Ground-truth of potential Malleefowl mounds detected by Lidar in the Western Australian Great Victoria Desert

Report to Great Victoria Desert Biodiversity Trust

National Malleefowl Recovery Group

August 2020

Executive Summary

Introduction

- In 2019 the Great Victoria Desert Biodiversity Trust (the Trust) organised a LiDAR survey to locate malleefowl mounds within a sample of the GVD, focussing on areas that were accessible and of suitable habitat type. The purpose of the survey was to examine the distribution of the species and provide a basis for monitoring.
- The Trust engaged the National Malleefowl Recovery Group (NMRG) to ground-truth the results of the LiDAR survey. Our objectives were to visit as many of the potential malleefowl mounds detected by LiDAR as possible within the allocated time, determine whether they were indeed malleefowl mounds, and prepare for annual monitoring.

Method

- Ground truthing involved inspecting each selected LiDAR point to determine whether it was a malleefowl mound, recording information in accordance to national malleefowl monitoring standards and procedures.
- The Trust provided us with 23,663 point records of potential malleefowl mounds derived from LiDAR data analysed by Anditi Pty Ltd. Each record from Anditi consisted of a location and a rating reflecting their confidence the structure was a malleefowl mound.
- Primary targets for ground truthing were 83 Rating 1 and Rating 2 that were deemed accessible considering covid-19 restrictions and because their locations were within 1km from vehicle tracks.
- Secondary targets included at least 25 Rating 3 and 25 Rating 4 points that were accessible, thus making a total ground truth target of 133 LiDAR points. A sample of Rating 3 and 4 points was important in order to assess the utility of the Anditi rating system.

Results

- We attempted to visit all accessible Rating 1 and Rating 2 points; however a number of tracks were overgrown or blocked by fallen trees. This reduced access to 12 Rating 1 and one Rating 2 LiDAR points. We compensated for this loss by including other Rating 1 and 2 points that were more than 1km from tracks but close to other potential mounds.
- In total, we ground truthed 165 LiDAR points which ranged up to 1.7 km from vehicle tracks (mean= 760m); 82 (50%) of these points were confirmed as malleefowl mounds.
- Ground truthed points comprised: 71 Rating 1 points (99% confirmed); 10 Rating 2 points (80% confirmed); 24 Rating 3 (4% confirmed); and 60 rating 4 (2% confirmed).
- The most common cause for the false positive was found to be naturally occurring elevations in substrate caused by tree roots or shrubs
- We incidentally encountered 2 mounds that were not detected by LiDAR analysis; these were both small and at the lower end of the distribution of mound heights and diameters detected by LiDAR.
- None of the 82 malleefowl mounds that we inspected were ‘active’ in the sense of likely to contain eggs (mounds are not expected to contain eggs before September). However, 10 mounds (12%) showed fresh or recent (within the past year or two) evidence of malleefowl. An additional 14 mounds were regarded as having been used by malleefowl within the past 2-5 years.

- Malleefowl mounds were most commonly encountered in Woodland (60% of mounds), typically mulga (*Acacia anuera*) with a diverse shrub understory, in habitat that had not been burnt for at least 20 years.
- 16% of mounds were in habitat that had burnt in the past year or so, indicating the previous fire season had been particularly severe.

Discussion

- Monitoring data were collected for all 82 confirmed mounds in accordance with national standards and procedures and locations, data and photos of these mounds have been uploaded on the National Malleefowl Monitoring Database (NMMD), in preparation for monitoring. Access to these data is restricted to the Trust and the NMRG and is not publically available.
- LiDAR proved to be a useful and successful means for rapidly searching for mounds over the project area, and the rating system successfully reflected the likelihood of a structure being a malleefowl mound. The focus on Rating 1 and 2 points was validated.
- The LiDAR survey did not detect all malleefowl mounds within the scanned areas: two small mounds were encountered incidentally within the scanned areas showing that the survey missed some mounds. However, it is likely that the survey identified most mounds that are likely to be used by malleefowl for future breeding. This is because malleefowl are more likely to re-use taller mounds, which are more easily detected by LiDAR, than very low mounds that may be missed by LiDAR.
- Signs of malleefowl within the past year or so, such as prints and work by the birds on mounds, suggest that the species is currently widespread but thinly spread in the areas surveyed. However, conditions in the 2020 winter were exceedingly dry in the GVD, and have been for several years. Consequently, it is likely that the resident populations have declined or not bred. Despite the current adversity, it is likely that the species will bounce back when more suitable rainfall patterns return provided other threats are controlled (especially fire and possibly predators).
- Annually monitoring the known mounds in the GVD would provide both an understanding of the conditions that malleefowl require, and critical information on the how the population is faring. In particular, annual monitoring would provide a basis for the development and assessment of management actions, such as predator control.
- There is an opportunity for the Trust to contribute to the National Adaptive Management Predator Experiment (AMPE) which is designed to assess the effectiveness of predator control at increasing malleefowl populations.

Introduction

Malleefowl (*Leipoa ocellata*) is a unique and iconic species of mound-building bird that occurs in semi-arid and arid shrublands across the southern half of Australia in every mainland state of Australia except Queensland. The species is regarded as Vulnerable nationally, and endangered or vulnerable in every state and territory in which it occurs (Benshemesh 2007). Past clearing of the wheat-belts, which included much of the prime habitat for the species, has led to marked declines in Malleefowl populations, and existing populations are threatened by a range of factors that include habitat clearing and modification, fire, introduced predators and overgrazing by competitors.

Within the arid zone, the species still occurs in the Great Victoria Desert (GVD), but has disappeared from southern parts of the Great Sandy, Gibson and Tanami Deserts where it once occurred (Kimber 1985, Benshemesh 2007b); it is presumed extinct in the Northern territory. Within the South Australia GVD, there has been some work describing Malleefowl distribution in the Anangu-Pitjantjatjara-Yankunytjatjara Lands (APYL) (Benshemesh 1997, Benshemesh 2007a, Benshemesh 2015) and Maralinga Tjarutja Lands (Bellchambers 2007, Benshemesh 2017), but its status in these remote areas remains poorly known.

Understanding the ecology of Malleefowl in a vast and remote area such as the GVD is a considerable challenge. The birds are well camouflaged, shy and cryptic and rarely heard or sighted. However, the extraordinary incubator-mounds of Malleefowl are relatively conspicuous and provide a means of both measuring the past and present occurrence of the species in an area, and an efficient way of monitoring their population trends and responses to management interventions and environmental factors.

Monitoring provides vital information on the stability of populations and is regarded as an essential prerequisite for Malleefowl conservation and management in the National Recovery Plan for Malleefowl (Benshemesh 2007b). Across Australia, Malleefowl are currently monitored at over 120 sites each year, involving more than 4,000 mounds, under the auspices of the National Malleefowl Recovery Team (Benshemesh *et al.* 2018). The resulting data are used to determine population trends and understand the factors that may underlie these. Monitoring data are also used to improve management practices through rigorous adaptive management experiments that are designed to reveal the most effective management practices (Hauser *et al.* 2019).

In 2019 the Great Victoria Desert Biodiversity Trust (henceforth the Trust) organised a LiDAR survey to locate Malleefowl mounds within a vast sample of the GVD, focussing on areas that were accessible and of suitable habitat type. LiDAR is a relatively new technique (Saffer & Peak 2014) that has recently been used in Vic, SA, WA and NSW for mapping Malleefowl mounds over large areas using airborne laser scanners. Along with photogrammetry (Thompson *et al.* 2015), these new techniques are enabling rapid survey for Malleefowl mounds over large and remote areas where previously such surveys had been too difficult to contemplate.

The current project involved ground truthing the results of a LiDAR survey, run by the data science company Anditi Pty Ltd (henceforth Anditi), undertaken in the GVD. Our objectives were to visit as many of the potential Malleefowl mounds detected by Anditi as possible within the allocated time, determine whether they were indeed Malleefowl mounds, and prepare for annual monitoring.

Methods

Field work in the GVD was undertaken over an 8 day period between 4th and 11th July 2020 by skilled staff of the National Malleefowl Recovery Team.

Point data of potential Malleefowl mounds were derived from the LiDAR data and provided to us by the Trust, comprising 23,663 point records (Table 1). Anditi analysed the LiDAR data and provided point data of likely Malleefowl mounds. Each record consisted of a location and was associated with a rating provided by Anditi which reflected the confidence they had that the structure was in fact a Malleefowl mound.

Table 1. Potential Malleefowl mounds detected by analysis of LiDAR data and provided with a confidence rating by Anditi (Rating 1 representing highest confidence).

Confidence Rating	Count
1	102
2	22
3	1,826
4	21,713
	23,663

Our original plan was to visit all 124 Rating 1 and Rating 2 points provided by Anditi, plus a selection of 25 Rating 3 and 25 Rating 4 points in order to check Anditi's rating system and empirically assess the value of ground truthing more of these lower confidence Lidar points.

However, due to covid-19 restrictions, we were unable to use access tracks on Yilka/Ngaanyatjarra Lands. Furthermore, on receiving the LiDAR points and maps of access tracks from GVDBT, it was apparent that many of the Rating 1 and Rating 2 points were actually much further from access tracks than the 600m that was originally assumed; while the LiDAR scans were about 600m wide and flown to approximately follow the access tracks, in actuality the scans often deviated from tracks. This was probably unavoidable considering the limited manoeuvrability of airborne equipment, but had the effect that some LiDAR points were well over 1000m from access tracks, making them less attractive targets for on-going monitoring. Accordingly, we reached agreement with the Trust that we should target 83 Rating 1 and 2 LiDAR points, including all those within two proposed experimental management sites, and elsewhere where points were within 1km of vehicle access. We also agreed to ground truth a selection of up to 25 Rating 3 and 25 Rating 4 points that were within our anticipated area of travel, thus making a total ground truth target of 133 LiDAR points.

Ground truthing involved inspecting each selected LiDAR point and recording the following information:

- If the point was a Malleefowl mound:
  - The mound was described in accordance to national Malleefowl monitoring standards and procedures (National Malleefowl Recovery Group 2016)
  - The mound was photographed
  - Habitat was broadly categorised according to DBCA Malleefowl Report Form and photographed.

- If the point was not a Malleefowl mound,
  - The likely source of the false signal was identified (eg. outcrop, human disturbance, shrub)
  - A photo was taken of the false positive point.
  - Habitat was broadly categorised according to DBCA Malleefowl Report Form and photographed.

In all our field activities we watched out for Malleefowl signs, particularly mounds that may have not been detected by LiDAR, and the bird's foot prints. We also kept an eye out for other threatened species that were of particular interest to the Trust.

All field data were collected on smartphones (Samsung J2) using the Cybertracker application customised specifically for the national Malleefowl monitoring program. Selected LiDAR points were navigated to using GPS (Garmin Etrex).

Results

Ground truth

- Appendix 1 provides maps showing mounds and on-mounds
- Appendix 2 lists mounds with basic mound data
- Appendix 3 lists Rating 1 and 2 LiDAR points that we did not visit and the reasons for not visiting the point.
- Appendix 4 lists sightings

We attempted to visit all Rating 1 and Rating 2 points that were accessible, however we encountered a number of tracks that were blocked by fallen trees or that were overgrown. This reduced access to 12 Rating 1 and one Rating 2 LiDAR points which we were unable to visit (Appendix 3). In the field we also found that 17 Rating 1 and five Rating 2 LiDAR points were greater than 1000m from vehicle tracks and were consequently not visited. In order to compensate for these inaccessible LiDAR points, we visited a number of Rating 1 and 2 points that were greater than 1000m from tracks but were otherwise accessible, particularly if they were in the vicinity of other points.

Table 2 shows a breakdown of the results of the ground truth in regards to the priority ratings. In total, 165 LiDAR points were ground truthed of which 80 (48%) were confirmed as Malleefowl mounds. Nearly all (99%) Rating-1 points were confirmed to be Malleefowl mounds, compared to 80% for Rating-2, and 4% for Rating-3, and 2% of Rating-4 points (Table 2)

Table 2. Breakdown of ground-truth results of LiDAR points.

Rating	Total	Mound	Not mound	%Mound
1	71	70	1	99%
2	10	8	2	80%
3	24	1	23	4%
4	60	1	59	2%
1,2,3,4	165	80	85	48%

Where LiDAR points were revealed to not be Malleefowl mounds (Table 3), the most common cause for the false positive was found to be naturally occurring elevations in substrate caused by tree roots or shrubs which together accounted for 44% of cases, followed by human disturbance (e.g. dozer works) which accounted for 31% of false positives. Other suspected causes were of minor importance. In 15% of cases, no structure was obvious that might have triggered the false positive LiDAR result.

Mound characteristics

A summary of the dimensions of the 82 mounds that were visited is provided in Table 3. Mounds with larger outer diameters tended to be higher and have larger rim diameters (r^2= 36% and 41% respectively; p<0.001; Pearson correlation); the correlations between depth and other dimensions were also significant but accounted for much less variation (r^2< 16%).

Table 3. Likely causes of false positives (LiDAR points that were not Malleefowl mounds)

Likely cause of false positive	n	%
Human disturbance	26	31%
Soil build up under bush	20	24%
Tree root uplift	17	20%
Can't see anything	13	15%
Other	8	9%
Outcrop	1	1%
	85	100%

Table 4. Summary of mound dimensions.

	Height (cm)	Depth (cm)	Diameter (m)	Rim (m)
Mean	33	36	6.1	2.8
Sd	15	17	1.8	0.8
Min	14	4	1.3	0.3
Max	115	80	11.7	4.9
n	82	80	82	80

The frequency distribution of the mound outer diameters (Figure 1) shows that while most mounds were 4-5 metres in diameter, the distribution is bimodal with a secondary peak around 7m. One of the two mounds that were encountered incidentally by us (but were not detected by LiDAR) was within the 4-5 metre size class, whereas the other was the smallest diameter mound that we measured.

The frequency distribution of the mound heights (Figure 2) shows that most mounds were 25-30 cm in height. The two mounds that were encountered incidentally by us were at the lower end of the distribution of mounds detected by LiDAR, although 5 mounds of similar or lower height were detected by LiDAR.

Only about 30% of mounds showed obvious signs of eggshell (Table 5) indicating they had been used to incubate eggs in the past, while 80% had a crusty surface suggesting they had not been worked for a few years. Herbs and moss/lichen were rarely observed on mounds.

Table 5. Summary of mound surface characteristics (definitions follow (National Malleefowl Recovery Group 2016)).

	Eggshell	Crust	Moss	Herb
None	71%	20%	98%	74%
Some	20%	12%	1%	22%
Lots	10%	68%	1%	4%

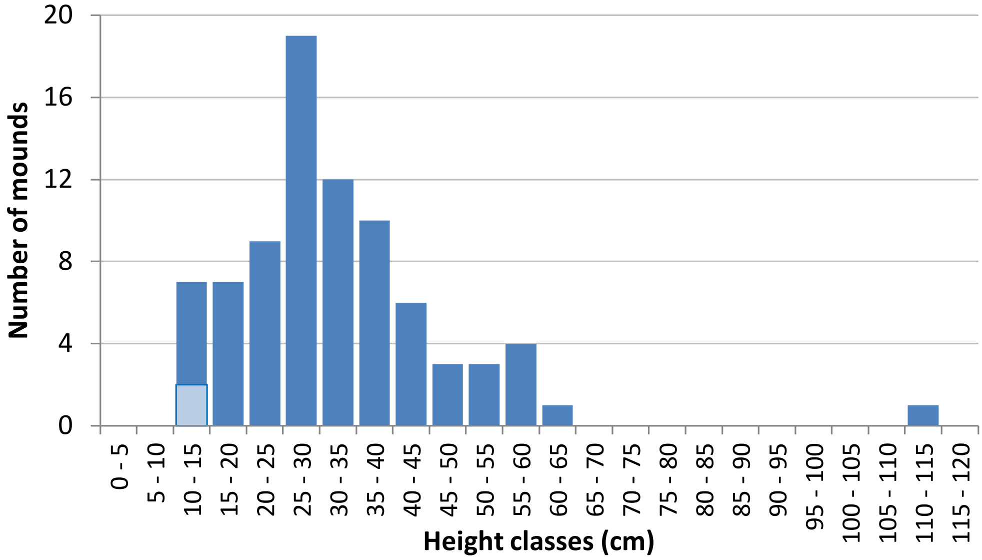

Figure 1. Frequency distribution of number mounds in height categories. Lighter shading indicates the 2 mounds that were not detected by Lidar.

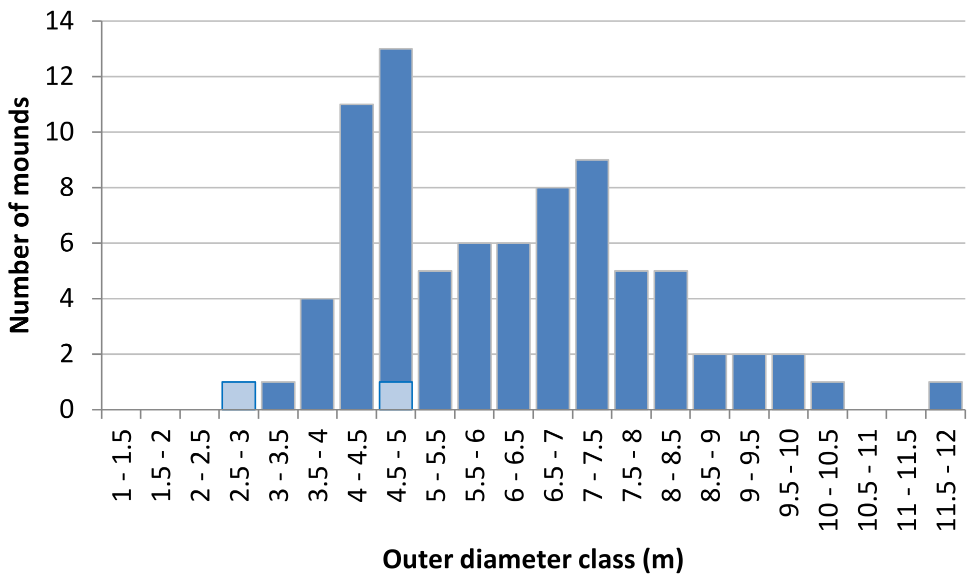

Figure 2. Frequency distribution of number mounds in diameter categories. Lighter shading indicates the 2 mounds that were not detected by Lidar.

Malleefowl signs at mounds

None of the 82 mounds that we inspected were 'active' in the sense of likely to contain eggs (National Malleefowl Recovery Group 2016), and this result was not surprising considering the field work occurred before the spring egg laying season. However, Malleefowl prints and other fresh signs were found at six mounds (Table 6; Appendix 1), and another four mounds had been filled with leaf litter in the current or recent years, so that a total of 10 mounds (12%) showed evidence of Malleefowl within the past year or two. Another 14 mounds were regarded as having been used by Malleefowl within the past 2-5 years (Table 6).

Habitat

Malleefowl mounds occurred in Woodland (60% of mounds) typically comprising mulga (*Acacia anuera*) with a diverse shrub understory, and lower Shrublands including regenerating mulga and other acacias (33% of mounds) but also occurred in Mallee (*Eucalyptus* spp.) (6% of mounds) and Heath (1% of mounds). In contrast, LiDAR points that were not mounds were most commonly in Shrubland (44%) and were only half as likely to occur in Woodland than mounds (Figure 3). The difference in habitat type of mounds and non-mounds might indicate a preference of Malleefowl within the study area for the Woodland habitat over both Shrublands and Mallee. Removing Human Disturbance records from the non-mound records did not appreciably change the habitat distribution pattern. However, it should be noted that the habitat distribution on non-mounds may also reflect other habitat factors, such as fine scale topography, that might trigger false positive LiDAR detections.

Most mounds (74%) were located in habitat that were estimated to have not been burnt for at least 20 years (in the field), although 16% of mounds were in habitat that had burnt in the past year or so (Figure 4) indicating the previous fire season had been particularly severe. Non-mounds followed a similar fire-age distribution.

Table 6. Mounds at which there was recent evidence of Malleefowl.

Lidar#	Age	Evidence of Malleefowl
1038	Fresh	Profile 2 (deep excavation) and fresh digging by Malleefowl
1047	Fresh	Profile 3 (filling with litter) and malleefowl prints
1050	Fresh	Profile 3 (filling with litter) and malleefowl prints
1053	Fresh	Malleefowl prints
1086	Fresh	Malleefowl prints and fresh digging
2003	Fresh	Malleefowl prints
1023	1-2y	Profile 3 (filling with litter)
1030	1-2y	Profile 3 (filling with litter)
1045	1-2y	Profile 3 (filling with litter)
1072	1-2y	Profile 3 (filling with litter)
1003	2-5y	Recently used mound
1026	2-5y	Recently used mound
1029	2-5y	Recently used mound
1037	2-5y	Recently used mound
1039	2-5y	Recently used mound
1042	2-5y	Recently used mound
1062	2-5y	Recently used mound
1063	2-5y	Recently used mound
1067	2-5y	Recently used mound
1068	2-5y	Recently used mound
1077	2-5y	Recently used mound
1084	2-5y	Recently used mound
1091	2-5y	Recently used mound
2010	2-5y	Recently used mound

Signs of other animals at mounds

Kangaroo prints and scats were the most common signs of animals on Malleefowl mounds (Table 7). Mounds were often covered with lateritic gravel on which only the prints of larger animals were evident.

Table 7. Percentage of Malleefowl mounds (n = 82) where prints and scats of malleefowl, kangaroos and foxes were recorded.

Prints		**Scats**			
Malleefowl	Kangaroo	Malleefowl	Kangaroo	Fox	Rabbit
6%	49%	2%	51%	2%	1%

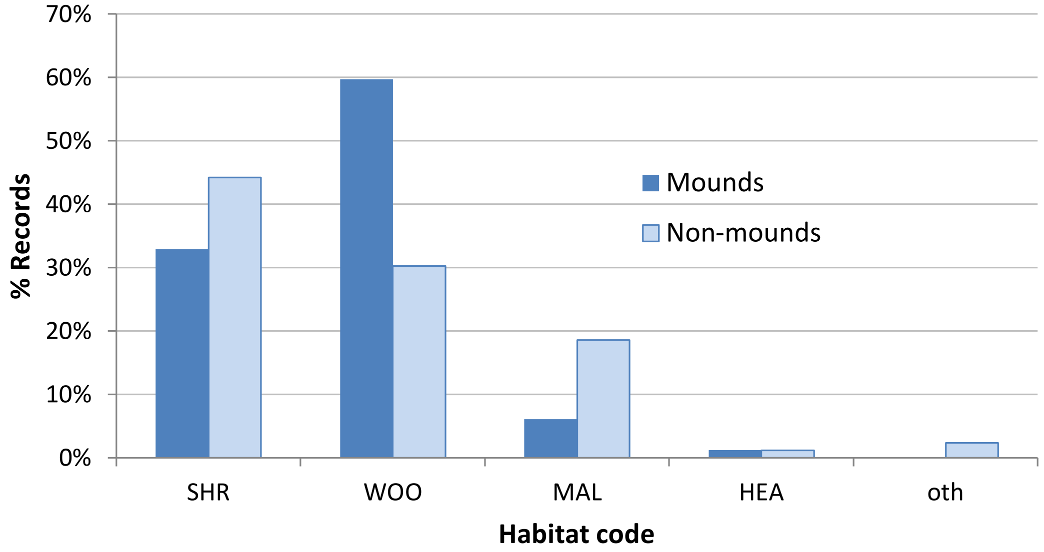

Figure 3. Frequency distributions of mounds and non-mounds by habitat type. SHR: Shrubland. WOO: Woodland. MAL: Mallee. HEA: Heath. Oth: Other.

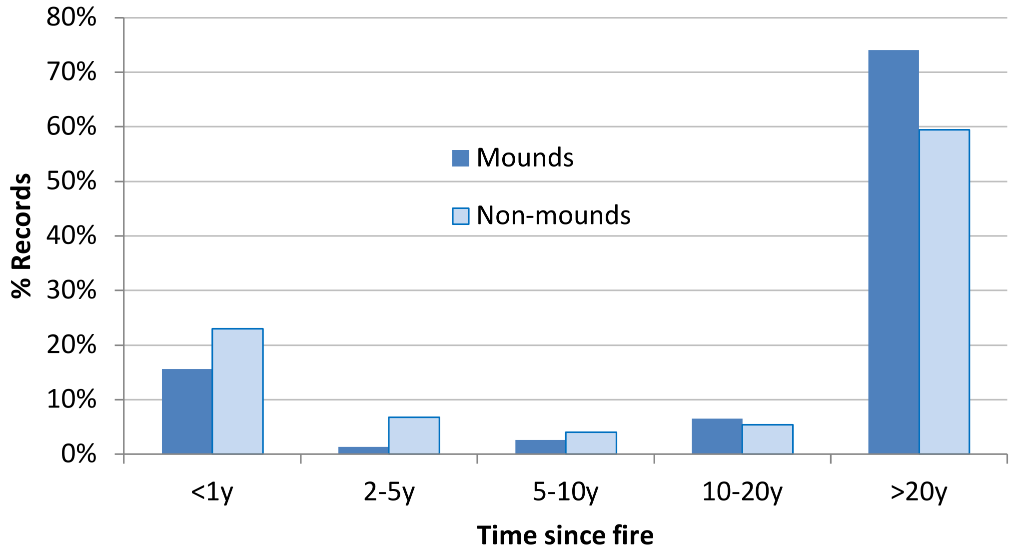

Figure 4. Frequency distributions of mounds and non-mounds by estimated fire-age class (time since fire).

Discussion

Ground truth

In this project we inspected 165 points that were detected by an analysis of LiDAR data undertaken by Anditi Pty Limited. These points ranged up to 1.7 km from vehicle tracks (mean= 760m), and as we walked to points we kept an eye out for Malleefowl prints and mounds that had not been detected by LiDAR.

LiDAR proved to be a useful and successful means for rapidly searching for mounds over the project area. The initial analysis of the LiDAR data produced a large number of points and to help prioritise fieldwork, Anditi also provided confidence ratings for all of these points. The results of our ground truthing clearly showed that these ratings strongly reflected the probability that the structure detected was in fact a Malleefowl mound rather than some other structure (a false positive): 99% of Rating 1 (most confident) and 80% of Rating 2 detections were found to be Malleefowl mounds, but this fell to 4% of Rating 3 and 2% of Rating 4 detections being confirmed as Malleefowl mounds. These findings vindicate the decision by the Trust to prioritise all accessible Rating 1 and Rating 2 mounds for ground truthing, and to only ground truth Rating 3 and Rating 4 detections when they were close to other targets and easily accessible.

LiDAR clearly performed well in detecting mounds, but the technique failed to detect two mounds that we encountered on route to other LiDAR points and that appear to have been within the LiDAR swathe. Both these mounds were relatively low with an average height of 15 cm; while LiDAR did detect 5 confirmed mounds that were similar or smaller height, this probably reflects the limit of LiDAR mound detection (at least at the resolution at which LiDAR was flown in this project). In essence, LiDAR produces a detailed digital elevation map of the surface, and the analysis undertaken by Anditi identifies potential mounds by their shape and height. Consequently, a mound that is low and inconspicuous in shape is less likely to be detected than taller, more well-defined mounds.

We suspect that other low and inconspicuous Malleefowl mounds were also likely to have been undetected, but that this does not necessarily undermine the value of the survey in understanding the distribution of Malleefowl in the project area. Malleefowl are more likely to re-use taller mounds (Benshemesh 2007c), and the poor detectability of low mounds by LiDAR is consequently not a major problem for establishing a monitoring program. Indeed, the re-use rate of mounds of 10 cm or lower height is so low that that are routinely consigned to a 5 year rather than annual monitoring interval (National Malleefowl Recovery Group 2016).

Thus, while the LiDAR survey of the GVD most likely did not detect all Malleefowl mounds within the scanned areas, it is likely that it successfully detected most mounds that Malleefowl are likely to renovate for breeding.

Malleefowl Monitoring

Monitoring data were collected for all 82 confirmed mounds in accordance with national standards and procedures, except that we visited mounds in July rather than the October-January period that is recommended for monitoring (National Malleefowl Recovery Group 2016). The locations of these mounds have been registered on the National Malleefowl monitoring database (NMMD), and monitoring data and photos have been uploaded onto the NMMD describing their condition during the 2019/20 season.

Fresh prints of Malleefowl were found at only 6% (5) mounds but together with the condition of mounds this suggested that at least 12% of mounds had been visited or worked by the birds within the past year or two. Another 17% of mounds were thought to have been used by the birds within the past 5 years.

The results suggest that Malleefowl have a low presence in the areas surveyed. However, our results should be viewed with consideration to two important points. Firstly, most mounds we examined were covered in lateritic gravel (buckshot) or a hard crust that made it difficult to recognise Malleefowl prints; similarly the ground surface in mulga woodlands and shrublands where mounds were most often found was generally crusty and unsuitable for tracking. In these circumstances, an absence of Malleefowl prints does not suggest an absence of the birds.

Secondly, and most importantly in regard to the low incidence of working mounds, conditions were clearly very dry throughout the study area with an almost complete absence of growing herbs or recent germination of plants. At Laverton Airport, the nearest BoM weather station, rainfall over the previous 12 months was only 30% of the long term mean, while May-July rainfall, a critical period for Malleefowl breeding preparation (Benshemesh *et al.* 2020), in 2020 was only 11% of the long term mean (1991 to present). Moreover, these exceedingly dry conditions appear to have been typical over the recent past with May-July rainfall averaging only 26% of the long term mean over the past four years.

Under these conditions it is not surprising that we encountered few signs of Malleefowl, or mounds that were being prepared for breeding. Considering that Malleefowl depend largely on herbs for food during the winter (Frith 1962), and the series of dry winters that have occurred, it is perhaps remarkable that the birds have been able to maintain a presence in the GVD at all. Nonetheless, we did find evidence of the birds in many areas. Despite the current adversity, it seems likely that the species will bounce back when more suitable rainfall patterns return.

Understanding the trends and ecology of Malleefowl in the GVD is vital to their effective conservation. Annually monitoring the known mounds in the GVD would provide both an understanding of the conditions that Malleefowl require, and critical information on the how population is faring. In particular, annual monitoring would provide a basis for the development and assessment of management actions. Malleefowl monitoring in the GVD would also be valuable for assessing their conservation at the national scale, and if combined with management of introduced predators, may enable the Trust to contribute to the national Adaptive Management Predator Experiment (AMPE) which is designed to assess the effectiveness of predator control at increasing Malleefowl populations (Hauser et al. 2019).

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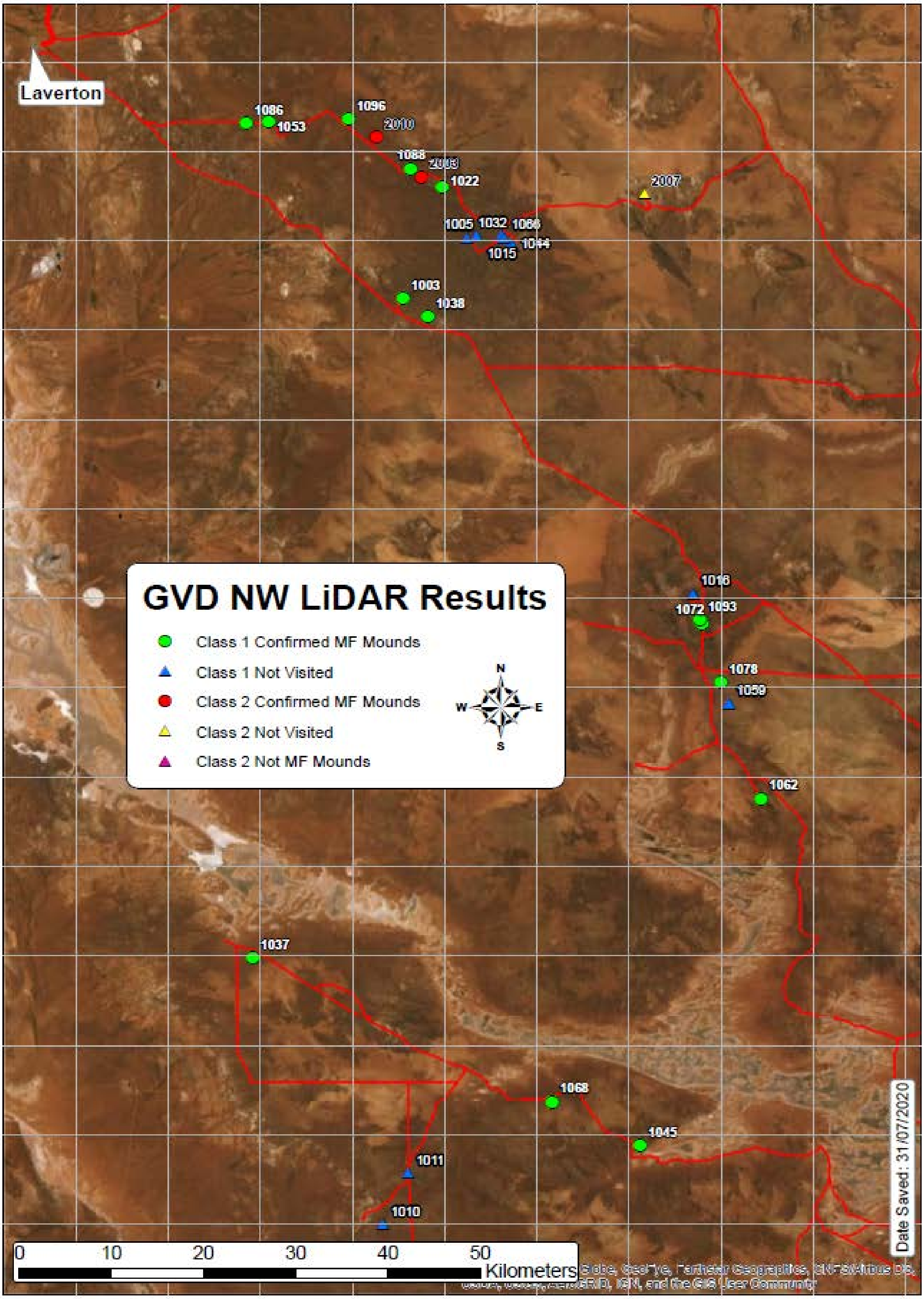
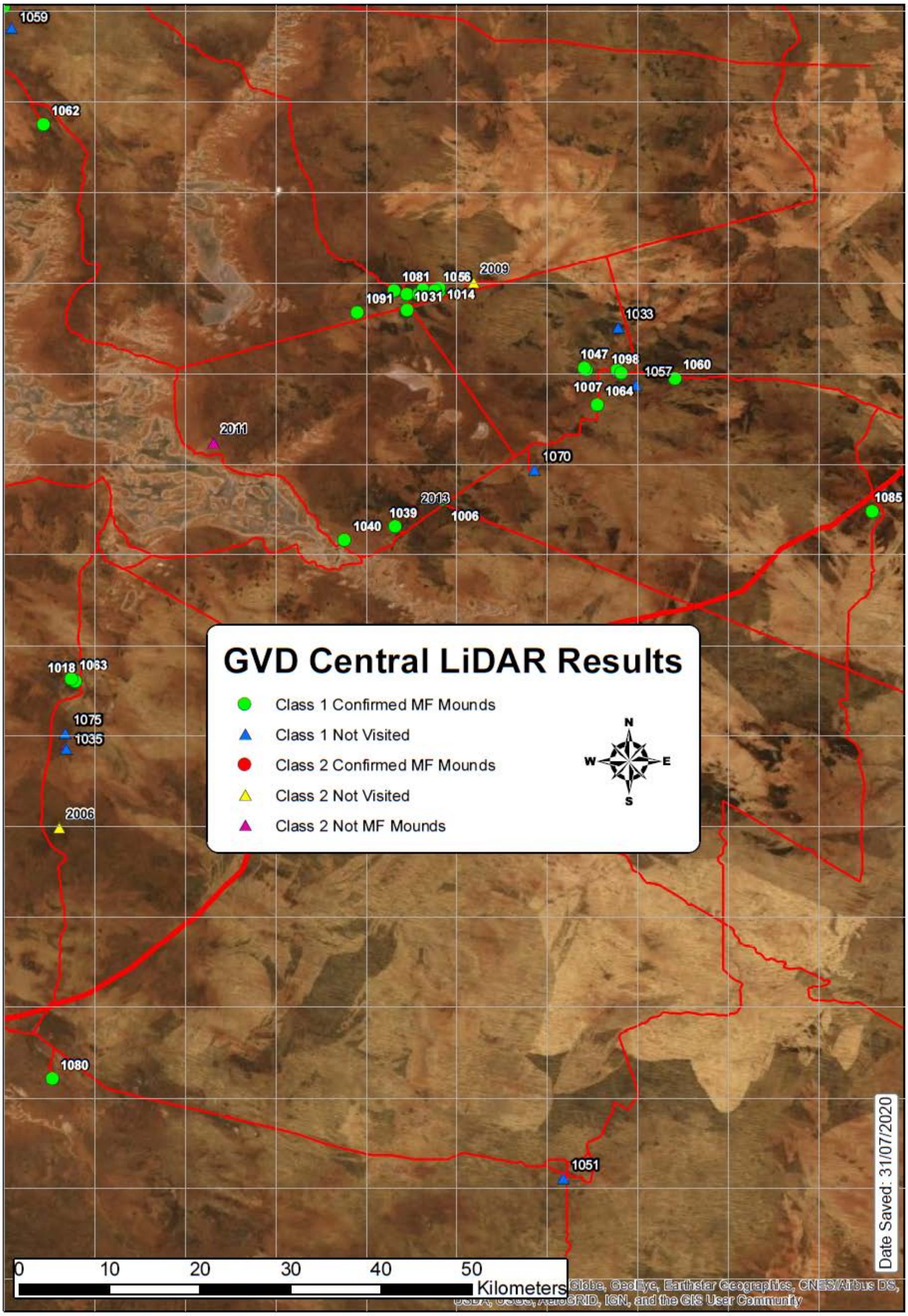
Appendix 1. Maps showing the locations of Rating 1 and 2 points and whether or not they were malleefowl mounds.




GVD Central LiDAR Results
Class 1 Confirmed MF Mounds
Class 1 Not Visited
Class 2 Confirmed MF Mounds
Class 2 Not Visited
Class 2 Not MF Mounds
N
W
E
S
1059
1062
1081
1056
2009
1091
1031
1014
1033
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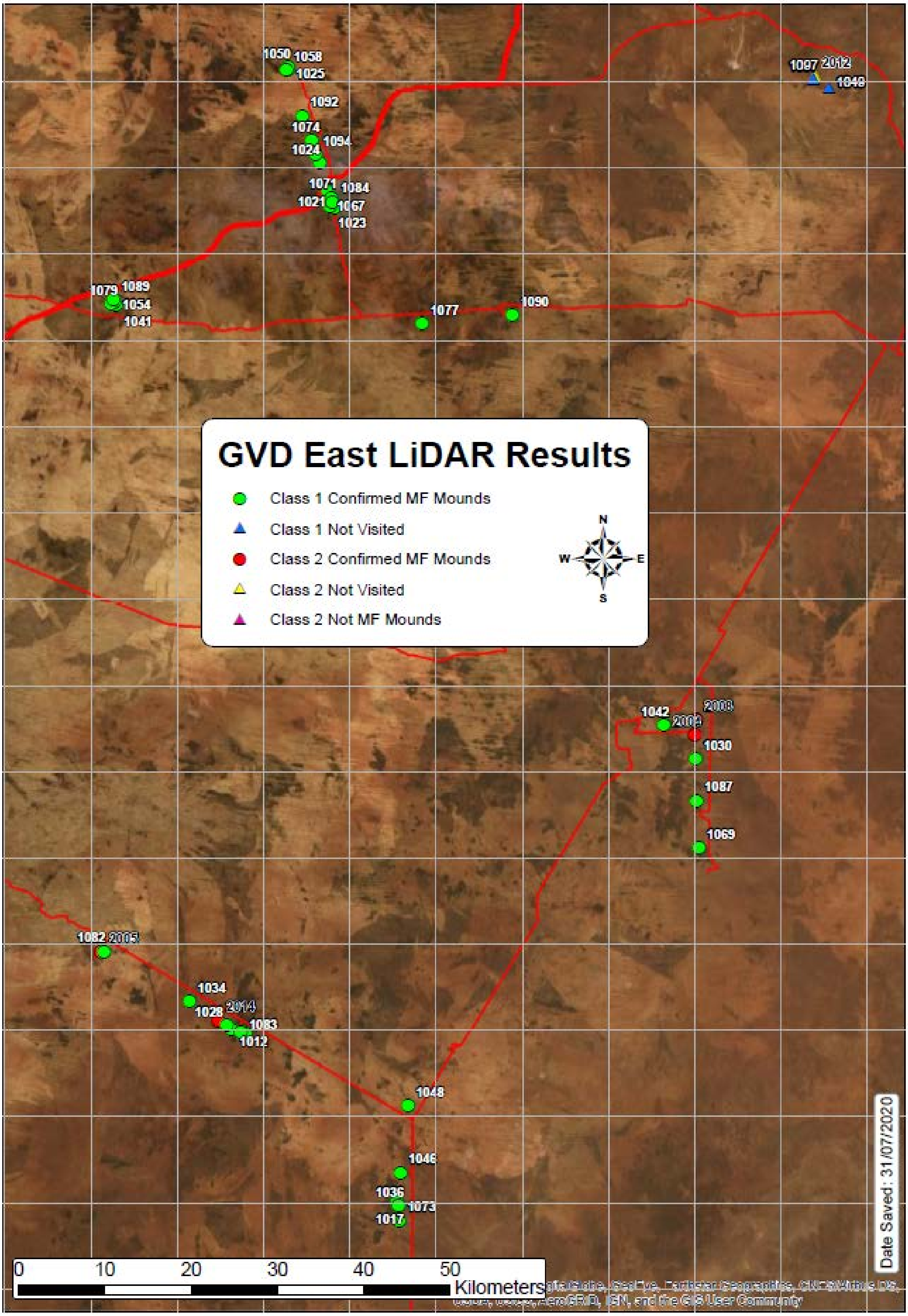
Kilometers
Date Saved: 31/07/2020


GVD East LiDAR Results
Class 1 Confirmed MF Mounds
Class 1 Not Visited
Class 2 Confirmed MF Mounds
Class 2 Not Visited
Class 2 Not MF Mounds
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Kilometers
Date Saved: 31/07/2020

Appendix 2. Summary of features recorded for the 82 confirmed mounds. Abbreviations: prf =profile; scra= scraped; egg= eggshell; crst= crust; moss= moss/lichen; herb= herbage; ht= average height; dpt= depth; diam= perimeter diameter; rim= rim diameter; LF= landform; Veg= Vegetation type.

LiDAR #	Latitude	Longitude	prf	scra	egg	crst	moss	herb	ht	dpt	diam	rim	LF	Veg	Notes
	-29.45648	124.30614	p1	n	N	L	N	N	15	35	290	160	FLA	WOO	Incidental find
	-30.04096	124.70003	p1	n	N	L	N	N	15	23	450	280	FLA	WOO	Incidental find
1002	-29.43315	123.50098	p1	n	N	L	N	S	38	20	710	330	FLA	WOO	
1003	-28.84947	122.75890	p1	n	N	N	N	N	57	41	920	300	FLA	SHR	recent work by Malleefowl
1004	-30.20875	124.21806	p1	n	N	L	N	N	42	20	840	350	FLA	MAL	trees to 4m shrubs to 1m Limestone
1006	-29.61233	123.50421	p2	n	N	L	N	N	35	67	800	330	FLA	WOO	Trees to 8m shrubs to 1.5m FE >5yrs
1007	-29.50105	123.64654	p1	n	N	L	N	N	55	45	900	350	FLA	SHR	gravel biggest inner 2 to 3 cm biggest outer 5cm
1008	-29.45181	124.30415	p1	n	N	S	N	S	34	27	820	370	FLA	WOO	Trees to 7m shrubs to 1.5m FE >5yrs
1012	-30.20412	124.20342	p1	n	N	L	N	N	43	45	720	260	FLA	WOO	Trees to 6m shrubs t0 2m
1014	-29.43016	123.50003	p1	n	N	L	N	N	33	47	450	250	FLA	WOO	
1017	-30.35993	124.37612	p1	n	N	L	N	S	30	40	720	320	FLA	WOO	Trees to 8m shrubs 1.5m FE >5yrs
1018	-29.76956	123.13954	p1	n	N	L	N	N	39	10	790	230	FLA	WOO	Trees to 8m shrubs to 1.5 Limestone >5yrs
1019	-29.43565	123.46910	p1	n	N	N	N	N	60	40	950	490	FLA	SHR	double mound: nth side is dug out evenly like mf but no definite signs. xtra photos.
1020	-29.44718	124.30352	p1	n	N	S	N	S	33	25	850	370	FLA	WOO	Trees to 5m Old burn FE >5yrs Camel scats
1021	-29.46309	124.31099	p1	n	N	L	N	L	26	30	690	330	FLA	WOO	Trees to 4m US to 1m FE and Loam >5yrs
1022	-28.74240	122.77650	p1	n	N	N	N	N	115	58	1170	330	SLO	SHR	On mega mound. Base stones up to 2 fists upper mound 1 small fist mostly 2 3cm. top mound loose sides in crater but no eggshell. Looks like used maybe 10ya?
1023	-29.46094	124.30590	p3	n	S	S	N	N	38	40	510	300	FLA	WOO	Trees to 7m shrubs to 2m 20% FE & Loam

LiDAR #	Latitude	Longitude	prf	scra	egg	crst	moss	herb	ht	dpt	diam	rim	LF	Veg	Notes
1024	-29.42221	124.29507	p1	n	N	L	N	S	29	35	710	390	FLA	WOO	
1094	-29.41431	124.29065	p1	n	N	L	N	N	30	45	650	350	FLA	WOO	2m regrowth mulga, 20m from old growth edge. great buckshot mound but no signs
1025	-29.33774	124.26264	p1	n	N	L	N	N	48	30	800	340	FLA	SHR	Buckshot mound little sand and no shell under surface. v v old.
1026	-29.43513	123.48023	p2	n	N	L	N	S	52	55	1000	350	FLA	WOO	Trees to 6m shrubs to 1.5 <5yrs
1028	-30.20098	124.19867	p2	n	S	N	N	N	41	35	550	280	FLA	MAL	Trees to 5m Sandy & limestone
1029	-29.43177	123.48453	p2	n	L	N	N	N	57	65	650	340	FLA	WOO	Trees to 6m shrubs to 1m Limestone rubble & Loam <5yrs
1030	-29.96092	124.68643	p3	n	L	S	N	N	48	35	560	290	FLA	WOO	
1031	-29.44959	123.46833	p1	n	N	L	N	S	35	40	790	370	FLA	WOO	Trees to 6m shrubs to 1m FE >5yrs
1034	-30.17981	124.16002	p1	n	N	L	N	N	34	15	420	160	FLA	MAL	Mallee to 5m shrubs 2m
1036	-30.36322	124.37734	p1	n	N	L	N	N	31	42	490	270	FLA	WOO	Trees to 7m Sparse shrubs to 1m
1037	-29.42852	122.61243	p1	n	L	L	N	N	45	30	440	210	FLA	WOO	Trees to 5m Loam <5yrs
1038	-28.86624	122.78293	p2	n	L	N	N	N	44	80	720	260	SLO	SHR	Fresh mf work, good p2. no prints but lots kangaroo mucking surface
1039	-29.63622	123.45678	p2	n	N	L	N	N	24	50	560	310	FLA	WOO	Trees Recently burnt No shrubs FE & Loam <5yrs
1041	-29.55142	124.08333	p1	n	N	L	N	N	36	25	950	460	FLA	WOO	Thick shrub under 5m mulga as all in this patch. Measures and photo west-east due to poor access
1042	-29.93117	124.65323	p1	n	N	L	N	S	29	5	470	150	FLA	WOO	Trees to 6m Recently burnt shrubs to 1m Sandy Loam <5
1045	-29.59283	122.98992	p3	n	S	N	N	N	30	30	540	320	FLA	WOO	Trees to 5m shrubs to 1.5m Loam & Limestone rubble <5m
1046	-30.33376	124.37953	p1	n	N	L	N	N	25	75	590	380	FLA	SHR	
1047	-29.49925	123.64442	p3	y	S	N	N	N	49	60	560	220	SLO	SHR	Filling but very dry will prob not go ahead unless rain soon. diverse shrubs under mulga and some mallee

LiDAR #	Latitude	Longitude	prf	scra	egg	crst	moss	herb	ht	dpt	diam	rim	LF	Veg	Notes
1048	-30.27363	124.38733	p1	n	S	L	N	S	36	4	420	110	SLO	MAL	Habitat bunt maybe 10y ago. Diverse shrubland scattered triodia under mallee red sand with calcrete nodules. Dead shrub in crater = unused for maybe 10y. Had been great habitat!
1050	-29.33503	124.26250	p3	y	N	L	N	N	36	43	740	380	FLA	SHR	Fresh mf tracks and spot digs. Neat p3 this season or last. Buckshot no shell under. 20 to 50 yo burnt mulga. Very dry, very thick patch. NB forgot xsticks
1053	-28.69436	122.62788	p1	n	S	N	N	N	39	42	410	220	FLA	SHR	Recently used 1 to 2 y. pure sand mound. fresh mf prints
1054	-29.54815	124.08165	p1	n	S	N	N	N	29	30	470	260	FLA	WOO	Very sandy but still buckshotty. v thick habitat walking in
1056	-29.43246	123.49678	p1	n	L	L	N	N	25	46	490	280	FLA	WOO	Camel prints on mound
1058	-29.33806	124.26027	p1	n	N	L	N	N	28	40	630	300	FLA	SHR	Possible mf print and 2 small digs on inner rim but could not see full print. no prints around outside mound. Buckshot. 20 to 50yo mulga.
1060	-29.50824	123.73475	p1	n	N	L	N	S	29	32	400	210	FLA	WOO	
1061	-29.50109	123.67761	p1	n	N	L	N	N	30	38	680	330	RID	SHR	Before burn thee was already lots of shrubs in inner. Long unused
1062	-29.28887	123.10770	p1	n	S	N	N	N	63	50	870	230	FLA	SHR	Inner very loose used perhaps 3 to 5ya. Mound of sand and pebbles on larger stone apron up to fist size
1063	-29.76753	123.13527	p2	n	L	N	N	N	40	70	430	270	FLA	WOO	Trees to 6m shrubs to 1.5 Loamy some FE <5yrs
1064	-29.53108	123.65778	p1	n	N	L	N	N	27	37	690	300	FLA	SHR	
1067	-29.45612	124.30499	p1	n	S	L	N	N	24	37	380	160	FLA	WOO	Trees to 6m shrubs to 1m FE & Loam <5yrs
1068	-29.55408	122.90406	p4	n	L	S	N	S	35		450		FLA	WOO	Trees to 6m No shrubs Loam & Limestone <5yrs

LiDAR #	Latitude	Longitude	prf	scra	egg	crst	moss	herb	ht	dpt	diam	rim	LF	Veg	Notes
1069	-30.04128	124.69004	p1	n	N	L	N	N	26	24	504	30	FLA	HEA	20m inside recent fire area. nest burnt out
1070	-29.45343	124.30772	p2	n	N	L	N	N	38	47	700	350	FLA	WOO	Trees to 6m Recently burnt No shrubs FE >5yrs
1072	-29.13525	123.05010	p3	y	L	N	N	N	29	70	450	320	FLA	SHR	Filling with mulga leaves from west but prob abandoned or even last yr as leaves a bit bleached.
1073	-30.37674	124.37827	p1	n	N	L	S	N	45	20	450	180	FLA	WOO	Trees to 5m shrubs 1.5 Loam >10 yrs
1074	-29.40175	124.28712	p1	n	N	L	N	S	19	32	540	330	FLA	WOO	
1077	-29.56799	124.40228	p1	n	S	S	N	S	28	30	480	280	FLA	WOO	Recently bunt No shrubs Sandy FE <5 y
1078	-29.18713	123.06622	p1	n	S	L	N	N	36	20	130	320	FLA	MAL	Neat long unused 5-10+y all fresh burnt
1079	-29.54946	124.07796	p1	n	N	S	N	N	31	53	710	340	FLA	WOO	notes as previous mounds
1080	-30.11124	123.11680	p1	n	N	S	N	N	18	10	410	130	FLA	WOO	Trees to 6m shrubs 2m Sandy Loam Limestone >5 yrs
1081	-29.43257	123.45563	p1	n	N	L	N	N	20	40	540	330	FLA	WOO	Trees to 5m N0 shrubs Burnt FE & Loam >5yrs
1082	-30.13493	124.07086	p1	n	N	L	N	N	20	25	600	280	FLA	SHR	Trees to 5m shrubs to 1.2m
1083	-30.20697	124.21339	p2	n	N	L	N	N	29	35	620	300	FLA	WOO	Trees to 6m shrubs to 1.5m FE
1084	-29.45717	124.30883	p1	n	N	L	N	N	34	40	770	240	FLA	WOO	Trees to 5m shrubs to 2m FE & Loam <5yrs
1085	-29.62312	123.93096	p1	n	N	L	N	L	33	40	600	330	FLA	WOO	Myall to 6m shrubs to 1m Limestone >5yrs
1086	-28.69527	122.60633	p1	n	S	N	N	N	27	52	360	220	FLA	SHR	old litter exposed recent 1 to 3 yr.
1087	-29.99885	124.68762	p1	n	N	L	N	N	14	23	590	340	FLA	WOO	unburnt
1088	-28.73522	122.76650	p1	n	N	L	N	S	25	25	660	300	FLA	SHR	Run down. Riddled with Goanna? holes
1089	-29.54630	124.08042	p1	n	S	S	N	N	25	55	480	300	FLA	WOO	Used in last 10y, trace eggshell nearly none. v thick mulga over Eremophila latrobei and other shrubs. Some grass all dead no herb.

LiDAR #	Latitude	Longitude	prf	scra	egg	crst	moss	herb	ht	dpt	diam	rim	LF	Veg	Notes
1090	-29.56004	124.49612	p1	n	N	L	N	N	14	25	640	320	FLA	WOO	Recently burnt N0 shrubs FE >5yrs
1091	-29.45137	123.41943	p1	n	S	L	N	N	18	10	440	210	FLA	WOO	Trees to 5m shrubs to 1.5m Loam <5yrs
1092	-29.37919	124.27707	p1	n	N	L	N	S	15	44	490	340	FLA	WOO	
1093	-29.13202	123.04786	p1	n	S	N	N	N	22	31	410	230	FLA	SHR	Some litter in mound. Prob used < 10y
1096	-28.69146	122.70570	p1	n	N	L	N	N	17	36	380	250	FLA	SHR	
1098	-29.50381	123.68096	p1	n	N	L	N	N	31	34	760	330	SLO	SHR	Fresh burn long unused had mulga 5cm thick growing inner crater
2003	-28.74247	122.77655	p2	y	N	N	N	N	54	80	820	330	SLO	SHR	Clear recent work see extra photos
2004	-29.93962	124.68572	p1	n	N	L	N	N	30	32	780	320	FLA	SHR	Old mulga grove. veg all grey thru here; severe drought/frost conditions? No sign of egg did dig some. Obv v old
2005	-30.13536	124.06763	p1	n	N	L	N	N	23	15	620	180	FLA	SHR	Veg to 5m shrubs 1.5m Flat FE
2008	-29.92576	124.68750	p1	n	N	L	N	S	28	4	440	120	FLA	SHR	Burnt habitat maybe 5yr.
2010			p1	n	S	S	N	N	28	28	430	200	FLA	SHR	Used last couple of years. Litter in mound used but still intact dry and was not covered wet. Neat sand mound but with some buckshot
2011	-29.56363	123.27641	p4	n	N	L	L	S	14		360		SLO	WOO	Shrubs to 1m Clay >5yrs Not 100% sure it is MF mound
2013	-29.62369	123.47467	p1	n	N	L	N	N	19	18	670	310	FLA	WOO	Recently burnt No shrubs FE & Loam >5yrs
2014	-30.19689	124.18990	p1	n	N	L	N	N	15	10	480	250	FLA	SHR	Trees to 5m shrubs to 2m Fe
	-29.56451	124.42398	p1	n	N	L	N	S	58	18	650	200	FLA	WOO	Recently burnt No shrubs Sandy limestone rubble >5yrs
51877	-29.54771	124.07733	p1	n	N	L	N	L	25	35	700	320	FLA	WOO	Very overgrown, ancient, with dead trees and shrubs lying flat on it. same habitat as 1079 and others

Appendix 3. Rating 1 & 2 Lidar points that were not visited (of the original 124 points provided).

Lidar#	Latitude	Longitude	Reason point not visited
1001	-28.54935	124.23566	Access track not accessible
1005	-28.79641	122.82112	Access track not accessible
1009	-28.80195	122.86398	Access track not accessible
1010	-29.66104	122.73955	>1000m off track
1011	-29.61667	122.76396	Access track not accessible
1013	-28.55007	124.25074	Access track not accessible
1015	-28.79376	122.85478	Access track not accessible
1016	-29.10928	123.04137	Restricted area (Lord Byron Mine)
1027	-28.74937	124.30653	>1000m off track
1032	-28.79397	122.83068	>1000m off track
1033	-29.4644	123.67819	Access track not accessible
1035	-29.82759	123.13073	Access track not accessible
1043	-28.74276	124.29427	>1000m off track
1044	-28.80374	122.86615	Access track not accessible
1049	-29.35379	124.82539	>1000m off track
1051	-30.19668	123.62436	Road distance too great for one point
1052	-28.56454	124.3903	>1000m off track
1055	-28.5502	124.24416	Access track not accessible
1057	-29.51412	123.69616	>1000m off track
1059	-29.20529	123.07647	>1000m off track
1065	-28.56678	124.32236	>1000m off track
1066	-28.79606	122.85709	Access track not accessible
1070	-29.58715	123.59579	Access track not accessible
1075	-29.81441	123.13016	>1000m off track
1076	-28.563	124.36637	>1000m off track
1095	-28.7373	124.29547	>1000m off track
1097	-29.34579	124.8094	>1000m off track
1099	-28.15558	123.78291	Yilka Country
1100	-28.3456	124.88012	>1000m off track
1101	-28.36323	124.98566	>1000m off track
1102	-28.29821	125.45189	>1000m off track
2001	-28.30894	126.4389	Road distance too great for one point
2002	-28.29907	126.04399	Road distance too great for one point
2006	-29.89548	123.12345	>1000m off track
2007	-28.75784	122.99439	>1000m off track
2009	-29.42538	123.53455	Access track not accessible
2012	-29.34317	124.81113	>1000m off track
2015	-28.31841	124.77114	>1000m off track
2016	-28.42388	123.2685	Yilka Country
2017	-28.18558	124.57939	>1000m off track
2018	-27.93938	123.92518	Yilka Country
2019	-28.12871	123.7184	Yilka Country
2020	-27.88806	122.89061	Yilka Country

Appendix 4. Sightings of malleefowl prints

Date	Latitude	Longitude	DoWhat	Notes
4/07/2020	-30.2087	124.2187	Sighting	MF Print
4/07/2020	-30.2086	124.2210	Sighting	MF Print
7/07/2020	-29.335	124.2625	Mound 1050	MF Prints on mound
8/07/2020	-29.5045	123.6578	Sighting	MF Print
8/07/2020	-29.5044	123.6578	Sighting	MF Print
8/07/2020	-29.5043	123.6582	Sighting	Lots of MF prints. habitat shots taken
8/07/2020	-29.5042	123.6580	Sighting	MF prints. Possible pair.
8/07/2020	-29.5027	123.6485	Sighting	MF Print
8/07/2020	-29.5016	123.6488	Sighting	MF Print in burnt on edge of small unburnt patch.
8/07/2020	-29.4994	123.6444	Mound 1047	MF Prints on mound
8/07/2020	-29.4269	122.6115	Sighting	MF Print
9/07/2020	-28.7721	122.8222	Sighting	MF Print: Malleefowl seen fly off and diggings
9/07/2020	-28.7424	122.7765	Mound 2003	MF Prints on mound
9/07/2020	-28.6953	122.6063	Mound 1086	MF Prints on mound
9/07/2020	-28.6944	122.6279	Mound 1053	MF Prints on mound