Short Note

Alberto González-Gallina, Mircea G. Hidalgo-Mihart*, Freddy Pérez-Garduza, Jesús A. Iglesias-Hernández, Adán Oliveras de Ita, Andrés Chacón-Hernández and Octavio Vázquez-Zúñiga

Home range of a male jaguar spatially associated with the landfill of the city of Playa del Carmen, Mexico

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Abstract: Understanding how jaguars (*Panthera onca*) adapt to disturbed landscapes, especially urbanized areas, can help us prevent adverse situations, thus reducing conflict, and perhaps even achieve coexistence with these predators. Playa del Carmen, a city located in the middle of a natural corridor linking two jaguar conservation units (JCUs; Sian Ka'an and Yum Balam), is facing intense pressure from tourism-related city growth. From January 2013 to March 2014, we tracked an adult male jaguar using a satellite collar and found that the presence of the Playa del Carmen landfill had a clear influence on a male jaguar's home range and movements. We observed that this particular jaguar had the smallest seasonal home range and core areas reported in the literature (particularly during the dry season in 2013, where the home range was only 16.22 km^2 and the core area was 2.5 km^2) and also that the seasonal core areas overlapped with the area covered by the landfill (with a number of important locations within the landfill). Our results showed that male jaguars are surviving in areas previously not considered as jaguar habitat and are taking advantage of the human resources within. We hope that these results encourage more jaguar studies to be carried out in areas disturbed by human activities.

Keywords: food subsidy; landfill; *Panthera onca*; Yucatan Peninsula.

***Corresponding author: Mircea G. Hidalgo-Mihart,** División Académica de Ciencias Biológicas, Universidad Juárez Autónoma de Tabasco. km 0.5 Carretera Villahermosa-Cárdenas, Villahermosa, Tabasco, 86039, Mexico, e-mail: mhidalgo@yahoo.com
Alberto González-Gallina: Instituto de Ecología A.C., Red de Ambiente y Sustentabilidad. Carretera Antigua a Coatepec No. 351, El Haya, Xalapa, Veracruz, 91070, México
Freddy Pérez-Garduza: División Académica de Ciencias Biológicas, Universidad Juárez Autónoma de Tabasco. km 0.5 Carretera Villahermosa-Cárdenas, Villahermosa, Tabasco, 86039, Mexico
Jesús A. Iglesias-Hernández, Adán Oliveras de Ita, Andrés Chacón-Hernández and Octavio Vázquez-Zúñiga: Sistemas Estratégicos para la Gestión Ambiental SEGA, S.A. de C.V. Río Mixcoac No. 36 Int. 1001, Col Actipan, Delegación Benito Juárez, Ciudad de México, 03230, México

Over the last 20 years, it has been demonstrated that some felids have the ability to live in human-dominated areas, even suburbia. This has been observed for mountain lions *Puma concolor* Linnaeus, 1771 (Riley et al. 2006), leopards *Panthera pardus* Linnaeus, 1758 (Athreya et al. 2013) and even tigers *Panthera tigris* Linnaeus, 1758 (Athreya et al. 2014). The ecology of big cats in urban and suburban areas is poorly known, especially for densely populated areas, where the potential for conflict is high. For instance, jaguars (*Panthera onca* Linnaeus, 1758) are generally considered to be a species that avoids human settlements (Colchero et al. 2011), to the point where habitat modeling uses proximity to urban areas as a factor that reduces the capacity of an area to be occupied by this species (e.g. Rabinowitz and Zeller 2010, Rodríguez-Soto et al. 2011). It is hard to say how jaguars adapt to urbanized areas as most studies on jaguar ecology and behavior have been conducted in areas lacking a large human population in the proximity or within natural protected areas (e.g. de la Torre and Medellin 2011, Núñez-Pérez 2011, Avila et al. 2015). Jaguars in Mexico have lost most of their distribution range to humans, with only around 16% of the country's land remaining as potentially suitable as jaguar habitat (Rodríguez-Soto et al. 2013). One relevant area for jaguar conservation is located in the northeastern part of Quintana Roo state. Here, the tourism industry has been the main driver of development (94.2% of the GDP in 2006), affecting regional ecological patterns (Pérez-Villegas and Carrascal 2000, Cascelli de Azevedo and Murray 2007). Becoming the top tourist area of southern Mexico has triggered high mean annual population growths, particularly in the cities of Cancun and Playa del Carmen. Both of these cities have had growth rates in the last 20 years, reaching up to 20.5% a year (1995–2000), with serious repercussions on the regional natural ecosystems (Campos-Cámara 2007, Cascelli de Azevedo and Murray 2007, Pérez-Villegas and Carrascal 2000). These cities stand between two jaguar conservation units (JCUs; Sian Ka'an and Yum Balam). The extensive areas that still have preserved natural ecosystems and link both the JCUs (Navarro-Serment et al. 2007, Chávez-Tovar and Zarza 2009, Rabinowitz and Zeller 2010, Rodríguez-Soto et al. 2013) will eventually narrow due to human development thus becoming corridors. Playa del Carmen is amidst the corridor connecting Sian Ka'an and Yum Balam JCUs. Jaguars have been reported in the outskirts of the city (Navarro-Serment et al. 2007), and have had conflicts with the settlers, because of jaguars preying on pet dogs (*Canis familiaris* Linnaeus, 1758; Remolina-Suárez 2014). Given the rapid growth of Playa (from 10,531 inhabitants in 1990 to 135,512 in 2005 and increasing; Campos-Cámara 2007, Secretaría de Desarrollo Urbano y Vivienda de Quintana Roo 2010), it is possible that interactions between humans and jaguars will increase, particularly far from the coast where new settlements are being built in areas previously covered by jungles (Cascelli de Azevedo and Murray 2007, Remolina-Suárez 2014). Management activity, given the lack of more complete knowledge on carnivores living in human-dominated areas has been to relocate animals to a nearby protected area (Athreya et al. 2007). In most cases, this means relocating the problem as well. However, evidence shows these animals as part of natural populations sharing the space with densely populated human settlements (Athreya et al. 2013). Given this situation, it is necessary to understand how jaguars use the areas close to human settlements and the influence on their behavior by human-generated food resources for wildlife. Little is known about how food sources of anthropogenic origin (without including livestock) influence the movement and spatial patterns of felids (Newsome et al. 2014a).

The study area is the vicinity of Playa del Carmen city, in Quintana Roo state, Mexico (Figure 1). Because of the city's growth rate, it has spread in a disorderly fashion over the surrounding landscape such that on the outskirts of the town, wild habitat now intermingles with urban areas, making it possible to encounter a wide variety of wildlife, even jaguars (Remolina-Suárez 2014). The original vegetation in the area was tropical evergreen forest (Rzedowski 2006), but due to regular hurricanes and slash-and-burn agricultural fires, most of the area is now covered by a gradient of succession stages. Playa del Carmen's city landfill (UTM 16N WGS84 483789, 2292051) covers 40 hectares and receives 400 tons of solid municipal waste daily. The landfill is located outside the city, embedded in a natural habitat matrix. As the landfill is inside an area with natural vegetation, it is visited by a wide array of wild species, including mammals such as raccoons (*Procyon lotor* Linnaeus 1758), coatis (*Nasua narica* Linnaeus 1766), grey foxes (*Urocyon cinereoargenteus* Schreber, 1775) and feral dogs, as well as birds including vultures (*Cathartes aura* Linnaeus 1758 and *Coragyps atratus* Bechstein 1793) and herons (*Bubulcus ibis* Linnaeus 1758; pers. obs.).

A male jaguar (4 years old and weighting 50 kg) was captured using an Aldrich snare trap (Aldrich Snare Co., Clallam Bay, WA, USA) (Logan et al. 1999) on January 26, 2013, 12 km away from the outskirts of Playa del Carmen and 7 km away from the city's landfill. The capture, management and collaring of the jaguar was carried out under the collection permit SGPA/DGVS/9611/12 (15 October 2012), granted to Mircea Gabriel Hidalgo Mihart by the Dirección General de Vida Silvestre-SEMARNAT-México, following the capture and management guidelines of the American Society of Mammalogists (Sikes et al. 2011). The jaguar was tracked using a satellite collar [Vectronic GPS Plus Pro (VECTRONIC Aerospace GmbH, Berlin, Germany) with Globalstar system and a drop-off device] during 2013–2014. The collar was programmed to take and send a GPS location every 6 h and the drop-off mechanism set for releasing the collar 1 year and 2 months after activation (from 26 January 2013 to 13 March 2014). The collar worked properly on the jaguar for the 411 days. VHF telemetry was used to locate the collar after drop-off. Once recovered, the collar had recorded 61.84% successful GPS locations, i.e. 1525 of 2466 tries). The jaguar's location data were distributed throughout three seasons as follows: 466 for the 2013 dry season (January–May 2013), 551 for the 2013 rainy season (June–October 2013), and 508 for the 2014 dry season (November 2013–March 2014).

The jaguar's home range and core areas were calculated by season, using all of the data obtained from the collar. Home range, understood as the outer limit of the animal's movement during its daily activities (Burt 1943), was calculated to determine the space used by the jaguar during his movements over a given period of time. We calculated core areas because they represent areas of more intense use and allow us to identify sites where resources appear to be clustered and are important to the animal, providing a better understanding of the specific life requirements of the animal rather than simply delimiting the peripheral areas (Harris et al. 1990, Powell 2000). Home range calculations were made using the 95% minimum convex polygon (MCP; Mohr 1947) and at 95% with the adaptive Kernel method (Kernel; Worton 1989).

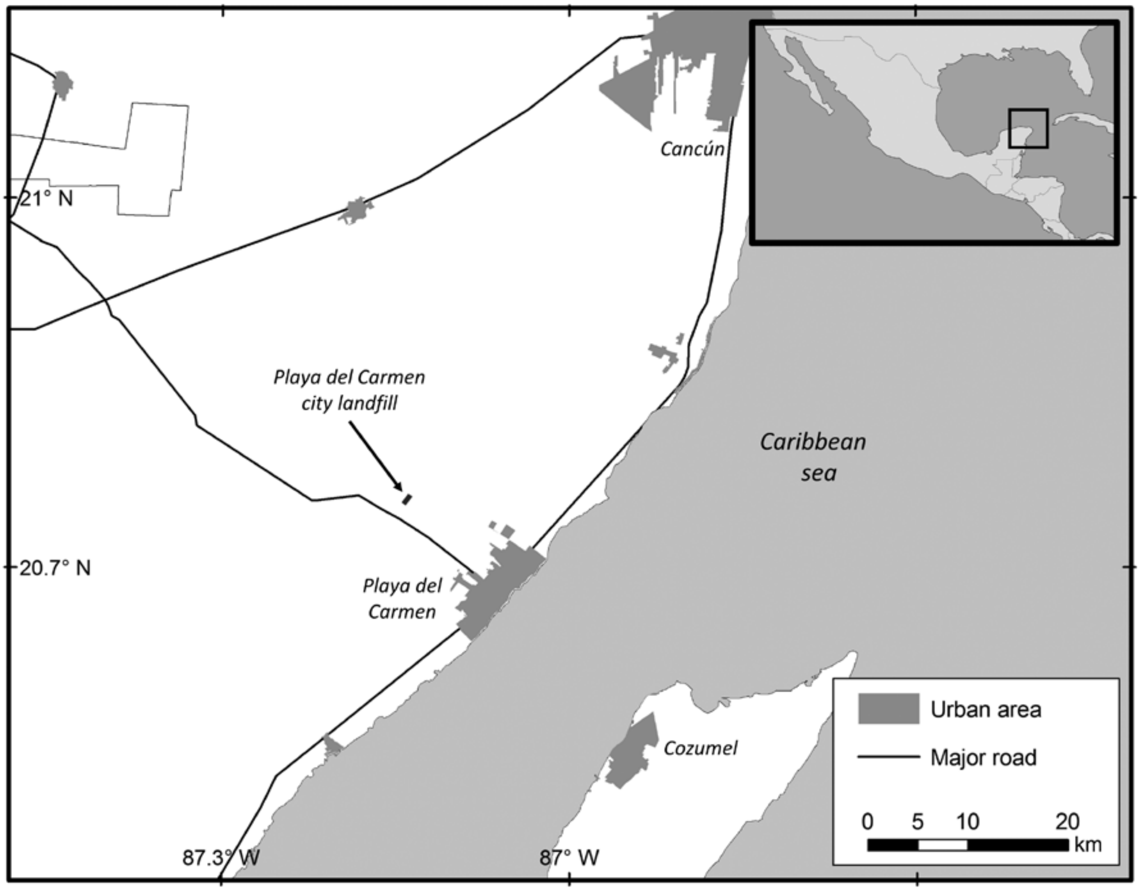

Figure 1: Location of the study area in the northwest of the city of Playa del Carmen in the municipality of Solidaridad in the state of Quintana Roo, Mexico and south of the Merida-Cancun highway.
The area has an elevation between 5 and 10 m above sea level. Climate is warm sub-humid with average annual temperatures ranging from 26°C to 33°C. Mean annual rainfall is 1300 mm and normally falls from June to October (Instituto Nacional de Estadística y Geografía 2013). Main vegetation is a gradient of succession stages of evergreen forest. In the figure, the position of the Playa del Carmen city landfill is highlighted.

Also, core areas were calculated using the 50% MCP and the Kernel estimators (Worton 1989). All home range calculations were made using the Home Range Tools extension for ArcGis (Rodgers et al. 2007). Seasonal home ranges in square kilometers for the dry season of 2013, the rainy season of 2013 and the dry season of 2014 with MCP (95%) were 163.3, 123.9 and 106.08 km^2 and with Kernel (95%; Figure 2) were 16.22, 97.46 and 82.38 km^2, respectively. In the case of core areas the seasonal home ranges for the dry season of 2013, the rainy season of 2013 and the dry season of 2014 with MCP (50%) were 11.91, 31.64, 38.15 km^2 and with Kernel (50%; Figure 2) were 2.5, 2.55 and 2.48 km^2, respectively. Seasonal differences in the home range sizes and core areas were calculated with a χ^2-test contrasting observed sizes against the expected values, being the average of the home range size and core area for the three seasons (Siegel and Castellan 1995). The seasonal home range sizes varied from 16.22 to 97.6 km^2 with significant differences between seasons ($\chi^2 = 307.5$, d.f. 2, $p > 0.001$). The average core area size was 2.5 km^2, with little variation reflecting our finding of no seasonal differences ($\chi^2 = 0.001$, d.f. 2, $p < 0.99$). The seasonal home range overlap was obtained with Kernohan et al.'s (2001) index $HR_{i,j} = A_i/A_{ij}$ (and $HR_{j,i}$) calculated with the areas of Kernel (95% and 50%). The spatial overlap index showed values of $HR_{i,j}$ between 0.17 (dry season of 2014 against dry season of 2013) and 1.75 (dry season of 2013 against rainy season of 2013). Core areas (Kernel 50%) were even more stable, with seasonal overlap between 0.97 and 1.

Our results showed that there was association of the jaguar's range with the Playa del Carmen landfill, as the landfill polygon formed part of the animal's core areas during all three seasons (Figure 2). Throughout the study period, 21.3% of the jaguar locations (325) were within the first 500 m from the landfill polygon, including 51 inside the landfill (26 during the 2013 dry season, 18 in

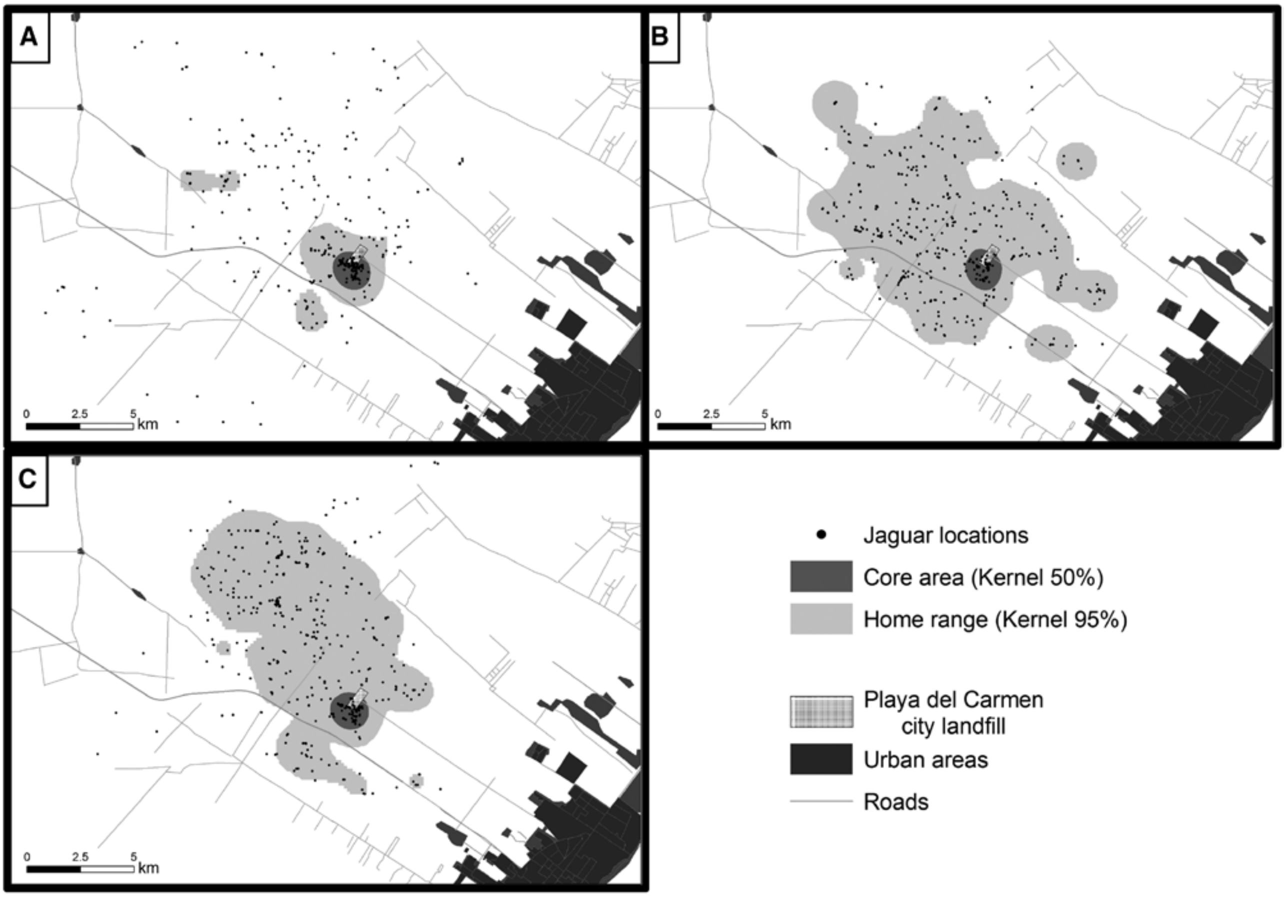

Figure 2: Seasonal locations, home ranges and core areas of the studied jaguar relative to the Playa del Carmen city landfill, Quintana Roo, Mexico.
Home ranges and core areas were generated by the adaptive Kernel method at 95% and 50%, respectively. (A) Dry season 2013 (January–May 2013), (B) rainy season 2013 (June–October 2013) and (C) dry season 2014 (November 2013–March 2014).

the 2013 rainy season and 7 in the 2014 dry season). To test if the landfill polygon had an effect on the observed jaguar locations, we calculated the seasonal distance from each jaguar location to the landfill polygon and compared it with the distance obtained from an equal number of random points within the jaguar seasonal MCP at 95% (we used MCP because it is not biased by the frequency of use of specific areas and allowing us to identify areas that are potentially used by the jaguar). Once we obtained the seasonal observed and random location distances from the landfill, we divided the distances in 500-m intervals to construct an observed and random location distance frequency table (Figure 3). We compared the observed and random tables using the nonparametric Kolmogorov-Smirnov test (K-S, Siegel and Castellan 1995). The K-S test showed that in all seasons the observed distance frequencies from the landfill were different from the random generated ones (for 2013 dry season K-S = 198.391, $p < 0.001$; for 2013 rainy season K-S = 21.521, $p < 0.001$; 2014 dry season K-S = 24.571, $p < 0.001$). Finally, the results showed that 58.33% of the occasions that the jaguar was in the landfill polygon were during the night (between 18:00 and 06:00 h; 35 locations) and the rest of the occasions (41.67%; 15 locations) were during the day (between 06:00 and 18:00 h).

Male jaguars' seasonal home ranges reported in literature in Mexico varied from 63 km^2 (Núñez-Pérez 2006) to 380 km^2 (Chávez-Tovar 2009). This Playa del Carmen jaguar, despite having a seasonal home range up to 97 km^2, had a home range of only 16.22 km^2 during the 2013 dry season. This, to our knowledge, is the smallest home range described for a jaguar in the literature to date along its distribution. It is quite possible that this jaguar behaves like other carnivores in the presence of the concentrated resources offered by the landfill (food) reducing his home range. The increase in home range in response to the rainy season has been documented for jaguars in areas where seasonality is marked, probably as a consequence of the greater mobility of potential prey as water sources are no longer spatially concentrated (e.g. Núñez-Pérez 2006,

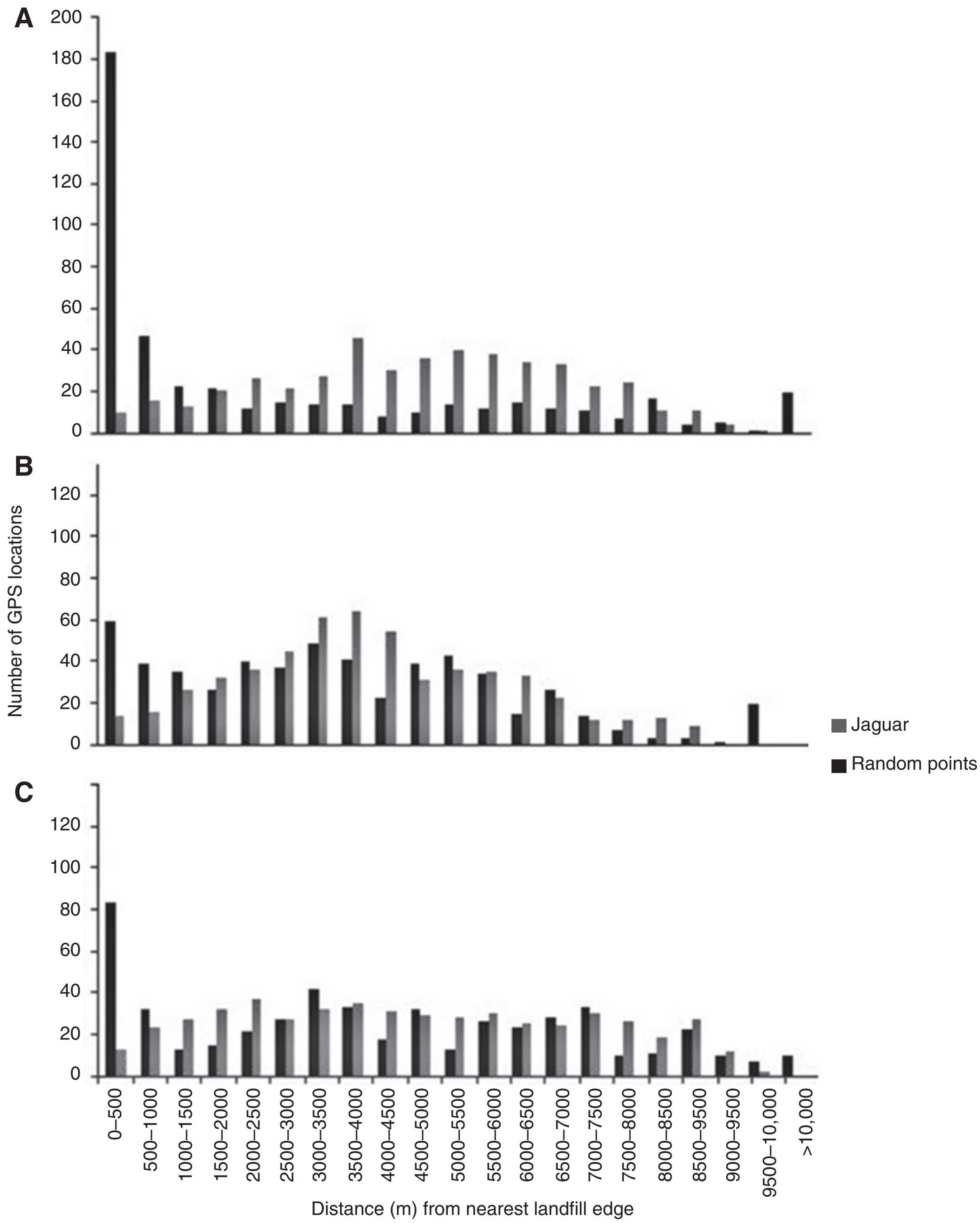

Figure 3: Comparison of the observed and randomly generated distances of the jaguar's GPS locations relative to the Playa del Carmen landfill polygon during the three studied seasons.
(A) Dry season 2013 (January–May 2013), (B) rainy season 2013 (June–October 2013) and (C) dry season 2014 (November 2013–March 2014).

Cavalcanti and Gese 2009, Chávez-Tovar 2009). There is evidence that predators alter their activity patterns and home range sizes in response to resource subsidies (Newsome et al. 2014a). Home range size decreases in a way consistent with the presence of a resource subsidy, such as a landfill, because it offers a predictable and concentrated food source (Blanchard and Knight 1991, Hidalgo-Mihart et al. 2004, Bino et al. 2010). Whenever the predators use an anthropogenic food subsidy they generally avoid human presence (Gehrt et al. 2009, Valeix et al. 2012). This is likely occurring with the jaguar we tracked because most of his locations within the landfill polygon were recorded during the night (38) when human activity is minimal, if any at all. However, it is interesting to observe that 24% (12) of the locations within the polygon were recorded during the day (from 06:00 to 13:00 h), perhaps indicating that the jaguar was searching for diurnal prey despite the risk involved.

The jaguar probably became associated with this landfill because he identified it as a reliable food source. In general, jaguars are considered to be opportunistic predators that vary their diet according to prey density and ease of capture (Crawshaw and Quigley 2002, de Oliveira 2002, Polisar et al. 2003, Hernández-San Martín et al. 2015). Jaguars have a great dietary plasticity, including over 85 documented species. The main prey items being terrestrial diurnal animals with a body mass >1 kg, though other mammals, birds and reptiles are also important components of the jaguar diet (Da Silveira et al. 2010, Foster et al. 2010). In natural preserved habitats of similar Mayan jungles in Belize, jaguars depend on medium-sized prey such as armadillos (*Dasypus novemcinctus*) and large prey (>10 kg). In disturbed areas, on the other hand, the jaguar's diet consists more of small wild prey complemented with domestic species such as cattle and to a lesser degree, dogs (0.3%, Foster et al. 2010). Jaguars even occasionally feed on carrion (López-González and Lorenzana-Piña 2002), but like most felids, they have a clear preference for live prey (Newsome et al. 2014a). Thus, a jaguar that constantly roams a landfill is more likely to be attracted by the species that visit the place and feed on the waste, such as dogs, raccoons, coatis or vultures, all of which are regularly observed inside the landfill and its surroundings (most natural prey items) rather than by the human waste itself, although it can not be ruled out that once in a while jaguars feed on disposed meat. Changes in the diet of carnivores in the presence of anthropogenic subsidies have been demonstrated (Dahle et al. 1998, Yirga et al. 2012, Newsome et al. 2014b); such a change was seen in this particular jaguar that seemed to have learned to exploit the black vultures (*Coragyps atratus*) that gathered in great numbers around the landfill (González-Gallina, pers. com.). Jaguars have been reported to prey on domestic animals on numerous occasions (e.g. Hoogesteijn et al. 2002, Navarro-Serment et al. 2007, Cavalcanti and Gese 2010, Amit et al. 2013); however, in the study area, there were virtually no cattle, so the jaguar was likely complementing his diet with dogs. Despite the few documented cases (e.g. Belize and México; Foster et al. 2010, Cruz et al. 2011), these predation incidents were reported in an informal manner in many parts of Central and South America (Butler et al. 2014). In the surroundings of Playa del Carmen, this behavior had already led to a jaguar's relocation (Remolina-Suárez 2014). Public policies regarding environmental education and conflict prevention should be applied in critical areas of high probability of conflicts, such as the outskirts of Playa del Carmen in order to reduce conflicts to a minimum in particular issues related to dog predation and human safety. Also, interacting with the fauna attracted to the landfill – especially dogs – puts jaguars at risk of contracting diseases such as canine parvovirus, canine distemper virus (CDV), rabies, *Sarcoptes*, etc. Knobel et al. 2014 for a review). For instance, CDV is capable of producing severe infections in captive jaguars (Appel et al. 1994), and the presence of dogs has been associated with high degrees of seropositivity in wild jaguars (Furtado et al. 2013). There are records of dogs living on the periphery of the Playa del Carmen area exhibiting the symptoms of CDV (Remolina-Suárez 2014), but despite this our jaguar was in good physical condition and had no evident signs of injury or severe parasitosis.

We hope that this note serves to encourage more jaguar studies to be carried out in areas disturbed by human activities, and to promote conservation actions in the corridors that join the currently protected areas, in addition to generating new spaces for the conservation of this species, even in disturbed areas that still have a high environmental value.

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