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Insights into the spatial ecology of the world's most ancient dog: High-altitude movements of New Guinea dingoes

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A R T I C L E I N F O

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A B S T R A C T

Knowledge of an animal's activity patterns, home range size and space use is fundamental to understanding their basic ecology, and obtaining spatial data is an important research priority for newly discovered species, data-deficient species of conservation concern, or species of great scientific or public interest. Here we report the first spatial data obtained from wild-living dingoes near Puncak Jaya, New Guinea. Based on information from four dingoes monitored with GPS tracking collars between 2018 and 2022, we report that dingo home range sizes can be up to 128 km^2, dingoes travel up to 56.8 km per day, and they utilise rainforest and alpine habitats up to 4630 m above sea level. Dingoes at the site regularly traversed steep, rocky and barren alpine mountain crevasses to access more fertile areas at lower altitudes on the other side. These results imply that New Guinea dingoes may have physiological and genetic adaptations that enable them to live in high-altitude low-oxygen environments similar to Himalayan wolves, Ethiopian wolves, and other canids found in high-altitude areas. As the first domesticated animal and the world's most ancient dog, and given their historic and current cultural significance, their illusiveness in the wild, and their trophic position as the largest terrestrial predators on the second-largest island in the world, we believe that further research on the ecology of New Guinea dingoes will continue to reveal important insights valuable for our understanding of human and animal ecology in this global biodiversity hotspot.

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1. Introduction

Knowledge of an animal's activity patterns, home range size and space use is fundamental to understanding their basic ecology (Barbosa and Castellanos, 2005). Such spatial data is also critical for implementing effective management actions that seek to limit or expand their distribution, or to reduce or increase their abundance. Spatial data is also valuable for informing many other aspects of animal ecology, such as diet or energetics (e.g. Cagnacci et al., 2010), and can be used as a powerful engagement tool for raising interest in understudied or lesser-known animals (Wall et al., 2014). Obtaining spatial data is therefore an important research priority for newly discovered species, data-deficient species of conservation concern, or species of great scientific or public interest.

The island of New Guinea is a global biodiversity hotspot with high levels of endemism (Flannery, 1995). It is the second-largest island in the world (after Greenland), and the third-largest expanse of tropical rainforest on the planet, where forest cover remains intact in almost all areas (Alamgir et al., 2019). Separated from Asian faunal communities by the Wallace Line, the fauna of New Guinea are much more similar to Australian fauna than the fauna in south-east Asia (Lavery et al., 2013; Brodie et al., 2018), but little else is known about many fauna species in New Guinea. Modern expeditions to the island frequently reveal species new to science (e.g. Helgen et al., 2011; Günther et al., 2018). Despite the pristine and contiguous nature of the forest there, urban development and expansion is rapidly increasing and forested areas are quickly being truncated by roads and transport corridors, threatening the loss of biodiversity before it is even well documented (Alamgir et al., 2019; Broekman et al., 2024). Obtaining information on animal ecology in New Guinea is high priority for many people and agencies.

Apex predators are functionally important to many ecosystems, can be reliable biodiversity indicators, and can sometimes be considered umbrella species or keystone species (Sergio et al., 2008; Natsukawa and Sergio, 2022). The largest terrestrial predator in New Guinea is the New Guinea dingo (*Canis familiaris*; IUCN DWG, 2023), otherwise called the New Guinea Highland Wild Dog (e.g. McIntyre et al., 2020; Surbakti et al., 2020) or New Guinea Singing Dog (e.g. Koler-Matznick, 2002; Koungoulos, 2020). Dogs were the first animals to be domesticated by humans in Asia about 15,000 years ago (Fleming et al., 2017), dingoes are the world's most ancient dog, and the dingoes of New Guinea are the most ancient of those (Surbakti et al., 2020). Besides several such studies on the taxonomy and relatedness of New Guinea dingoes among other canids (e.g. Oskarsson et al., 2012; Pugach et al., 2013; Sacks et al., 2013; Dinets, 2015; Greig et al., 2018; Bergström et al., 2020; Surbakti et al., 2020; Koungoulos, 2020), almost nothing else is known about the ecology of New Guinea dingoes. Their entire captive population stems from eight individuals which were captured in the 1950s and 1970s and displayed in zoos or kept as pets (Koler-Matznick et al., 2007). From these founders, the captive population has since grown to around 200 animals (Surbakti et al., 2020; IUCN DWG, 2023). Research on these captive 'singers' has yielded valuable information on some aspects of their biology (Koler-Matznick et al., 2007), but information on wild animals is incredibly sparse. A small number of anecdotal observations of their presence in remote, high-altitude landscapes along the Central Cordillera, or the series of mountain ranges that run from east to west across the island of New Guinea, have led to speculation that their distribution may be restricted to high-altitude landscapes (Dwyer and Minnegal, 2016), but their true distribution and density or abundance is entirely unknown. Recent reports of a wild or semi-wild dingo population near a high-altitude gold mine on the western (or Indonesian) side of the island confirmed the presence of a breeding population there (McIntyre et al., 2020), but their use of space was not reported.

Here we report the first spatial data obtained from wild-living dingoes in New Guinea, collected from the same area described by McIntyre et al. (2020). Our data are not exhaustive, but nevertheless offer important insights into the world's most ancient and illusive wild dogs. Thus, our simple aims were to explore the home range sizes and activity patterns of New Guinea dingoes, and to identify altitudinal characteristics of their activities. From these we develop a series of predictions or hypotheses that we hope are investigated in the future.

2. Methods

2.1. Study site

We studied New Guinea dingoes at the Grasberg Gold Mine located near Puncak Jaya, the highest summit of Mount Jayawijaya (4884 m above sea level; asl) in the Sudirman Range in the western central highlands of Papua Province, Indonesia (West Papua). Mean minimum and maximum daily temperatures recorded at Tembagapura (1900 m asl) range from 11.6 °C to 19.9 °C in winter and 12.5 °C to 23.3 °C in summer. Minimum and maximum temperatures recorded at the mine site (4270 m asl) between 2018 and 2023 were 0.7 °C and 14.0 °C, respectively (K. Kusuma, unpublished data). Rainfall follows a strong altitudinal gradient, with the mine site receiving up to 5 m of rain annually (9.8–15.0 mm per day) and more rain falling at lower altitudes (Rinaldi et al., 2018). Snowfall with ground accumulation occurs occasionally at the mine site, and is more common at higher altitudes. High mountain lakes, steep valleys and rare equatorial glaciers dominate the landscape. Alpine meadows and barren, rocky areas characterize higher elevations and tropical rainforests characterize lower elevations, with a transition zone occurring at ~ 4000 m asl. The study area straddles this transition zone and sits between 2400 and 4700 m asl, immediately below the East Carstensz Glacier (latitude − 4.083285, longitude 137.181965).

2.2. Animal capture and collaring

We captured dingoes in 2018 and 2022 using two treadle-plate cage traps measuring 60 cm wide, 60 cm high, and 120 cm long. During an 8-day pre-feeding period, we placed boiled pieces of chicken in and around the trap, as well as urine from female New Guinea dingoes (in estrus) collected from captive animals held in the USA. Coyote *Canis latrans* calls were played over a speaker to invoke curiosity from resident dingoes, and a school bell was also rung each time the chicken was replaced in attempts to condition animals to the provision of a chicken reward. Traps were checked at least twice per day in the morning and late afternoon during the active trapping phase. Captured animals were sedated in the cage with a jab-stick using a combination of 1.8 mL medetomidine (0.1 mg/kg) and 0.5 mL ketamine (2.5–3.0 mg/kg), and a variety of measurements and samples were collected (e.g. age, sex, hair, tissue etc.). We captured eight dingoes in total, but four of them were too small to receive a collar, and were released unharmed. Four large, male dingoes (see below) were fitted with Lotek Pinnacle Pro L GPS collars (www.lotek.com). One new or unused collar was programed to record a GPS point at two-hour intervals (12 points per day), two used or refurbished collars were programmed to record a GPS point at 20-min intervals (72 points per day), and the remaining new and unused collar was programmed to record a GPS point at 10-minute intervals (144 points per day). All data obtained by the collars were transmitted remotely to a server via satellite, and later downloaded for analysis. Refurbished collars weighed 410 g, and new collars weighed 300 g. Collars were equipped with a magnetized release mechanism intended to fall off the animal when the battery was exhausted. Sedation was reversed with atipamezole (0.25 mg/kg) and animals were given time to recover in the covered cage before being released, which took approximately two hours after reversal drugs were administered.

2.3. Data curation

Raw GPS collar data were curated before analysis in the following ways:

1. Remove any GPS points that occurred before the animal was collared or after the animal died or the collar had dropped off.
2. Remove all data from the incomplete day at the beginning and end of the collaring period for each animal so that only whole-days remained.
3. Remove any GPS points received more than five minutes outside of the programmed schedule.
4. Sequentially remove GPS points with high HDOP values until the remaining points reflect those with an on-ground spatial inaccuracy of < 50 m (i.e. GPS points with HDOP values greater than 5 were removed).
5. Visualize the remaining GPS points on a map and remove any points that were obviously inaccurate (i.e. in the ocean, or hundreds of kilometres away).

Altitude values recorded by the GPS collars were unreliable (J. McIntyre, unpublished data), presumably because the collars had difficulty triangulating with satellites in the steep and rugged terrain, so we used altitude values obtained through GPS Visualizer (https://www.gpsvisualizer.com/elevation).

2.4. Home range size estimation

We generated 95 % kernel density home range estimates using the kernelUD function within the adehabitatHR package in the statistical software R (version 4.3.0). We initially attempted to use the Least Square Cross Validation (h_{LSCV}) method for calculating the smoothing parameter because it is generally accepted as the more reliable approach (Walter et al., 2011). However, h_{LSCV} is known to fail for large datasets (> 1000 locations) or where animals exhibit intensive use of core areas, as was the case for our data, which meant that our dataset did not result in a converged estimation and we could not use h_{LSCV}. We therefore selected the reference smoothing method (h_{ref}) despite its tendency to overestimate home range size (Walter et al., 2011).

Table 1
Details of four dingoes collared and released near Grasburg Gold Mine, Puncak Jaya, Indonesia (West Papua).

Animal ID	George	Bruce	Blackie	Adam
Age (approx. yrs)	8	10	10–12	2
Sex	M	M	M	M
Weight (kg)	13.7	15.8	13.5	14.9
Date collared	19-Oct-22	20-Oct-22	20-Aug-18	23-Aug-18
Date of last GPS location	09-Nov-22	02-Oct-23	28-Aug-18	11-Sep-18
N days collared (days)	21.8	347.5	8.4	19.1
Collar schedule (min)	10	120	20	20
Expected no. of GPS points	3133	4170	604	1377
Actual no. of GPS points	3230	4190	176	262
No. of GPS points used after curation	2100	2930	89	177
% of expected no. of GPS points used	67.0	70.3	14.7	12.9
% of actual no. of GPS points used	65.0	69.9	50.6	67.6
Home range size (km^2)	51.3	64.6	128.4	36.7
Mean daily distance travelled (km)	39.1	8.5	14.5	7.6
Minimum altitude (m a.s.l.)	3312.5	2474.0	2956.9	3428.6
Maximum altitude (m a.s.l.)	4552.4	4630	4480.4	4401.1
Altitudinal range (m)	1239.9	2156	1523.5	972.5

2.5. Movement and activity patterns

Maps of dingo space use were generated in QGIS (version 3.22.16), with 500 m contours obtained from a digital elevation model (DEM) from USGS Earth Explorer (www.earthexplorer.usgs.gov).

We estimated the daily distance travelled by first using the Points to Path tool in QGIS (version 3.22.16). This tool creates a line string, connecting points in a given order (i.e. chronologically). The Explode tool was then used to separate the line string at its vertices, allowing interpolated distance to be calculated between each point using the field calculator. Activity levels, or travel speed, were then calculated as a function of distance and the time between sequential GPS points. Forays were defined as temporary movements at least 2 km beyond the boundary of their estimated home range (Thomson et al., 1992).

3. Results

Four adult male dingoes were captured, collared and released at the study site: 'Blackie 1(A)' and 'Adam 2(B)' in 2018, and 'George 622' and 'Bruce 822' in 2022 (Table 1). We obtained 50–70 % of expected GPS points from each collar before data curation. After curation, collar performance was poor for the two animals collared in 2018, which yielded < 15 % of the expected GPS points. A total of 5297 curated GPS points were available for analysis (see Supplementary material), although over 55 % of these were from Bruce (Table 1). Three of the four collars yielded less than 22 days of data, though Bruce's collar recorded data for over 347 days.

The location of each home range was associated with the mine site (Fig. 1). Home range sizes ranged between 36.7 km^2 and 128.4 km^2 during the study period (Table 1), and encompassed rugged areas between 2474 and 4630 m asl. (Fig. 2). Approximately 60 % of dingoes' time was spent between 3900 asl and 4200 asl (Fig. 3). The maximum altitude recorded for any dingo during the study was 4630 m asl, by Bruce on April 12, 2023 at 11 am.

A more detailed exploration of data from Bruce suggested that home range sizes varied over time, exhibiting two seasonal peaks from December to January and from June to July, and troughs from March to May and from September to October (Fig. 3). His mean daily activity level was highly variable over time, but was most variable between March and May when his monthly home range size was smallest (Fig. 4). Dingoes travelled approximately 7.6–39.1 km per day, on average (Table 1).

A more detailed exploration of three forays by George revealed dingoes' ability to traverse narrow crevasses along steep, rocky, and barren mountain ranges to access more fertile and vegetated valleys on the other side of the mountain, before returning back to the mine site (Fig. 5). For example, George followed a particular path along one crevasse three times during the three weeks that his collar was operating. Forays lasted 3–40 h and covered a ~ 20 km circuit (Table 2). The altitudinal range traversed during these three forays was 449–1030 m.

4. Discussion

New Guinea dingoes are the world's most ancient and illusive dog, and obtaining information on their spatial ecology is a high priority (Koler-Matznick et al., 2007; McIntyre et al., 2020). From the four animals we collared, we learned that home range sizes can be up to 128 km^2, they travel up to 56.8 km per day, they utilise rainforest and alpine habitats up to 4630 m asl, have an altitudinal range of up to 2156 m (Table 1), with frequent activity at around 4000 m asl (Fig. 3). Though the activity of the animals we collared was focused around the mine (Figs. 1 and 2), home range size also appeared to fluctuate seasonally, with some indication that home range size was inversely related to daily activity levels (Fig. 4). The consistency of these findings across other populations of New Guinea dingoes is unknown, but they nevertheless reveal valuable insights into the biology and ecology of New Guinea dingoes.

Australian dingo home ranges can be as small as 0.5 km^2 in sub-tropical peri-urban areas (McNeill et al., 2016) to over 1000 km^2 in arid desert areas (Newsome et al., 2013), and home ranges sizes are known to fluctuate seasonally for some populations (Allen, 2009; Purcell, 2010). Home range sizes are typically larger during the breeding season (March–May) when dingoes are seeking mates, and

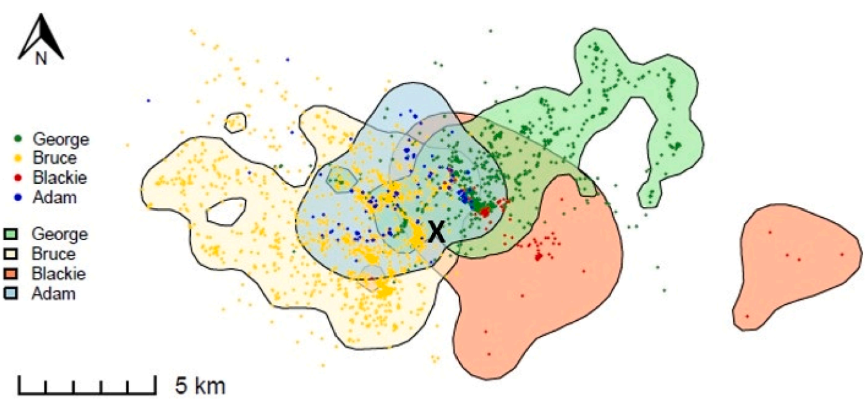

Fig. 1. Home range size and location of four dingoes captured at the Grasburg Gold Mine, Puncak Jaya, Indonesia (West Papua). 'X' denotes the location of the mine pit.

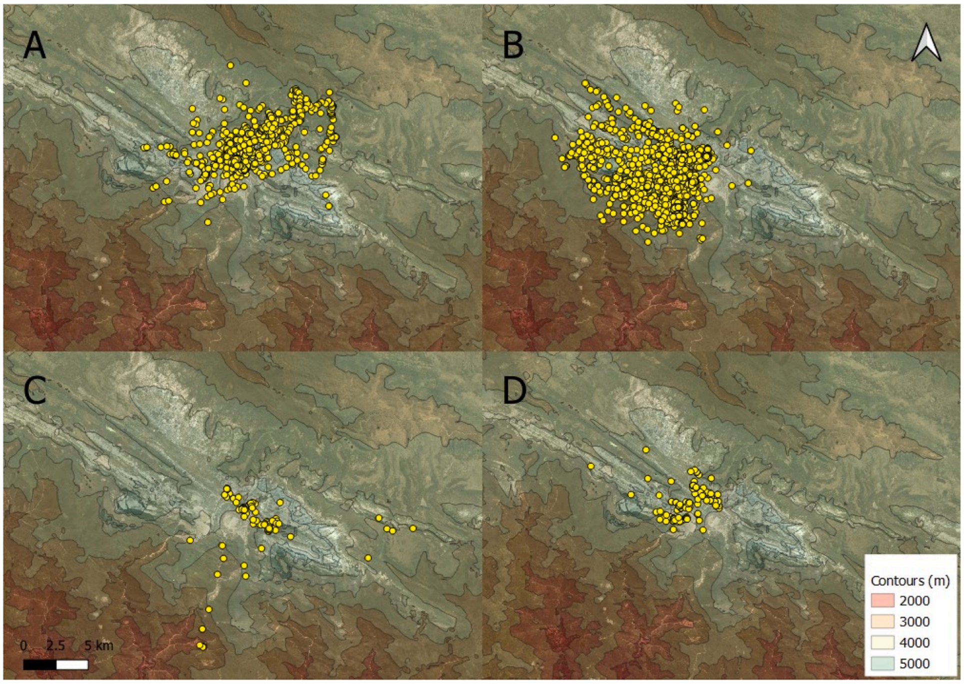

Fig. 2. Movements of dingoes (A) George, (B) Bruce, (C) Blackie and (D) Adam captured at the Grasburg Gold Mine, Puncak Jaya, Indonesia (West Papua).

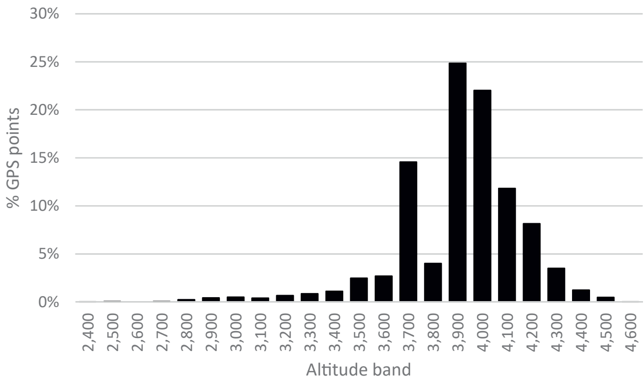

Fig. 3. Altitudinal range of dingoes at the Grasburg Gold Mine, Puncak Jaya, Indonesia (West Papua).

are typically smallest during whelping (August–October) when dingoes are raising their litters. Australian dingoes are annual breeders with one, relatively small breeding season each year (Cursino et al., 2017). New Guinea dingoes (in captivity) have a prolonged estrus season (Koler-Matznick et al., 2007), suggesting that the seasonal drivers of home range size that affect Australian dingoes may not necessarily be apparent in New Guinea dingoes, or that captive conditions somehow extend their breeding season. The concept of 'seasonality' is also questionable at our study site, where temperature and precipitation patterns vary little throughout the year (see above). One of the dingoes we captured at the mine exhibited fluctuating home range size and activity patterns (Fig. 3) similar to Australian dingoes, but much more data are needed to determine how common this phenomenon is or what drives this apparent seasonality.

That New Guinea dingoes traverse glaciated landscapes up to 4600 m asl indicates that they are among the highest-altitude living canids in the world. The Himalayan wolf *Canis lupus chanco* has been recorded at 3900–5600 m asl across the continuous Himalayan landscape (Werhahn et al., 2018, 2020), at elevations where less than 12.7 % effective oxygen is available, in contrast to the 21.9 % available oxygen at sea level (West et al., 2007). The domesticated Tibetan mastiff *Canis familiaris* has been modified by deliberate selection in a relatively short period of time to adapt to the extremely high altitudes of the Tibetan Plateau (typically ~ 4500 m; Cai et al., 2022), and the Ethiopian wolf exclusively inhabits the high-altitude (3000–4500 m) regions of the Bale Mountains in Ethiopia (Mooney et al., 2022). Our findings (Table 1) therefore place New Guinea dingoes squarely within the same ballpark of these other wild

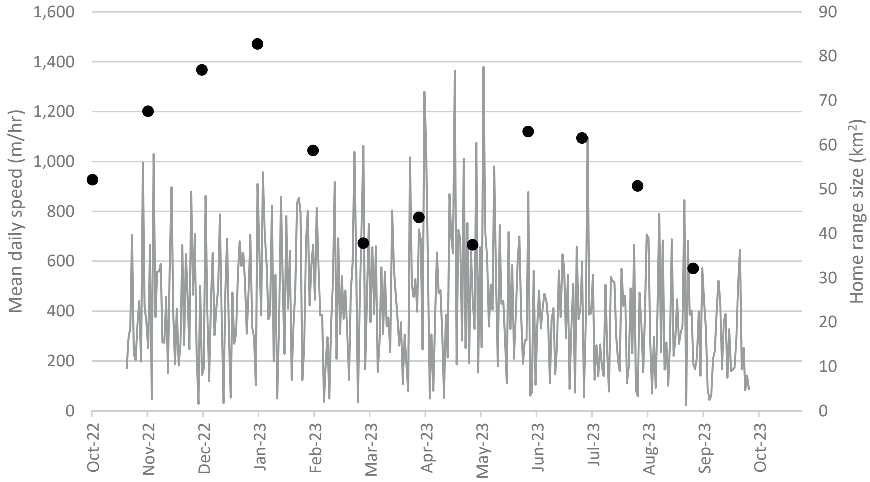

Fig. 4. Temporal variation in (A) monthly home range size and (B) daily activity levels for dingo Bruce, October 2022–October 2023.

canids and imply that, like them, New Guinea dingoes may also possess physiological adaptations to cold, low-oxygen environments at high altitude.

Only a few extant bird and mammal species occur in the harsh environment at higher altitudes in New Guinea (Flannery, 1995; Helgen et al., 2011). Based on the material present in 25 scats collected at the same time as our study, dingoes at the site have been recorded to consume a variety of rodents, possums *Phalanger sp.*, and tree kangaroos *Dendrolagus sp.* (McIntyre et al., 2020), suggesting that these species also occupy high altitude environments or that dingoes hunt these prey species at lower altitudes where they are available. Anthropogenic food items were also detected in some scats. This consumption of anthropogenic food and their fidelity to the mine site (Fig. 2) further suggests that the dingo population we studied may not be completely wild. Coupled with our small sample sizes and limited data collection period, this implies that our observations of their spatial ecology may not be representative of other New Guinea dingo populations found elsewhere. The ecology of Australian dingoes is highly variable across their range (Corbett, 2001; Fleming et al., 2001), so we might expect to find similar variability in future studies of New Guinea dingoes. Regardless, our findings nevertheless enable us to develop a suite of predictions or hypotheses about New Guinea dingo biology that should be investigated in future studies, as follows.

4.1. *Prediction 1: distribution and abundance*

We predict that New Guinea dingoes will principally be found in areas above ~ 2000 m a.s.l. This is not because dingoes cannot thrive at lower altitudes, but because areas below this threshold are more densely occupied by modern domestic dogs, where the unique genetic identity of New Guinea dingoes becomes lost (Dwyer and Minnegal, 2016; Surbakti et al., 2020). Given the large size of the island, the general remoteness and inaccessibility of most highland areas, and the relatively frequent discovery of new species whenever these areas are comprehensively surveyed, we predict that New Guinea dingoes might also be a lot more common and widespread than is presently assumed.

4.2. *Prediction 2: high altitude adaptations*

We predict that New Guinea dingoes will display hypoxia suspected related genes associated with adaptation to low-oxygen environments at high altitude. The presence of these genes in Himalayan wolves and Tibetan mastiffs has enabled their differentiation from Holarctic wolves in Eurasia and Africa (Werhahn et al., 2018), and we suspect these genes might also be present and influence dingo physiology in New Guinea.

4.3. *Prediction 3: home range size and activity levels*

We predict that the home range sizes and activity levels of New Guinea dingoes will be similar to those found in Australian dingoes occupying similar habitats with similar faunal communities. Our results are broadly consistent with this view (compare Tables 1 and 3), but more spatial data from wild populations unassociated with humans is required to confirm this hypothesis.

4.4. *Prediction 4: breeding seasonality*

The birth of Australian dingo pups has been observed in every month of the year, but dingo births have a clear peak in winter (Corbett, 2001; Cursino et al., 2017). Given this, we predict that wild New Guinea dingoes will exhibit similar breeding peaks in winter.

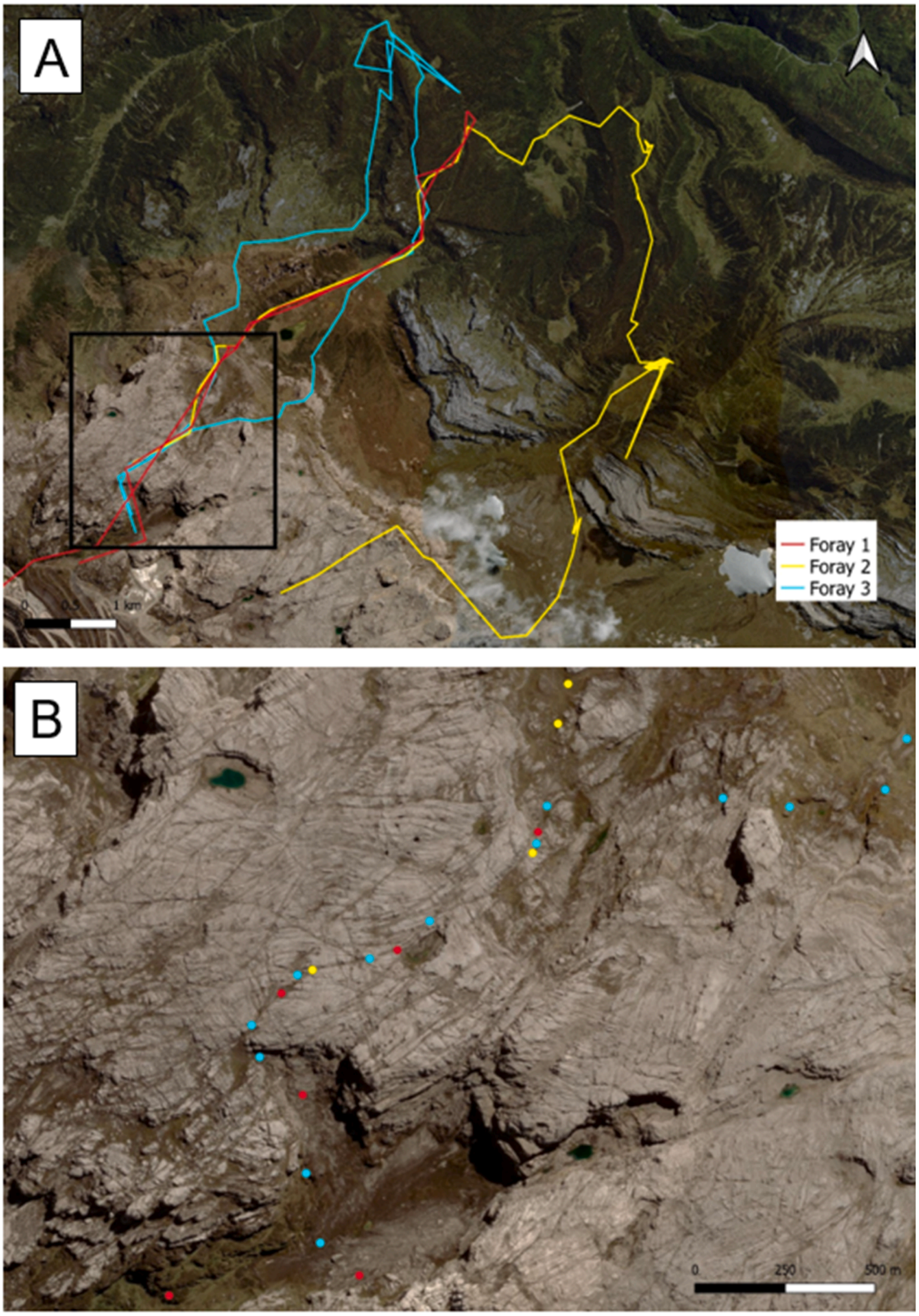

Fig. 5. The route of three forays taken by dingo George during the study period (see also Table 2). The area within the box in A is shown in more detail in B, identifying one specific crevasse George followed over the mountain on each foray.

However, given their unique estrus cycles in captivity (Koler-Matznick et al., 2007) and the relatively stable climate in high altitude areas of New Guinea, we speculate that this breeding season may be more prolonged in wild New Guinea dingoes than is most often observed in Australian dingoes. This seasonality is also reflected in relative abundance fluctuations detected across Australia (from camera trap and sand plot studies; Allen et al., 2013, 2014), and we predict that such tools will also detect these fluctuations in New Guinea should they be deployed for a sufficient period.

The technical and operational challenges we experienced also provided useful learnings for future work in this area. In hindsight, it would have been advantageous to obtain data from males and females, and to program all collars to be on the same duty cycle. Testing

Table 2
Characteristics of three forays taken by George during the study period (see also Fig. 4).

Foray #	1	2	3
Start date and time	30/10/2022 16:40	4/11/2022 13:00	28/10/2022 20:20
End date and time	1/11/2022 9:10	5/11/2022 13:10	28/10/2022 23:30
Duration (h)	40.5	24.2	3.2
Approximate distance (km)	~ 20	~ 13	~ 7
Mean speed (km/h)	1.3	1.8	2.5
Minimum altitude (m a.s.l.)	3495.5	3610.8	3693.2
Maximum altitude (m a.s.l.)	4526.3	4518.4	4143.0
Altitudinal range (m)	1030.8	907.6	449.8

Table 3
Home range sizes of resident dingoes from seven different studies across a variety of ecosystems across northern Australia, adapted from Fleming et al. (2012). NB These ecosystem types are not found within the study site in New Guinea.

Ecosystem	Home range size km^2 (s.e. or range)	n	Method
Semi-arid tropics	77.3 (22.1)	19	pooled mean 95 % MCP
Arid	67 (32–126)	5	not stated
Monsoonal	39 (15–88)	18	not stated
Arid monsoonal	25 (7–110)	24	not stated
Arid monsoonal	414.9 (103.5)	9	85 % Kernel
Mine site	8.0 (2.4)	4	85 % Kernel
Arid	24 (13–32)	7	95 % MCP

collar performance at the study site prior to deployment on animals would have also identified technical issues before they had opportunity to influence the quality and quantity of data we collected. Regardless, we believe these preliminary data to be a useful starting point for exploring the spatial ecology of New Guinea dingoes. We highlighted four (above), and many more speculative predictions might be generated given the paucity of data for this population of dingoes, but we assert that what *is* known about them is sufficient to demand further investigation of these and other aspects of their biology and ecology (see also Koler-Matznick et al., 2007). As the first domesticated animal and the world's most ancient dog, and given their historic and current cultural significance, their illusiveness in the wild, and their trophic position as the largest terrestrial predators on the second-largest island in the world, we believe that further research on the ecology of New Guinea dingoes will continue to reveal important insights valuable for our understanding of human and animal ecology in this global biodiversity hotspot.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics statement

Ethical clearance for the study was provided by PT Freeport Indonesia, confirming that all necessary permits to undertake the project were approved. The study was conducted in accordance with these permits.

Funding statement

PT Freeport Indonesia (PTFI) and the Grasberg Mine sponsored the study and provided the majority of funds necessary to undertake the study, with supplementary funding from the New Guinea Highland Wild Dog Foundation.

Authorship statement

JKM and LW conceptualized the study. HKM, LAM, SS and KIK provided in-country logistics and participated in the field work. JKM collected the data. CM and BLA analysed the data. BLA prepared the first draft and wrote the majority of the manuscript. All authors edited and approved the final drafts of the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e03264.

Data availability

All data described in the paper are available in the Supplementary material.

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