Supplementary information to Methods in Barker et al., *Space use and simultaneous movement analyses of lions and spotted hyenas*.

Ethics statement

Relevant permits required to carry out the research were obtained from the Ministry of Environment and Tourism, Namibia (Research/Collecting Permits 1724/2012, 1834/2013, 1956/2014) and from the Department of Wildlife and National Parks, Botswana (Research Permit EWT 8/36/4 XXVIII (35)). All animal handling procedures were conducted with the ethical clearance of the Animal Research Ethics Committee of the University of KwaZulu-Natal, South Africa (009/13/Animal), and the Institutional Animal Care and Use Committee of University of California at Berkeley (IACUC Protocol #R217-0512B) and Virginia Tech (IACUC Protocol # 15-012). Namibian specimens were shipped to RSA and Germany under CITES permits for the Regulations of Threatened or Protected Species (Permit/Certificate No. 0045192 and 157940).

Etosha National Park

Etosha National Park, a 22,270km^2 fenced reserve in northern Namibia (Fig. 1), is classified as semi-arid savanna [1], with perennial water available only natural artesian springs or from pumped boreholes [2]. The 9000km^2 Etosha site occupied the central regions of Okaukeujo and Halali, and included an area outside the southeastern boundary of the park that a collared individual had dispersed to. Seasonal rainfall occurs mainly between November and April, with the highest monthly rainfall in January and February [3]. The area is interspersed with dolomite

inselberge and sandy bushveld, and is comprised mainly of grasslands, short-grass plains, shrub-land, dwarf-shrub and mixed tree savanna, including Mopani (*Colophospermum mopane*) [4].

Chobe/Linyanti River system

The Chobe National Park, a 11,700km^2 unfenced reserve in northeastern Botswana, and the Linyanti Conservancy, a 1660km^2 community managed wildlife area within the Chobe Enclave surrounded by the Chobe National Park (Fig. 1) form part of the core component of the Kavango-Zambezi (KAZA) Transfrontier Conservation Area. The 7500km^2 Botswana site occupies the floodplains of the northern Kalahari bounded by the waters of the Chobe and Linyanti Rivers, complete with papyrus swamps, lagoons and marshes. The Linyanti-Chobe Rivers, fed by the Kwando and Zambezi rivers, and the Cubango River that feeds into the Okavango Delta are the main sources of permanent water for this ecosystem [5]. Seasonal rainfall occurs mainly between November and March with a mainly dry season from April to October. The vegetation of the area is highly varied with riparian and mopane woodlands, Baikiaea forests (*Baikiaea plurijuga*), open grasslands and mixed Acacia savanna (*Vachellia spp.*), with *Terminalia sericea* and *Philenoptera nelsii* in sandveld communities [6,7].

Data collection

A total of 17 lions (13 females and 4 males) and 14 spotted hyenas (10 females and 4 males) were fitted with global positioning system (GPS) satellite telemetry collars (IridiumTrackM, Lotek Wireless Inc., Newmarket, Ontario, Canada) programmed to record GPS fixes every 30 minutes during nocturnal periods (18h00 – 6h00 or 17h00 – 8h00) and every 5

minutes for two hours after sunset (19h00 – 21h00) and before sunrise (4h00 – 6h00). All collars recorded diurnal fixes at 10h00 and 14h00 to aid in locating individuals prior to night follows.

Collars were also outfitted with dual-axis accelerometers, which measure acceleration on the *x*-axis (representing forward-backward movement), and on the *y*-axis (representing the sideways or rotary movement) continuously in 8 second bursts, and averaged over 240 seconds. Activity was measured four times per second simultaneously on each axis as the difference in acceleration between two consecutive measurements and given a relative range between 0 and 255 (activity monitor values [AMVs]), characterizing the mean activity/acceleration. The activity data were downloaded from all retrieved collars, and any activity from more than 7 consecutive tracking days were used for subsequent analysis.

Collared animals were located in the field from daily uploads of GPS locations via satellite uplink, and, when necessary, radio-tracked from a vehicle with a handheld 3-element yagi antenna (Lotek), and a custom built vehicular-mounted 5-element antenna with a SRX 600 telemetry receiver. Lions and spotted hyenas were monitored on a daily basis via satellite to ensure no mortality events occurred. Individuals whose locations were accessible by the road network prior to sundown were selected for night follows for the maintenance of demographic records and observations of social dynamics. All collared individuals were monitored each day from daily satellite uploads of relocations and up to two or three individuals were selected each day according to their proximity to accessible roads for continuous follows during the night for the ground-truthing of acceleration data and to record any predated events or competitive interactions that occurred.

In the Etosha National Park, 17 collars were deployed on 9 lions and 8 spotted hyenas in the late dry season of 2013 (Supplementary Table 1, Additional File 2). Two collars (1 lion and

1 hyena) suffered structural failures during the dry season and were retrieved. A collar was also recovered from a lioness that had been shot outside the park. Subsequently, an additional two lions and one hyena were collared in the wet season of 2014. During the wet season, five additional collars (4 lions and 1 hyena) suffered structural failures and four lion collars were recovered. All but two hyena collars were retrieved at the end of the study in Etosha, including a collar from a hyena killed by a lion, and a collar from a hyena that had dispersed 120 km outside of the park.

In Botswana, 11 collars were deployed on 6 lions and 5 spotted hyenas along the Chobe/Linyanti (hereafter "Chobe") riverfront in the dry season of 2015 (Supplementary Table 1, Additional File 2). All hyena collars included remote drop-off features, eliminating the need to immobilize hyenas for collar retrieval. The drop-off units were programmed to release in the dry season of 2016, but failed to release. Two collars were recovered via wildlife authorities from a hyena shot by a local farmer, and a lioness that had been lured across the river and poached by a Namibian wildlife official. At the end of the study, two collars were recovered from the remaining nine collars whose batteries had depleted. Collars unable to be removed would eventually fall off due to the deterioration of the collar material.

Prior to collaring, we determined the individuals of lion prides and hyena clans within the study areas over a period of 8 months in Etosha and 5 months in Chobe. We identified lion individuals using whisker/scarring patterns, and used spot patterns/pelage colouration for hyenas. We placed a collar on each of the known groups within the study areas, and data therefore represent the movements and behaviour of the species groups within these areas.

Capture and sample collection

All immobilizations were undertaken by registered wildlife veterinarians or under supervision of a veterinarian by persons who successfully passed the Zimbabwe wildlife capture and handling course. All animals were darted with a cartridge-fired projector system (Pneu-Dart, Inc.) from a range of 10-50 m. Most of the animals were darted at night using red-filtered spotlights from vehicles for deployment. In the case of a collared spotted hyena that had dispersed outside of Etosha onto privately owned ranchland, this individual was tracked and darted on foot with permission from the landowner. Initial drug combinations consisted of 3.81 ± 2.17 mg/kg Ketamine hydrochloride, 2.55 ± 1.20 mg/kg Xylazine, 1.48 ± 0.51 mg/kg Tiletamine/Zolazepam hydrochloride (Zoletil), and 0.07 ± 0.02 mg/kg Medetomidine reversed with 0.20 ± 0.07 mg/kg Atipamazole and 0.43 ± 0.19 mg/kg Yohimbine. Later drug combinations consisted of 0.31 ± 0.11 mg/kg Butorphanol with 0.05 ± 0.01 mg/kg Medetomidine and 0.15 ± 0.03 mg/kg Midazolam, reversed with 0.58 ± 0.19 mg/kg Naltrexone and 0.27 ± 0.05 mg/kg Atipamazole, or 1.12 ± 0.65 mg/kg Zoletil and 0.07 ± 0.04 mg/kg Medetomidine, with 1.05 ± 0.87 mg/kg Ketamine as required, reversed with 0.24 ± 0.20 mg/kg Atipamazole and 0.22 ± 0.13 mg/kg Yohimbine.

Recumbency in animals occurred 9 ± 4 mins after darting and immobilizations lasted for 80 ± 65 mins. Eyes were covered with a blindfold to reduce stress and stimuli during handling. Specimens were collected from all animals and included blood, tissue, and feces, with anal gland excretions collected from spotted hyenas only and stored in vials with ethanol. External parasites were noted and visually estimated, with a subset extracted and placed into vials filled with ethanol or methylated spirits. Morphometric measurements were undertaken on all animals after de Waal et al. [8], and included the length of the mane of male lions at four points (B.

Stapelkamp, pers. comm). Morphometric measures and spinal palpations were used to assign a body condition score to each individual (for lions, Dikeman, unpub.; Treiber & Mann, unpub.; for spotted hyenas, Watts & Holekamp, 2008). Once assigned, the animal's body condition was monitored visually throughout the tracking period and was confirmed during collar retrieval when the animal was immobilized again. In cases where the animal's condition deteriorated or improved, the score was taken as an average between the two values. All animals collared were fully mature, and age estimates of lions from Etosha were compared against a database of branded lions of known ages. Lion ages were estimated from visual scoring of body size and pelage colouration, facial scarring, mane development, nose darkness, and based on teeth wear after Smuts et al. [10]. Spotted hyena ages were estimated from visual scoring of body size and pelage colouration, facial scarring, and based on teeth wear after van Horn et al. [11].

Collar accuracy

We tested collar accuracy by placing all collars out at known GPS locations under a variety of canopy cover ranging from low cover (grassland/shrubs) to very dense cover (heavily vegetated wooded areas) at different times. The location fixes collected by the collars (n = 5159) was used to measure the distances between each consecutive fix. This information was then averaged to give a fix accuracy error rate of 3.49 ± 3.80 m, and is representative of the accuracy of collars deployed on the animals.

Statistical analysis

All statistical analyses were conducted in R version 3.5.1 (R Core Team, 2018), and all GIS applications were conducted in ArcGIS (ESRI ArcMap v.10.0, Redlands, CA, USA). The *t*-

test was used to examine for differences in the proportion of overlaps among lion and spotted hyena home ranges and core use areas. We examined with the *t*-test whether lions and hyenas had higher intensity of spatially overlapping hulls within the outer edge or within the inner area or the center of their home ranges. We also used the *t*-test to compare for equal means between time-matched and randomly paired centroid distances for temporally overlapping hulls. In addition, for each of the distance intervals available for a dyad, we calculated the 95% confidence interval of certain movements (i.e., *moving towards* and *moving away*) between the two individuals of the dyad. We assessed the proportion of a specific movement type (whether moving towards or moving away) over the total number of all movements calculated for that dyad. We then plotted the distribution of all movement types for each individual in the pair. Finally, we calculated the ratio between the specific movement type and the sum of all movement types to determine whether individuals were moving mostly towards or away, or randomly with respect to their counterpart in the dyad.

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