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1 **Spatial ecology of an endangered carnivore, the Pilbara northern**
2 **quoll**

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9

10 **Abstract**

11 Understanding the spatial requirements of a species allows one to tailor actions that can help
12 protect species and their habitats. We investigated the spatial needs of the endangered
13 northern quoll (*Dasyurus hallucatus*) in the Pilbara. We analysed field data based on GPS-
14 telemetry or a combination of GPS and VHF telemetry for 11 northern quolls with data
15 collected over two weeks. Using MCP and Kernel methods, we found average short-term
16 ranges of 193 ha and 115 ha for males, and for the only female with reliable data the
17 estimates were 34 ha and 23 ha, respectively; with Kernel-based core areas that were
18 between five and three times smaller for males and the female, respectively. We found
19 support for our hypothesis that ranges differ between seasons, but with a seasonal trend that
20 was different to that expected. The ranges of males during the pre-mating/mating season were
21 smaller than during the pouch young season. Our study provides the first detailed attempt to
22 define and understand short-term movement behaviour of the Pilbara northern quoll. The
23 information derived from our study can help to increase the accuracy of predictive outputs
24 and better inform habitat prioritisation and conservation management of the Pilbara northern
25 quoll population.

26 **Additional keywords**

27 *Dasyurus hallucatus*, Dasyuridae, home range, MCP, Kernel

28

29 **Introduction**

30 In order to protect and manage high quality habitat for conservation it is important to
31 understand both the broad and the fine scale requirements of a species (e.g. for shelter and
32 foraging habitat), especially within core areas of habitat ([Haby et al. 2013](#)). This allows
33 management actions to be tailored to the target species ([Burbidge et al. 2008](#)). Aspects of a
34 species autecology and behaviour may affect their vulnerability to various threatening
35 processes. Behavioural choices, along with the resources available across the landscape, can
36 alter the density, distribution, and area needed by individuals in different habitats
37 ([Chetkiewicz et al. 2006](#); [Dennis et al. 2013](#)). Consequently, individual spatial requirements
38 can deepen our understanding of needs within populations, species, and groups of species.
39 This is particularly relevant because natural habitats are likely to come under further pressure
40 in the coming decades and a thorough knowledge of species requirements will be critical in
41 conserving areas most suitable for each species ([Cardoso et al. 2009](#); [Geyle et al. 2018](#)).

42 A home range is the area needed by an individual to meet its needs ([Fieberg and](#)
43 [Börger 2012](#); [Rodgers and Kie 2011](#)), and its size is related to habitat productivity and sex
44 (for dimorphic species), among other factors, such as mortality risk (perceived or true).
45 Productivity is related to resource availability, and with it, to the area needed to fulfil
46 requirements of each individual. Thus, individuals tend to have larger home ranges in
47 landscapes and/or seasons that are less productive (resource poor), as has been seen with
48 jaguars (*Panthera onca*) monitored in a diversity of habitats in Paraguay ([Hernandez-Santin](#)
49 [2007](#)). Moreover, a variation of energetic demands between males and females that exhibit
50 sexual dimorphism translate into home range sizes that differ by sex in many species
51 ([Chamberlain et al. 2003](#); [Fisher et al. 2013](#); [Koehler and Pierce 2003](#); [Schradin et al. 2010](#)).

52 Home ranges are measured by identifying the position in space of a moving target
53 (individual) fitted with a collar, where the location is acquired by triangulation that can be
54 calculated ‘manually’, when using Very High Frequency (VHF) telemetry, or by satellites,
55 when using Global Positioning System (GPS) telemetry. Each system has its own advantages
56 and disadvantages. The accuracy of VHF-telemetry is often compromised by factors such as
57 the number of locations that can be gathered, the time of the day, weather conditions, and
58 changes in animal behaviour due the proximity of the researcher ([Calenge and Dufour 2006](#);
59 [Graves and Waller 2006](#)). Alternatively, GPS-telemetry is more accurate and frequent, and
60 allows data to be collected anytime of the day or year, regardless of weather conditions
61 ([Graves and Waller 2006](#); [Hebblewhite and Haydon 2010](#); [Matthews et al. 2013](#)). However,
62 compared to VHF-telemetry, GPS-telemetry has not been available for a wide range of
63 species. Until recently, one of the biggest limitations of GPS-telemetry for species with mass
64 lower than five kilograms was associated with the mass of GPS-units, as units should weigh
65 less than five percent of the body mass of the animal to ensure its wellbeing by allowing the
66 individual to maintain normal movement and behaviour ([Sikes and Gannon 2011](#)). The
67 miniaturisation of GPS-technology has overcome the mass per unit issue to some extent, by
68 compromising battery life, data storage capabilities, and unit-retrieval mechanisms.

69 Our study focussed on a geographically distinct population of the northern quoll
70 (*Dasyurus hallucatus*) in the Pilbara region of Western Australia. The northern quoll is an
71 endangered and nocturnal carnivorous marsupial that has shown recent rapid and extensive
72 declines across much of its range ([Cramer et al. 2016](#)). Northern quolls show sexual
73 dimorphism across their range; for example, in the Pilbara, males have been reported to
74 weigh ~50% more than females, weighing up to 645 ± 24 g during the pre-mating/mating
75 season ([Hernandez-Santin et al. 2019](#)). Fitness for males is related to reproductive success,
76 maximised by ensuring mating with as many females as possible, while that of females is

77 related to offspring survival, maximised by inhabiting areas high in resources ([Fisher et al.](#)
78 [2013](#); [Oakwood 2002](#)). The Pilbara population of the northern quoll has been assigned a high
79 conservation, research, and management priority because it is genetically and
80 demographically distinct from all other populations, retains its pre-European genetic
81 diversity, is currently outside of the cane toad's distribution, and has much of its habitat still
82 intact ([Cramer et al. 2016](#)).

83 Our aim was to determine the spatial needs of northern quolls in the Pilbara. In so
84 doing, we predicted: 1) males would have larger ranges than females, 2) there would be
85 seasonal differences in male ranges reflecting the need for larger ranges during and close to
86 the mating season, and 3) there would be differences in range sizes across sites. Low samples
87 sizes precluded robust statistical analyses and our data describe short-term ranges. Insights
88 derived from such short-term investigations still provide a useful insight into what may occur
89 over longer time periods. We focus on comparing sex and season, and make qualitative
90 assessment of whether the data are consistent with our predictions.

91 **Materials and Methods**

92 *Study Area*

93 The Pilbara region of Western Australia is a semi-arid desert with a wet season between
94 December and March, characterised by high temperatures with a summer average of 38°C
95 and a winter average of 25°C ([McKenzie et al. 2009](#)). The region holds extensive arid coastal
96 plains, stony pavements, spinifex grasslands, and mountain ranges comprised of deep gorges
97 and rough escarpments ([Carwardine et al. 2010](#)). The most common vegetation genera
98 include *Acacia*, *Aristida*, *Ptilotus*, *Senna*, and *Triodia* ([van Vreeswyk et al. 2004](#)). The
99 vegetation of the Pilbara region is varied and complex and is largely influenced by both
100 geology and fire history ([Maslin and van Leeuwen 2008](#)).

101 We monitored four sites, previously studied by the Department of Biodiversity,
102 Conservation, and Attractions (formerly Parks and Wildlife) and Roy Hill Holdings Pty Ltd,
103 because they were known to provide rocky, high quality, habitat for northern quolls (Fig. 1).
104 One site at Python Pool, in Millstream Chichester National Park, is located in the Chichester
105 Ranges, 77 km southeast of Karratha and 180 km southwest of Port Hedland. The remaining
106 three sites are in the Abydos Plain, south of Port Hedland, located at different distances along
107 or near the Roy Hill Special Rail Lease (SRL). Site A is situated approximately 57 km from
108 Port Hedland at section 57 of the Roy Hill Special Rail Lease (RSL). Red Rock (also known
109 as Site B) is located 3.7 km southwest of Rail Camp 1 on Indee Station, 52 km south of Port
110 Hedland. Site C is at the central and eastern extent of the Chichester Ranges on the SRL
111 section 255-288 it is situated 5.7 km North of Rail Camp 4 ([Johnson and Anderson 2014](#)).

112 *Study design*

113 This research was undertaken in two components that had small differences in duration,
114 trapping, and monitoring methods. We visited two sites (Python Pool and Red Rock) three
115 times a year for two years between September 2013 and June 2015 (see [Hernandez-Santin et](#)
116 [al. \(2019\)](#) for details) and three sites (Site A, Red Rock, and Site C) 3 times between June
117 and July 2015 (see [Henderson \(2015\)](#) for details). This resulted in the attachment of
118 transmitters and tracking of quolls in Sept-Oct 2014 at Red Rock and Python Rock and in
119 June-July 2015 at Red Rock, Site A, and Site C.

120 *Live-trapping*

121 Following standard operating procedures from the Department of Biodiversity, Conservation,
122 and Attractions for northern quoll trapping in the Pilbara, we used transects of wire cage traps
123 (45 cm x 17 cm x 17 cm, Sheffield Wire co, Welshpool WA) baited with a mixture of peanut
124 butter, oats, and sardines ([Dunlop et al. 2014](#)). Trapping was undertaken using 6 to 50 traps with
125 distances between 25 and 50 m between traps, set for 1 to 5 nights (11 nights for one site) (see

126 [Hernandez-Santin et al. \(2019\)](#) and [Henderson \(2015\)](#) for further details). All trapped quolls
127 were processed and released on site after taking morphological measurements, fitting a
128 unique injectable transponder (12-mm FDX-B; Allflex®, Queensland, Australia), and
129 attaching GPS-units to individuals that had enough mass to carry the units (i.e. GPS-units did
130 not exceed 5% of their body weight).

131 *GPS-telemetry*

132 GPS-units were attached either as backpacks or collars. Units attached as backpacks were
133 created using CatTrack® loggers (South Carolina, USA) that were modified to reduce mass
134 and create the harness (Jaime Heiniger, University of Queensland, personal communication,
135 2013) using materials that varied in mass, resulting in units that weighed 18-30 g. GPS-
136 collars were pre-made, weighed 20 g, included a VHF transmitter (100-150 MHZ; Sirtrack
137 Ltd, Havelock North, New Zealand), and were tested by the Department of Biodiversity,
138 Conservation, and Attractions in April 2015. Due to limitations of battery life, backpacks were set
139 on a “high” fix acquisition rate (every 15 minutes for up to 16 days, including trapping sessions),
140 while collars were set to acquire a maximum of 50 locations taken between 1800 h and 600 h at
141 four or two hour intervals reaching a “medium” fix rate (8 fixes per night, for 6 nights) or a “low”
142 fix rate (4 fixes per night, for 11 nights). Medium and low fix rates were compensated for by
143 adding VHF locations that were acquired by homing in on quolls within their burrows during the
144 day. GPS-units had to be recovered by re-trapping individuals after 10-15 days of monitoring,
145 using methods described above. We retrieved 6 backpacks (4M and 1F) with a 22% recovery rate,
146 as well as 10 collars (4M and 2F) with an 80% recovery rate. The female with a GPS-backpack
147 was excluded from the study due its low number of locations (n=7).

148 We tracked more males than females. The sex bias responds to the relationship
149 between collar mass and sexual dimorphism, where males are larger than females and,
150 therefore, more likely to have sufficient body mass to carry GPS-units. In fact, we were only

151 able to partially monitor two females, two in the lead up to the mating season (June-July) and
152 one when females are carrying pouch young (September-October). One of these females had
153 the lowest number of locations for the whole study (11). Thus, we concentrate our discussion
154 on spatial use by males, or compare with the female with most locations (24 points) when
155 possible.

156 *Pre-processing*

157 All data was pre-processed to eliminate errors. Locations were considered as errors when the
158 previous and subsequent locations were in one area, but the focus location was in a distinctly
159 different one. These errors, as well as missing fixes during the day, could be partly attributed to
160 quolls denning in rock crevices during the day, which can impair the unit-to-satellite
161 communication, as has been previously noted ([Graves and Waller 2006](#); [Körtner et al. 2016](#)).
162 To compensate for differences in monitoring methods without losing valuable information, we
163 resampled data from high fix acquisition rates (data from GPS-backpacks) to exclude trapping
164 days/nights (when behaviours and activities could be altered) and to randomly select one point
165 per hour (Table 1).

166 *Data analysis*

167 We used ArcGIS ([ESRI 2016](#)) and Home Range Tools ([Rodgers et al. 2015](#)) to determine
168 home ranges during single trips using 95 and 50% (core areas) of the locations of individual
169 quolls monitored. We estimated home ranges based on two methods: adaptive Kernel Density
170 Estimation (Kernel) and Minimum Convex Polygon (MCP) based on floating mean. Kernel
171 analysis has become one of the most accepted methods to use with GPS technology ([Calenge
172 and Dufour 2006](#); [Kie et al. 2010](#); [Walter et al. 2011](#)). However, it has been criticised due to
173 errors in bandwidth selection and violation of independence assumptions, especially when
174 used with large datasets ([Walter et al. 2011](#)). On the other hand, the simplicity of the MCP
175 method allows equitable comparison among studies ([Burgman and Fox 2003](#)), although it

176 often leads to inclusion of areas where tracked individuals were never recorded and therefore
177 may lead to overestimation of home ranges. This has led to the inclusion of both estimates in
178 many studies. The use of both becomes particularly important, considering that the Kernel
179 method allows users to investigate the intensity of use within the designated home range area,
180 an estimate which the MCP cannot make.

181 The furthestmost locations of a given individual may represent exploratory movements
182 that are outside of the normal range and normal movements of the individual ([Calenge and](#)
183 [Dufour 2006](#)). Therefore, the most common calculations exclude the outermost five percent
184 of the locations, resulting in 95% Kernel and MCP ranges reported in the literature. Another
185 common measurement represents the core area, or area of heaviest use by an individual,
186 which includes the innermost 50% of the points for MCP, or the areas where 50% of the
187 range is most intensively used for Kernel. Therefore, MCP areas are often represented by a
188 single polygon, while Kernel areas can be represented by multiple smaller polygons.

189 **Results**

190 We tracked 11 northern quolls (2F and 8M) with nine in the mating season and four in the
191 pouch young season. We calculated short-term home ranges of the 11 individuals, based on
192 11 to 135 locations obtained from quolls in four different locations (red rock, python pool,
193 site A, and site C), over two seasons (September-October and June-July). On average, males
194 had 95% ranges of 193 ± 55 ha (\pm indicates standard error) using MCP and of 115 ± 28 ha
195 using the Kernel method, while the three females monitored had estimates between 1.35 and
196 23 for Kernel and between 2.19 and 34 ha for MCP (Table 2). The 50% core area Kernel
197 estimates were between five and three times smaller than the 95% range for males and the
198 female monitored, respectively. For MCP, the core areas were five and nine times smaller
199 than the 95% ranges for males and the female, respectively. For males, ranges during the pre-

200 mating/mating season were smaller than those captured during the pouch young season
201 (Table 2).

202 **Discussion**

203 *Study limitations*

204 Our study had a low sample size compared to previous studies based on VHF-telemetry,
205 which have successfully monitored at least twice as many quolls in the Mitchell Plateau
206 ([Cook 2010](#)) and Kakadu National Park ([Oakwood 2002](#)), with 21 (9F and 12M) and 35
207 quolls (14F and 21M), respectively. There are at least three reasons that contributed to our
208 comparatively low sample sizes, ignoring potential (but unknown) differences in population
209 densities. First, mass per unit restrictions permitted only the inclusion of the largest
210 individuals that were mostly unavailable during the recruitment season (March-April). Our
211 units had a mass of 18 to 30 g, while those used in the Mitchell Plateau had a mass per unit of
212 10.5 to 12.5 g ([Cook 2010](#)) and of 13 to 21 g in Kakadu ([Oakwood 2002](#)). Second, technical
213 failures related to the exploration of materials to attach backpacks appropriately led to the
214 low number of individuals successfully tracked (and the low backpack-recovery rate of 22%).
215 Third, changes in environmental conditions altered the potential number of individuals that
216 could be trapped and monitored in April and June 2015, when a harsh dry summer translated
217 into lower capture rates in 2015 that eliminated (in Python Pool, where quolls were
218 temporally extinct in the area) or reduced (at other sites) the number of quolls ([Hernandez-
219 Santin et al. 2019](#)).

220 Although our low sample sizes and bias towards monitoring the largest individuals within
221 their populations prevents making conclusions for the species as a whole, our study sheds
222 light on the spatial use of individuals of an endangered species that can inform conservation
223 management. This enables us to gain valuable insights into differential home ranges related to

224 sexes and seasons but do not represent absolute values. Assessments of spatial needs can then
225 be refined when technological improvements allow to overcome the limitations encountered
226 during this study.

227 *Home ranges, how do they compare?*

228 An understanding of the habitat requirements and spatial ecology of Pilbara northern quolls
229 was identified as a research priority by [Cramer et al. \(2016\)](#) and on the national recovery plan
230 [for the species \(Hill and Ward 2010\)](#). To the best of our knowledge, our study represents the
231 first successful attempt to monitor home ranges of northern quolls using nocturnal data based
232 on GPS-telemetry. Previous studies of space use of northern quolls have used day-time VHF-
233 telemetry ([Cook 2010](#); [Oakwood 2002](#)) or have been based on locations taken from the
234 trapping grid ([Braithwaite and Griffiths 1994](#); [King 1989](#)). Such attempts have acknowledged
235 that their efforts have likely resulted in the underestimation of the whole area where collared
236 individuals conduct their normal activities, therefore representing a partial or short-term view
237 of the home ranges. While we had the advantage of using GPS-telemetry with plenty of night
238 locations per male quoll (Table 1), previous detailed studies had the advantage of monitoring
239 for longer, up to 48 days in the Mitchell Plateau in the Kimberley Region of Western
240 Australia ([Cook 2010](#)) and up to 266 days in Kakadu National Park in the Northern Territory
241 ([Oakwood 2002](#)). GPS-tracking of the spotted-tailed quoll (*Dasyurus maculatus*) revealed it
242 took individuals 3 to 4 weeks to cover their home range ([Körtner et al. 2016](#)). Given that such
243 information is not available for northern quolls and the much longer span that northern quolls
244 have been previously monitored, we can only consider our results as partial estimates of
245 northern quoll movements, representing short-term home ranges.

246 Our average estimates (193 ± 55 ha 95% MCP), which represent short-term ranges,
247 are larger than those observed in the Mitchell Plateau ([Cook 2010](#)) and Kakadu ([Oakwood](#)
248 [2002](#)), with average estimates of 64 ± 37 and 84 ± 16 ha, respectively. Examining individual

249 home ranges, the maximum range obtained for males during our study (436 ha), was 2.8
250 times larger than the maximum home range of 152 ha recorded in Kakadu ([Oakwood 2002](#)),
251 but similar to the maximum of 421 ha reported in the Mitchell Plateau ([Cook 2010](#)). For
252 females, the maximum (and only reliable) area recorded in our study was 34 ha, a number
253 that is 2.3 times larger than the maximum area of 15 ha, and five times larger than the
254 average of 7 ± 2 ha, recorded in the Mitchell Plateau ([Cook 2010](#)) and 1.8 times smaller than
255 the maximum estimate of 66 ha, and about the same size as the average of 35 ± 6 , in Kakadu
256 ([Oakwood 2002](#)). Differences between ecosystems can help explain differences in home
257 range sizes among studies. VHF-tracking of spotted-tailed quolls has shown home ranges that
258 are not substantially different between dry woodlands and wet forests ([Claridge et al. 2005](#)).
259 However, the semi-arid Pilbara is much harsher than the savanna woodlands characteristic of
260 the Mitchell Plateau and Kakadu. Thus, as related to ecosystem productivity, we would
261 expect the larger home ranges of northern quolls observed in the Pilbara.

262 *Seasonal variation*

263 Although we found seasonal differences in range sizes as expected, we found a
264 seasonal trend that was different than that expected. During the mating season, males will
265 attempt to get access to as many females as possible ([Oakwood 2002](#)), a behaviour that would
266 be expected to translate into larger home ranges during the mating season. However, we
267 found that home ranges of males during the pre-mating/mating season were smaller than
268 during the pouch young season. Such a discrepancy could result from: 1) differences in
269 monitoring methods within our study, 2) males trying to find females to mate with, beyond
270 the mating season, or 3) differences in resource availability.

271 Although differences in monitoring methods can result in variations of home range
272 estimations, our observations suggest that methods did not drive differences in seasonal home
273 ranges. Data obtained from GPS-backpacks had similar number of locations per male, yet, the

274 home range estimation of the only male monitored during the pre-mating/mating season had a
275 home range (MCP 95% = 65 ha) that was 2.5 to 7 times smaller than those monitored during
276 the pouch young season (164 to 437 ha; Table 1). Similarly, one pair of males monitored
277 during the pre-mating/mating season using GPS-collars had similar home ranges (65 ha) to
278 the male monitored with a GPS-backpack during the same season (Table 1).

279 The possibility of mating beyond the core mating season arises from the observation
280 of a single female carrying pouch young at a time when young should have already been
281 recruited into the population (in April), suggesting fertilisation via a second mating (in
282 February) or to sperm storing ([Hernandez-Santin et al. 2019](#)). If we were to consider second
283 mating events as fact, the inherent unavailability of most females (already carrying pouch
284 young) would force males to travel even further than during the mating season in their search
285 for available females. The sexual behaviour of male quolls have also been noted for spotted-
286 tailed quolls, where it has been used to explain higher movement rates ([Glen and Dickman](#)
287 [2006](#)) and home ranges that were three times larger than those of females ([Körtner et al.](#)
288 [2016](#)). Similar behaviours have been observed for other carnivores. For example, [Koehler](#)
289 [and Pierce \(2003\)](#) analysed sexual differences in home range sizes of black bears (*Ursus*
290 *americanus*) and suggested that getting access to oestrus females could surpass males'
291 energetic needs. Information beyond our anecdotal observation is needed to refute or support
292 the hypothesis of space use for a second-mating chance for northern quolls.

293 Temporal variability of resource availability is expected to affect the area needed by
294 each individual to conduct their normal activities, resulting in the expansion and contraction
295 of home ranges. Home ranges are expected to be small where and when resources are widely
296 available, but large where and when resources are scarce and individuals need to travel
297 further to meet their needs. Northern quolls are omnivorous and are thought to select their
298 food opportunistically ([Dunlop et al. 2017](#)). Seasonal analysis of diet in our study area

299 revealed that quolls consumed more invertebrates during the pre-mating/mating season and
300 more vertebrates during the pouch young season, which could suggest that invertebrate
301 availability may not cover the energetic needs of quolls during the latter ([Hernandez-Santin](#)
302 [2017](#)). However, this shift in diet could also suggest that individuals need to travel further to
303 meet their energetic needs, resulting in the larger home ranges we observed during the
304 September-October period. Notably, temporal variability of resources can be more drastic
305 between years than between seasons in some areas, as evidenced by the local temporal
306 extinction of northern quolls at Python Pool in 2015 ([Hernandez-Santin et al. 2019](#)), followed
307 by natural re-colonisation the following year (Judy Dunlop, Department of Biodiversity,
308 Conservation, and Attractions, personal communication, 2019). However, population models
309 tested by [Hernandez-Santin et al. \(2019\)](#) showed that season (and sex) had a stronger effect
310 than year in predicting differences in survival of northern quolls in our area during our study
311 period.

312 Considering our low sample sizes, particularly when corrected for sex, site, and
313 season, it is possible that our data carries confounding factors of influence higher than
314 resources to determine the area needed for one or more of such groups, or to determine
315 whether that influence overrides site differences or not. Visual exploration of our results
316 shows high variability in short-term home ranges sizes within sites on the same season (Table
317 1). Differences within sites could arise from fluctuations in quoll mass, population density, or
318 social dynamics within the population. Mass is expected to shape home range sizes in that
319 larger individuals will need larger areas to meet their energetic needs. Population density and
320 social dynamics play a role because they can dictate whether the home range of an individual
321 falls within optimal habitat or not. Individuals inhabiting suboptimal areas will be expected to
322 have larger home ranges than those in optimal areas, when corrected for other factors such as
323 sex, season, and mass. Social dynamics of northern quolls have been hypothesized by

324 [Braithwaite and Griffiths \(1994\)](#), who suggested that creeks would be prime habitat in
325 Kakadu National Park.

326 *Insights and future directions*

327 [Cramer et al. \(2016\)](#) identified the need to further understand Pilbara northern quoll
328 habitat use as a priority for conservation management of the species. Our study provides the
329 first detailed attempt to define and understand home ranges of the Pilbara northern quoll.
330 Such information is also critical in further refining detailed species distribution models for
331 the species. [Molloy et al. \(2017\)](#) constructed the first species distribution model for Pilbara
332 northern quolls but found that accurate data beyond species occurrences was lacking and this
333 precluded more detailed analyses of required home range sizes and habitat use. Thus, the
334 addition of information derived from our calculations would allow to increase the accuracy of
335 predictive outputs and better inform habitat prioritisation and conservation management of
336 the Pilbara northern quoll population. The challenges we faced with tracking included high
337 fix acquisition rates at the expense of low recovery rates of GPS-backpacks, high recovery
338 rates of GPS-collars at the expense of medium to low fix acquisition rates, low battery life of
339 all GPS-units, poor or no fix rates in denning sites, and high rates of dispersal by some
340 individuals. These considerations should be incorporated into future research, hopefully
341 allowing valuable insights by tracking quolls over long periods to encompass all seasons, as
342 well as greater portions of the population to understand aspects of spatial organisation within
343 and between sexes. .

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360 **Conflicts of Interest**

361 The authors declare no conflicts of interest.

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541 **Tables and figures**

542 **Table 1:** Number of locations available per individual. The column ‘one per hour’ represents
 543 a subsample of the original number of locations that can be represented in the column ‘all
 544 points’. Quolls with suffix ‘so’ correspond to the September-October 2014 trapping season,
 545 while the suffix ‘jj’ correspond to the June-July 2015 trapping season. The female 69730so
 546 was excluded from the analyses due its low number of locations. Days represent the number
 547 of days that each individual was monitored. Values (in hectares) are the 50% and 95% areas
 548 based on Kernel density and Minimum Convex Polygon (MCP) methods.

Attachment mechanism (GPS-unit)	Quoll ID	Sex	Days	Number of locations		Kernel		MCP	
				all points	one/hour	50	95	50	95
<i>Backpack</i>	69730so	F	14	29	7				
	98322so	M	11	537	120	25	141	63	340
	99027so	M	10	559	132	132	27	160	61
	99464so	M	9	510	117	35	241	68	437
	99531jj	M	9	641	135	8	50	28	65
<i>Collar</i>	00257jj	M	16	21	1	4	2	5	
	44748jj	M	16	32	6	16	7	50	
	53468jj	M	13	13	7	53	2	65	
	24287jj	M	14	20	18	114	20	128	
	53828jj	F	13	24	8	23	5	34	
	00079jj	F	29	11	0.3	1.4	0.2	2	

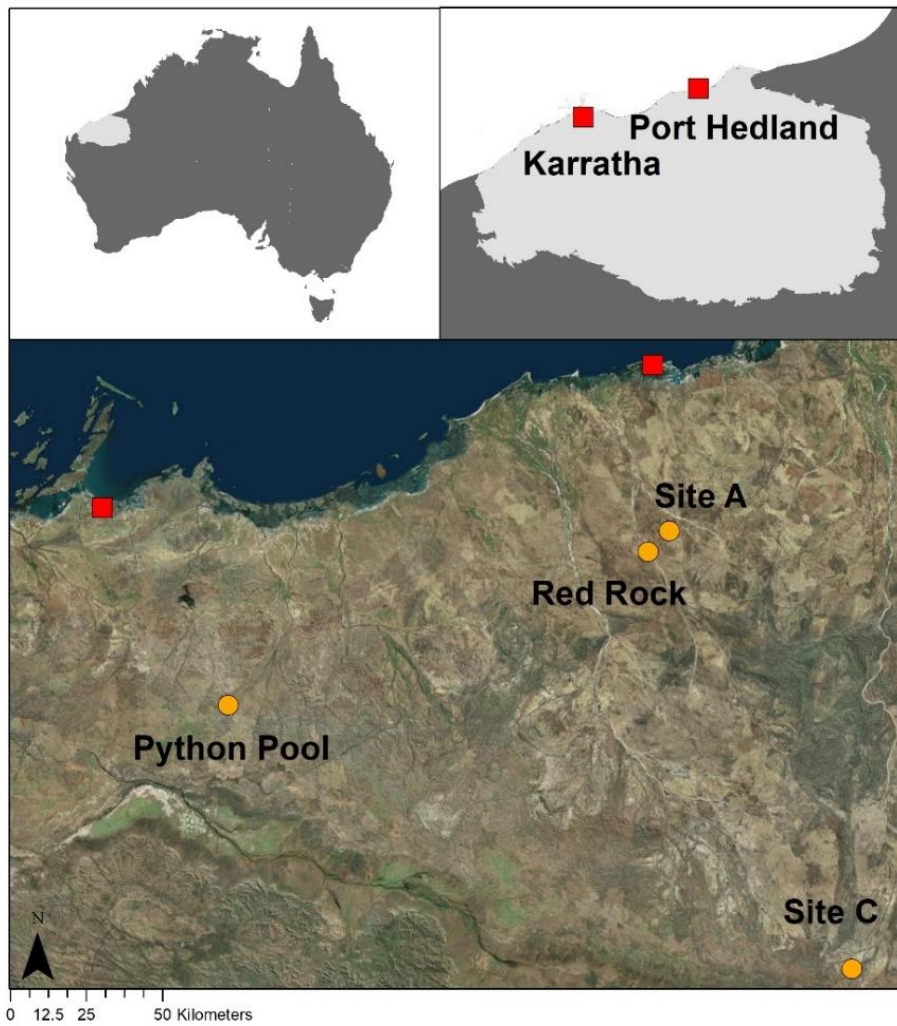
549

551 **Table 2** Average and standard error of short term ranges of male northern quolls(in hectares)
 552 during the post-mating (3M) and pre-mating/mating season (5M). Values are shown for 50%
 553 and 95% isopleths of adaptive Kernel and Minimum Convex Polygon (MCP) methods.

			<i>average</i>	<i>SE</i>
<i>Kernel</i>	50	Post-mating	32.9	11.2
		Pre-mating/mating	7.5	2.5
		Total	20.2	6.7
	95	Post-mating	182.5	26.4
		Pre-mating/mating	48.3	17.1
		Total	115.4	28.6
<i>MCP</i>	50	Post-mating	66.4	64.4
		Pre-mating/mating	15.1	17.9
		Total	40.8	55.0
	95	Post-mating	321.5	64.4
		Pre-mating/mating	65.7	17.9
		Total	193.6	55.0

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556

557 **Figure 1.** Geographic distribution of study sites. Light grey area on top insets represent the
 558 Pilbara, squares represent major towns in the area, dots represent study sites. Background
 559 imagery obtained from ArcMap's base maps ([ESRI et al. 2017](#)).

560