Biodiversity and Conservation Science

# Northern Quoll (*Dasyurus hallucatus*) Home Range Synopsis

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Synopsis prepared for Roy Hill Pty Ltd

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Cover image supplied by Mitch Cowan: Northern quoll being fitted with a VHF collar by Judy Dunlop.

# Contents



# Acknowledgements

The authors would like to acknowledge Dr. Lorna Hernandez-Santin, Melinda Henderson, Dr. Rob Davis, A/prof Diana Fisher, Dr Shaun Molloy, Chris Knuckey from Biologic, Jessica Johnston from Astron Environmental Services, and Kyle Hodgson from Mineral Resources Ltd. for access to data. We would like to thank A/prof Dale Nimmo, Dr Michael Wysong, and Dr Bronwyn Hradsky for assisting with data cleaning and data analysis. We would also like to thank Colin and Betty Brierly for access to Indee Station, where much of this northern quoll tracking occurred.

# Summary

Understanding the space use of a species is important in order to guide conservation practices and measure the scale of negative impacts. One species where this information is limited is the northern quoll (*Dasyurus hallucatus*), particularly in the Pilbara region. We measured the home ranges of northern quolls using GPS and VHF data collected between 2013 and 2018 from six sites within the Pilbara. We used two methods of home range estimation; minimum convex polygons (MCP) and kernel density estimation (KDE), and excluded the outermost 5% of GPS points to account for potential errors or outliers in the data. Female northern quolls (19.8 ± 6.11 ha using MCP, 24.2 ± 6.7 ha using KDE) had smaller home ranges compared to males (152.06 ± 61.62 ha using MCP, 492.31 ± 150.78 ha using KDE), and VHF home ranges using denning locations resulted in smaller home ranges compared to GPS home ranges which recorded locations while northern quolls were active and moving around. This suggests that GPS data is better suited to measuring home range than VHF data as northern quolls may use dens—which are recorded with a VHF antenna—within smaller areas to that in which they forage or move between landscapes.

## Background

Species movement patterns such as home range size are important to measure, in order to improve species conservation, and inform direct management interventions (Rechetelo et al., 2016). Improving the knowledge surrounding the spatial ecology of northern quolls (*Dasyurus hallucatus*) has been identified as a research priority for the species within the Pilbara bioregion (Cramer et al., 2016). Previous studies of northern quoll home range have taken place in Kakadu National Park, NT (Oakwood, 2002), and in the Kimberley region, WA (Cook, 2010), with some early and current studies in the Pilbara (King and King, 1989, Hernandez-Santin et al., 2020), and Northern Territory (Heiniger et al., 2020). Majority of the early home range studies used techniques available at the time (i.e., VHF units, cage trap arrays), which provided basic measures of home range. Remote tracking devices must weigh less than 5% of an animals' body mass, and should be small enough to not interfere with its survival or daily activities. However, only recently have GPS units within this weight range become practically accessible for use on northern quolls, which are the smallest species of quoll—adult males range from 540–1120 g and adult females from 350–690 g (Oakwood, 1997). Roy Hill has supported several student-led projects since 2015, which trapped and tracked northern quolls in the Pilbara using GPS telemetry (Henderson, 2015, Cowan et al., 2020, H. Moore, unpubl. data). The honours data collected by Henderson (2015), has been summarised in Hernandez-Santin et al. (2020), but the remaining data from these Roy Hill supported studies has yet to be summarised. We seek to summarise this data supplemented with data collected by other studies within the Pilbara (i.e., Astron Environmental Services, 2013, Biologic, 2016), to determine whether there is enough fine-scale data to calculate northern quoll home range size. It is important to investigate the spatial ecology of northern quolls in the Pilbara as there are relatively few details surrounding their space use and habitat selection (Hernandez-Santin et al., 2020), and further knowledge will help to advance species distribution models and predictive site-based habitat modelling (Cramer et al., 2016).

# Methods

*Sites and studies*

Data from six studies was used in this analysis. Studies took place between 2013 and 2018 with three studies being student-led projects supported by Roy Hill (Table 1). Northern quolls were tracked at six sites within the Pilbara between 2013 and 2018. Studies occurred primarily on Karriyarra, Nyamal, and Yinjibarndi country. Sites were broadly similar in that they had common features of complex rocky outcrops or mesas within spinifex sandplains, and all sites have had records of northern quoll occupation for several years. Specific sites were:

1) Red Rock (-20.88, 118.59) —monitored in 2014, 2015, and 2016—a large inselberg Formation south of Port Hedland located adjacent to the seasonal Turner River and flat *Triodia* grassland.
2) Python Pool (-21.34, 117.25)—monitored in 2014—a creek bed within Millstream-Chichester National Park lined by four-metre-high tumbledown basalt walls nestled within *Triodia* grassland.
3) Cattle Gorge (-20.55, 120.25)—monitored in 2016—a decommissioned iron ore mine site east of Port Hedland containing a mining pit, waste rock piles, and other infrastructure (i.e. roads, buildings). The site also contains rocky escarpments and *Triodia* sandplain.
4) De Grey Ridge (-20.84, 118.59)—monitored in 2018—a thin granite ridge south of Port Hedland surrounded by dense *Triodia* grassland and *Acacia* shrubland.
5) Rail Camp Ridge (-20.81, 118.65)—monitored in 2015—a granite ridge surrounded by spinifex sandplain south of Port Hedland and within 500 m of an occupied Roy Hill Rail Construction Camp during monitoring.
6) Poondano (-20.45, 118.84)—monitored in 2013—an active iron ore mine east of Port Hedland (now decommissioned) with a series of mesas, mining pits, and infrastructure within the tenement.

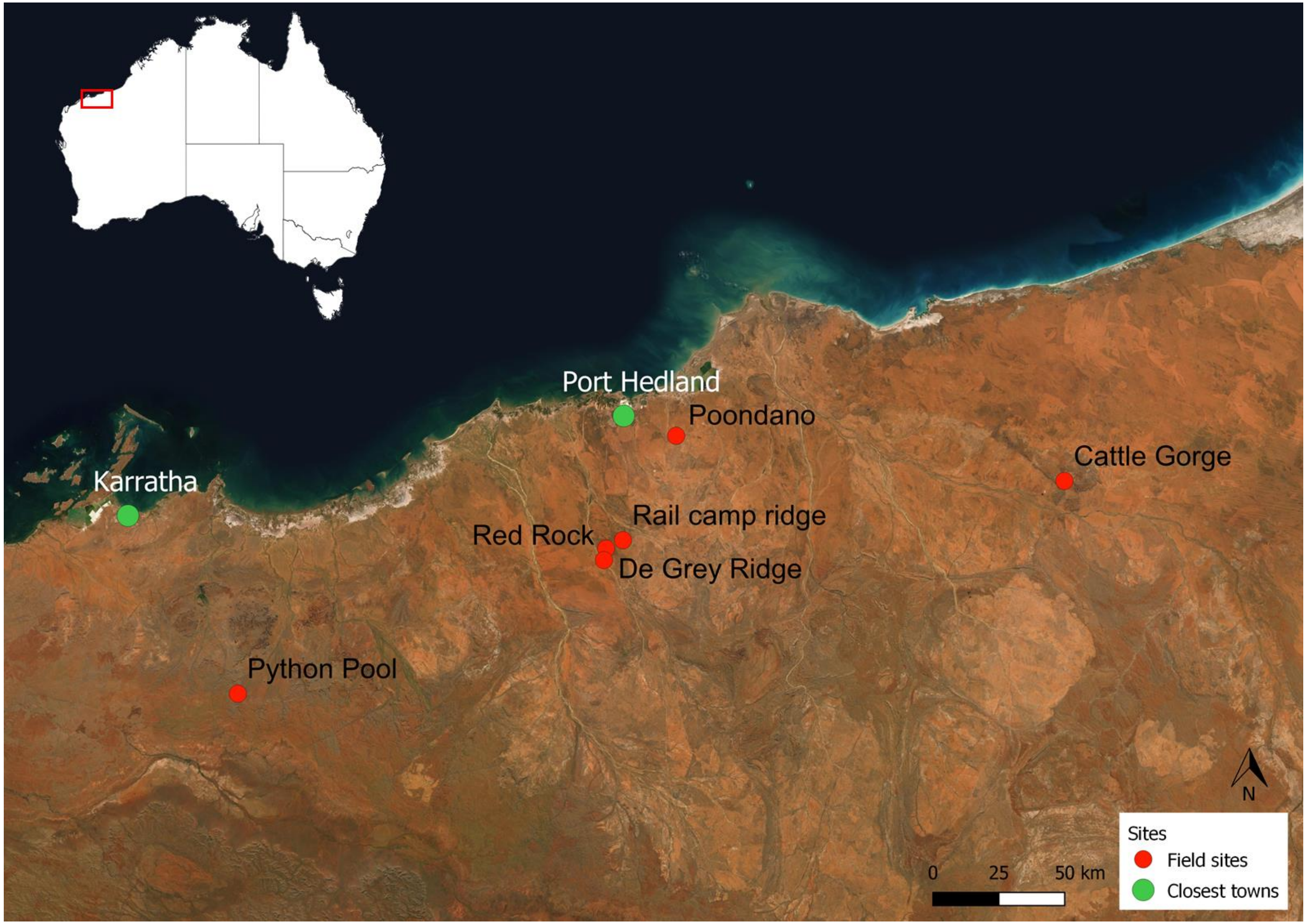


Figure 1: The northern quoll monitoring sites used for this study within the Pilbara, WA.

Table 1: Northern quoll spatial movement studies.

| Study | Description | Year(s) | Site(s) included in this study |
|---|---|---|---|
| Astron Environmental Services (2013) | A study to determine northern quoll habitat and refuge use within the Poondano Iron Ore Project area | 2013 | Poondano |
| Hernandez-Santin et al. (2020) | A PhD study to measure the home range of northern quolls in the Pilbara (includes data from Henderson (2015)) | 2014<br>2015 | Red Rock<br>Python Pool |
| Henderson (2015) | An Honours study to determine the impact of mining and rail infrastructure on northern quoll movement | 2015 | Red Rock<br>Rail Camp Ridge |
| Biologic (2016) | A study to determine the interaction of northern quolls with mine pits | 2016 | Cattle Gorge |
| Cowan et al. (2020) | An Honours study to find and study northern quoll natural and artificial dens | 2018 | De Grey Ridge |
| H. Moore, unpubl. data | A PhD study to determine the fine-scale movement and habitat interactions of northern quolls | 2018 | Red Rock |

*Data collection*

All studies used baited wire cage traps (45 cm × 17 cm × 17 cm, Sheffield Wire Co., Welshpool, WA) to capture northern quolls, baited using either the universal bait (peanut butter and oats), or a combination of the universal bait and raw chicken. Tracking methods however, differed slightly among studies, but GPS or VHF units did not exceed 5% of the individuals body weight in all cases (Table 2). The study undertaken by Astron Environmental Services (2013), had the only data used for this analysis which recorded northern quoll dens using a VHF unit, instead of recording northern quolls while they actively moved around using a GPS unit.

Table 2: Tracking methods undertaken by each study.

| Contributor/Study | GPS | VHF | Unit & brand | Fix interval * | Start record # | End record # | Max collar days + | Males ^ | Females ^ |
|---|---|---|---|---|---|---|---|---|---|
| Astron | | X | GPS/VHF Pinpoint 50 (Sirtrack Ltd, Havelock North, New Zealand) | 24 hours | *NA* | *NA* | 72 | 2 | 2 |
| Hernandez-Santin | X | | CatTrack® GPS loggers (Catnip Technologies, South Carolina, USA) | 1 hour | 09:00 | 00:00 | 15 | 4 | 0 |
| Henderson | X | | GPS/VHF Pinpoint 50 (Sirtrack Ltd, Havelock North, New Zealand) | 4 hours | 18:00 | 06:00 | 17 | 1 | 1 |
| Biologic | X | | FLR V Micro GPS collars (Telemetry Solutions, California, USA) | 30 mins | 18:30 | 06:00 | 37 | 2 | 0 |
| Cowan | X | | Custom made GPS collars with i-gotU components (Mobile Action Technology, Taipei, Taiwan) | 5 mins | 18:00 | 09:00 | 9 | 0 | 1 |
| Moore | X | | Custom made GPS collars with i-gotU components (Mobile Action Technology, Taipei, Taiwan) | 1 min | 17:00 | 07:00 | 14 | 0 | 6 |

* The fix interval is the period between GPS fixes

# Start and end record time when GPS or VHF units were set to actively record locations

+ Maximum number of days a northern quoll was collared

^ The number of males and females are the number used from the datasets to calculate home range for this synopsis, not the number of quolls tracked in each of these studies.

*Data cleaning*

Data was cleaned using techniques devised by Wysong et al. (2020), Hradsky et al. (2017), and (Bjørneraas et al., 2010), where unrealistic fixes were removed based on the average maximum movement speed of northern quolls (4.5 m/s, Wynn et al., 2015). In addition, GPS points collected before 12 pm on the day of collaring or between 12 pm and 12 am on the date of collar retrieval were removed, as these points may have been affected by quolls being caught in a trap. Individuals with less than 10 fixes were removed, as well as those that failed within the first day, because there was likely insufficient data to measure home ranges accurately (Girard et al., 2002, Seaman et al., 1999). While some studies suggest standardising fix rates between datasets, we did not, because doing so resulted in many unusable individuals with too few GPS locations, and differences in fix rate are rarely significant at the home range scale when using kernel density estimation (Mitchell et al., 2019, Peris et al., 2020, Huck et al., 2008).

*Data analysis*

We used the “rhr” package (Signer and Balkenhol, 2015), in R version 1.3.959 (R Core Team, 2020), to determine home range using two methods: minimum convex polygons (MCP), and fixed kernel density estimation (KDE).

Minimum convex polygons are created by connecting the outermost GPS points and measuring the area of the resulting polygon (e.g. Hernandez-Santin et al., 2020). This allows comparison between studies due to the simplicity in design, however it often leads to the inclusion of areas where animals do not exist, and may lead to the overestimation of home ranges (Burgman and Fox, 2003).

Kernel density estimation uses a smoothing parameter or bandwidth to smooth the GPS points, creating a probability density estimate which allows knowledge of the intensity of use within the home range (Kie, 2013). We used the reference bandwidth ($h_{ad\ hoc}$) method to determine the smoothing parameter as it is not often affected by sample size, has only moderate positive bias, rarely excludes areas part of the true home range, and rarely includes areas not part of the true home range (Kie, 2013). The $h_{ad\ hoc}$ method of determining the smoothing parameter often outperforms other methods including, least squares cross-validation ($h_{lscv}$) and reference bandwidths ($h_{ref}$), and is consistent and repeatable (Kie, 2013). We used fixed kernel density estimation—where the kernel width remains the same regardless of the distance between points (Powell, 2000, Kernohan et al., 2001).

The outermost locations of an animal range may represent movements that are outside their normal range or incorporate device errors, as such the outermost 5% of GPS points were excluded to give the 95% MCP and KDE home ranges (Figure 2–17). In addition, we also measured core area, which includes the innermost 50% of the points for MCP, or the area where 50% of the range is most heavily used for KDE. Means are reported as mean ± SE unless stated otherwise.

## Results

Home ranges were calculated for a total of 19 northern quoll individuals (F = 12, M = 7), across six sites (Table 1).We measured home range for four northern quolls tracked by Astron Environmental Services (2013), two by Biologic (2016), one by Cowan et al. (2020), two by Henderson (2015), four by Hernandez-Santin et al. (2020), and six by H. Moore (unpubl. data) (Table 1). Home ranges were determined for the ten female and nine northern quoll males tracked in all studies.

Female 95% home ranges ranged from 0.5 ha to 63.65 ha (average = 19.8 ± 6.11 ha) using MCP, and 3.42 ha to 70.71 ha (average = 24.2 ± 6.7 ha using KDE.  Female core 50% home ranges ranged from 0.09 ha to 45.15 ha (average = 9.33 ± 3.73) using MCP, and 0.13 ha to 15.58 ha (average = 5.25 ± 1.62 ha) using KDE. Overlap between female home ranges occurred, particularly for individuals tracked at Red Rock (Figure 2–3), where six females were tracked.

Male 95% home ranges ranged from 0.25 ha to 404.18 ha (average = 152.06 ± 61.62 ha) using MCP, and 19.22 ha to 1022 ha (average = 492.31 ± 150.78 ha) using KDE. Male core 50% home ranges ranged from 0.06 ha to 115.4 ha (average = 42.04 ± 16.53 ha) using MCP, and 0.84 ha to 57.92 ha (average = 27.61 ± 8.95 ha) using KDE. Overlap between male home ranges occurred, particularly for individuals tracked at Red Rock (Figure 4–5), where six females and four males were tracked.

Northern quolls with positive location fixes on less than 10 days had 95% home ranges of 60.05 ± 38.91 ha using MCP, and 181.90 ± 104.1 ha using KDE. Northern quolls with positive fixes on 10 or more days had slightly higher 95% home ranges of 77.94 ± 38 ha using MCP, and 213.06 ± 114.85 ha using KDE.

Average 95% home ranges using VHF collars to locate northern quoll dens were smaller than those created by GPS data which logged locations while northern quolls where active. The average 95% home ranges using den locations tracked via VHF telemetry were 3.12 ± 2.10 ha using MCP, and 17.49 ± 12.12 ha using KDE. In comparison, 95% home ranges using locations gathered while northern quolls were active were 90.86 ± 32.35 ha using MCP, and 287.26 ± 91.98 ha using KDE.

Table 1: Tracking information and home range estimates for northern quolls GPS tracked in 2013, 2014, 2015, 2016, and 2018 within the Pilbara, Western Australia.

| | | | | | | | MCP (ha) | | KDE (ha) | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Contributor/Study** | **Site** | **Year** | **PIT** | **Sex** | **Total fixes** | **Days with fixes** | **50%** | **95%** | **50%** | **95%** |
| Astron | Poondano | 2013 | 84583 | F | 28 | 28 | 0.09 | 0.5 | 0.13 | 3.42 |
| Astron | Poondano | 2013 | 74542 | M | 29 | 29 | 0.40 | 9.09 | 13.03 | 59.01 |
| Astron | Poondano | 2013 | 74892 | M | 22 | 22 | 0.06 | 0.25 | 2.48 | 19.22 |
| Astron | Poondano | 2013 | 82501 | F | 29 | 29 | 0.15 | 1.58 | 1.16 | 14.47 |
| Biologic | Cattle Gorge | 2016 | E6A572 | F | 83 | 26 | 45.15 | 63.65 | 13.61 | 70.71 |
| Biologic | Cattle Gorge | 2016 | E6CA67 | F | 282 | 29 | 16.22 | 57.14 | 15.58 | 57.22 |
| Cowan | De Grey Ridge | 2018 | 44751 | F | 389 | 8 | 3.59 | 17.25 | 5.09 | 23.15 |
| Henderson | Red Rock | 2015 | 44748 | M | 25 | 9 | 9.49 | 34.07 | 51.21 | 286.21 |
| Henderson | Rail Camp Ridge | 2015 | 953828 | F | 21 | 12 | 17.19 | 33.88 | 13.47 | 55.74 |
| Hernandez-Santin | Python Pool | 2014 | 98322 | M | 120 | 11 | 66.79 | 325.76 | 45.11 | 847.84 |
| Hernandez-Santin | Red Rock | 2014 | 99027 | M | 132 | 10 | 70.64 | 209.64 | 22.7 | 789.9 |
| Hernandez-Santin | Red Rock | 2014 | 99464 | M | 117 | 9 | 115.40 | 404.18 | 57.92 | 1022.3 |
| Hernandez-Santin | Red Rock | 2014 | 99531 | M | 135 | 9 | 31.47 | 81.41 | 0.84 | 421.68 |
| Moore | Red Rock | 2018 | 23891 | F | 364 | 5 | 1.45 | 6.6 | 1.41 | 8.84 |
| Moore | Red Rock | 2018 | 44828 | F | 84 | 2 | 0.95 | 6.53 | 1.41 | 7.48 |
| Moore | Red Rock | 2018 | 45146 | F | 974 | 4 | 3.3 | 6.68 | 1.9 | 7.86 |
| Moore | Red Rock | 2018 | 46324 | F | 1053 | 6 | 4.42 | 11.76 | 3.99 | 15.4 |
| Moore | Red Rock | 2018 | 953815 | F | 400 | 3 | 14.43 | 22.4 | 3.74 | 17.68 |
| Moore | Red Rock | 2018 | 961514 | F | 615 | 3 | 5 | 9.59 | 1.56 | 8.42 |

## Discussion

We analysed home ranges for 19 northern quolls tracked within the Pilbara between 2013 and 2018. We found that female home ranges were smaller on average when compared to male home ranges using both the MCP and KDE methods. This follows trends in other parts of their range where female northern quolls generally have smaller home ranges than males (Cook, 2010, Oakwood, 2002). There were differences in monitoring methods and technology available, resulting in some northern quolls recorded positive GPS fixes over longer periods than others. Home range estimation can be heavily impacted by the length of tracking duration, because animals often cover larger periods over longer periods of time, until they reach their complete home range and home range size does not increase further (Körtner et al., 2015, Mitchell et al., 2019). Home range estimates were slightly higher for northern quolls with positive fixes on more than 10 days compared to those with positive fixes on less than 10 days. The closely related spotted-tailed quoll (*Dasyurus maculatus*) can take up to 30 days to cover its' entire range—1549 ± 808 ha for males and 509 ± 152 ha for females using MCP (Körtner et al., 2015)—and while this information is not yet available for northern quolls, this study indicates that 10 days may not be long enough to determine a northern quoll's complete home range. We identified that home ranges estimated using VHF collars were much smaller than those using GPS collars, due to the fact VHF collars measured only the refuges of northern quolls and not their movement activity. More advanced GPS technology has allowed us to estimate home ranges more accurately than previous studies and suggests that northern quolls use larger areas when active than they use to take refuge during inactivity.

A key research priority defined by Cramer et al. (2016) was to "*define areas of critical habitat for northern quolls in the Pilbara*". GPS data like those presented here can be used for habitat selection studies where the fine-scale and broad-scale habitat use of northern quolls is investigated (e.g. Wysong et al., 2020). We found that many female home ranges overlapped at Red Rock, and the same trend was seen for males at the same site. This overlap may be due to high habitat quality within the study area allowing multiple individuals to co-exist (McLoughlin et al., 2000), but this remains to be demonstrated. Home range estimates in this study are much higher than those of northern quolls on Groote Eylandt in the Northern Territory (Heiniger et al., 2020). This is likely due to environmental differences between the sites, Groote Eylandt has higher annual rainfall and higher prey productivity than the Pilbara region, which is drier and sees more sporadic rainfall events (Bureau of Meteorology, 2020). This likely contributes to differences in predator and prey assemblages (Heiniger et al., 2020). Cowan et al. (2020), and H. Moore (unpubl. data), used collars with high fix rates—with between one and five-minutes between fixes—much higher than all other studies analysed in this synopsis. The higher fix rate capabilities can be attributed to advances in technology since many of the other studies took place between two and five years prior. Data of this scale is required for fine-scale habitat analysis, which can show us exactly how animals use the resources available within their home ranges (Johnson, 1980, van Beest et al., 2011), so technology such as this will be an important tool for the exploration of the space use and habitat selection of a species.

If animal tracking using two different methods (e.g. GPS and VHS) use each method at comparable times (i.e. when the animal is active), studies of home range can show similar results (Kochanny et al., 2009). This is because many animals—including northern quolls—are active during certain times over a 24 hour period, and locations taken when they are inactive may not reflect the true area of that which they use (Vernes and Pope, 2001). Many previous methods of home range estimation for northern quolls have used VHF telemetry, including Astron's example used in this synopsis (Oakwood, 2002, Astron Environmental Services, 2013, Cook, 2010). However, when comparing home range estimates from GPS northern quoll location data and the VHF den location data retrieved by Astron Environmental Services (2013), VHF estimates were much smaller. Den locations were taken during the day when northern quolls were inactive. This may suggest that northern quolls use dens within a smaller area compared to the area they use when actively moving or finding food. This may also suggest that previous studies of northern quoll home range using locations from camera trap arrays (King and King, 1989, Braithwaite and Griffiths, 1994), or VHF locations from dens (Oakwood, 2002, Cook, 2010), underestimated complete northern quoll home range. This is likely due to differences in space use when choosing areas for food, movement, and shelter (McKeown et al., 2020). GPS telemetry has come a long way since most of these early studies took place, enabling us to track northern quolls when they are active at scales previously impossible, allowing for more accurate home range estimates.

The data presented here was intended to reflect the space use of northern quolls in the Pilbara. This information is beneficial in order to help understand the size of the area that northern quolls use within the semiarid landscapes of the Pilbara. Further—and in response to the research priority defined by Cramer et al. (2016)—we believe that this data would be suited to an analysis of habitat selection by northern quolls, which identifies the key landscape features that northern quolls select the most within their home range (i.e., rock, spinifex). We are currently in the process of applying the datasets used in this synopsis to an investigation of northern quoll habitat selection within the Pilbara. The habitat selection analysis will be treated separately to this home range synopsis and focusses on the key landscape features that northern quolls select, rather than solely the area covered. A study focussed on northern quoll habitat selection within their home ranges will compliment this synopsis and help to guide future conservation practices—improving the efficiency of management and monitoring, using camera traps and cage traps, as well as informing feral animal control programs (i.e. *Eradicat*® baiting). Long-term GPS tracking studies (up to three months, e.g. Körtner et al., 2015) gathering northern quoll location data would be beneficial to build on existing spatial ecology studies (e.g. Hernandez-Santin et al., 2020), and further define the complete home ranges of northern quolls in this landscape.

# Recommendations

- Adapted igot-U collars are suitable for use with northern quolls, provided they have a weak link point on the collar and are designed to drop off in the situation where an animal is not recaptured, or becomes snagged.
- VHF data comprising of denning locations is not suitable for analysis of complete home range, being more suited to measuring the denning range. Updated GPS collars with inbuilt VHF capabilities have been developed and may be more suitable for movement data with the ability to capture many fixes over a long period of time, with the added ability to also record den locations (e.g. Cowan et al., 2020). Any tracking devices must be below 5% of body mass and must not impede movement or daily activities.
- Other newer collaring options with high fix-rate potential include Lotek collars with real-time GPS logging—using satellite systems including Globalstar, ARGOS, and ICARUS—as well as other adapted pet and fitness GPS loggers (i.e. ATLAS). Much of this technology is designed for animals larger than quolls or for non-cryptic species, so these methods would be completely experimental and further design and alterations would be required.
- The data collated in this synopsis is not sufficient to be published as a standalone home range analysis, however, we believe it would be useful to form the basis of an analysis of northern quoll habitat selection, to inform future conservation actions and management decisions.
- Körtner et al. (2015), found that spotted tailed quolls in New South Wales took 3-4 weeks to cover their entire home range, so hence a similar study for northern quolls would be useful to guide future home range studies.
- A rigorous study to determine the best methods for northern quoll home range estimation would ideally require at least ten adult male and ten adult female northern quolls collared in each season to establish the effect of season on home range—excluding summer (November – February), to reduce the impact on females carrying or caring for young. GPS tracking should occur over a minimum of four sites with at least two differing landscape types (e.g., creek line vs rocky outcrop) in order to establish the effect of site on home range. Sites should have the potential to track several individuals (five minimum), to increase the sample size per site. The length of time for a rigorous northern quoll home range study is currently unknown, but each tracking session within each season should last at least one month—the time it takes for spotted tailed quolls to cover their range (Körtner et al., 2015).
- The period of time that it takes northern quolls to cover their entire range will be determined by the time it takes for home range size to reach an asymptote—where home range size does not significantly increase despite increased time (Heiniger et al., 2020).

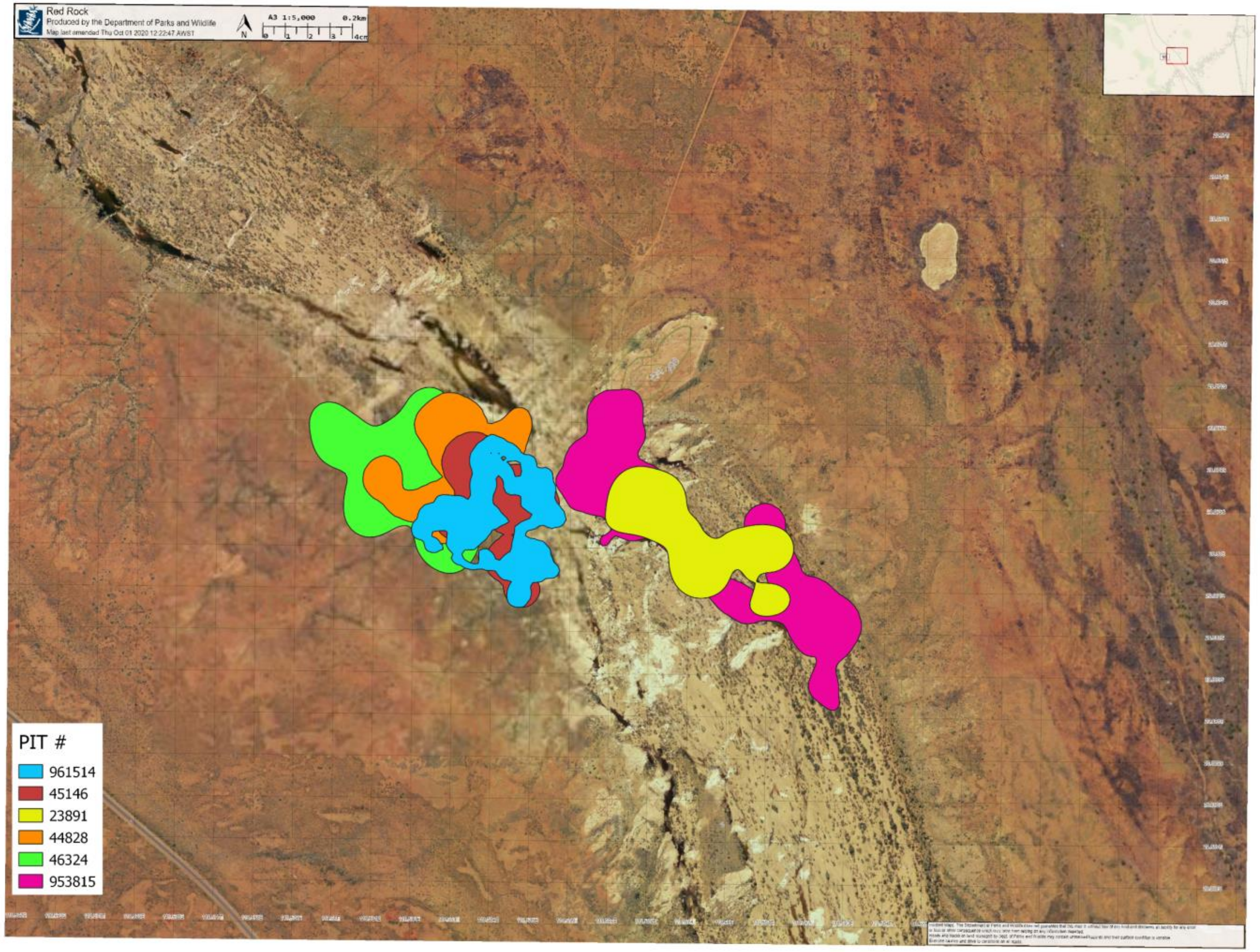


Figure 2: 95% kernel density estimates for all female northern quolls tracked at Red Rock.

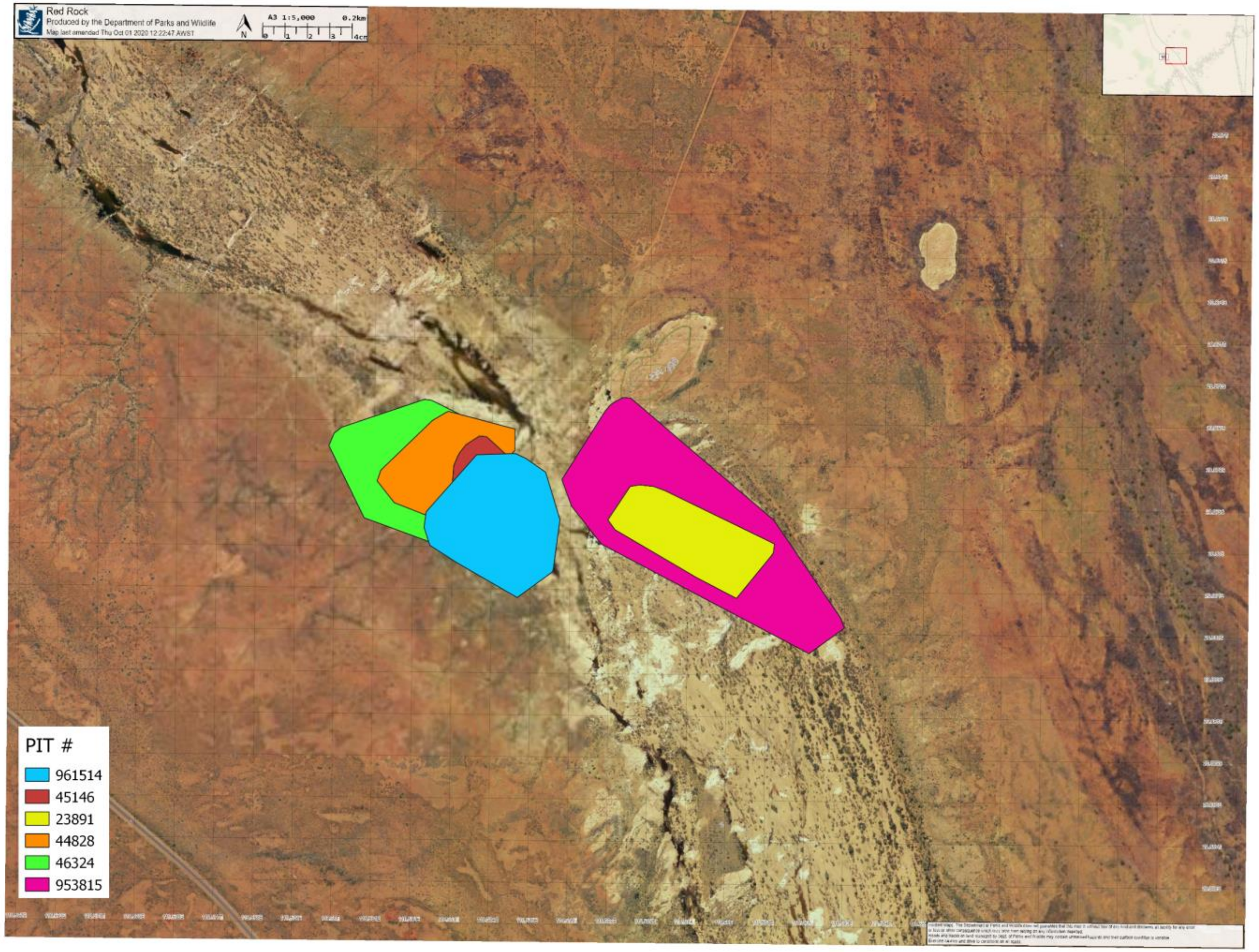


Figure 3: 95% minimum convex polygons for all female northern quolls tracked at Red Rock.

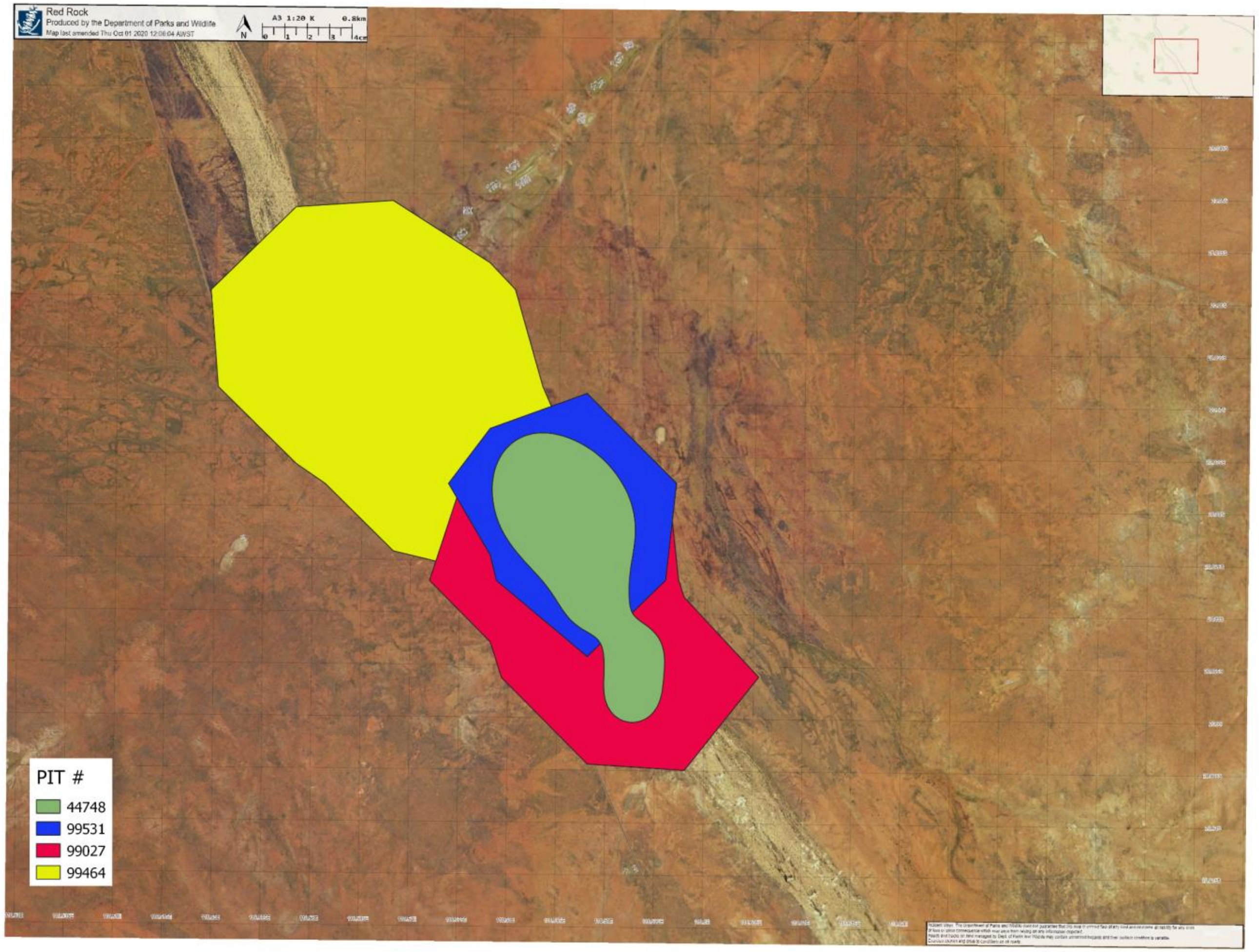


Figure 4: 95% kernel density estimates for all male northern quolls tracked at Red Rock.

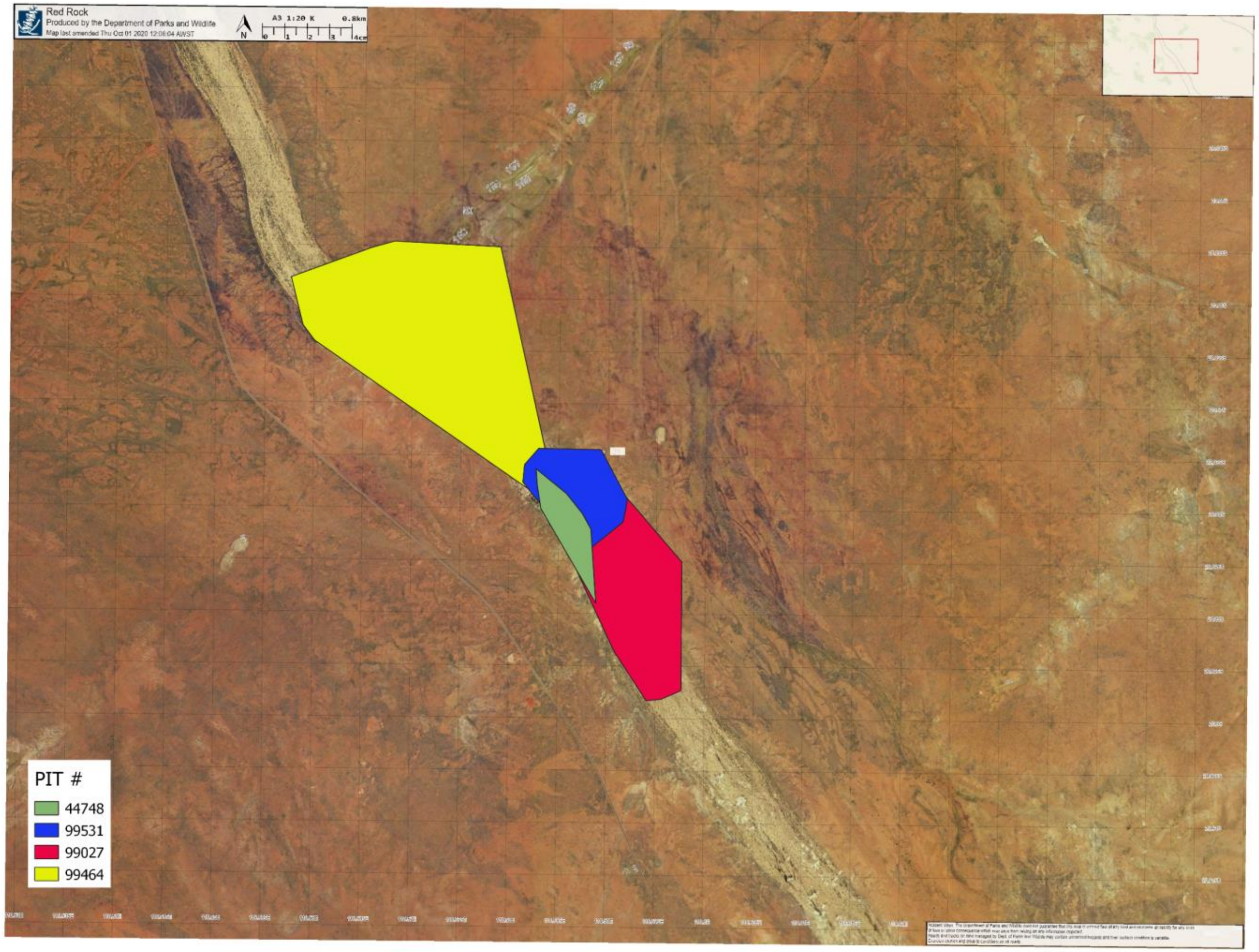


Figure 5: 95% minimum convex polygons for all male northern quolls tracked at Red Rock.

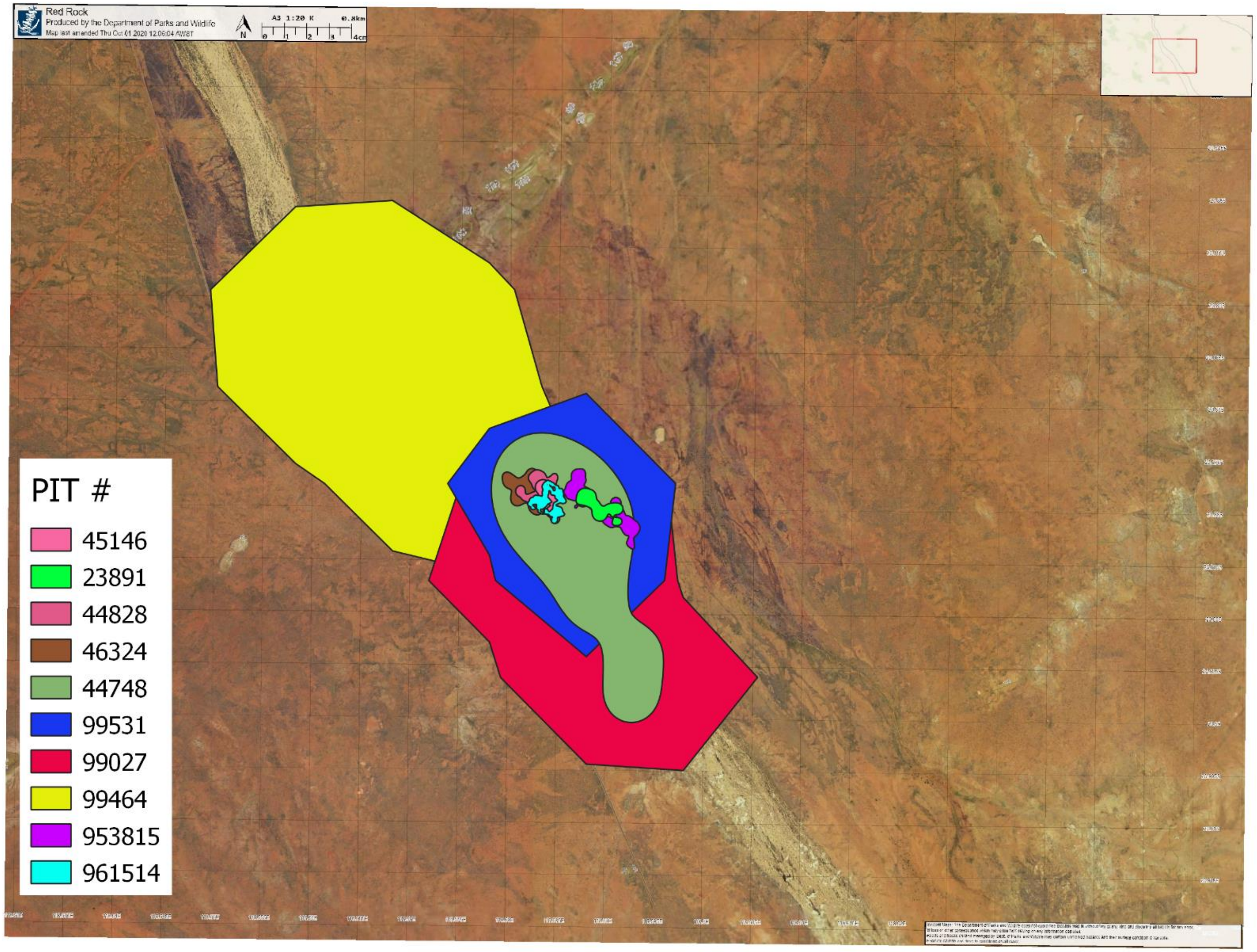


Figure 6: Overlapped 95% kernel density estimates for all male and female northern quolls tracked at Red Rock.

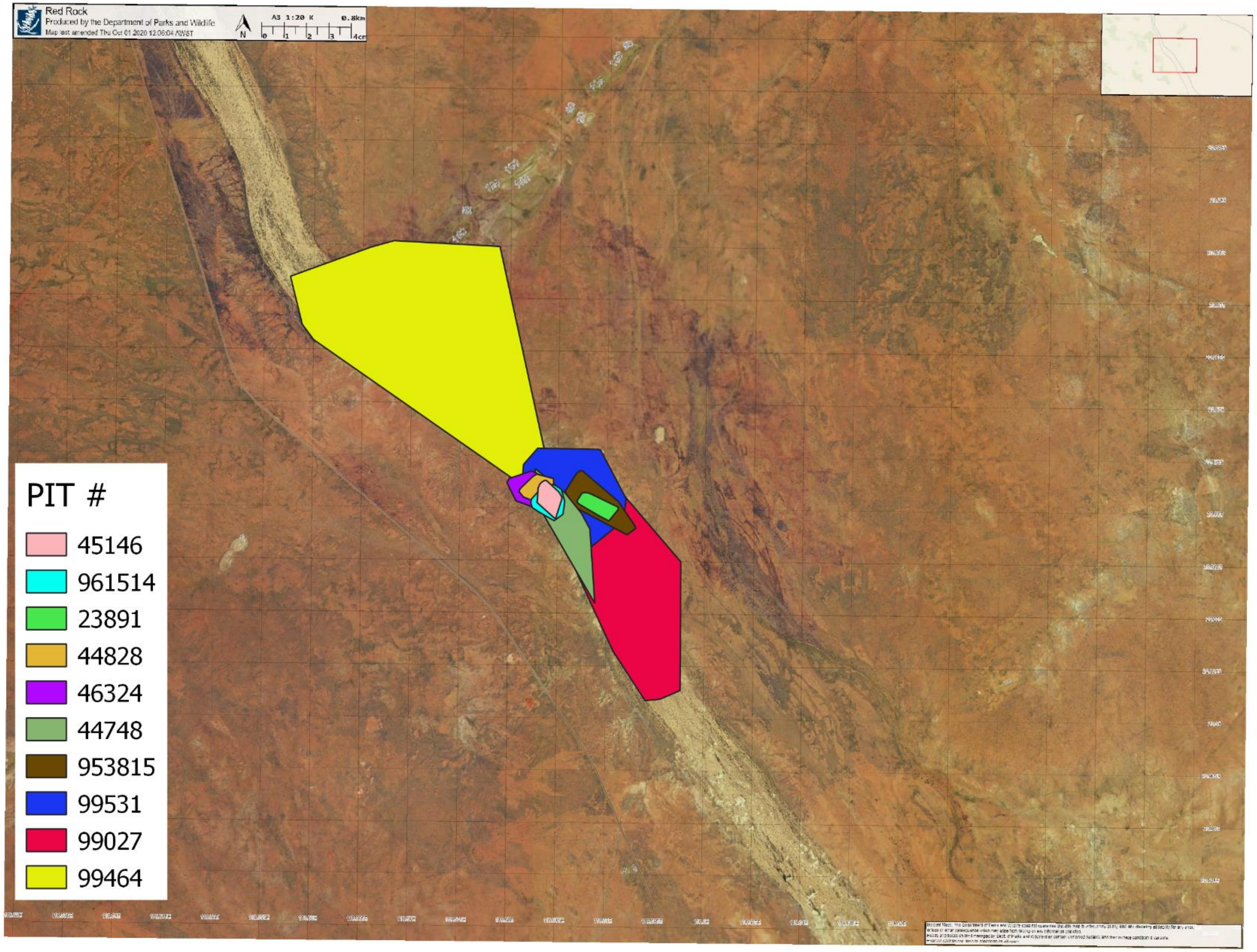


Figure 7: Overlapped 95% minimum convex polygons for all male and female northern quolls tracked at Red Rock.


Figure 8: 95% kernel density estimate for the female northern quoll tracked at De Grey Ridge.

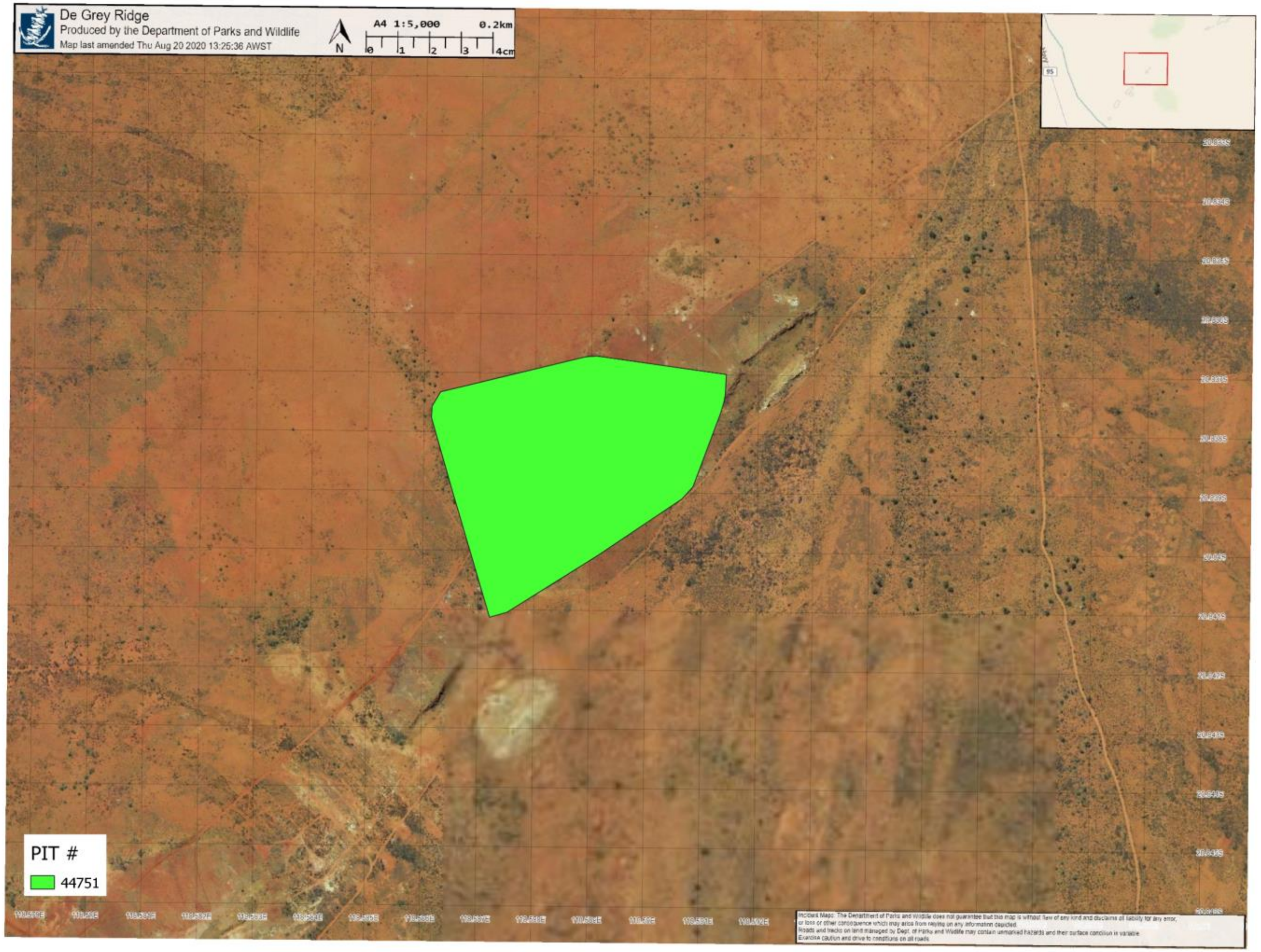


Figure 9: 95% minimum convex polygon for the female northern quoll tracked at De Grey Ridge.

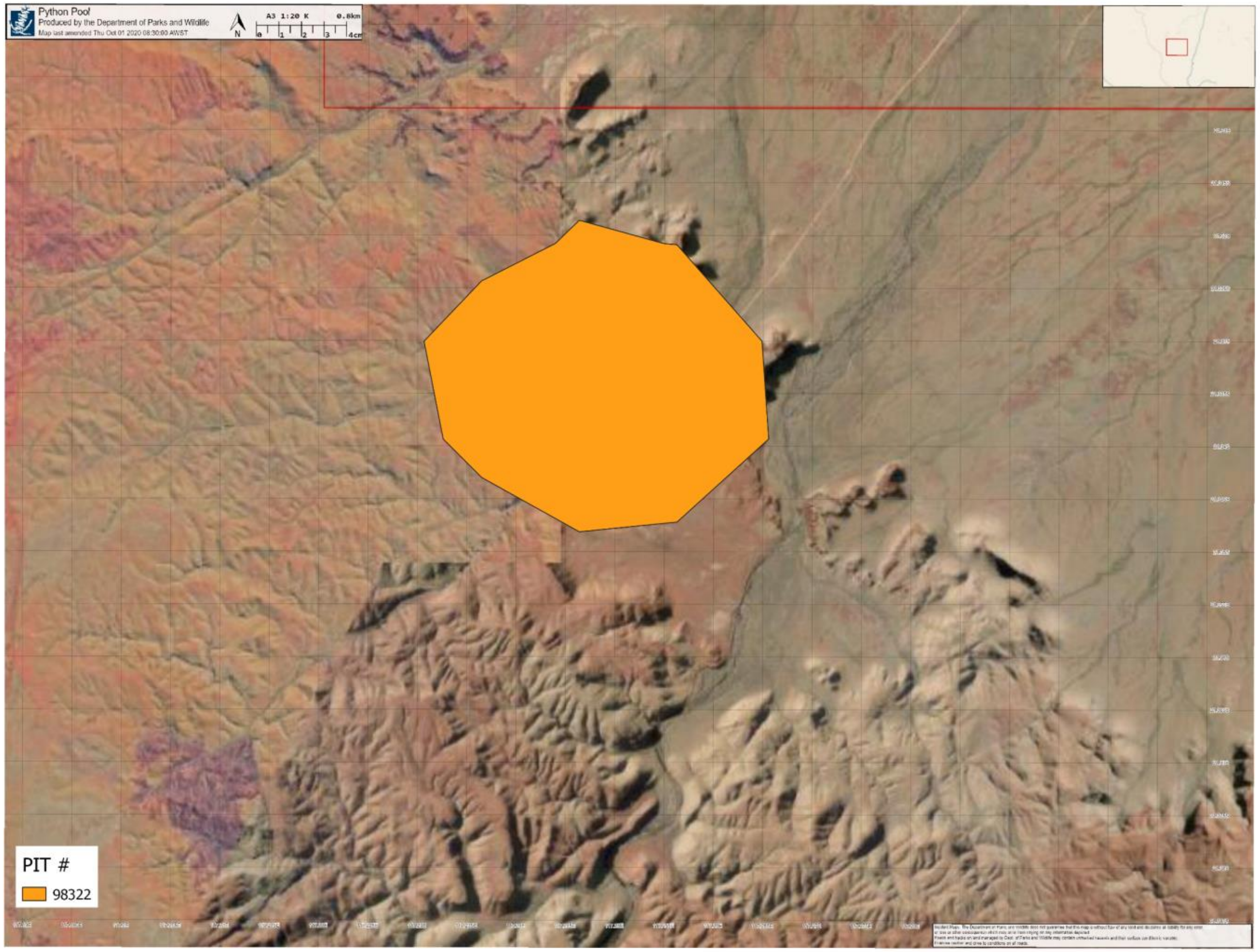


Figure 10: 95% kernel density estimate for the male northern quoll tracked at Python Pool.

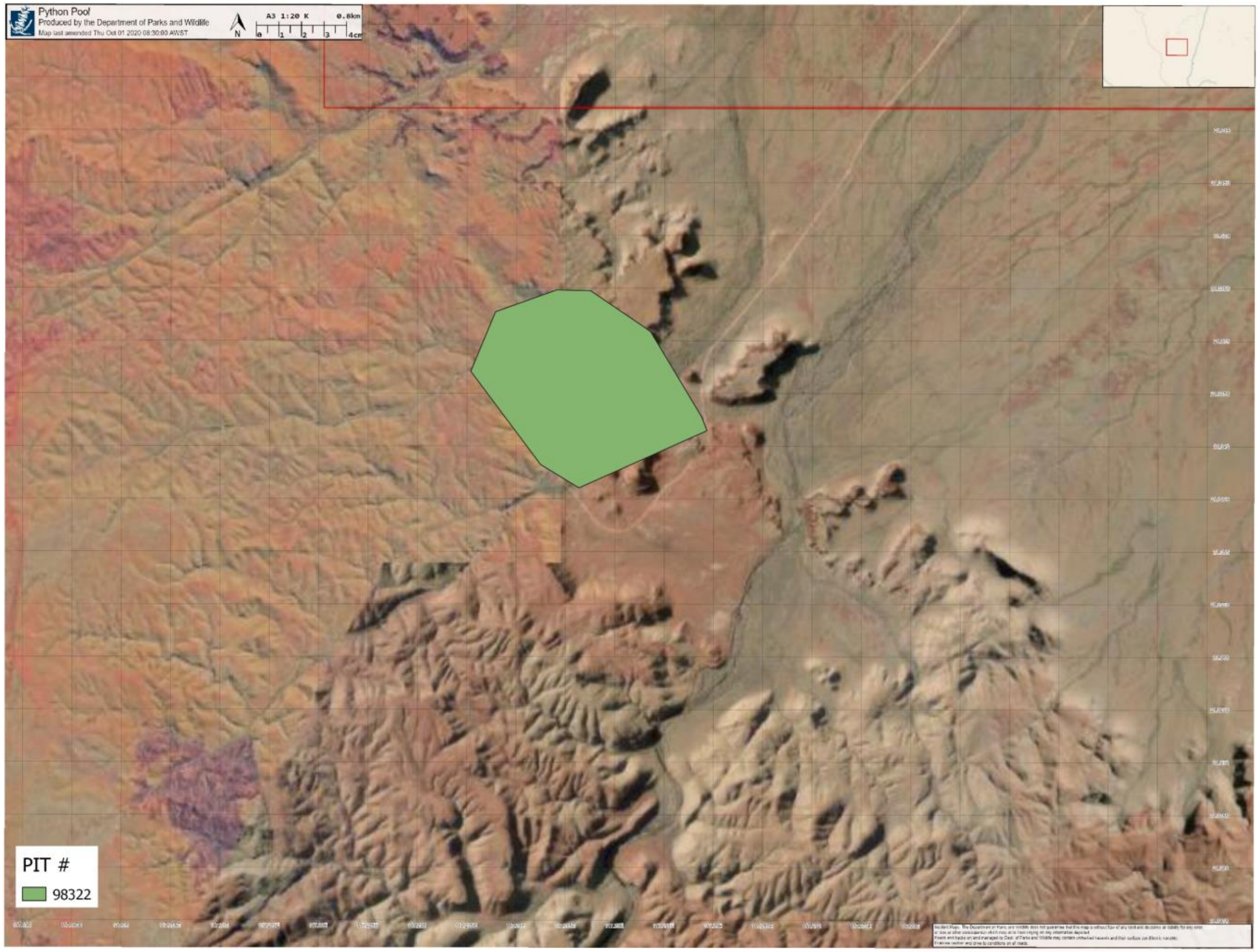


Figure 11: 95% minimum convex polygon for the male northern quoll tracked at Python Pool.

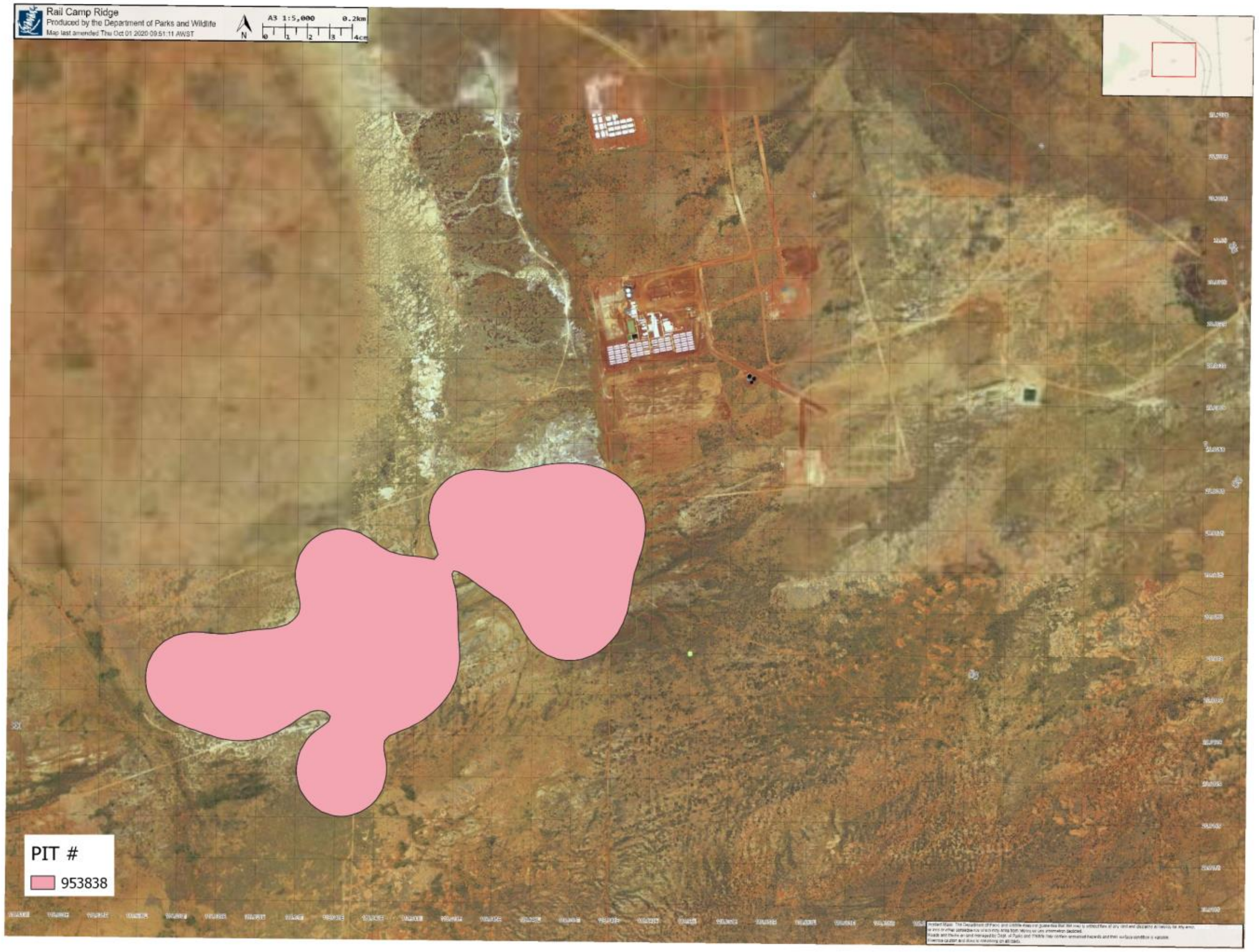


Figure 12: 95% kernel density estimate for the female northern quoll tracked at Rail Camp Ridge.

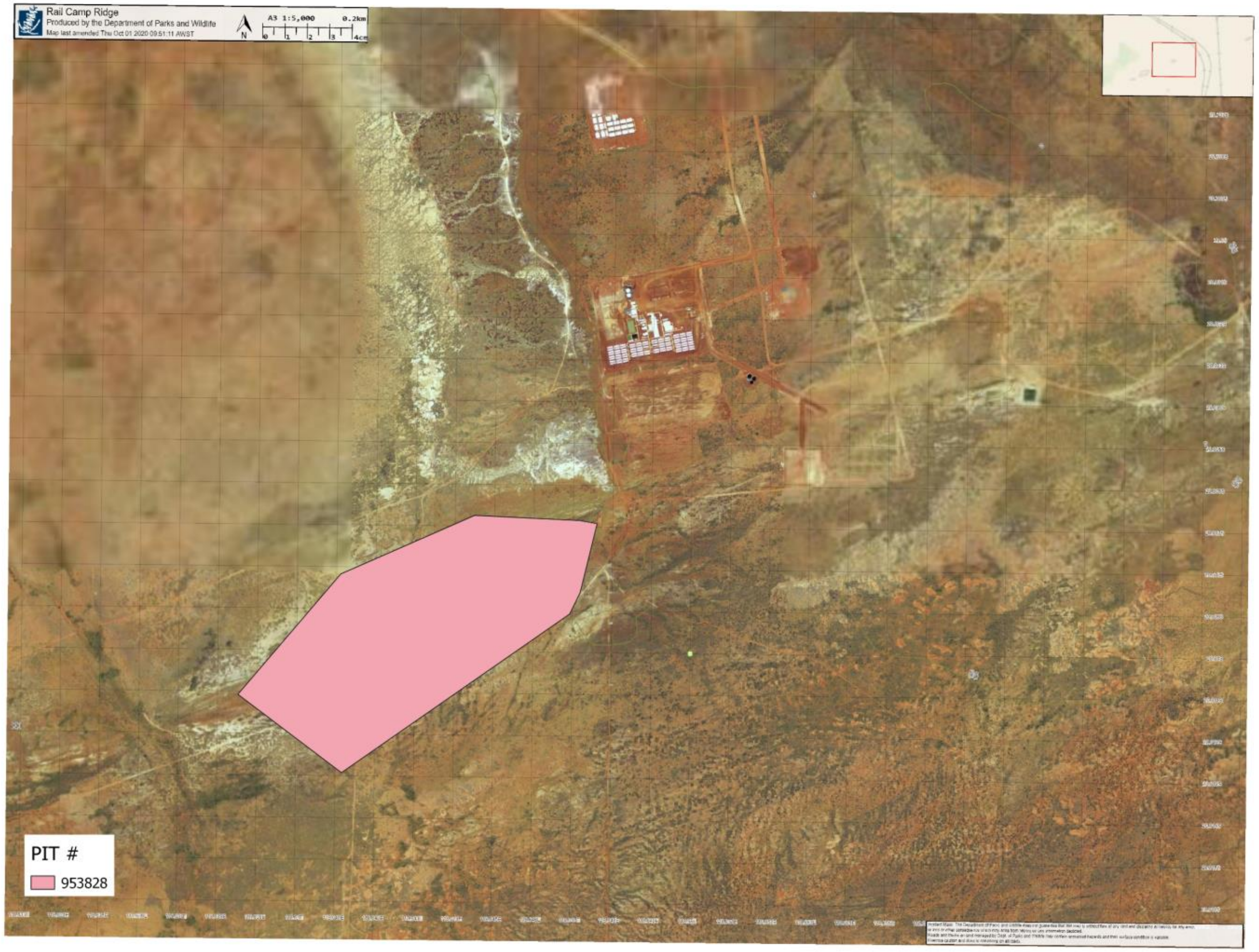


Figure 13: 95% minimum convex polygon for the male northern quoll tracked at Rail Camp Ridge.

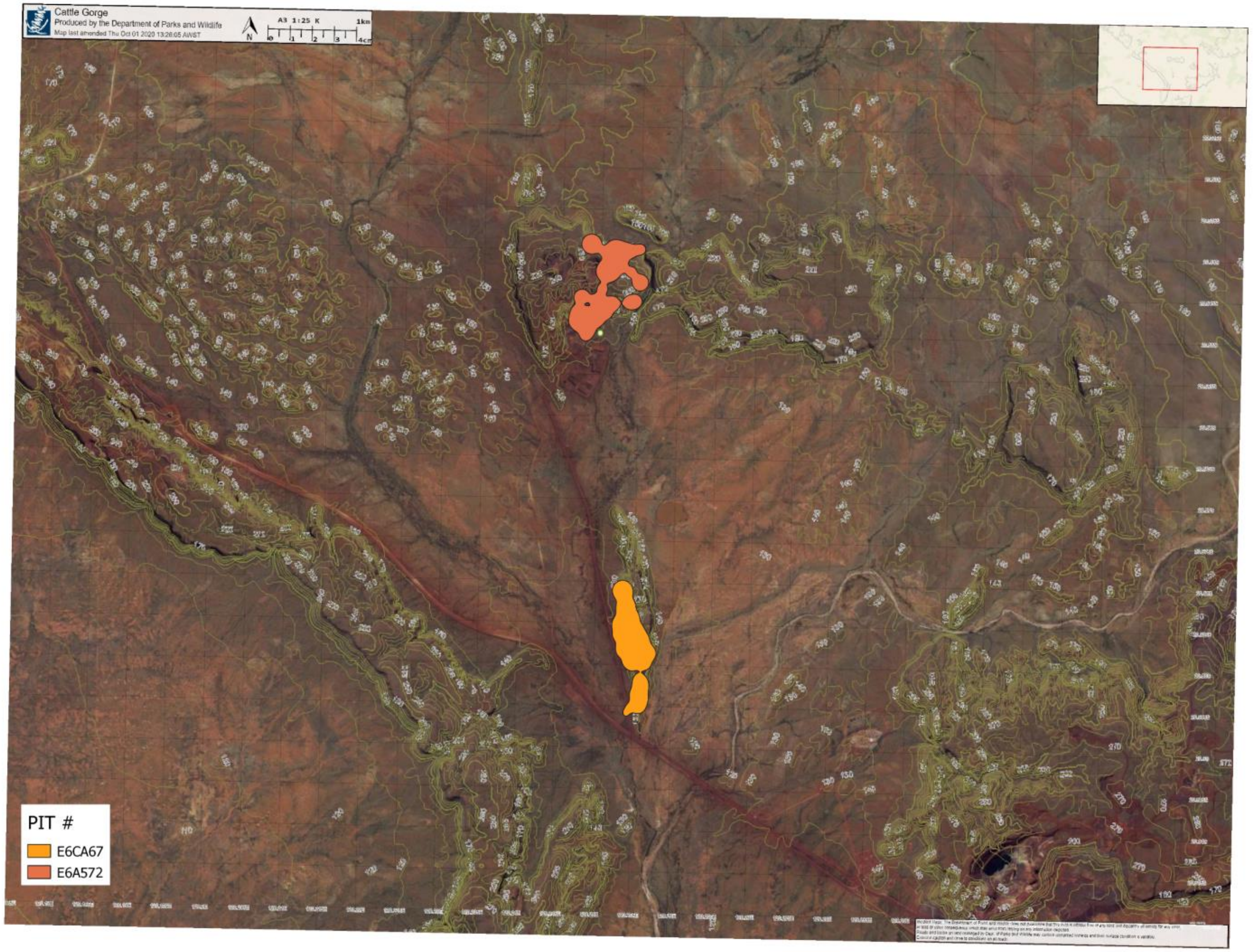


Figure 14: 95% kernel density estimates for both female northern quolls tracked at Cattle Gorge.

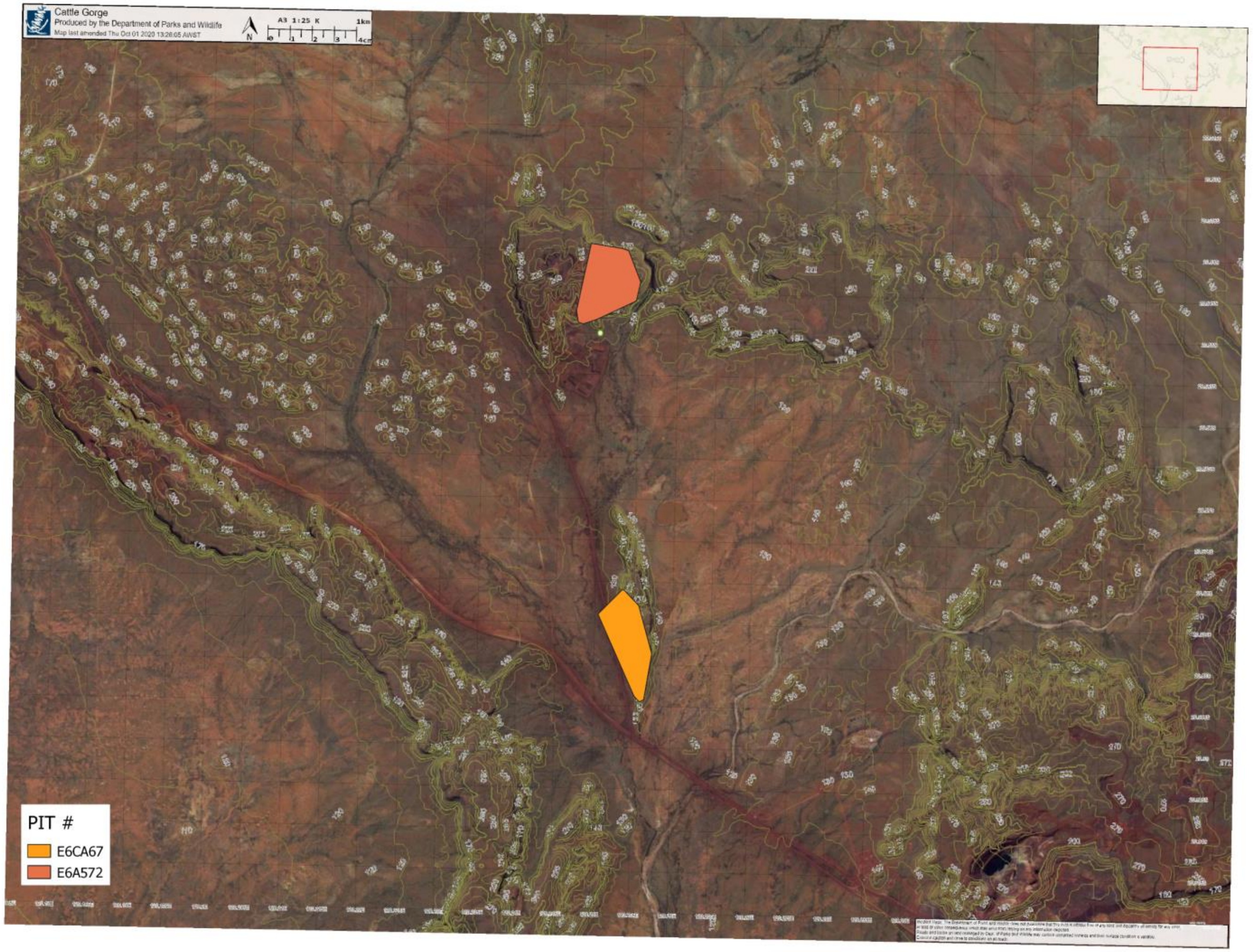


Figure 15: 95% minimum convex polygons for both female northern quolls tracked at Cattle Gorge.

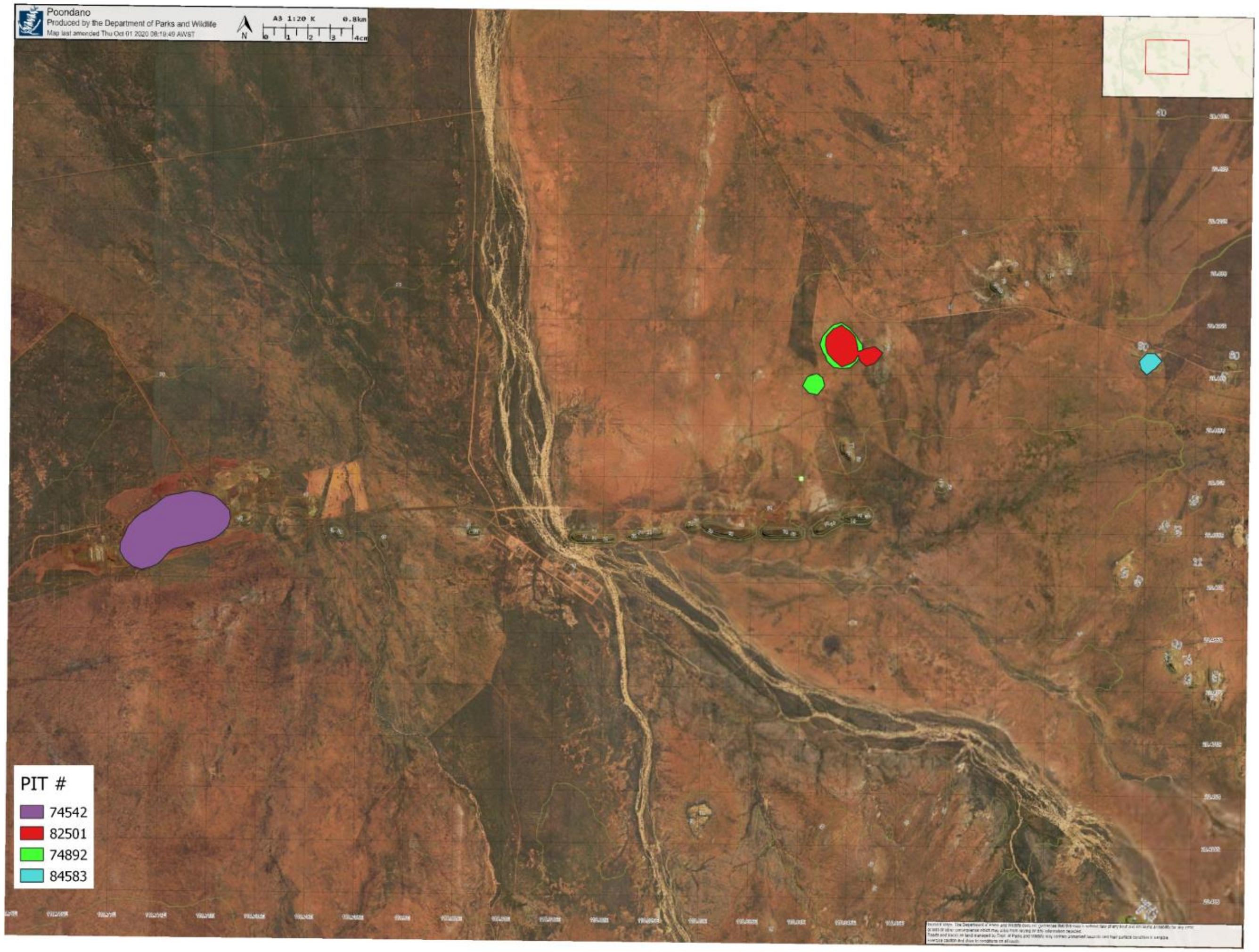


Figure 16: 95% kernel density estimates for all male and female northern quolls tracked at Poondano. Males = 74542, 74892; Females = 82501, 84583.

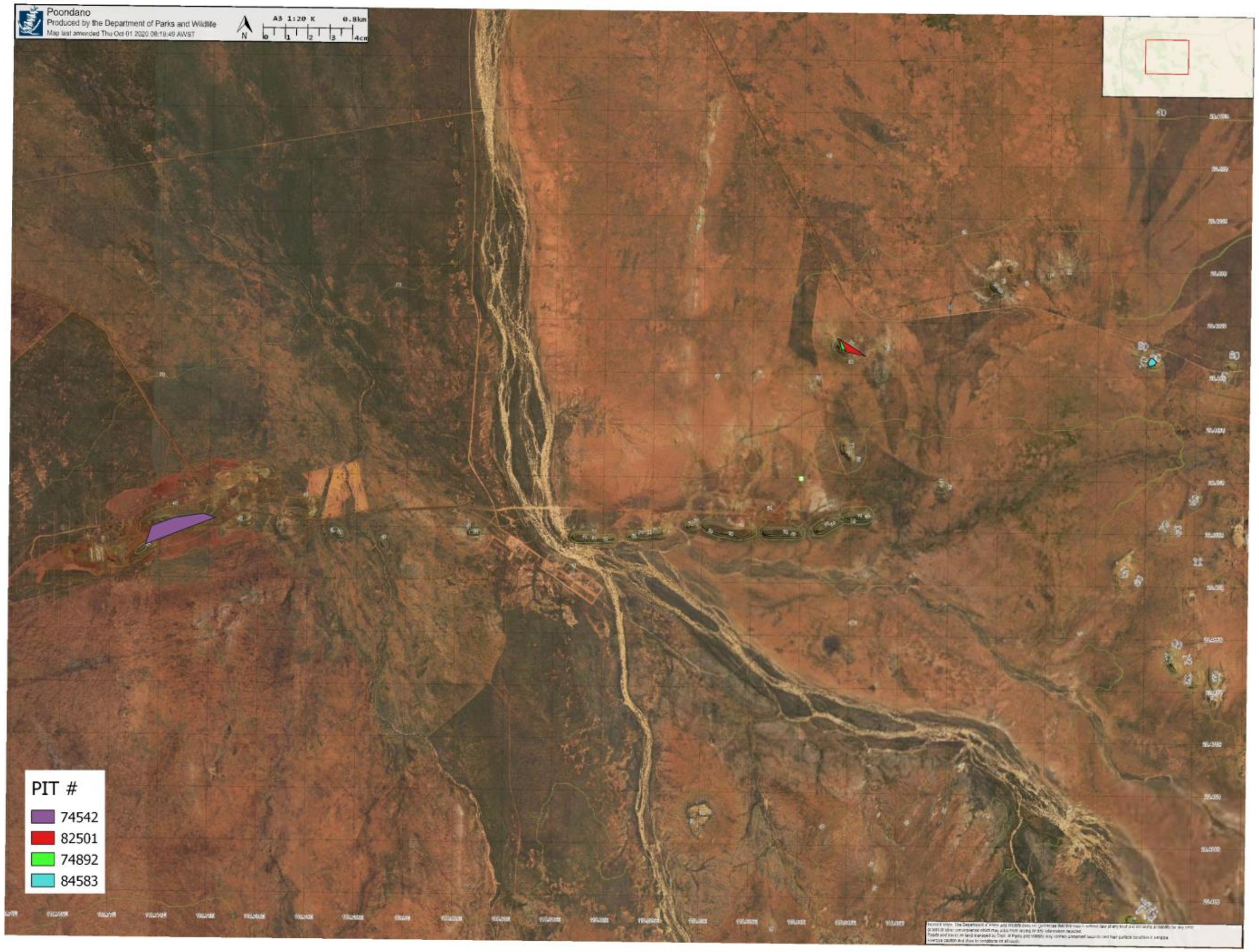


Figure 17: 95% minimum convex polygons for all male and female northern quolls tracked at Poondano. Males = 74542, 74892; Females = 82501, 84583.

# References


ASTRON ENVIRONMENTAL SERVICES 2013. Poondano Iron Ore Project Northern Quoll Radio-Tracking Study. Perth: Report prepared for Polaris Metals Pty Ltd: Astron Environmental Services.

BIOLOGIC 2016. Cattle Gorge and Callawa West Vertebrate Fauna Studies. Perth: Report prepared for BHP Billiton Iron Ore Pty Ltd: Biologic.

BJØRNERAAS, K., VAN MOORTER, B., ROLANDSEN, C. M. & HERFINDAL, I. 2010. Screening Global Positioning System Location Data for Errors Using Animal Movement Characteristics. *The Journal of Wildlife Management,* 74**,** 1361-1366.

BRAITHWAITE, R. W. & GRIFFITHS, A. D. 1994. Demographic variation and range contraction in the northern quoll, *Dasyurus hallucatus* (Marsupialia : Dasyuridae). *Wildlife Research,* 21**,** 203-217.

BUREAU OF METEOROLOGY. 2020. *Climate Data Online* [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_004032.shtml [Accessed 30 July 2018].

BURGMAN, M. & FOX, J. 2003. Bias in species range estimates from minimum convex polygons: Implications for conservation and options for improved planning. *Animal Conservation,* 6**,** 19-28.

COOK, A. 2010. *Habitat use and home-range of the northern quoll, Dasyurus hallucatus: effects of fire.* Master's, The University of Western Australia.

COWAN, M. A., DUNLOP, J. A., TURNER, J. M., MOORE, H. A. & NIMMO, D. G. 2020. Artificial refuges to combat habitat loss for an endangered marsupial predator: How do they measure up? *Conservation Science and Practice,* 2**,** e204.

CRAMER, V. A., DUNLOP, J., DAVIS, R. A., ELLIS, R., BARNETT, B., COOK, A., MORRIS, K. & VAN LEEUWEN, S. 2016. Research priorities for the northern quoll (*Dasyurus hallucatus*) in the Pilbara region of Western Australia. *Australian Mammalogy,* 38**,** 135-148.

GIRARD, I., OUELLET, J.-P., COURTOIS, R., DUSSAULT, C. & BRETON, L. 2002. Effects of Sampling Effort Based on GPS Telemetry on Home-Range Size Estimations. *The Journal of Wildlife Management,* 66**,** 1290-1300.

HEINIGER, J., CAMERON, S. F., MADSEN, T., NIEHAUS, A. C. & WILSON, R. S. 2020. Demography and spatial requirements of the endangered northern quoll on Groote Eylandt. *Wildlife Research,* 47**,** 224-238.

HENDERSON, M. 2015. *The Effects of Mining Infrastructure on Northern quoll Movement and Habitat.* Bachelor of Science (Conservation and Wildlife Biology), Edith Cowan University.

HERNANDEZ-SANTIN, L., HENDERSON, M., MOLLOY, S. W., DUNLOP, J. A. & DAVIS, R. A. 2020. Spatial ecology of an endangered carnivore, the Pilbara northern quoll. *Australian Mammalogy***,** -.

HRADSKY, B. A., ROBLEY, A., ALEXANDER, R., RITCHIE, E. G., YORK, A. & DI STEFANO, J. 2017. Human-modified habitats facilitate forest-dwelling populations of an invasive predator, *Vulpes vulpes*. *Scientific Reports,* 7**,** 12291.

HUCK, M., DAVISON, J. & ROPER, T. J. 2008. Comparison of two sampling protocols and four home-range estimators using radio-tracking data from urban badgers *Meles meles*. *Wildlife Biology,* 14**,** 467-477, 11.

JOHNSON, D. H. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. 1980.

KERNOHAN, B. J., GITZEN, R. A. & MILLSPAUGH, J. J. 2001. Analysis of animal space use and movements. *Radio tracking and animal populations.* Academic Press.

KIE, J. G. 2013. A rule-based ad hoc method for selecting a bandwidth in kernel home-range analyses. *Animal Biotelemetry,* 1**,** 13.

KING, D. & KING, D. 1989. An Assessment of the Hazard Posed to Northern Quolls (Dasyurus-Hallucatus) by Aerial Baiting With 1080 to Control Dingoes. *Wildlife Research,* 16**,** 569-574.

KOCHANNY, C. O., DELGIUDICE, G. D. & FIEBERG, J. 2009. Comparing Global Positioning System and Very High Frequency Telemetry Home Ranges of White-Tailed Deer. *The Journal of Wildlife Management,* 73, 779-787.

KÖRTNER, G., HOLZNAGEL, N., FLEMING, P. J. S. & BALLARD, G. 2015. Home range and activity patterns measured with GPS collars in spotted-tailed quolls. *Australian Journal of Zoology,* 63, 424-431.

MCKEOWN, B., WALTON, Z. & WILLEBRAND, T. 2020. Does recursive use of resource locations shape a home range? Exploring the red fox's cognitive map. *Wildlife Biology,* 2020.

MCLOUGHLIN, P. D., FERGUSON, S. H. & MESSIER, F. 2000. Intraspecific Variation in Home Range Overlap with Habitat Quality: A Comparison among Brown Bear Populations. *Evolutionary Ecology,* 14, 39-60.

MITCHELL, L. J., WHITE, P. C. L. & ARNOLD, K. E. 2019. The trade-off between fix rate and tracking duration on estimates of home range size and habitat selection for small vertebrates. *PLOS ONE,* 14, e0219357.

OAKWOOD, M. 1997. *The ecology of the northern quoll, Dasyurus hallucatus.* Doctor of Philosophy, Australian National University.

OAKWOOD, M. 2002. Spatial and social organization of a carnivorous marsupial *Dasyurus hallucatus*. *Journal of Zoology,* 257, 237-248.

PERIS, A., CLOSA, F., MARCO, I., ACEVEDO, P., BARASONA, J. A. & CASAS-DÍAZ, E. 2020. Towards the comparison of home range estimators obtained from contrasting tracking regimes: the wild boar as a case study. *European Journal of Wildlife Research,* 66, 32.

POWELL, R. A. 2000. Animal home ranges and territories and home range estimators. *Research techniques in animal ecology: controversies and consequences,* 442, 65-110.

R CORE TEAM. 2020. R: A language and environment for statistical computing.

RECHETELO, J., GRICE, A., RESIDE, A. E., HARDESTY, B. D. & MOLONEY, J. 2016. Movement patterns, home range size and habitat selection of an endangered resource tracking species, the black-throated finch (Poephila cincta cincta). *PLoS One,* 11, e0167254.

SEAMAN, D. E., MILLSPAUGH, J. J., KERNOHAN, B. J., BRUNDIGE, G. C., RAEDEKE, K. J. & GITZEN, R. A. 1999. Effects of Sample Size on Kernel Home Range Estimates. *The Journal of Wildlife Management,* 63, 739-747.

SIGNER, J. & BALKENHOL, N. 2015. Reproducible home ranges (rhr): A new, user-friendly R package for analyses of wildlife telemetry data. *Wildlife Society Bulletin,* 39, 358-363.

VAN BEEST, F. M., RIVRUD, I. M., LOE, L. E., MILNER, J. M. & MYSTERUD, A. 2011. What determines variation in home range size across spatiotemporal scales in a large browsing herbivore? *Journal of Animal Ecology,* 80, 771-785.

VERNES, K. & POPE, L. C. 2001. Stability of nest range, home range and movement of the northern bettong (<emph type="2">Bettongia tropica</emph>) following moderate-intensity fire in a tropical woodland, north-eastern Queensland. *Wildlife Research,* 28, 141-150.

WYNN, M. L., CLEMENTE, C., NASIR, A. F. & WILSON, R. S. 2015. Running faster causes disaster: trade-offs between speed, manoeuvrability and motor control when running around corners in northern quolls (Dasyurus hallucatus). *J Exp Biol,* 218, 433-9.

WYSONG, M. L., HRADSKY, B. A., IACONA, G. D., VALENTINE, L. E., MORRIS, K. & RITCHIE, E. G. 2020. Space use and habitat selection of an invasive mesopredator and sympatric, native apex predator. *Movement Ecology,* 8, 18.