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Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo sub-Basin, Northern Territory

Wet Season Baseline Methane Concentrations:

Interim Report for GISERA Project G5

Stuart Day, Cindy Ong, Bruce Maney and Mederic Mainson

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Executive Summary

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory submitted its final report to the Northern Territory Government in March 2018. Among other things, the Inquiry recommended that baseline monitoring of methane be undertaken ahead of the granting of exploration approvals for unconventional gas. Specifically, Recommendation 9.3 of the Inquiry's final report states:

> *That baseline monitoring of methane concentrations be undertaken for at least six months prior to the grant of any further exploration approvals. In areas where hydraulic fracturing has already occurred, the baseline monitoring should be undertaken at least a year prior to the grant of any production approvals.*

In response to this recommendation, the Northern Territory Government commissioned CSIRO through GISERA to conduct baseline methane monitoring in the Beetaloo Sub-basin which is a prospective gas production region in the NT.

This report documents the results from the third and final survey conducted as part of the "GISERA Project G5 - Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo sub-Basin, Northern Territory" project.

As documented in the first report (Ong et al. 2018), the overall aim of the project described in this report is to provide:

- background landscape concentrations of methane in the Beetaloo Sub-basin; and,
- Investigate methane emission rates (fluxes) and identify the sources of any elevated methane levels found.

In this report, we present the results of the last of three surveys conducted in the Beetaloo Sub-basin. This final survey was conducted during the wet season over a 7-day period between 30th January and 5th February 2019.

Like the previous two field campaigns, this survey of atmospheric methane concentrations within the Beetaloo Sub-basin region was conducted using mobile surveys with gas analysers mounted in a four-wheel-drive vehicle. In this survey and two gas analysers were used. Although methane was the principal gas of interest, carbon dioxide was also measured during many of the surveys to assist with identifying the source of emissions. The use of two analysers was important to provide a level of redundancy in the event of equipment failure in the remote and harsh operating conditions of the survey region.

This vehicle survey covered approximately 4050 km on trafficable roads and tracks during the 7-day survey period. This is somewhat less than previous survey (which each covered over 5000 km) due to many of the tracks being impassable because of large amounts of water across much of the area. Despite the reduced distance, the survey covered as much as trafficable the routes traversed during the first and second set of surveys; the main areas where traversing was not possible was on the Origin and Pangea leases.

In common with the previous surveys, methane concentrations were mostly similar to natural ambient concentrations with an average of 1.81 ppm. Slightly higher concentrations were detected throughout the survey which were mostly associated with grazing cattle.

A gas pipeline riser along the Daly Waters to MacArthur River gas pipeline, which had been found on two previous occasions to have slightly elevated methane emissions about 10 m away was revisited. As on other occasions low level methane emissions were detected with a maximum concentration of 2.3 ppm (60 ppb above background). Measurements conducted at the site indicated that the emission rate from the source was approximately 0.12 kg CH_4 day^{-1}. Following the report of this leak, on 8th January 2019, a service provider to the owner of the pipeline at the request of the Department of Primary Industry and Resources, investigated it and found that during their monthly inspection no leak had been detected. However, they initiated an additional survey and detected a small leak which originated from a grease nipple on a ball valve. The nipple cover was tightened as it was found to be only finger tight. A gas level reading was again taken 150 mm from the nipple which indicated there was no leak present. An additional step has now been

included in the valve check sheet, which requires that all grease nipple covers be tightened. Subsequent to that, measurements were performed by CSIRO during the survey. Low level methane emissions were detected with a maximum concentration of 1.88 ppm. Measurements using the plume traverse method conducted at the site indicated that the emission rate from the source was approximately 0.12 kg CH_4 day^{-1}. This emission rate is 40-80% of the amount cattle produce. Cattle produces from 0.15-0.3 kg CH_4 day^{-1}.

Where accessible, measurements were replicated in close proximity to the abandoned petroleum wells and water bores that were visited during the first and second surveys. No elevated atmospheric methane concentrations were detected at any of these sites.

Using flux chamber measurements, termite mounds were found to be another source of methane, releasing approximately 3.3 mg CH_4 per m^3 of termite mound per day. This contrasts with previous measurements made during the dry season where no measureable atmospheric methane emissions (elevated levels of methane were only found within the interior of the termite mound itself) were found. It is clear that termite emissions are strongly seasonal in nature and this is consistent with other reported studies of termite emission characteristics.

Like termites, soil emissions appeared to be showing seasonal behaviour. During the wet season survey, surface flux measurements of wet ground showed that methane is being released from the soil and free water. However, since for much of the year these sites will be dry, emissions of methane will be much less or even a nett sink of methane.

1 Introduction

The Northern Territory Government's 'Scientific Inquiry into Hydraulic Fracturing' Final Report requires that methane (CH_4) measurement and monitoring occur before the advent of exploration and production activities by gas companies (Andersen et al. 2018). Specifically, Recommendation 9.3 of the Final Report requires:

> '*That baseline monitoring of methane concentrations be undertaken for at least six months before the grant of any further exploration approvals. In areas where hydraulic fracturing has already occurred, the baseline monitoring should be undertaken at least a year before the grant of any production approvals.'*

This project (GISERA Project G5) specifically addresses the first component of this Recommendation that refers to the measurement and monitoring of ambient CH_4 concentrations throughout the prospective gas region before the granting of exploration approvals.

Throughout this report we use the term 'concentration' to mean the abundance of a gas (e.g. CH_4) in the atmosphere expressed as the volume of that gas as a proportion of the total volume of air. For atmospheric concentrations, units are typically parts per million (ppm) or parts per billion (ppb). We also use the terms flux or emission rate which refers to the rate of flow of gas per unit time from a particular emission source. The units of flux may be in m^3 per unit time (on a volumetric basis) or in g or kg per unit time (on a mass basis). Information on both concentration and flux is required to be able to provide a baseline and quantify the natural and anthropogenic CH_4 emissions, identify where these background emissions are occurring and how much CH_4 is being released to the atmosphere.

The objective of this project is to quantify the landscape background concentration levels of CH_4 and identify the locations of sources where elevated CH_4 levels are found and, where applicable, quantify the fluxes related to these sources.

This interim report documents the findings of the third survey conducted over a 7-day period between 30th January and 5th February 2019 where CH_4 concentrations in the region were measured using two gas analysers mounted in a four-wheel-drive vehicle. A total of 4050 km was traversed during this survey, and CH_4 measurements were acquired continuously along the route. Data collected during this survey provides indicative background CH_4 concentrations during the wet season of 2019 and identifies the main sources of CH_4 during this season.

2 Experimental Methods

During this survey (and the previous two surveys), baseline monitoring was principally conducted by mobile surveys of the Beetaloo Sub-basin region. Surveys are conducted using a 4wd vehicle fitted with one or more CH_4 analysers which continuously measure ambient CH_4 concentrations and a GPS receiver to track the path of the vehicle during the survey. As discussed in the first interim report, this approach has the advantages that it can be deployed rapidly, can cover a large area in a relatively short timeframe and is capable of locating and identifying CH_4 sources. In some cases, data from mobile surveys may be used to determine emissions rates under favourable conditions. Because of the versatility of the mobile survey method, it has been widely used previously in Australia, the United States and the United Kingdom and is now a well-developed technique for undertaking baseline measurements of landscape CH_4 concentrations and fluxes (Ong et al. 2017; Phillips et al. 2013; Zazzeri et al. 2015).. Comprehensive discussions on the mobile survey method can be found in the first interim report (Ong et al., 2018).

The instrumentation and procedures used during the surveys have been described in the previous two reports (Ong et al. 2019; Ong et al. 2018) but are also briefly described in the following sections.

2.1 Instrumentation

This survey was performed using two CH_4 analysers that operated simultaneously during the surveys:

- PICARRO G2301 $CO_2/CH_4/H_2O$ analyser, which is a cavity ringdown spectrometer.
- Los Gatos Research (LGR) Ultraportable $C_2H_2/CH_4/H_2O$ Methane/Acetylene Gas Analyzer s a tracer gas in experiments designed to measure emission rates from some CH_4 sources). The LGR is an OA-ICOS system.

Both instruments are capable of reliably detecting changes in CH_4 concentration as low as 2 ppb and have high levels of stability necessary for mobile operation (e.g. Crosson (2008)). Although both instruments have similar capability with regard to measuring CH_4 concentrations, the harsh nature of the surveys undertaken in the Beetaloo region (i.e. high temperature and humidity, vibration during off-road surveys) previous experience has shown that redundant capability is prudent in case of problems encountered during remote surveys.

During the first surveys made in July and August 2018, a third analyser was also used; an AERIS Technologies PICO Analyser. The AERIS was undergoing development for longer term fixed monitoring applications and was not available for the surveys made during February 2019.

As well as CH_4, the PICARRO instrument simultaneously measures CO_2 concentrations. This instrument also has the capability of measuring the ratio of the carbon isotopes $^{13}C/^{12}C$ in both CH_4 and CO_2. Isotopic ratios can in some cases provide information on the origin of the source of CH_4, provided concentrations are sufficient for reliable measurements.

The LGR measures CH_4 and C_2H_2 (acetylene) simultaneously. Acetylene can be used as a tracer when determining emission fluxes from some sources, but this method was not used during this field trip as the elevated CH_4 concentration found were not sufficiently large to warrant flux measurements. Generally, flux measurements are conducted in cases where elevated concentrations larger than 2-3 ppm are found. If suitable CH_4 sources are located during subsequent campaigns, the tracer method may be employed to measure fluxes.

Each analyser had its own dedicated GPS receiver (Garmin 18X, Hemisphere R330 DGPS and Gill Maximet GMX500, respectively) to enable positional data to be recorded simultaneously with the gas concentration data. Local meteorological data (wind speed and direction, temperature and humidity) was measured with the Gill Maximet GMX500 Compact Weather Station fitted to the top of the field vehicle (Figure 1). Note that wind speed and direction measurements were made only when the vehicle was stationary. Because of the large and variable nature of the meteorology conditions, the temperature and humidity are important to monitor the performance of the instruments to understand the impacts on the resulting measurements.

Where these impacts are found to be significant these meteorological data may be used to account for departures related to meteorological conditions. Positional data were combined with the gas concentration data to produce maps of CH_4 concentration across the study region.

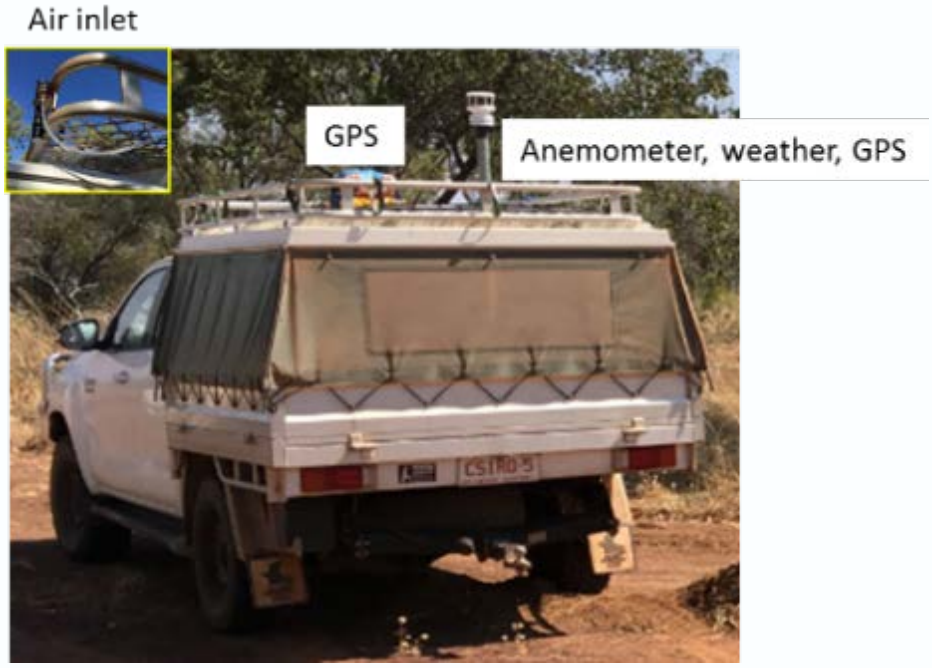

Figure 1: Survey vehicle showing the location of sampling lines, GPS and combined anemometer, GPS and weather station.

The survey vehicle is shown in Figure 1. The GPS for the LGR analyser was located on the roof rack at the front middle of the vehicle, and the Gill combined anemometer, weather station and GPS were also located on the roof rack at the front right-hand side of the vehicle. The inlet of the sampling line was located on the roof rack (see insert on the top left of Figure 1.) on the front left-hand side of the vehicle. The location of the inlet was such that it was not affected by the vehicle's exhaust while travelling. The same sampling line was used for both analysers and during surveying air was drawn from the front of the vehicle to the rear of the vehicle via a single pump. The air stream from the inlet line was then distributed via two separate lines to each analyser located at the tray of the ute (shown in Figure 2). The distances between the two distribution lines were small, and the length of lines between the intake and each analyser was approximately equal.

The analysers were fitted in the rear seat in the vehicle's cabin as shown in Figure 2.

Figure 2: PICARRO and LGR analysers mounted in the rear of the field vehicle. Note that the back seat has been removed.

2.2 Flux Measurements

On some occasions during the surveys, CH_4 emission flux measurements were attempted where possible; specifically, emissions measurements were made at a gas pipeline riser near the Carpentaria Highway which had previously been found to be emitting small amounts of CH_4, and some termite mounds. Soil flux measurements were also made at some locations. The methods used for these measurements are briefly described below.

2.2.1 TRACER METHOD

In one approach to determine CH_4 emission rates, a stable tracer gas (such as acetylene) can be released at a known rate from the same location as the source of CH_4. Provided that the tracer gas is released sufficiently close to the CH_4 emission point and mixes into the CH_4 plume, the CH_4 emission rate can be readily calculated

by multiplying the acetylene release rate by the ratio of the CH_4 and acetylene concentrations downwind of the source.

2.2.2 PLUME TRAVERSES

In some circumstances it is possible to estimate CH_4 emissions using a plume dispersion method. In this method, the CH_4 concentration profile in a plume originating from the source is measured downwind by performing traverses across the plume. The emission flux, *F*, may be estimated by integrating the CH_4 concentration enhancement, *C*, of the plume in the horizontal, *y*, and vertical, *z*, directions and multiplying by the average wind velocity, *u*.

$$F = u \int_{-y}^{y} \int_{0}^{z} C(y,z) dy dz \quad (2.1)$$

Because concentration measurements are made only at ground level, the vertical dispersion must be estimated by reference to plume dispersion models such as the Pasquill-Gifford curves of σ_z (i.e. the standard deviation of the distribution of CH_4 concentration in the vertical direction) as a function of downwind distance under given atmospheric turbulence conditions. The vertical concentration profile of CH_4 within the plume is assumed to decrease from the ground level concentration with height according to a Gaussian distribution. However, because the vertical concentration is estimated based on plume modelling methods, the uncertainty of this approach may be significant.

2.2.3 FLUX CHAMBERS

Some measurements were made on various ground surfaces to determine soil CH_4 flux. For these measurements, a metal bucket approximately 30 cm in diameter with a total volume of about 9 L and an area of coverage of 0.07 m^2 was placed on the ground at each sampling point. The chamber was connected to the LGR CH_4 analyser in the field vehicle via a ¼" nylon tube and the CH_4 concentration within the chamber, *C*, continuously measured over a period of several minutes. The flow rate of the sample stream from the flux chamber to the analyser was approximately 100 mL min^{-1}, which was returned to the chamber via a second tube (Figure 3).

The CH_4 emission flux, *F*, was calculated according to Equation 2.2:

$$F = \frac{dC}{dt} \times \frac{V}{A} \quad (2.2)$$

where *V* is the volume of the chamber, *dC/dt* is the rate of change in the CH_4 concentration over time, *t*, and *A* is the area of surface covered by the chamber.

Figure 3. Surface flux chamber used for measuring soil CH_4 emissions. This chamber was also used for measuring CH_4 emissions from some termite mounds. The particular measurement was taken on saturated soils.

2.3 Daily Surveying Procedure

Prior to field deployment, a schedule of work was prepared. Stakeholders were contacted, and a daily route was agreed that minimised the impacts on the environment, farming and community activities. Wherever possible the surveying route was the same as that used during the initial surveys.

A typical daily survey involved start up procedures for the vehicle and the equipment, route planning and liaisons with local stakeholders. Once mobile, gas concentrations were automatically logged; periodic recording of weather observations was manually completed while the vehicle was stopped. Any CH_4 spikes were recorded in the log as they occurred to assist with the later analysis.

Before departure, daily prestart checks on the equipment followed a set procedure to ensure the computers, PICARRO, LGR, weather station and GPS were all in good working order. Prestart checks on the vehicle were completed to ensure the daily task could be completed safely. Any activity on private land required a local site liaison to escort the test equipment on site. Verification of the route and road conditions and any other important information that may affect the relationships with stake holders were discussed prior to deployment.

With safety in mind, vehicles typically travelled in convoy with consideration for minimising interference from the escort vehicle's emissions or a disturbed dusty road. This was achieved by setting designated meeting points and staggering the start of each vehicle. A log was kept recording time, date, location and weather observations throughout the day. Typically every 30 minutes the vehicle was stopped to log wind speed, wind direction, temperature, humidity and barometric pressure. If a significant deviation in CH_4 was observed the vehicle speed was reduced or stopped, the peak gas concentration was logged and efforts made to identify

the source of CH_4. As repeated weather observations were recorded, it was reasonable to conclude that cattle seen up wind of the equipment would be the most likely source of CH_4 spike. Conversely, cattle downwind of the equipment would not trigger a response from either analyser, again verifying the equipment was functioning correctly. Particular interest was given to dams and water troughs supplied from underground sources and gas well and gas pipelines and where possible the vehicle was positioned down wind, or a circuit of the site was performed.

At the end of each surveying day, calibration checks were performed on both instruments using four reference gasses with compositions as shown in Table 1. No adjustments were made to the equipment (in accordance with the manufacturers' instructions), but any corrections were applied during the processing of the data. All of the data and the daily log were sent back to Perth for overnight analysis. Comparisons of the recorded data from the PICARRO and LGR confirmed a successful survey and confirmation given to continue with the next day's scheduled program of work.

Table 1. Reference gas compositions used for calibration checks on the PICARRO and LGR analysers.

	Methane (ppm)	Acetylene (ppm)	CO_2 (ppm)	Oxygen (%)	Nitrogen
Reference 1	1.02	1.00	-	20.8	Balance
Reference 2	3.02	-	496	20.9	Balance
Reference 3	4.07	3.97	-	20.9	Balance
Reference 4	10.2	-	1010	20.9	Balance

3 Data Processing

The main processing of the data collected during this survey included:

- correction of the measured CH_4 concentration data to account for humidity;
- alignment of each of the respective data to a common reference to account for the different response time of each analyser; and
- combination of GPS location data with the corresponding concentration data for producing concentration maps of the survey region.

As noted in previous interim reports, ambient moisture concentration data are not strictly required for the CH_4 and CO_2 analyses but differences in humidity at different times yield slightly different CH_4 and CO_2 concentrations because the moiture in the air occupies a certain volume, which increases with relative humidity and temperature (under some conditions water may comprise more than 3 % of air by volume). During this and previous surveys, large changes in moisture concentrations were observed over even short timeframes, especialy during rain events. Hence, to allow direct comparison with data collected under different humidity conditions, the CH_4 and CO_2 concentratons are reported on a 'dry air' basis (i.e. the CH_4/CO_2 are corrected to a moisture content of 0 %). CH_4 and CO_2 concentrations reported from global monitoring stations (e.g. the CSIRO Cape Grim station in Tasmania) are generally reported on a dry basis. Concentrations (dry basis) are calculated from the raw (i.e. moist basis) according to Equation 3.1.

$$CH4dry = \frac{CH4raw}{(1-H2O)} \qquad (3.1)$$

Where *CH4dry* is the dry basis CH_4 concentration, *CH4raw* is the as-measured CH_4 concentration, and *H2O* is the water vapour concentration.

Both the PICARRO and LGR instruments have the capbility to measure water and provide a dry-basis result but continuing problems with the water channel on the PICARRO, which were described in the previous report (Ong et al., 2019), meant that all dry basis corrections to both the PICARRO and LGR datasets were made using the water data from the LGR instrument.

Before commencing the first field programme, each analsyer was subjected to a multi-point calibration using up to five reference gasses in the CSIRO Kensington laboratories in Perth. The calibration standards contained CH_4 at concentrations ranging from approximately 1.8 ppm (close to ambient air concentration) up to 102 ppm, which were selected to cover the range of concentrations likely to be encountered in the field. At the time of the calibration, all instruments were linear over this range. This calibration exercise was repeated at the end of the third survey.

Daily calibration checks against the four reference gasses shown in Table 1 were used to account for any day-to-day instrument drift during the field campaign.

The response time of each analyser is a function of the size of the sample cell within the instrument, the flow rate of the gas into the analyser which in turn is a function of the pump capacity and size of the inlet valve into the analyser. Previous work has shown that the PICARRO instrument has a slightly slower response time than the LGR, hence CH_4 peaks detected by the PICARRO appear to spatially lag the LGR peaks when plotted in GIS software. Time corrections were therefore applied to each instrument's results to ensure CH_4 peaks were properly aligned.

Like the previous survey there were persistent problems with the GPS logging systems used to locate CH_4 concentration data collected by the gas analysers. These problems have since been traced to communication problems between the logging computers and the GPS receivers. Fortunately, GPS data were recorded for the entire survey although a significant amount of post-processing of the data was required to align the time stamps of the GPS and analyser data.

4 Results

A total of approximately 4050 km was traversed during the period 30th January to 5th February 2019. Typically, between about 200 and 600 km was covered each day with the coverage area guided by the previous surveys. That is, where accessible, the areas covered in the first and second surveys were replicated as closely as possible. However, this final survey was made during the wet season and vehicle access to many sites was difficult or impossible due to the poor state of many of the roads (Figure 4). As a result, the total distance travelled during this survey was less than on the previous two surveys, which each covered over 5000 km. The main areas that were not accessible during this final survey were on the Origin and Pangea leases.

Figure 4. CSIRO survey vehicle during the wet season surveys showing the conditions of some of the tracks. The bottom photograph shows the vehicle after it had become bogged on one of the tracks – it was subsequently winched out.

Like the previous surveys, CH_4 levels were generally typical of concentrations found in natural areas. Over the entire survey period, CH_4 concentrations were mostly between about 1.77 and 1.88 ppm (dry basis). The mean concentration of all of the data was 1.81 ppm. For comparison, the CH_4 concentration measured at the CSIRO Cape Grim atmospheric monitoring station during January 2019 was 1.802 ppm. Cape Grim is located on Tasmania's west coast (40.68°S, 144.69°E), one of the three premier Baseline Air Pollution Stations in the World Meteorological Organization-Global Atmosphere Watch (WMO-GAW) network. (https://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/Latest-greenhouse-gas-data).

Small peaks of CH_4 up to about 2.5 ppm were detected during mobile surveys; these were mostly associated with cattle grazing by the roadside. As in previous surveys, slightly elevated CH_4 concentrations were found next to a pipeline riser on the Daly Waters to MacArthur River gas pipeline (location of the site is 16.5437°S, 134.7087°E); however, the largest CH_4 concentration measured at this location was 1.88 ppm, which is lower than previous occasions.

Other slightly elevated CH_4 concentrations were detected near urban areas at Katherine, Mataranka, Larrimah, Daly Waters and Elliot along the Stuart Highway. The sources of these elevated values were likely to be associated fuelling stations, seepages of natural gas from domestic or commercial usage, vehicles, waste water treatments and landfills. In all of these cases, the levels observed were only slightly above background (as in previous surveys) suggesting that the emission rates from these sources are low.

The previous survey conducted during the fire season in November 2018 was affected by bushfires which contributed to generally elevated CH_4 concentrations across the region (Ong et al., 2019). During the current survey no elevated methane concentrations were related to fire.

The CH_4 concentrations measured during the survey are shown in Figure 5. The map shown in Figure 5 was plotted from data yielded by the LGR instrument; very similar results were obtained with the PICARRO analyser, apart from minor differences due to differing instrument response times, which has been discussed in the previous reports.

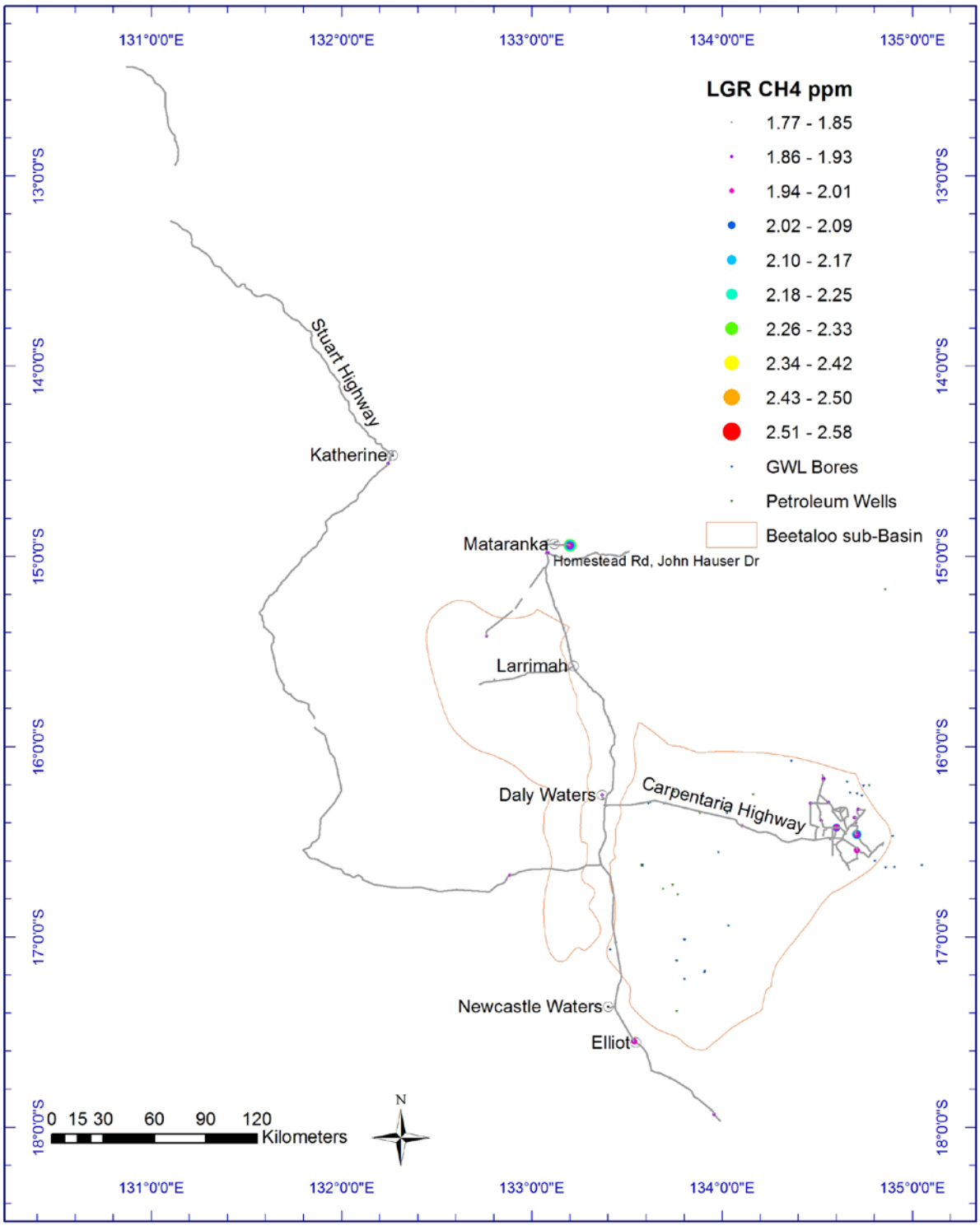

Figure 5. Methane concentration measured using the LGR analyser along tracks and roads across the Beetaloo sub-basin. The isolated elevated CH_4 levels indicated were due to nearby grazing cattle.

It is interesting to note that most of the higher levels of CH_4 detected were in an area adjacent to the Carpentaria Hwy, towards the west in Figure 5. Similar clustering was observed on both of the previous visits to the region. This area is located on the Tanumburini Station and during the surveys made across this property on all three occasions, large numbers of cattle were grazing near the tracks traversed.

Like the previous surveys, CO_2 concentrations were measured concurrently with CH_4. A plot of the concentrations measured with the PICARRO analyser is shown in Figure 6.

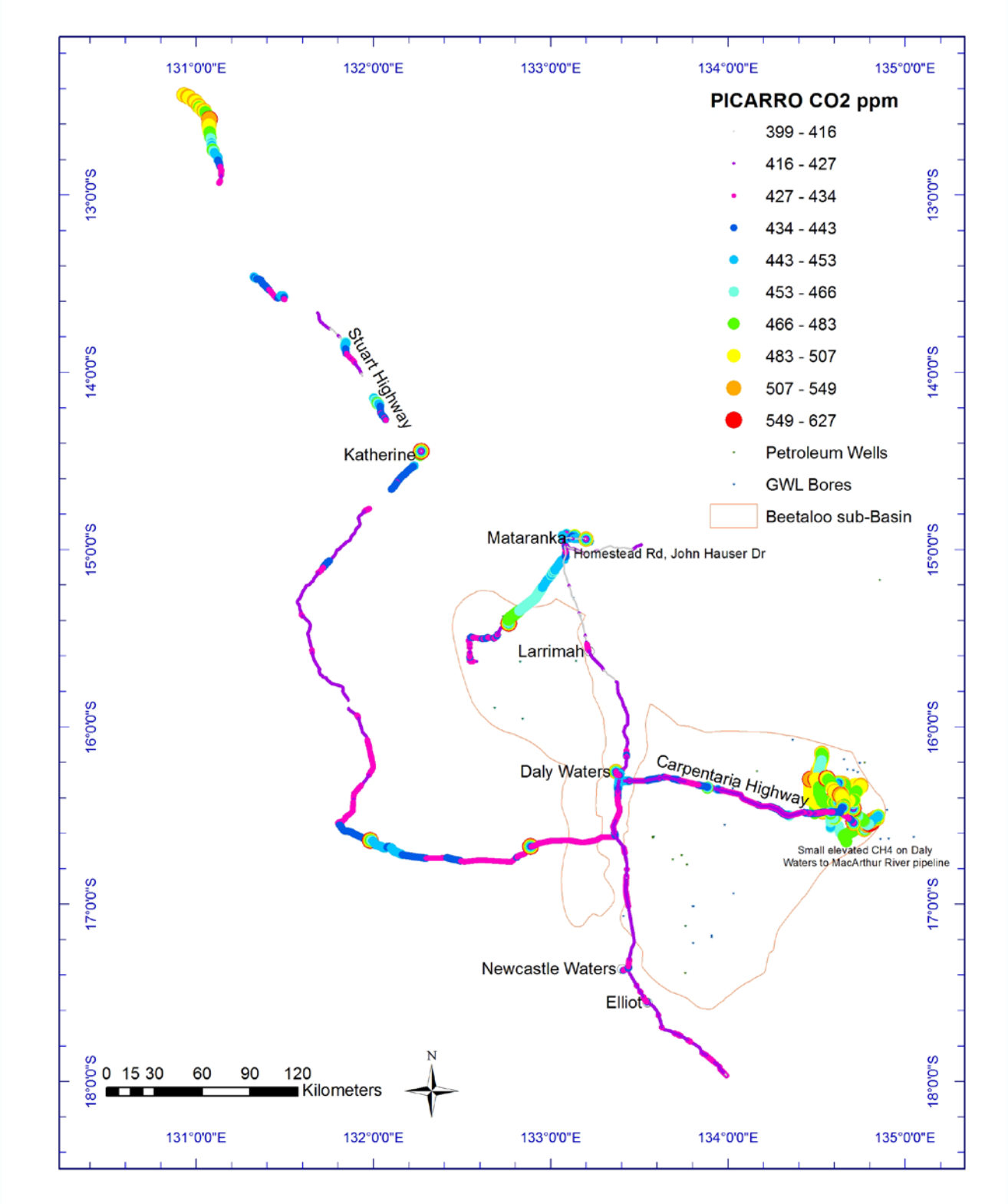

Figure 6. Carbon dioxide concentration measured using the PICARRO analyser along tracks and roads across the Beetaloo sub-basin.

Carbon dioxide levels were, as in previous surveys, more variable than CH_4, although in the latest surveys, fires were not a significant source of CO_2. Much of the variability observed in CO_2 levels may be due to the presence of vehicle exhaust. Note that there is also a clustering of higher CO_2 concentrations across the Tanumburini Station. Although care was taken during the surveys to ensure that the sample air was not

affected by vehicle exhaust, on the rough tracks which required low speed driving and an escort vehicle, there were occasions when CO_2 in vehicle exhaust was detected by the gas analysers.

In previous surveys, a number of plugged and abandoned and suspended wells were visited to determine CH_4 concentrations in the vicinity. Visits were also made to some of these wells during the current survey, although due to track conditions, only seven of the original 11 could be accessed:

1. Wyworrie 1
2. Tarlee S3
3. Birdum Creek 1
4. Kalala S1
5. Amungee
6. Burdo
7. Tanumburini 1

Details and location of the wells are provided in the first and second interim reports (Ong et al., 2018; Ong et al., 2019). In common with previous surveys, no elevated CH_4 concentrations were detected at any of the well sites visited.

In addition to the petroleum wells, CH_4 concentration measurements were repeated at (or close to) 13 of the 21 water bores examined during the first survey. Details of the water bores are provided in the previous interim reports (Ong et al, 2018; Ong et al., 2019).

1. Motel Bore# RN24618
2. Unnamed water bore at Beetaloo Station
3. RN037655
4. RN033608
5. RN039693
6. RN038179
7. RN008101
8. RN007659
9. RN033671
10. RN38815
11. RN38817
12. RN38818
13. RN031244

Elevated concentrations were not detected in the vicinity of most of these bores. During the previous two surveys, indications of CH_4 were detected at the Motel Bore which were attributed to a nearby sewage treatment system. However, on this occasion, no CH_4 was detected. The differences may have been due to differing wind conditions at the time of the visits.

A revisit of one of the sources of natural sources of CH_4 expected in the area from wetlands and natural geological sources such as springs was made. A survey was conducted along the public roads: Homestead Rd and John Hauser Rd to determine the possible presence of CH_4 from the wetlands area around Bitter Springs and Mataranka Springs. No elevated concentrations were detected along these roads similar to the findings form the first survey.

PIPELINE RISER

During first and second surveys CH_4 measurements made alongside a section of the underground Daly Waters to McArthur River Gas Pipeline (photo in Figure 7) detected slightly elevated concentrations adjacent to a section of the pipeline that was above ground (a riser). The CH_4 concentrations measured at about 10 to 15 m downwind from the facility (unable to get closer due to fence) during these visits were low, with peaks less than about 0.5 ppm (usually less than 0.1 ppm) above background CH_4 concentrations, suggesting that the source of CH_4 was minor.

Figure 7: Photo (taken during the second survey) of the above ground section on the Daly Waters to MacArthur River gas pipeline where small elevated CH_4 values were found. The geographic location of the site is 16.5437°S, 134.7087°E.

In the current survey, we attempted to quantify this CH_4 source, initially using the acetylene tracer method described in Section 2.2.1. This method has been previously shown to yield accurate results when applied to CSG wells and other CH_4 sources (Day et al., 2016). However, because the pipeline riser was inside a fenced enclosure we were unable to position the acetylene outlet near the likely source. In some cases, this can be mitigated by conducting concentration measurements further downwind but the presence of thick vegetation restricted measurements to no more than about 20 m from the source, which was insufficient to allow acceptable mixing of the tracer acetylene with the source CH_4 plume.

Instead, we used the plume traversing method (Section 2.2.2) to estimate the emissions rate from the pipeline riser. The conditions for this method were favourable at the time of the visit with a steady breeze of about 3 m s^{-1} and consistent direction prevailing. Six circuits over about a 10-minute period were made around the fence about 15 m from the source. Like previous surveys, the peak CH_4 concentrations were very low, with the maximum concentration measured during the traverses less than 0.06 ppm (60 ppb) above background. The results of the traverses are plotted in Figure 8 where the CH_4 peaks detected during the traverses are clearly visible.

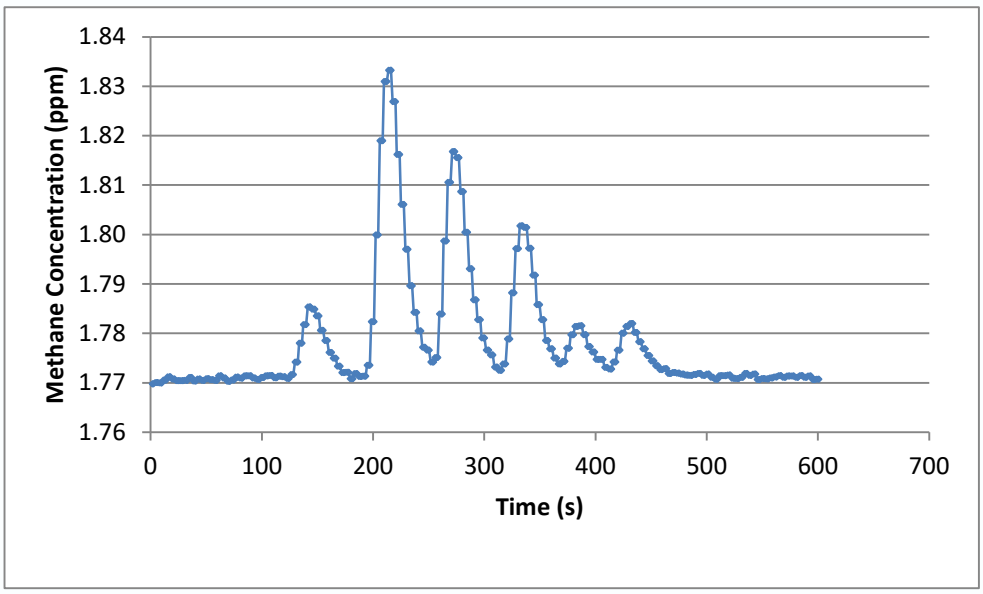

Figure 8. Methane concentration measured during six mobile traverses around the pipeline riser enclosure. The peaks measured during each traverse are clearly visible with the maximum concentration (second traverse) slightly above 1.83 ppm or less than 60 ppb above background.

The average emission rate estimated from the six individual traverses was approximately 80 mL CH_4 min^{-1} (about 120 g CH_4 day^{-1}).

SOIL EMISSIONS

Soil CH_4 fluxes were measured at eight sites throughout the survey and the results are summarised in Table 4 (in units of mg CH_4 m^{-2} day^{-1}). The last four measurements shown were made around a large stagnant water body on the Tanumburini Station (Figure 9).

Figure 9. Ground surface flux measurements near a body of stagnant water.

Table 2. Soil CH_4 fluxes measured during the survey.

Site Surface Description	Methane Emission Flux (mg CH_4 m^{-2} day^{-1})
Grassed edge of track – damp soil	-2.3
In free water on grassed verge (see photograph in Figure 3)	-1.4
Dry ground without vegetation	-3.8
Dry ground without vegetation	0.5
Grassed edge of large stagnant water body; Location 1	98.0
Grassed edge of large stagnant water body; Location 2	5.1
Grassed edge of large stagnant water body; Location 3	23.3
Stagnant water body – in the water	113

The small sample of measurements show a significant range of CH_4 fluxes with the highest associated with the stagnant water body. Some of the fluxes were negative (i.e. indicating that CH_4 is being consumed from the atmosphere). This is consistent with other measurements made in Australia and other parts of the world (e.g. (Dalal et al. 2008; Kreise et al. 2008; Day et al. 2016; Day et al. 2015; Ong et al. 2017) and is due to the presence of certain microorganisms capable of oxidising CH_4 in aerated soils.

Measurements made near the stagnant water were significantly higher with the maximum emission rate 113 mg CH_4 m^{-2} day^{-1}. This is not unexpected since wetlands are well known to produce CH_4 due to anaerobic microbial activity. This particular site was not a permanent wetland and for much of the year would be dry; it is likely therefore that emissions from the site would also be much lower.

Although the CH_4 fluxes from the wetland examined during this survey were significantly higher than other non-wetland areas, the highest emissions were generally less than 0.1 g CH_4 m^{-2} day^{-1} which was usually not sufficient to produce measureable elevated ambient CH_4 concentrations in the vicinity. However, the extent of wetlands during the wet season means that CH_4 from this source is likely to be a significant source of the CH_4 in the Basin, although the magnitude will be highly dependent on seasonal conditions.

TERMITES

During the first survey in the dry season (Ong et al., 2018) CH_4 flux measurements using the flux chamber were made at several termite mounds since it was expected that these would be a significant source of CH_4. However, none of the termite mounds examined were found to be emitting CH_4 despite the confirmation of presence of CH_4 within the structure. The lack of emissions was consistent with seasonal variability of emissions and hence further measurements of CH_4 emissions were attempted during the wet season survey.

Measurements were made at three small termite mounds that could be fully enclosed in the 9 L flux chamber. In each case CH_4 emissions were found. An example of the CH_4 concentration change over time within the flux chamber during one experiment is shown in Figure 10.

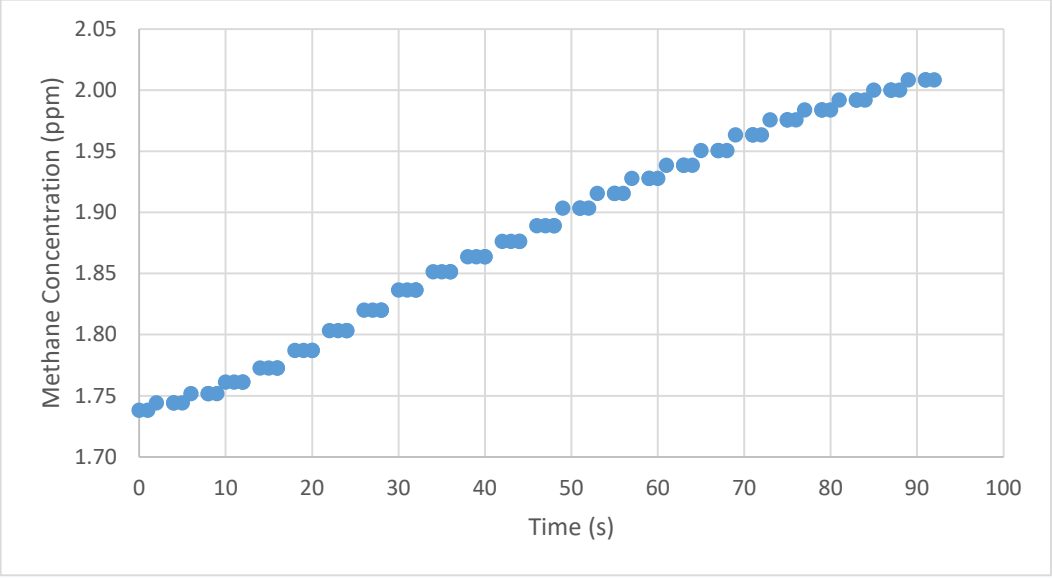

Figure 10. Methane concentration as a function of time inside the flux chamber during a measurement of emissions from a termite mound.

The CH_4 emissions measured on these mounds were reasonably consistent, ranging from 2.7 to 4.1 mg CH_4 per m^3 per day with an average value of 3.3 mg CH_4 per m^3 per day (note that the units used here are in terms of the mound volume rather than the area covered by the flux chamber as in other chamber results). There was also a strong CO_2 emission from the termite mounds averaging at approximately 1200 mg CO_2 per m^3 per day. Other studies have found similar rates of both CH_4 and CO_2 emissions in the Northern Territory (Jamali et al. 2011) and in other parts of the world (Seiler et al. 1984).

As noted previously, flux measurements made at the time of the initial survey during the dry season yielded virtually no CH_4 emissions from termite mound in the survey region. Jamali et al. (2011) conducted an extensive study of CH_4 emissions from termites in the Northern Territory and reported a ninefold difference in emission rates between the wet and dry seasons. This strong seasonal effect is consistent with our results.

5 Discussion

Overall, the CH_4 concentrations recorded across the survey area during this wet season survey were similar to the findings from the dry and fire season surveys. Baseline concentrations across the region were close to global average ambient concentrations. There were a number of elevated CH_4 concentrations up to approximately 2.5 ppm but like previous occasions, these were predominantly due to grazing cattle. In the first interim report CH_4 emissions from cattle were estimated for four large pastoral properties in the Beetaloo sub-basin was provided in the first interim report and yielded a combined emission rate of approximately 40 kg CH_4 per minute, which is about 21,000 t CH_4 per annum (Ong et al., 2018). This would represent one of the largest CH_4 sources in the region.

Other significant CH_4 sources identified during the three surveys include fires, termites and wetlands, all of which are periodic in nature. Emissions from fires were detected during both of the previous two surveys but not during the final wet season survey. Although CH_4 from large-scale fires such as those that occur in the Northern Territory may be high, they are of relatively short duration; quantifying CH_4 emission rates from fires is challenging and work is continuing in this area.

Termites are also a widespread CH_4 source but their emissions are subject to large seasonal variations. Measurements made during the wet season clearly showed CH_4 emissions, yet no emissions were detected from a selection of termite mounds during the dry months. It is not possible on the basis of these few measurements to quantify termite emissions but previous work has estimated CH_4 emissions in northern Australia to be 0.24 kg CH_4 ha^{-1} y^{-1} (Jamali et al., 2011). Although this would amount to a large emissions over the entire Beetaloo sub-basin, the authors of that study also estimated that soil uptake of CH_4 was 1.14 kg CH_4 ha^{-1} y^{-1}, which is nearly five times the amount of CH_4 emitted by termites.

Methane emissions from saturated soils were also detected during the wet season survey. Given that such surfaces are very extensive during the wet these emissions, although the measurement made during this survey indicated that they are low, are likely to account for significant CH_4 emissions to the atmosphere across the sub-basin. However, for much of the year these areas will be dry and may become CH_4 sinks rather than sources. Clearly, developing a detailed and accurate CH_4 budget for the region is a complex task and needs to account for both natural and other sources as well as the strong seasonal effects on these sources.

All of the surveys conducted during this project examined abandoned oil and gas wells and water bores, which are potential sources of methane since they could provide a route for methane from gas bearing strata to reach the surface. None of the abandoned wells showed any sign of methane emissions during any of the site visits. At a few of the water bores there were a small number of instances during the first and second surveys where slightly elevated methane levels were detected but these were due to nearby cattle (or in one case a sewage treatment system). However on subsequent visits during the wet season, no methane above background levels were detected.

During all three surveys we found slightly elevated methane concentrations up to about 2.3 ppm (against a background level of around 1.8 ppm) close to a pipeline riser on the Daly Waters to McArthur River gas pipeline. Following the report of this leak, , a service provider to the owner of the pipeline at the request of the Department of Primary Industry and Resources, investigated it and found that during their monthly inspection no leak had been detected. However, an additional survey was initiated on 8th January 2019 which detected a small leak that originated from a grease nipple on a ball valve. The nipple cover was tightened as it was found to be only finger tight. A gas level reading was again taken 150mm from the nipple which indicated there was no leak present. An additional step has now been include in the valve check sheet, which requires that all grease nipple covers be tightened. During this survey, the emission rate from this facility was estimated during the wet season survey and found to be approximately 0.12 kg day^{-1}, or about 44 kg y^{-1}. This emission rate is 40-80 % of the average of 120 to 300 g CH_4 day^{-1} produced per head for cattle (Charmley, 2016; Tomkins, 2011).

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CONTACT US

t 1300 363 400
+61 8 6436 8677
e enquiries@csiro.au
w www.csiro.au

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Division/Energy
Cindy Ong
t +61 8 6437 8677
e cindy.ong@csiro.au
w www.csiro.au/energy