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BAROSSA PIPELAY LIGHT MODELLING 2022

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For

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1 INTRODUCTION

In February 2020, to support development of the Barossa Gas Export Pipeline Installation Environment Plan (EP), ConocoPhillips engaged Pendoley Environmental (PENV) to undertake artificial light modelling of the proposed pipelay and construction vessel lighting emissions that would potentially be visible from nearby marine turtle nesting habitat on the Tiwi Islands, Northern Territory.

In mid-2020, Santos acquired the project and is now managing the development of the EP. Due to a change in the construction vessel likely to be used in the project, and updates in the modelling methodology since 2020, Santos engaged PENV to model the new construction vessel (the Fortitude), update existing modelling of the pipelay vessel (the Audacia), and update cumulative modelling of both vessels.

Accordingly, this technical memo details light intensity modelling undertaken for three scenarios:

- Pipelay vessel Audacia;
- Construction vessel Fortitude; and
- Both vessels located together (cumulative).

2 METHODOLOGY

2.1 Artificial Light Modelling

Currently, there are no standard commercial models for landscape scale modelling of artificial light emissions (Commonwealth of Australia 2020). Recognising this gap and the growing need to respond to both local and national regulatory concerns over artificial light impacts on wildlife, and on dark sky conservation values required to meet International Dark-Sky Association (IDA) Dark Sky Park certification requirements, PENV has invested in dedicated research and development effort to develop a landscape scale model of artificial light.

The base model used for this work was the ILLUMINA model that has been developed by Physics Professor Dr Martin Aubé of Sherbrooke University, Canada (Aube et al. 2005). This well-documented, open-source model was selected for its ability to represent light across large areas and distances and across the entire visible spectrum, including biologically meaningful light from 350 nm – 700 nm. PENV has developed software that incorporates this base model and generates quantitative outputs relevant to clients looking to assess the impacts of light on wildlife and/or the night sky.

Unlike commercially available engineering light models that are commonly used to design human-centric lighting for the relatively small footprint of single or multiple buildings, parking lots, streetlighting etc., ILLUMINA is a three-dimensional model that accounts for both line-of-sight light visibility in addition to the glow derived from atmospheric scattering of light. The model also addresses the attenuation/loss of light over landscape scale distances and, consequently, the areal extent of light glow across the sky can be modelled. Additional details on the equations and model parameterisation can be found in Aube et al. (2005). The model input parameters include project specific details about light type and spectral distribution, including any shielding, which substantially increases the model precision and accuracy. The model also includes project location-specific inputs such as surface reflectance and topographic values that are incorporated from aerial imagery supplied by NASA Earthdata and the NOAA (National Oceanic and Atmospheric Administration).

2.1.1 Units of Measurement

The model outputs in units of absolute radiance; W/m^2/sr, where W = Watts, m^2 = meters squared and sr = steradian. These units represent the intensity of direct, reflected, and scattered (glow) light visible by an observer from a specific location, and considers light equally across the entire visible spectrum, instead of weighted towards a specific vision curve (e.g. humans – which are most sensitive to green wavelengths and less sensitive to blue and red). As the results are unweighted, they are considered a “worst-case” measurement of the maximum amount of light that could be received at a location.

In the absence of any other published or generally accepted units of measurement, or scale, for measuring the impact of Artificial Light at Night (ALAN) on marine turtles, PENV has developed an approach based on the visibility of the full moon, the brightest natural light source visible within the region of the horizon used by hatchlings during sea finding. The output, in Full Moon Equivalents (FME; see **Section 2.1.1.1**), is modelled for the Orientation Field of View (OFOV; see **Section 2.1.1.2**) used by hatchlings during sea finding. This approach gives the model outputs some biological relevance when interpreting the results for environmental impact assessment.

2.1.1.1 Full Moon Equivalents

While the behavioural response of marine turtles to light is relatively well understood (see Witherington & Martin (2003) for review), there is currently no agreed upon intensity limits for determining what the impact of a given light might be. Several factors influence the visibility and impact of light on hatchlings, including light intensity, visibility (a function of lamp orientation and shielding), spectral power distribution (wavelength and colour), atmospheric scattering, cloud reflectance, spatial extent of sky glow, duration of exposure, horizon elevation, lunar phase, hatchling swimming speeds, species, tide and current speeds, and flow direction.

The range of moon brightness across a whole lunar cycle is a realistic representation of the natural ambient light levels that turtles eyes are adapted to. On a new moon, there is little to no ambient light, and this is when hatchlings are at greatest risk of mis- or dis-orientation due to artificial light sources. The amount of ambient light present on a full moon is substantial and may override any artificial light cues that could potentially influence hatchling orientation.

2.1.1.2 Orientation Field of View

The sensitivity of a hatchling turtle to directional light can be described by a specific 'cone of acceptance' which indicates how much of the world a hatchling views and measures at any one instant, defined by Lohmann et al. (1997) as 180° horizontally and 30° vertically. To understand potential impacts on hatchling behaviour, all pixels in the 180° x 30° window centred over the brightest light source at the observer viewpoint are averaged and described as the OFOV (**Figure 1**). This average radiance value is then compared to the brightness of a full moon that would be visible within the same field of view and converted to FME (**Figure 2**).

Impacts are assessed on a scale based on this proportion, where values equal to or greater than 1 FME are likely to have an impact, and values less than 1 FME having varying likelihoods of impact down to 0.01 FME (i.e. 1 % of the radiance of a full moon), which is considered to have no impact (**Table 2**).

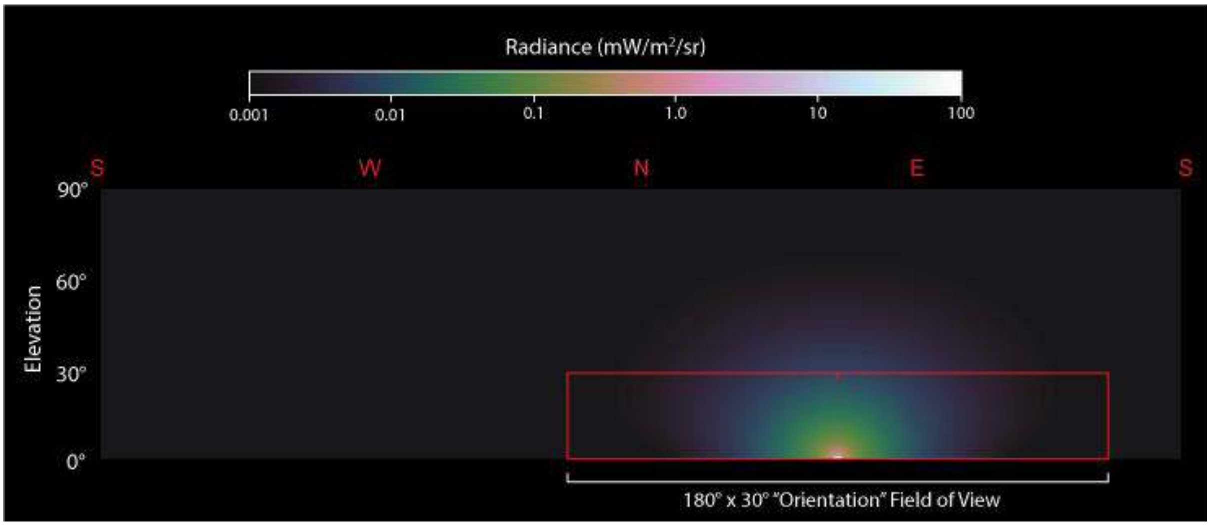

Figure 1: Orientation Field of View centred over the brightest light source in an example modelled output. Pixels within the red area are averaged and presented as OFOV in FME.

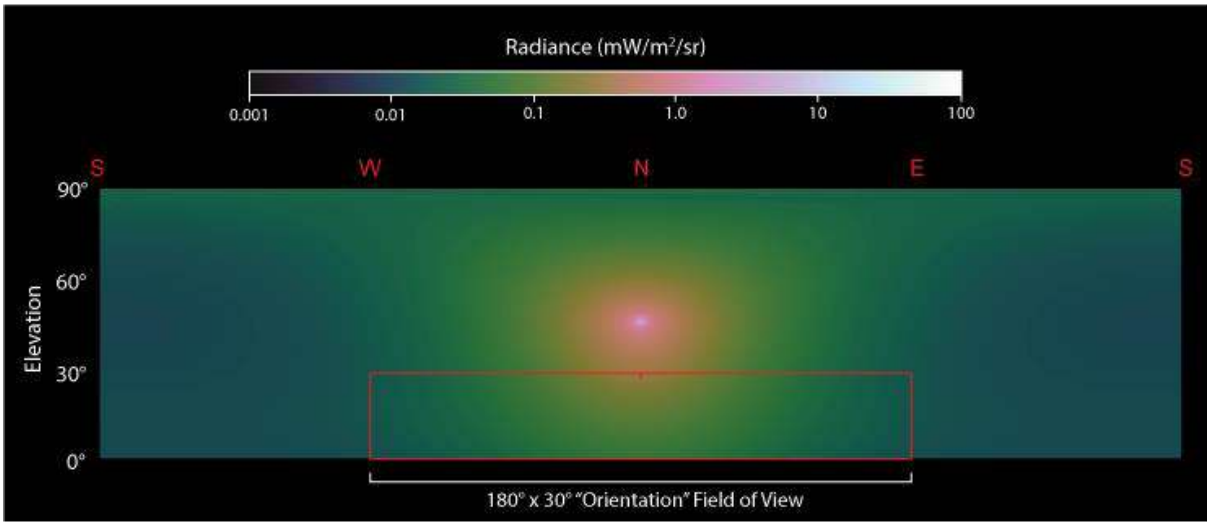

Figure 2: Orientation Field of View centred over the brightest area on a modelled full moon. Pixels within the red area are averaged and used as the value of 1 FME when calculating OFOV FME value of modelled outputs. Note, the moon is modelled at 45 degrees.

Table 1: Artificial light impact potential criteria for marine turtles. *Proportion of radiance of a full moon within orientation field of view, where 100 equals the radiance of one hundred full moons and 0.01 equals 100th the radiance of one full moon.

Impact Level	OFOV (FME) ranges*	Impact potential criteria for marine turtles
5	10 - 100	Light or light glow visible and impact likely. Represents a very bright light, equivalence of to up to 100 times the radiance of one moon. This light radiance will greatly override the moderating influence of the ambient full moon at the time of exposure.
4	1 - 10	Light or light glow visible and impact likely. Represents a bright light, equivalence of to up to 10 times the radiance of one moon. This light radiance will override the moderating influence of the ambient full moon at the time of exposure.
3	0.1 - 1	Light or light glow visible and behavioural impact possible, depending on ambient moon phase at the time of exposure, which will influence the visibility of the artificial light sources, equivalent to the light output. Artificial lights will be more visible to marine turtles under a first quarter moon than under a full moon.
2	0.01 - 0.1	Light or light glow visible but behavioural impact unlikely (i.e. not biologically relevant). Equivalent to the light output from the first quarter moon to new moon.
1	<0.01	Light or light glow is considered ambient and no impact expected. Equivalent to the light output from a new moon.

2.1.2 Modelling Scenarios

The scope of work included the modelling of three scenarios:

- Pipelay vessel Audacia;
- Construction vessel Fortitude; and
- Both vessels located together (cumulative).

2.1.3 Model Inputs

The following general parameters were used as inputs into the model:

- Weather conditions: all scenarios are considered free of any influencing atmospheric or weather conditions (i.e. sun, moon, rain, cloud).
- A detailed lighting inventory based on lighting layout drawings and luminaire manufacturer data sheets provided to PENV by Santos for both the Audacia pipelay vessel and Fortitude construction vessel. See **Appendix A** for detailed lighting information.
- 50 observer viewpoints located at increasing distances from the vessel positions (aligned linearly).

2.1.4 Model Outputs

The model determines the OFOV FME for a set of observer points at increasing distance away from the vessel. This allows for a function of vessel brightness and distance to be created to allow for determination of an impact threshold (i.e. the higher the OFOV FME value and the further the distance it extends, the greater the potential impact). From this output, a contour map can be generated which assesses the direct, reflected, and scattered (glow) light visible within the OFOV at different distances from the light source.

2.1.5 Visibility of Modelled Light at Marine Turtle Nesting Habitat

The closest nesting habitat to the offshore location of the vessels is situated ~7 km to the east at Cape Fourcroy on Bathurst Island in the Tiwi Islands. This habitat is known to support nesting activities of olive ridley and flatback turtles. To determine the visibility of light at this sensitive habitat, the OFOC FME at this habitat was determined for each modelled scenario.

2.1.6 Model Assumptions

The following assumptions were made when generating the model parameters:

- Search lights are excluded.
- All interior lighting is 100 % shielded and therefore not represented within the model.
- All LED lights are considered to be 4000K.
- There is no influence (blocking/shielding) of terrain or vegetation.

2.1.7 Model Limitations

- As this model is still developmental, results have not yet been definitively ground-truthed for large-scale projects (Linareset et al. 2018; Linares Arroyo et al. 2020). While the approach outlined within this report is considered sound at the time of writing, future model results may not be comparable due to updates in the science and methodology that underpin the current software.
- The precision of the model outputs is directly related to the level and accuracy of inputs provided to PENV.
- The model considers light equally across the spectrum (radiometrically) at 100 % sensitivity to all wavelengths. Therefore, it is not representative of the vision of marine turtles which have a high sensitivity to short wavelengths and less sensitivity to longer wavelengths (Commonwealth of Australia 2020). While it is possible to weight model outputs to a spectral sensitivity curve for marine turtles, that has not been done here as the current approach provides a conservative “worst case” scenario where light is assumed to be received at a maximum level across all wavelengths.

3 RESULTS

3.1 Artificial Light Modelling

Out of the modelled vessels, the pipelay vessel Audacia had the highest visible light emissions, reaching 10 OFOV FME at 160 m from the vessel and falling below 0.01 OFOV FME (no impact on hatchling behaviour; **Table 1**) at 14.8 km from the vessel (**Table 2** and **Figure 4a**). Light emissions from the construction vessel Fortitude reached 10 OFOV FME at 126 m from the vessel, and fell below the 0.01 OFOV FME at 10.9 km from the vessel (**Table 2** and **Figure 4b**). Cumulatively, light emissions from both vessels when they were together were the brightest of all scenarios, reaching 10 OFOV FME at 202 m from both vessels and falling below 0.01 OFOV FME at 21.5 km from both vessels (**Table 2** and **Figure 4c**).

Table 2: Distance in metres at which each OFOV FME impact level is reached for each modelled scenario. OFOV = Orientation Field of View, FME = Full Moon Equivalents.

OFOV FME	Impact Level	Distance from vessel (m)		
		Audacia (PV)	Fortitude (CV)	Cumulative
10 – 100	5	<160	<126	<202
1 – 10	4	160	126	202
0.1 – 1	3	724	557	957
0.01 – 0.1	2	3,274	2,469	4,542
<0.01	1	>14,804	>10,949	>21,559

3.2 Visibility of Modelled Light at Marine Turtle Nesting Habitat

OFOV FME at the nesting habitat at Cape Fourcroy on Bathurst Island (~7 km from the closest vessel approach) falls within the 0.1 – 0.01 across all scenarios (**Table 2** and **Figures 5 – 7**). Applying the impact criteria in **Table 1**, light and light glow is likely to be visible at the nesting habitat, but behavioural impacts on hatchlings are unlikely. Behavioural impacts become possible at distances less than 3.2 km for the Audacia, 2.4 km for the Fortitude, and 4.5 km for both vessels together.

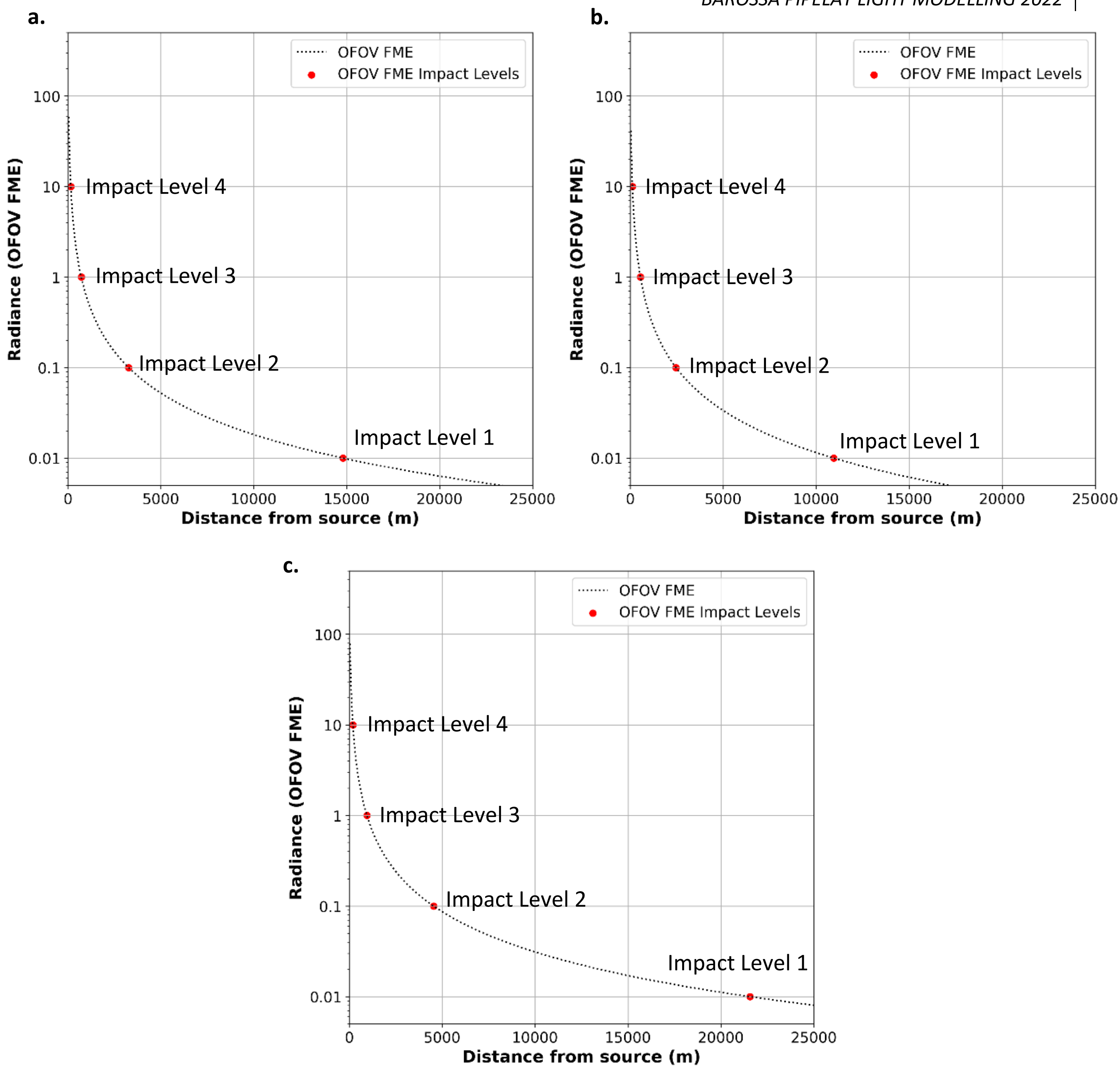

Figure 3: OFOV FME as a function of distance from a. Pipelay Vessel (Audacia); b. Construction Vessel (Fortitude); and c. Cumulative (both vessels). Red dots = Key OFOV FME Impact Levels.

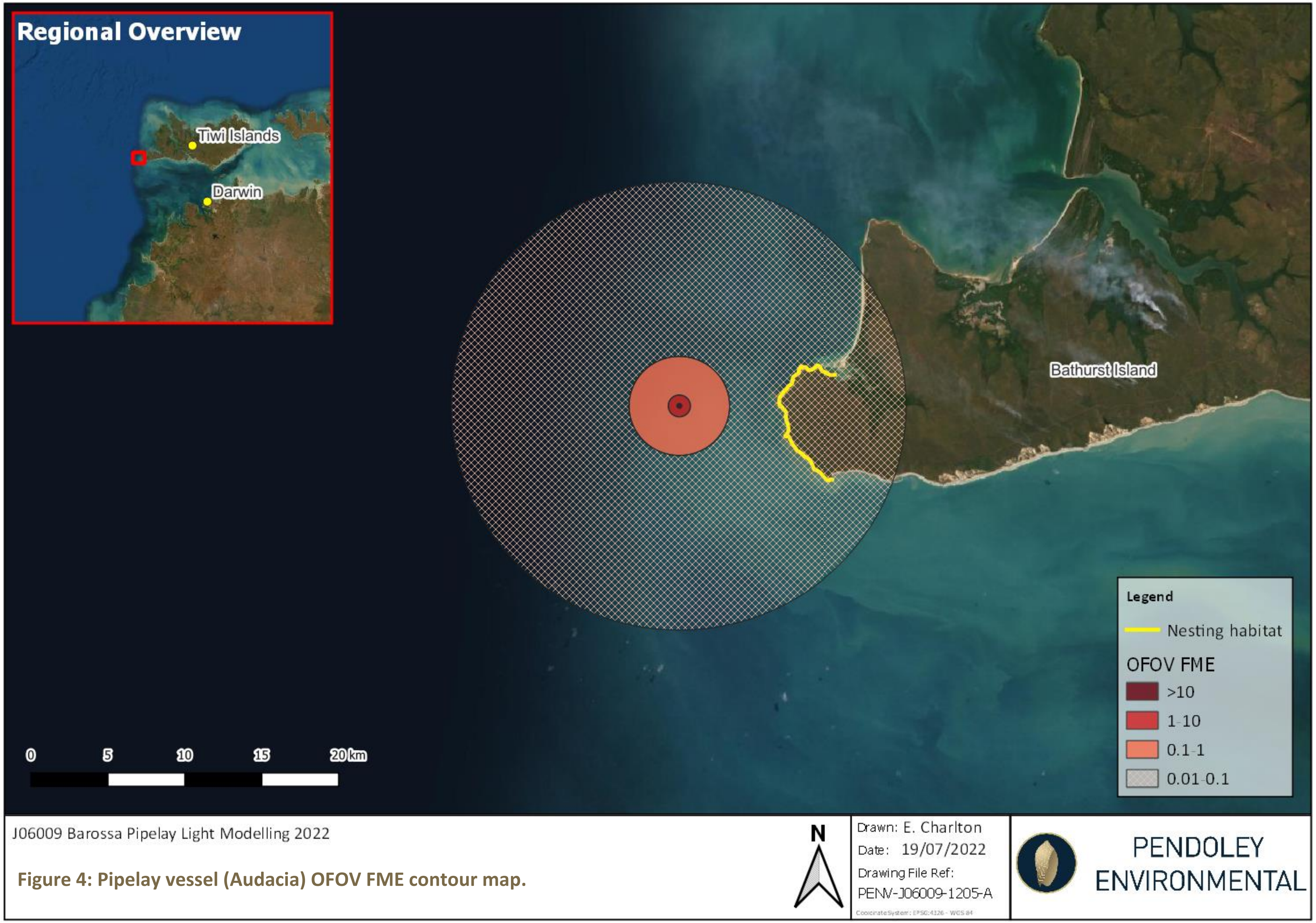

Figure 4: Pipelay vessel (Audacia) OFOV FME contour map.

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Figure 5: Construction vessel (Fortitude) OFOV FME contour map.

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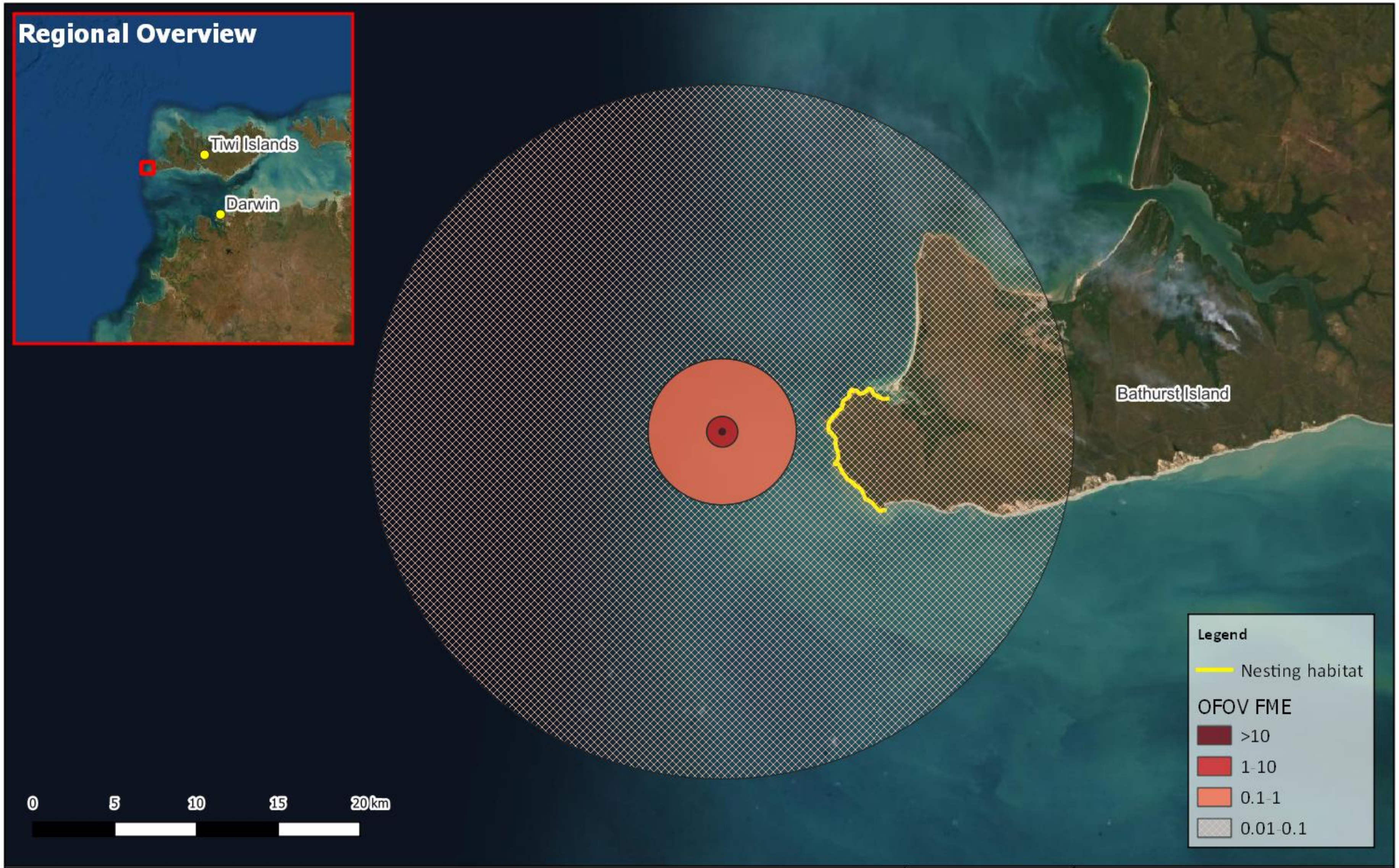

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Figure 6: Cumulative (Audacia + Fortitude) OFOV FME contour map.

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4 SUMMARY

ILLUMINA light modelling was undertaken for three scenarios associated with the Barossa Gas Export Pipeline installation activities:

- Pipelay vessel alone;
- Construction vessel alone; and
- Pipelay vessel and construction vessel located together (cumulative).

Model outputs are presented as a proportion of the radiance of a full moon visible within a hatchling turtle's field of view as a biologically suitable scale that is representative of the natural conditions experienced by a marine turtle hatchling in the field.

Light emissions are greater for the pipelay vessel Audacia compared to the construction vessel Fortitude. The greatest light emissions are predicted when both vessels are operating concurrently in the same location.

Light emissions were predicted to reduce to below ambient levels (0.01 OFOV FME, or 1 %, radiance of a full moon) at 14.8 km from the pipelay vessel Audacia, 10.9 km from the construction vessel Fortitude, and 21.6 km when both vessels are together. There is potential for behavioural impacts to turtles to occur (<0.1 OFOV FME, or 10 %, radiance of a full moon) within 3.3 km of pipelay vessel Audacia, 2.5 km of the construction vessel Foritude, and 4.5 km when both vessels are together. However, no terrestrial nesting habitat occurs within these distances from the vessels.

The OFOV FME received at the closest nesting habitat (~7 km away at Cape Fourcroy on Bathurst Island) falls within the 0.01 – 0.1 OFOV FME range (Impact Level 2) for all modelled scenarios. This means that light emissions are expected to be visible at the habitat, however behavioural impacts to olive ridley and flatback hatchling turtles on the beach are unlikely.

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Appendix A: Vessel light inventory detail

Table 1: Fortitude lighting inventory summary

Description	Power (lumens)	Quantity	Light Spectra
NUC/RAM light	14400	4	4000K LED
RAM/ deep draft	14400	2	4000K LED
Mast head Light	14400	1	4000K LED
White signal	4800	5	4000K LED
Green signal	4800	1	4000K LED
Anchor light	9600	1	4000K LED
Red signal	4800	4	4000K LED
Anchor light	9600	2	4000K LED
Stern light	9600	2	4000K LED
FL-Ceiling (SUS)	5760	10	Fluoro
FL-Ceiling Light (36)	5760	6	Fluoro
FL-Ceiling Light (18)	2880	2	Fluoro
FL-Ceiling (SUS)	5760	9	Fluoro
FL-Ceiling Light (36)	5760	2	Fluoro
FL-Ceiling Light (18)	2880	2	Fluoro
Sodium Flood 400	48000	16	HPS
FL-Ceiling (SUS)	5760	8	Fluoro
Halogen Flood	10000	2	Halogen
Sodium Flood 1000	120000	6	HPS
Sodium Flood 400	96000	14	HPS

Table 2: Audacia lighting inventory summary.

Name	Power (lumens)	Quantity	Light Spectra
VOLTACON LED-T8-12020-F-CW-SE 6000K 120 cm tube	4800	6	4000K LED
PHILIPS Master TL-D 36W/830 120 cm tube	6480	2	Fluoro
Philips HPI-T Plus 400 W E40	33200	8	QMH
PHILIPS Master TL-D 36W/830 120 cm tube	6480	6	Fluoro
Philips HPI-T Plus 400 W E40	33200	2	QMH
PHILIPS Master TL-D 36W/830 120 cm tube	6480	28	Fluoro
Philips HPI-T Plus 400 W E40	33200	6	QMH
PHILIPS Master TL-D 36W/830 120 cm tube	6480	24	Fluoro
VOLTACON LED-T8-12020-F-CW-SE 6000K 120 cm tube	4800	27	4000K LED
PHILIPS Master TL-D 36W/830 120 cm tube	6480	19	Fluoro
Philips HPI-T Plus 400 W E40	33200	2	QMH
VOLTACON LED-T8-12020-F-CW-SE 6000K 120 cm tube	4800	55	4000K LED
PHILIPS Master TL-D 36W/830 120 cm tube	6480	55	Fluoro
VOLTACON LED-T8-6010-F-CW-SE 6000 K 60 cm tube	1900	16	4000K LED
PHILIPS Master TL-D 18W/840 60 cm tube	5400	24	Fluoro
Philips HPI-T Plus 400 W E40	33200	24	QMH
VOLTACON LED-T8-12020-F-CW-SE 6000K 120 cm tube	4800	29	4000K LED
VOLTACON LED-T8-6010-F-CW-SE 6000 K 60 cm tube	1900	6	4000K LED
Philips SON-T 1000W E40	130000	7	HPS
Dialight LED Floodlight Double	53900	4	4000K LED
Dialight LED Floodlight Single	26226	10	4000K LED
Dialight LED Floodlight Single	26226	1	4000K LED
Dialight LED Floodlight Double	53900	1	4000K LED
VOLTACON LED-T8-12020-F-CW-SE 6000K 120 cm tube	4800	10	4000K LED
PHILIPS Master TL-D 36W/830 120 cm tube	6480	56	Fluoro
PHILIPS Master TL-D 18W/840 60 cm tube	5400	4	Fluoro