but reflects our intensive sampling. Before our field survey, there were only 49 historical records based on collecting data, literature and field surveys conducted in the study area (Appendixes 2 and 3 in Velázquez *et al.* 1996).

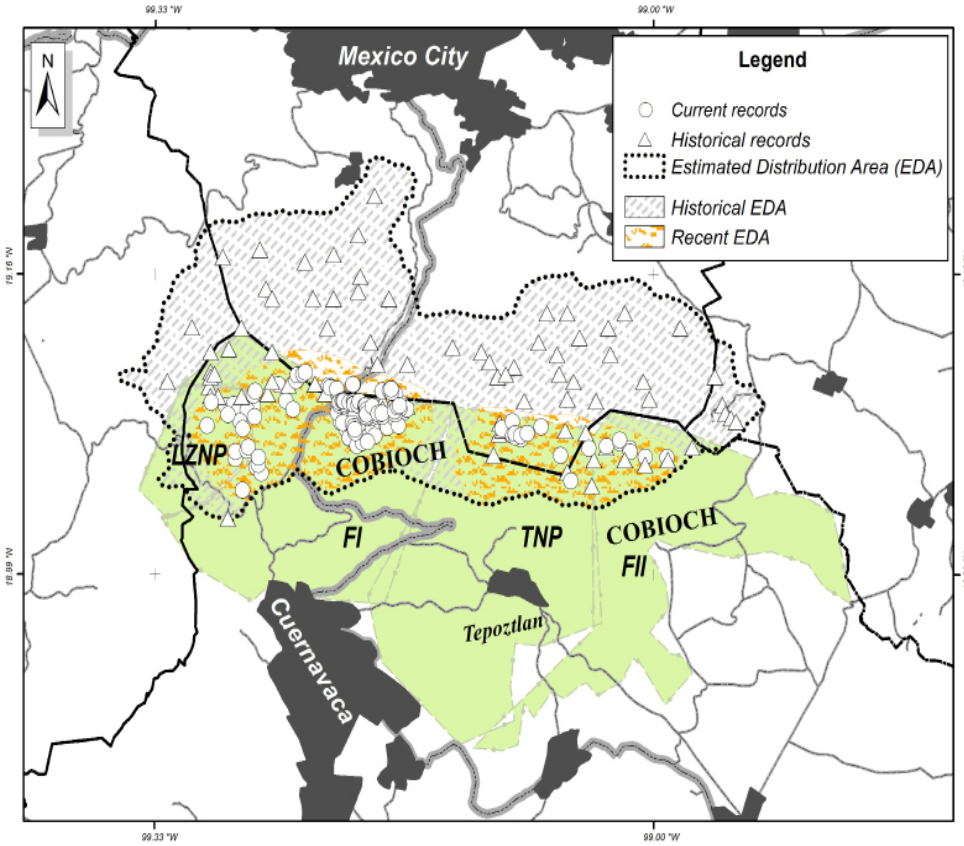

Figure 2. Distribution area of *Romerolagus diazi* within the Corredor Biológico Chichinautzin based on historical and recent records. LZNP, Lagunas de Zempoala National Park. FI, Fraction I. FII, Fraction II. TNP, El Tepozteco National Park. Estimated areas are provided in Table 1.

Velázquez *et al.* (1996) based on those records, together with an analysis of climate, elevation and vegetation maps along the Trans-Mexican Volcanic Belt, recognized six peripheral areas (isolated from each other) for the zacatuche rabbit within the area inside the COBIOCH. Our direct and indirect records point to a different scenario. First, the proximity of all the records indicates that the populations of the zacatuche rabbit might not be isolated from each other and that the rabbits are likely moving between landscapes. The only barrier to dispersal is the highway 95D (Mexico City-Cuernavaca), built in 1952, that crosses the COBIOCH and has barred connectivity between populations on either side of it (Uriostegui-Velarde 2014). Second, Velázquez *et al.* (1996) recognized as core distribution areas of *R. diazi* those with suitable habitat where rabbits were sighted and traces (pellets) were found. The results presented here clearly meet these criteria, therefore indicating that the COBIOCH must be also considered a core area of the zacatuche rabbit. Added to that, our result regarding the estimated annual density also provides evidence that the COBIOCH is one of the most important habitats for zacatuche rabbit populations. Density estimated

Table 2. Annual density (D) of *Romerolagus diazi* estimated using Akaike's information criterion (AIC) and the percent coefficient of variation (% CV) for each model.

Model	AIC	D	% CV
Half-normal + 1 cosine	614.24	4.2	10.1
Unifrom + 1 cosine	675.68	7.7	14.7
Hazard rate + 1 cosine	668.13	8.1	12.5

is higher than the only previous report of 1.2 rabbits/ha for the area of the Pelado Volcano using a similar methodology (Velázquez 1994).

These results make an important contribution to our knowledge of the distribution of *R. diazi*, and the evidence regarding its occurrence and density obtained during this study allow us to suggest that the COBIOCH provides a suitable habitat with conditions that are appropriate for *R. diazi* to establish and maintain populations with high abundances. It is therefore necessary to implement conservation actions that focus on habitat management and protection in order to avoid the habitat loss and fragmentation that result from grazing, crop cultivation and road construction.

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Appendix 1

List of sampled points used to document both distribution and estimated occupied area of *Romerolagus diazi* within the COBIOCH.

	X	Y		X	Y
1	481452.8630	2110266.7704	43	468505.3013	2110784.7857
2	478781.8766	2108370.8834	44	469682.3159	2110006.8160
3	479526.7436	2110152.6332	45	470225.3242	2107237.9499
4	478861.7115	2110455.5028	46	470238.8004	2107681.3369
5	477642.8210	2110156.6659	47	471039.5803	2107743.6436
6	469528.2843	2110561.6963	48	471139.3437	2107960.9222
7	470095.3161	2110646.8244	49	471508.5979	2111234.5920
8	470445.3828	2110280.5183	50	471635.9637	2111470.7897
9	478809.1557	2108203.6573	51	471849.9994	2106855.7496
10	478830.1949	2108710.7495	52	471862.5065	2107320.1455
11	478315.6355	2108526.9412	53	474542.1658	2112130.2452
12	478158.4247	2109034.2433	54	474630.8961	2112506.5556
13	478176.6789	2109642.7621	55	475018.2599	2112546.2835
14	478229.9038	2110171.3304	56	475210.9037	2112666.7673
15	479429.0815	2108525.6660	57	476852.6562	2111819.5911
16	479453.0189	2109026.6088	58	476968.6579	2111699.5974
17	477708.9807	2109529.6043	59	477487.0047	2110139.3884
18	477532.1418	2110694.6526	60	477742.3155	2110814.5933
19	477800.4594	2110267.1193	61	477865.0494	2109502.8715
20	479503.2318	2109506.0086	62	478043.0510	2110618.2535
21	478994.6300	2109395.9373	63	478257.6772	2109780.6970
22	479970.4083	2109148.9770	64	478317.6782	2108533.7618
23	480156.9184	2108666.2467	65	478590.6820	2111899.5868
24	480935.3395	2109691.9517	66	478613.6823	2111876.5880
25	481051.7239	2109200.0827	67	478635.6828	2109812.6953
26	481991.2748	2110720.4900	68	478876.6865	2108059.7864
27	482157.2441	2110111.7888	69	479007.7023	2110470.4311
28	481613.3426	2109734.2912	70	479029.6886	2110830.6423
29	474626.7103	2112185.9736	71	479262.6922	2108234.7773
30	473285.1538	2111895.8928	72	479355.0674	2110590.4048
31	473812.5856	2110887.0433	73	479590.6359	2110537.2276
32	474329.0247	2110336.1694	74	479623.9575	2110290.3604
33	471690.5902	2106706.9106	75	479627.6977	2108285.7746
34	472060.6061	2106318.7862	76	479803.1711	2110296.3301
35	470734.5925	2105250.0526	77	479907.4957	2109789.8364
36	471624.5502	2111464.7116	78	480668.2739	2111484.5282
37	471503.6491	2110564.6831	79	481182.3305	2111519.5964
38	471056.1302	2110288.7695	80	481344.1039	2111424.8213
39	471595.5202	2109881.6200	81	481642.5134	2111279.8588
40	470552.3788	2109576.5260	82	481763.5223	2109955.8276
41	470741.5907	2109112.1335	83	481840.9954	2109294.4620

	X	Y		X	Y
42	468210.2981	2109305.8626	84	482431.2751	2110350.7271
85	489211.6459	2109112.8611	127	477925.6722	2110676.6504
86	489946.5818	2109552.4782	128	478683.6835	2110448.6622
87	489958.9280	2108696.6827	129	477981.6730	2110646.6520
88	491000.6754	2108824.8860	130	478590.6820	2111899.5868
89	491996.6992	2109227.8650	131	478717.6840	2109849.6934
90	493376.7787	2107431.9383	132	477864.6714	2109502.7115
91	494102.9175	2105834.8814	133	498337.9753	2107662.8062
92	495393.7917	2107876.0152	134	477619.0386	2110806.2887
93	496656.6384	2108011.2581	135	477807.7744	2110858.5430
94	497617.1916	2108209.6678	136	477893.2357	2110876.4591
95	498305.8069	2107862.9158	137	477949.4276	2110846.6226
96	499402.8221	2107334.9533	138	478331.1302	2110758.0942
97	500963.8503	2107296.9553	139	478543.6815	2109444.7144
98	478591.6820	2111908.5864	140	478590.6820	2111899.5868
99	477435.6649	2111628.6010	141	478613.1484	2110814.6882
100	478694.6838	2109045.7352	142	478644.3449	2110663.8930
101	479592.6970	2110086.6810	143	478651.4440	2110648.8798
102	478676.6834	2110463.6614	144	478662.7023	2109246.1197
103	479541.6962	2110249.6725	145	478714.5491	2109067.4050
104	481348.7230	2111413.6119	146	478945.4344	2110604.2671
105	479543.6963	2110378.6658	147	479032.0286	2110827.5345
106	480008.7032	2110326.6685	148	479438.9327	2110545.8951
107	480402.7091	2109869.6922	149	479477.7503	2110453.7519
108	480681.7132	2109896.6908	150	479493.0675	2110066.1261
109	480681.7132	2109896.6908	151	479494.0925	2110433.4790
110	481936.7318	2110365.6663	152	479509.5507	2110450.2851
111	481592.7267	2110038.6833	153	479509.5507	2110450.2851
112	479526.6960	2110233.6733	154	479511.8728	2110579.1824
113	490556.8599	2108475.7641	155	479511.8728	2110579.1824
114	490169.8541	2108600.7576	156	479511.8728	2110579.1824
115	478363.6787	2110557.6566	157	479560.5735	2110287.1816
116	478645.6829	2110614.6536	158	479565.3606	2110016.3086
117	479063.6891	2110627.6529	159	479976.7657	2110526.3381
118	478746.6845	2108867.7444	160	480370.6836	2110069.6868
119	479509.6958	2110253.6723	161	480650.0997	2110096.7964
120	479597.6971	2109815.6951	162	481311.1034	2111624.8109
121	479525.6960	2109865.6925	163	481311.1034	2111624.8109
122	477839.6709	2110658.6514	164	481311.1034	2111624.8109
123	477651.6681	2110605.6542	165	481315.8615	2111613.7235
124	478977.6879	2110403.6645	166	481315.8615	2111613.7235
125	479471.6952	2110345.6675	167	481560.3622	2110238.3500
126	479387.6939	2110390.6652	168	481768.9663	2110476.9945
169	481904.4453	2110565.8179			

	X	Y	X	Y
170	490137.5356	2108800.6563		
171	490525.0064	2108675.4957		
172	491000.6754	2108824.8840		
173	497585.1912	2108408.6525		