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Testing, Research and Consulting

REPORT NO: 18525-2

CLIENT: Sunshine Coast Council

2022 Artificial Light at Night Survey for Turtle Nesting Beaches and Migratory Shorebird Habitats

Location: Sunshine Coast

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Report No: 18525-2

Test: 2022 ALAN survey repeat
Location: Sunshine Coast, QLD

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REPORT No: 18525-2 DATE OF ASSESSMENT: May-June 2022

CLIENT: Sunshine Coast Council
Locked Bag 2, Sunshine Coast Mail Centre
Queensland 4560

ASSESSMENT: Artificial Light at Night Survey for Turtle Nesting Beaches and Migratory Shorebird Habitats

LOCATION: Potential turtle nesting beaches and migratory shorebird habitats of the Sunshine Coast coastline

SURVEY REQUESTED: Artificial Light at Night (ALAN) survey at twelve (12) locations, repeat of the survey undertaken in the *Sunshine Coast and Moreton Bay Benchmark Artificial Light at Night Survey 2017* for comparison against the 2017 data (5-yearly survey), and at six (6) additional locations specified by Council. The survey locations include habitat for sea turtles and migratory shorebirds that is listed as 'habitat critical to survival' for EPBC listed species.

Three pre- and post-development ALAN surveys were also compared to the 2017 and 2022 survey results, where available.

Report No: 18525-2

Test: 2022 ALAN survey repeat
Location: Sunshine Coast, QLD

SUMMARY: The average zenith zone magnitude was compared to those measured as part of the 2017 ALAN survey.

Site Number	Beach	Site	2017 Zonal Magnitude (mag/arcsec²)			2022 Zonal Magnitude (mag/arcsec²)		
			Zen	WoS	Hor	Zen	WoS	Hor
1	North Bribie Island	Ocean Side	20.83	20.71	19.94	20.41	19.70	19.41
2	Bribie Island Spit	western side				19.89	18.73	17.48
3	Shelly	South	20.67	20.45	19.29	20.05	19.54	19.42
4	Shelly	North	20.62	20.47	19.56	20.07	19.79	20.07
5	Currimundi	Currimundi	20.34	20.24	19.41	19.92	19.60	19.79
6	Bokarina	South				19.76	19.30	19.32
7	Bokarina	North				19.65	19.24	19.16
8	Buddina	Coopers Lookout	19.72	19.55	18.55	19.49	19.46	19.72
9	Buddina	Pt Cartwright	20.19	20.09	19.05	19.85	19.49	19.45
10	Mooloolaba	Mooloolaba	19.77	19.67	18.79	19.49	19.05	18.12
11	North Shore	sand bank				19.75	19.06	18.31
12	Goat Island – Maroochy River	sand bank				**19.19**	**18.04**	**16.67**
13	Mudjimba	South	20.51	20.37	18.52	20.20	19.76	19.44
14	Mudjimba	North	20.64	20.51	19.24	20.28	19.89	19.70
15	Marcoola	Esplanade South				20.39	19.87	19.64
16	Yaroomba	South	20.86	20.74	19.75	20.53	20.09	19.84
17	Yaroomba	North	20.85	20.76	20.02	20.46	20.33	20.00
18	Coolum	North	20.31	20.19	19.14	20.09	19.50	19.17

Table 1: Magnitude (mag/arcsec²) for Sunshine Coast, including results from 2017 and 2022 surveys. Cells shaded pink represent increases in sky brightness between 2017 and 2022 and cells shaded green represent decreases in sky brightness between 2017 and 2022. The magnitude for the brightest location is shown with bold font.

The average magnitude has decreased by between 0.22 and 0.62 mag/arcsec² for the zenith zone since 2017, indicating the sky brightness has increased by between 22% and 77%. The least increase in zenith zone brightness was measured at Coolum North, and the greatest increase was measured at Shelly Beach South. The zenith magnitude at the brightest location, Goat Island, is 3.4 times brighter than the darkest location, Yaroomba North, due to high mounted, high intensity sources spilling light in the direction of Goat Island, beyond the intended park or road footprint, and residential and commercial lighting throughout Cotton Tree and Maroochydore.

The disruption to wildlife from artificial light at night can be mitigated by following Best Practice Lighting Design Principles[1].

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FIGURES

TABLES

IMAGES

Version control

Version	Date
Draft	May 2023
Final	August 2023
Amendment 1	July 2024

Amendment notes

Version	Details of changes
Amendment 1	Definition of brightness revised to reference equipment used. Definition of “brightness” included reference to naked eye however no species was listed, and measurements were taken using equipment. Reference to “visual magnitude” replaced with “magnitude”. Assumption included for comparison between 2017 and 2022 results.

1 DEFINITIONS

ALAN is Artificial Light At Night and refers to artificial light outside that is visible at night.

Artificial light is composed of visible light as well as some ultraviolet (UV) and infrared (IR) radiation that is derived from an anthropogenic source.

Artificial sky glow is the part of the sky glow that is attributable to human-made sources of light (see also **sky glow**).

Baffle is an opaque or translucent element to shield a light source from direct view, or to prevent light reflecting from a surface like a wall.

Brightness is the strength of the radiant energy produced by illuminated objects weighted to the spectral responsivity of the measurement device.

Colour temperature is the perceived colour of a light source ranging from cool (blue) to warm (yellow), measured in Kelvin (K). A low correlated colour temperature such as 2500K will have a warm appearance while 6500K will appear cold.

Correlated Colour Temperature (CCT) is a simplified way to characterize the spectral properties of a light source and is correlated to the response of the human eye. Colour temperature is expressed in Kelvin (K).

Cumulative light refers to increased sky brightness due to light emissions contributions from multiple light producers. Measured as **sky glow**.

Disorientation refers to any species moving in a confused manner e.g. a turtle hatchling circling and unable to find the ocean.

EPBC Act is the Commonwealth Environment Protection and Biodiversity Conservation Act 1999.

Illuminance is a **photometric** measure of the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted to correlate with human brightness perception. Illuminance is measured in **lux** (lx) or equivalently in **lumens** per square metre (lm/m^2).

Intensity is the amount of energy or light in a given direction.

Kelvin (K) is the absolute unit for temperature and is equal in magnitude to one degree Celsius. Kelvin is typically used to describe **Correlated Colour Temperature (CCT)**.

Lamp is a generic term for a source of optical radiation (light), often called a “bulb” or “tube”. Examples include incandescent, fluorescent, high-intensity discharge (HID) lamps, and low-pressure sodium (LPS) lamps, as well as light-emitting diode (LED) modules and arrays.

LED is a light-emitting diode, or a semiconductor light source that emits light when current flows through it.

Light fitting (**luminaire**) is the complete lighting unit. It includes the bulb, reflector (mirror) or refractor (lens), the ballast, housing and the attached parts.

Light is the radiant energy that is visible to humans and animals. Light stimulates receptors in the visual system and those signals are interpreted by the brain making things visible.

Light pollution is the brightening of the night sky caused by **artificial light**.

Light spill is the light that falls outside the boundaries of the object or area intended to be lit. Spill light serves no purpose and if directed above the horizontal plane, contributes directly to **artificial sky glow**. Also called spill light, obtrusive light or light trespass.

Lighting controls are devices used for either turning lights on and off, or for dimming.

LPS is a low pressure sodium lamp that produces a characteristic wavelength near 589 nm.

Luminaire refers to the complete lighting unit (fixture or light fitting), consisting of a lamp, or lamps and ballast(s) (when applicable), together with the parts designed to distribute the light (reflector, lens, diffuser), to position and protect the lamps, and to connect the lamps to the power supply.

Magnitudes per square arc second (**magnitudes/arcsec2)** (**radiometric term**) is a term used in astronomy to measure sky brightness within an area of the sky that has an angular area of one second by one second. The term magnitudes per square arc second means that the brightness in magnitudes is spread out over a square arcsecond of the sky. Each magnitude lower (numerically) means just over 2.5 times more light is coming from a given patch of sky. A change of 5 magnitudes/arcsec2 means the sky is 100x brighter.

Misorientation occurs when a species moves in the wrong direction, e.g. when a turtle hatchling moves toward a light and away from the ocean.

Mounting height is the height of the fitting or bulb above the ground.

Natural sky glow is that part of the **sky glow** that is attributable to radiation from celestial sources and luminescent processes in the Earth's upper atmosphere.

Outdoor lighting is the night-time illumination of an area by any form of outside light fitting (luminaire).

Outside light fitting means a light fitting (luminaire) that is attached or fixed outside or on the exterior of a building or structure, whether temporary or permanent.

Photocells are sensors that turn lights on and off in response to natural light levels. Some advanced mode can slowly dim or increase the lighting (see also **smart controls**).

Reflected light is light that bounces off a surface. Light coloured surfaces reflect more light than darker coloured surfaces.

Screens are physical barriers used to limit light from a source illuminating an area, and can be in the form of vegetation, buildings, fencing, blinds, or other materials which absorb light.

Shielded light fitting is a physical barrier used to limit or modify the light paths from a luminaire.

Sky glow is the brightness of the night sky caused by the cumulative impact of reflected radiation (usually visible light), scattered from the constituents of the atmosphere in the direction of observation. Sky glow comprises two separate components: natural sky glow and artificial sky glow (see also **natural sky glow** and **artificial sky glow**).

Smart controls are devices to vary the intensity or duration of operation of lighting, such as motion sensors, timers and dimmers used in concert with outdoor lighting equipment.

Spectral power curve provides a representation of the relative presence of each wavelength emitted from a light source.

Task lighting is used to provide direct light for specific activities without illuminating the entire area or object.

Visible light transmittance is the proportion of light transmitted by window glass which is recorded as either TVw (visible transmittance of the window) and is reported as a dimensionless value between 0 and 1, or 0 and 100%. A low TVw (e.g. < 30%) indicates little light is transmitted through the glass while higher TVw values are associated with increasing light transmittance. While the VLT/Tvw rating varies between 0 and 1, most double-glazed windows rate between 0.3 and 0.7, which means that between 30% and 70% of the available light passes through the window.

W/m2 is a measure of radiance, the radiant intensity emitted from a unit area of a source (see **radiance**). This is an appropriate measure for understanding how animals perceive light.

Wattage is the amount of electricity needed to light a bulb. Generally, the higher the wattage, the more **lumens** are produced. Higher wattage and more lumens give a brighter light.

Wavelength as light travels through space it turns a wave with evenly spaces peaks and troughs. The distance between the peaks (or the troughs) is called the wavelength of the light. Ultraviolet and blue light are examples of short wavelength light while red and infrared light is long wavelength light. The energy of light is linked to the wavelength; short wavelength light has much higher energy than long wavelength light.

Zenith is an imaginary point directly above a location, on the imaginary celestial sphere.

2 SURVEY LOCATIONS

Measurements were repeated at twelve survey locations to compare the change in sky glow since 2017. The comparison used data from the *Sunshine Coast and Moreton Bay Benchmark Artificial Light at Night Survey 2017*[5].

Measurements were taken at six (6) additional sites along the Sunshine Coast to obtain current levels for skyglow.

The following three (3) sites were added to the survey to assess the impact of artificial light on turtles.

- Bokarina South;
- Bokarina North; and,
- Marcoola Esplanade South.

The final three (3) sites were added as they were identified by Council as migratory shorebird habitat with significant nearby artificial light:

- Bribie Island Spit (western side);
- North shore; and,
- Goat Island (Maroochy River).

The locations of the sky glow measurements are shown in Table 1 and Figure 1.

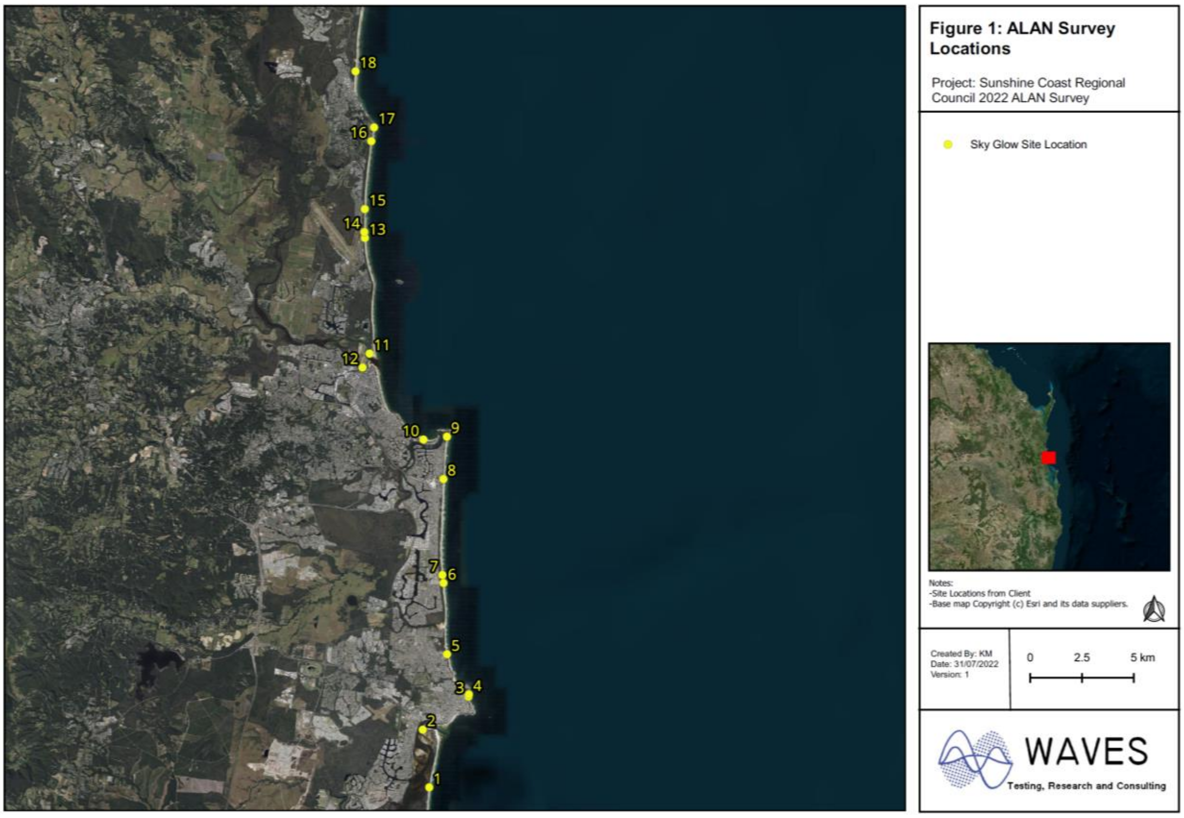


Figure 1: Measurement locations

Site No.	Beach	Site	Latitude	Longitude	New or Repeat
1	North Bribie Island	Ocean-side of Lion's Park	-26.83514	153.12917*	Repeat
2	Bribie Island Spit	Northern end, western side	-26.81000	153.12600	New
3	Shelly Beach	South	-26.79554	153.14821	Repeat
4	Shelly Beach	North	-26.79457	153.14838	Repeat
5	Currimundi	Currimundi	-26.77705*	153.13775*	Repeat
6	Bokarina	South	-26.74601	153.13600	New
7	Bokarina	North	-26.74251*	153.13543*	New
8	Buddina	Coopers Lookout / Kawana SLC	-26.70070	153.13589	Repeat
9	Buddina	Pt. Cartwright	-26.68221	153.13759	Repeat
10	Mooloolaba	Mooloolaba	-26.68348	153.12619	Repeat
11	North Shore	Southernmost point of beach	-26.64601	153.10000	New
12	Goat Island – Maroochy River	South east corner of Goat Island	-26.65209	153.09660	New
13	Mudjimba	South	-26.59300*	153.09745*	Repeat
14	Mudjimba	North	-26.58299*	153.09765*	Repeat
15	Marcoola	Esplanade South	-26.59559	153.09770*	New
16	Yaroomba	South	-26.55337	153.10078	Repeat
17	Yaroomba	North	-26.54737	153.10211	Repeat
18	Coolum	North	-26.52292	153.09311	Repeat

Table 2: Longitude and Latitude of Measurement Locations

* Locations shown with an asterisk represent locations which could not be repeated at the precise location used in the 2017 ALAN survey.

3 ARTIFICIAL LIGHT AT NIGHT SURVEY METHODOLOGY

3.1 Sky Glow Measurements

The sky glow assessment was undertaken to identify which suburbs and infrastructure are providing the greatest contribution to light pollution in the form of sky glow. The methodology used in the 2017 survey was repeated for this survey. The National Light Pollution Guidelines recommends the digital camera with fisheye lens technique as the best compromise between cost, amount of information provided, and ease of use when measuring sky glow[1].

Sky glow was measured using a digital camera and fisheye lens with a field of view covering 0-360° azimuth and ± 92° altitude. The camera and lens combination were calibrated by the manufacturer in July 2020. The calibration involved centre correction, vignetting correction, distortion correction, rotation correction and calibration against fundamental stars of defined astronomical magnitude. Corrections are made for airmass and light absorption in the atmosphere as part of the calibration process.

At each location, a series of photographs were taken throughout the night. Each survey began after last light and was finished prior to first light. Data was collected around the new moon in May and June 2022 on nights with clear sky.

Temperature and relative humidity were measured using a Digitech XC-0424 temperature and humidity data logger with manufacturer quoted accuracy of ± 1°C and ± 4% RH, respectively.

Sky brightness was quantified as magnitude (mag/arcsec^2), determined from radiance measurements weighted to the spectral response of the measurement system. For each site, the zenith, whole of sky and horizon zone magnitudes have been plotted. The results of the 2022 survey were analysed and compared to the results from the 2017 survey. Calculations were performed to determine the percentage change in sky brightness since 2017 and the number of times brighter the location was in 2022 than in 2017. For this comparison, it was assumed that equipment used in the 2017 and 2022 surveys had similar spectral responses.

Data for sites which were not part of the 2017 survey were included in the assessment and compared with natural, rural night skies with unaltered night sky horizon, represented by magnitude of 22 mag/arcsec^2.

3.2 Survey Limitations

At several locations (identified by an asterisk in table 1), the beach had been eroded and the location used in the 2017 survey was below the high tide mark for the 2022 survey. The Mooloolaba measurement location had undergone sand movement by machinery. At other locations, growth of trees or other vegetation occupied the zenith zone, which would have made results less reliable and comparable. For these sites, a new location situated at close proximity to the 2017 survey site was chosen which was above the high tide mark with the zenith zone unobstructed.

Artificial light can be one influencing factor which may deter turtles from nesting on a beach and cause a ‘turn-around’, or may influence foraging behaviour or increase susceptibility to prey for shorebirds. Taking sky glow measurements with bright light sources visible was unavoidable at some locations.

The brightness measurements of the horizon zone are subject to greatest variation simply due to the nature of the measurement. The horizon zone usually includes sand dunes, vegetation in the form of grass, shrubs or trees, light sources both direct and sky glow – which may be temporary or permanent, buildings and other obstructions. The horizon zone has the greatest range of brightness from dark, silhouetted vegetation to bright, visible light sources. Hence, slight changes in the measurement location may impact the use of horizon zone brightness for comparative studies.

4 RESULTS – Sky Glow Assessment

This section illustrates the results and analysis of each survey location. A series of figures and tables are provided to summarise the data collected at each site.

Three (3) zones have been reported for each summary table. Figure 2 illustrates the zenith, horizon and whole of sky zones.

- Zen: Zenith zone 0° - 30° altitude
- Hor: Horizon zone 80° - 90° altitude
- WoS: Whole of Sky zone 0° - 90° altitude

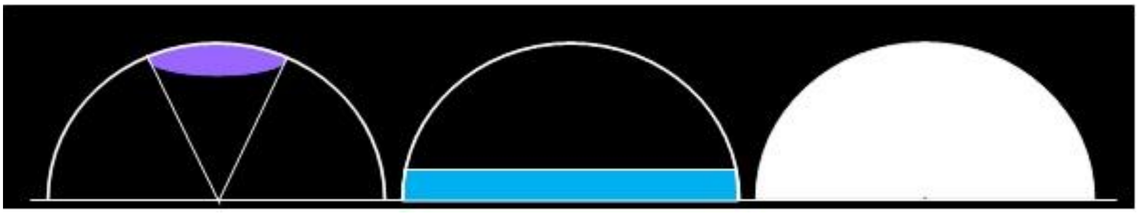


Figure 2: Diagram of the zenith, horizon and whole of sky zones for the sky glow measurements.

The magnitude scale used to represent the data, as per the 2017 ALAN survey, ranges from 16 mag/arcsec² representing bright skies to 24 mag/arcsec² representing intrinsically dark skies. Decreasing values of magnitudes over time indicate the brightness is increasing. The Y-axis of the graphs have been reversed so that the curves reflect the brightness in the images.

Summary results for each location include the 2022 magnitude for zenith, horizon and whole of sky zone, and the 2017 results where available. Cells shaded pink in tables indicate an increase in sky brightness for the comparison stated. Cells shaded green in tables indicate a reduction in sky brightness for the comparison stated.

In figures 3 to 15, the colour of the lines represents the following information:

- PURPLE – Zenith zone (0° - 30° altitude) sky brightness from 2022 ALAN survey
- BLUE – Horizon zone (80° - 90° altitude) brightness from 2022 ALAN survey
- WHITE – Whole of sky (0° - 90° altitude) brightness from 2022 ALAN survey
- RED – Magnitude of 22 mag/arcsec², representative of a rural sky, i.e. unaltered night sky horizon.

The zenith brightness is the most reliable metric for comparing sky glow as it essentially averages out the fluctuations around the horizon and shows the cumulative effect of all light sources and the atmosphere.

For the Shelly Beach South site, one measurement night there was a dwelling with illuminated interior lighting visible from the site, whereas on other measurement nights the dwelling lights were switched off. A comparison of the magnitude with the residential lights on and lights off for the different measurement nights has been provided.

Full hemisphere images used to calculate the magnitude have been included in Appendix 1.

4.1 North Bribie Island (ocean side of Lion's Park) (Site 1)

Figure 3: North Bribie Island (Ocean Side of Lion's Park) measurement site map

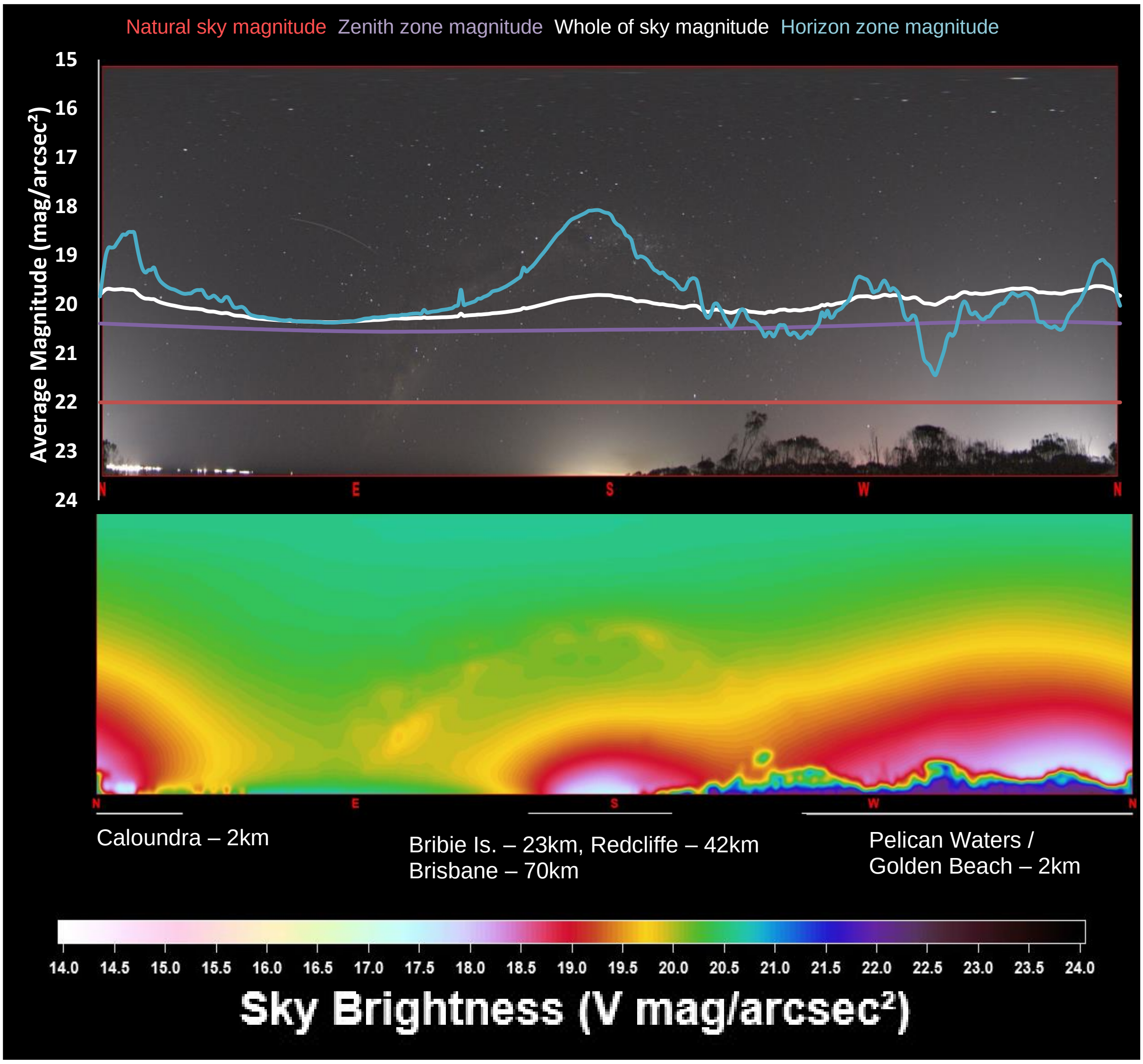


Figure 4: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Bribie Island north (ocean side of Lion's Park). X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

North Bribie Island	Zen	WoS	Hor
2017 (mag/arcsec²)	20.83	20.71	19.94
2022 (mag/arcsec²)	20.41	19.70	19.41
% increase since 2017	47	154	63
x brighter in 2022 than 2017	1.47	2.54	1.63

Table 3: Average magnitude (mag/arcsec²) for North Bribie Island (ocean side of Lion's Park) for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon magnitudes for North Bribie Island (ocean side of Lion's Park) on a clear night were 20.41, 19.70 and 19.41 mag/arcsec² respectively. These values were compared to the same measurements from the 2017 survey: 20.83, 20.71 and 19.94 mag/arcsec². The sky brightness has increased in all zones since 2017. The change in zenith magnitude (20.83 to 20.41 mag/arcsec² from 2017 to 2022) indicates the sky brightness has increased by approximately 47% between surveys. The whole of sky brightness from 2017 to 2022 has increased 2.5 times, and the horizon zone brightness has increased by 63%.

The glow from Caloundra is visible in the west and north-west and the glow from Brisbane and surrounds is visible beyond Woorim in the South. The individual effect of the suburbs of Brisbane, Port of Brisbane, Brisbane Airport, Redcliffe, Gold Coast and Bribie Island are not separable as they are at varying distances in the same general direction (bearing 165° – 195°). However, it is likely they are all contributing to the sky glow visible to the south of the location. Marine vessels were visible to the east.

In the southern direction, the seaward horizon is brighter than zenith due to the cumulative glow in that direction, and is otherwise generally approximately the same brightness as zenith. In remaining seaward directions, the sky above the seaward horizon is darker than the sky above the landward horizon due to significant sky glow from Golden Beach and Pelican Waters. Lights from Kings Beach Esplanade and the area around Lion's Park are visible from the measurement location.

Image 1: A view from the ocean side of Bribie Island north towards Caloundra, showing light sources visible along the Kings Beach foreshore with Lion's Park area producing the greatest light pollution.

4.2 Bribie Island Spit (Site 2) (Shorebird Site)

Figure 5: Bribie Island spit measurement site map

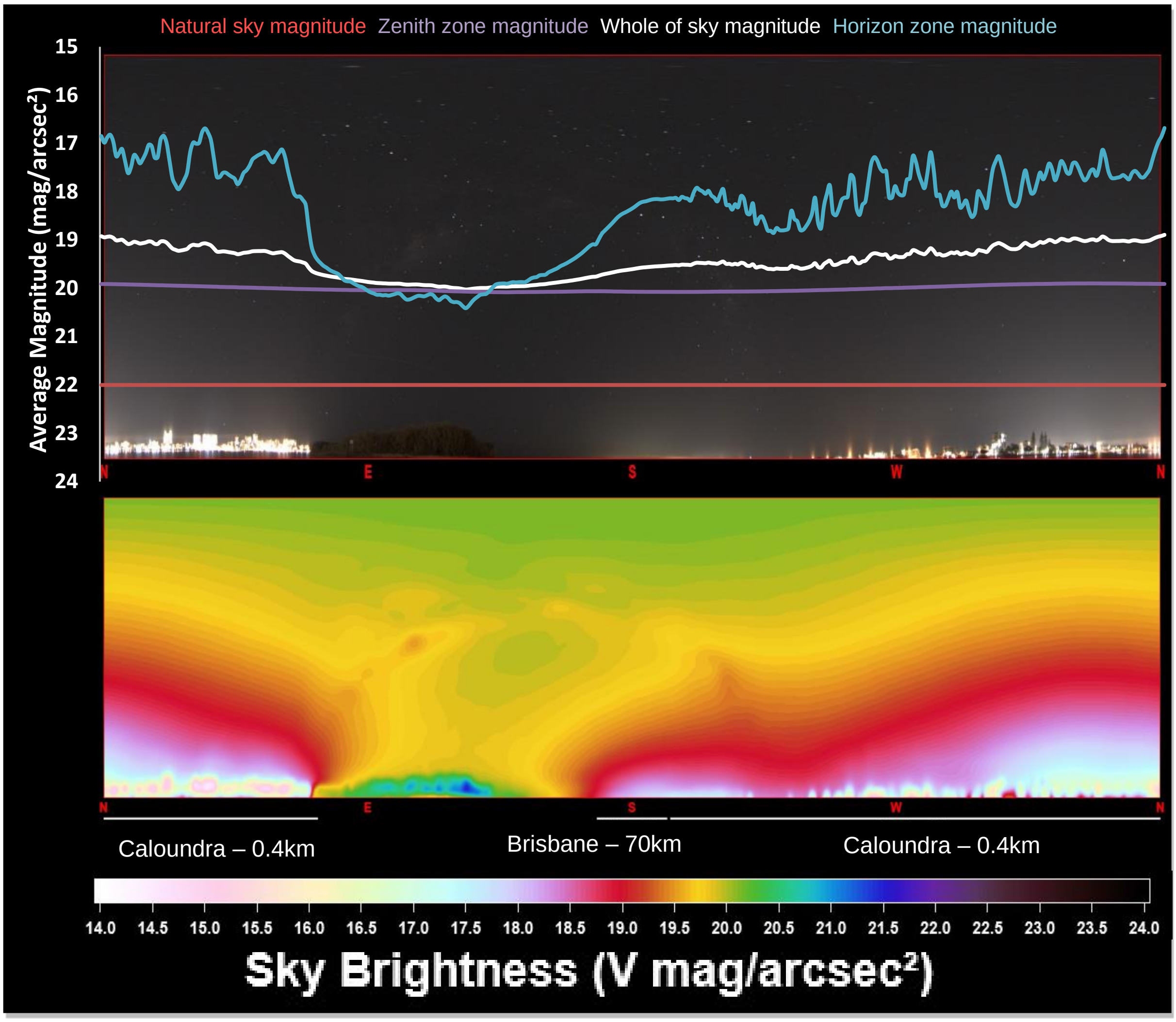


Figure 6: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Woorim Mid, Bribie Island. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Bribie Island Spit	Zen	WoS	Hor
2022 (mag/arcsec²)	19.89	18.73	17.48
x brighter than natural skies	7.00	20.3	64.6

Table 4: Average magnitude (mag/arcsec²) for Bribie Island spit for June 2022, and the number of times brighter the location is than the target magnitude of 22 mag/arcsec².

The average Zenith, Whole of Sky and Horizon magnitudes for the Bribie Island Spit on a clear night were 19.89, 18.73 and 17.48 mag/arcsec² respectively. The zenith zone is seven times brighter than the target magnitude of 22.0 mag/arcsec², and the horizon is 65 times brighter than the target magnitude experienced in locations free from artificial light.

There is significant artificial light, from street, footpath and park lighting, commercial lighting, residential lighting and vehicles which are visible from the measurement location. These sources extend from Kings beach in the north, through Bulcock Beach, along the Golden Beach Esplanade, and beyond, and contribute to significant sky glow in the area. Sky glow produced by Brisbane, at 70 km away, is visible from the Bribie Island spit.

4.3 Shelly Beach South (Site 3)

Figure 7: Shelly Beach South measurement site map

4.3.1 With dwelling lights OFF

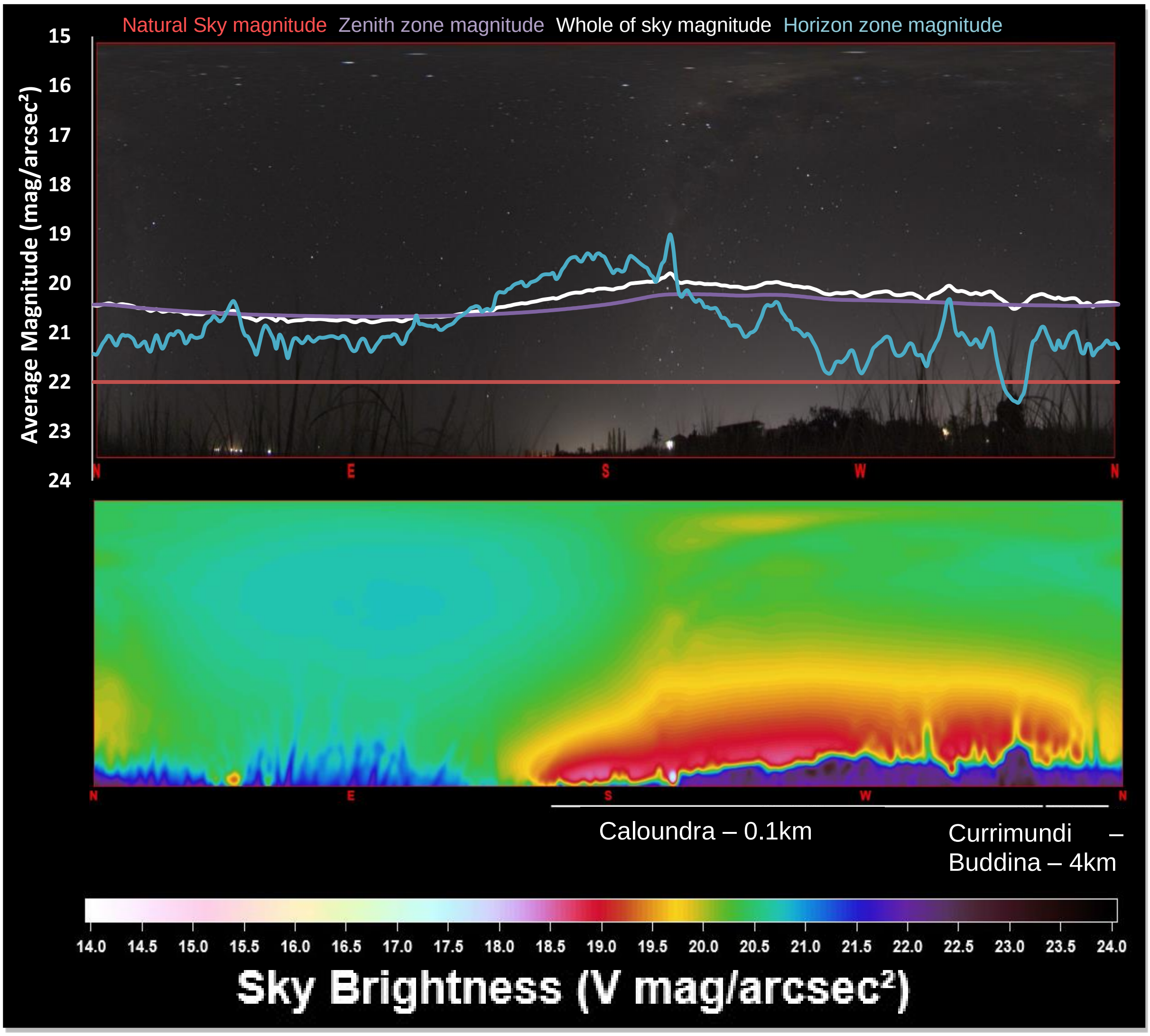


Figure 8: Bearing (°) and average magnitude in clear sky conditions, measured on Friday 24th June 2022 from Shelly Beach South, with dwelling lights OFF. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Shelly Beach South (lights OFF)	Zen	WoS	Hor
2017 (mag/arcsec²)	20.67	20.45	19.29
2022 (mag/arcsec²)	20.27	20.00	20.23
% increase since 2017	45	51	-58
x brighter in 2022 than 2017	1.45	1.51	0.42

Table 5: Average magnitude (mag/arcsec²) for Shelly Beach South (with dwelling lights OFF) for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon magnitudes for Shelly Beach South (with dwelling lights OFF) on a clear night were 20.27, 20.00 and 20.23 mag/arcsec² respectively. These values were compared to the same measurements from the 2017 survey: 20.67, 20.45 and 19.29 mag/arcsec². The change in zenith magnitude (20.67 to 20.27 mag/arcsec² from 2017 to 2022) indicates the sky brightness has increased by approximately 45% between surveys. The increase in whole of sky brightness from 2017 to 2022 is approximately 51%. There has been a reduction in horizon zone brightness between 2017 and 2022, which is likely caused by a difference in nearby residential lighting between the 2017 and 2022 survey times and changes in vegetation around the measurement site.

The seaward horizon is darker than the landward horizon and the peak brightness is landwards, impacted by the glow from Caloundra. The landward horizon was brighter than the seaward horizon due to sky glow caused by artificial light. The peak of the sky glow was in the direction of Caloundra.

4.3.2 With dwelling lights ON

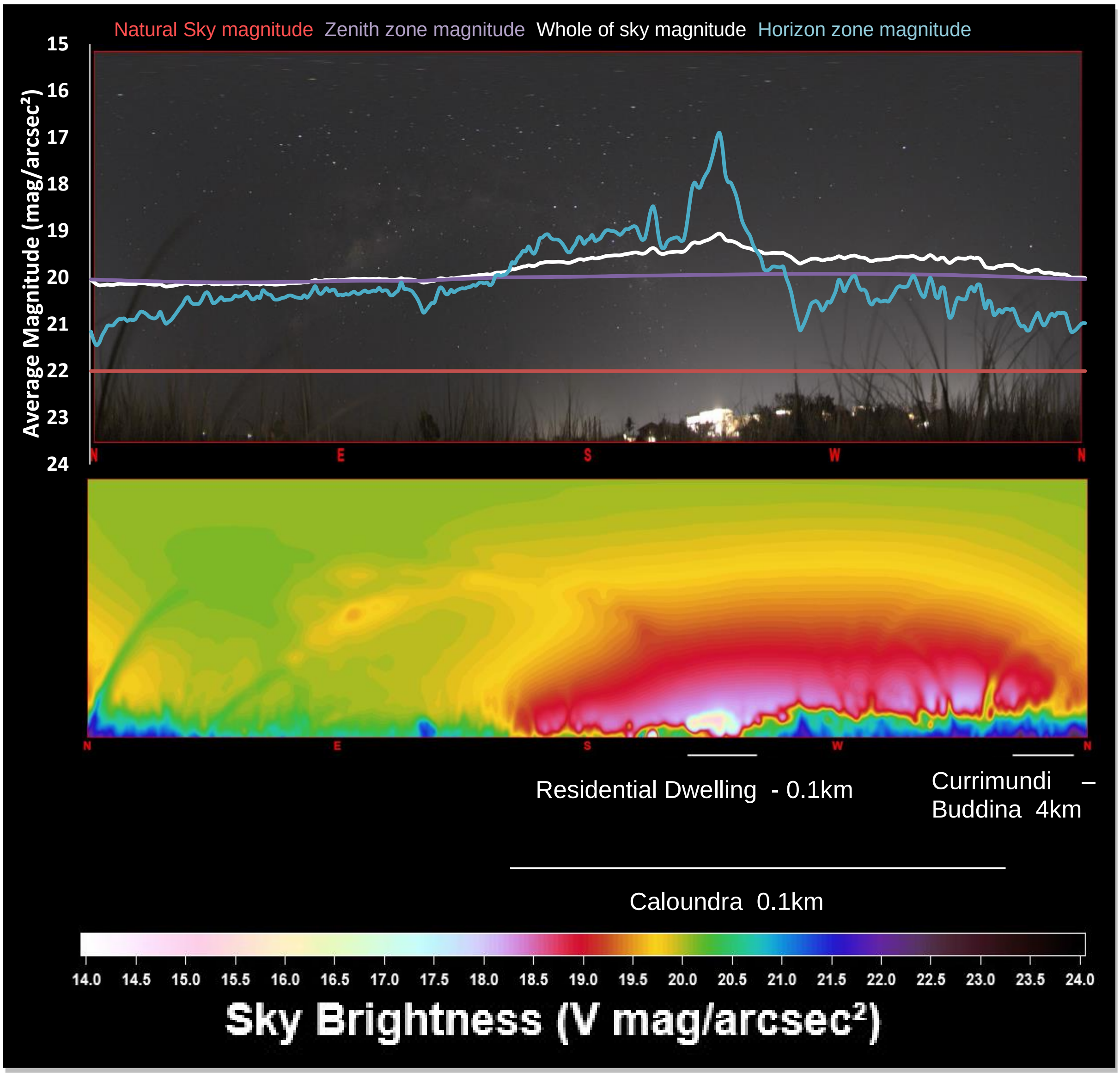


Figure 9: Bearing (°) and average magnitude in clear sky conditions, measured on Monday 27th June 2022 from Shelly Beach South with neighbouring residential lights ON. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Shelly Beach South (lights ON)	Zen	WoS	Hor
2017 (mag/arcsec²)	20.67	20.45	19.29
2022 (mag/arcsec²)	19.96	19.45	18.95
% increase since 2017	93	151	37
x brighter in 2022 than 2017	1.93	2.51	1.37

Table 6: Average magnitude (mag/arcsec²) for Shelly Beach South (with dwelling lights ON) for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The increase in zenith, whole of sky and horizon zone brightness, compared to 2017, is greater in 2022 with the dwelling lights on.

The sky above the seaward horizon is darker than the sky in the landward direction, and the peak brightness is due to lighting of the residential dwelling. The magnitude was compared for the lights ON and lights OFF scenarios for 2022.

Shelly Beach South (Lights ON/OFF Comparison)	Zen	WoS	Hor
2022 Lights ON (mag/arcsec²)	19.96	19.45	18.95
2022 Lights OFF (mag/arcsec²)	20.27	20.00	20.23
% brighter with lights ON	33	66	225
x brighter with lights ON	1.33	1.66	3.25

Table 7: A comparison of the average magnitude (mag/arcsec²) for Shelly Beach South with dwelling lights ON and OFF for 2022, the % change in sky brightness when dwelling lights are ON, and the number of times brighter the sky is when dwelling lights are ON.

The zenith, whole of sky and horizon zones were brighter with the dwelling lights ON. The lights OFF scenario was measured on a Saturday morning, just after midnight, and the lights ON scenario was measured at about 8 p.m. the following Monday. Generally, cumulative light levels are lower during the week and are greater from Friday to Saturday due to increased night-time activity by humans over the weekend, and lower at midnight compared to early evening. The difference in magnitude can be attributed to switching of the dwelling lights and expected changes in sky brightness due to taking the data on different nights and at different times.

4.4 Shelly Beach North (Site 4)

Figure 10: Shelly Beach North measurement site map

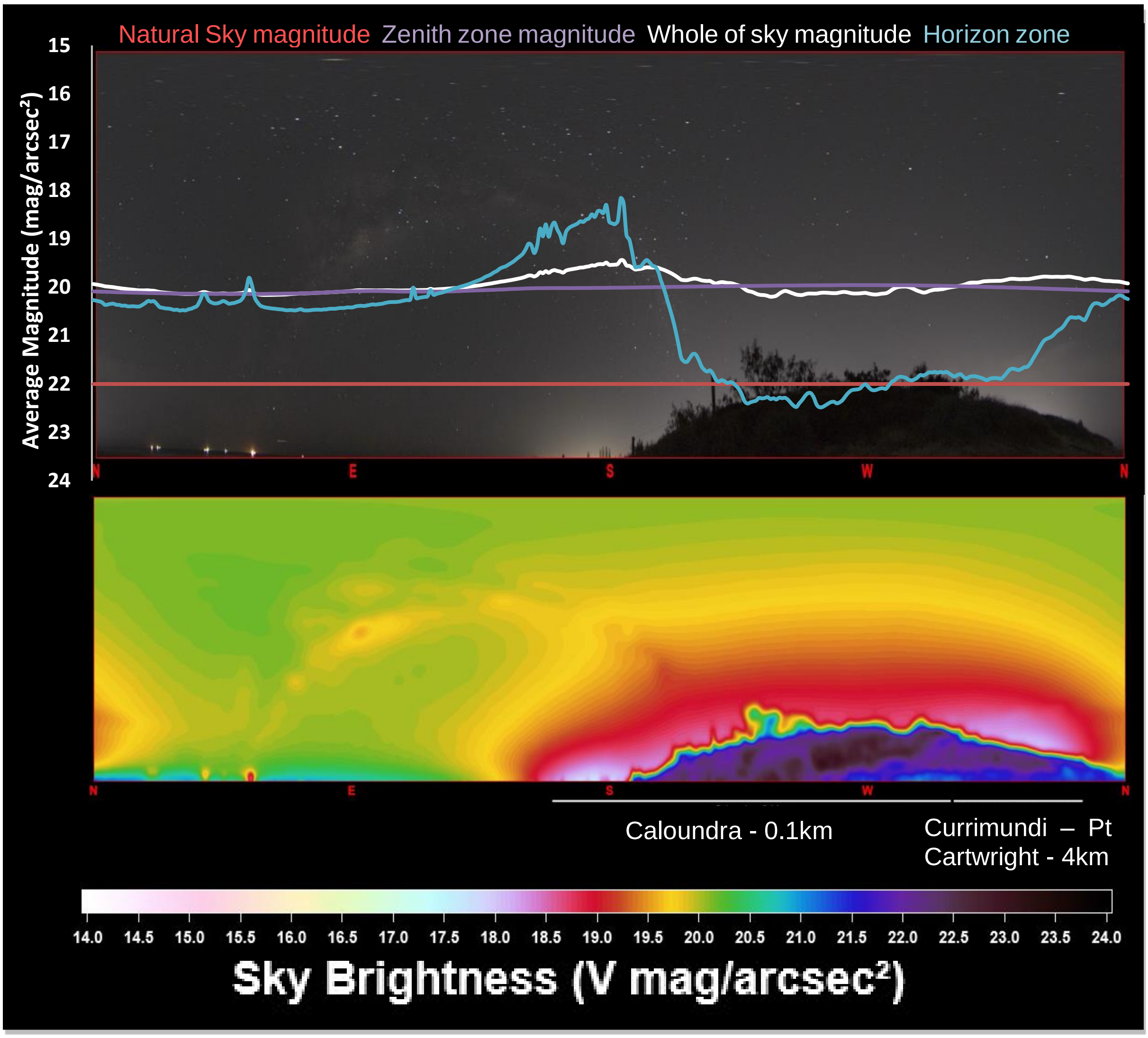


Figure 11: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Shelly Beach North. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Shelly Beach North	Zen	WoS	Hor
2017 (mag/arcsec²)	20.62	20.47	19.56
2022 (mag/arcsec²)	20.07	19.79	20.07
% increase since 2017	65	88	-38
x brighter in 2022 than 2017	1.7	1.9	0.6

Table 8: Average magnitude (mag/arcsec²) for Shelly Beach North for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon zone magnitudes for Shelly Beach North on a clear night were 20.07, 19.79 and 20.07 mag/arcsec² respectively. There was sky glow visible in the direction of Caloundra and the stretch of coastline from Currimundi to Pt Cartwright. Maroochydore, beyond the headland, is likely to be contributing to the sky glow in this direction.

The landward horizon is brighter than the seaward horizon. The peak sky brightness is south towards Caloundra.

4.5 Currimundi (Site 5)

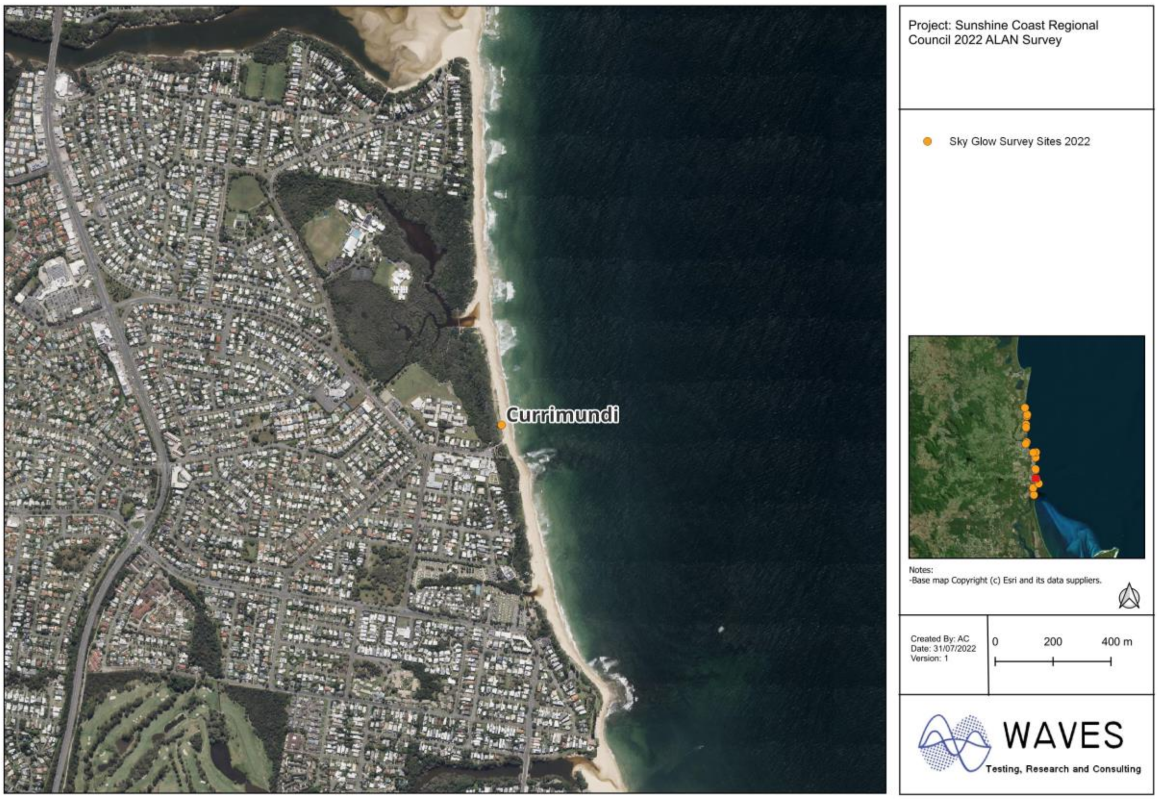


Figure 12: Currimundi measurement site map

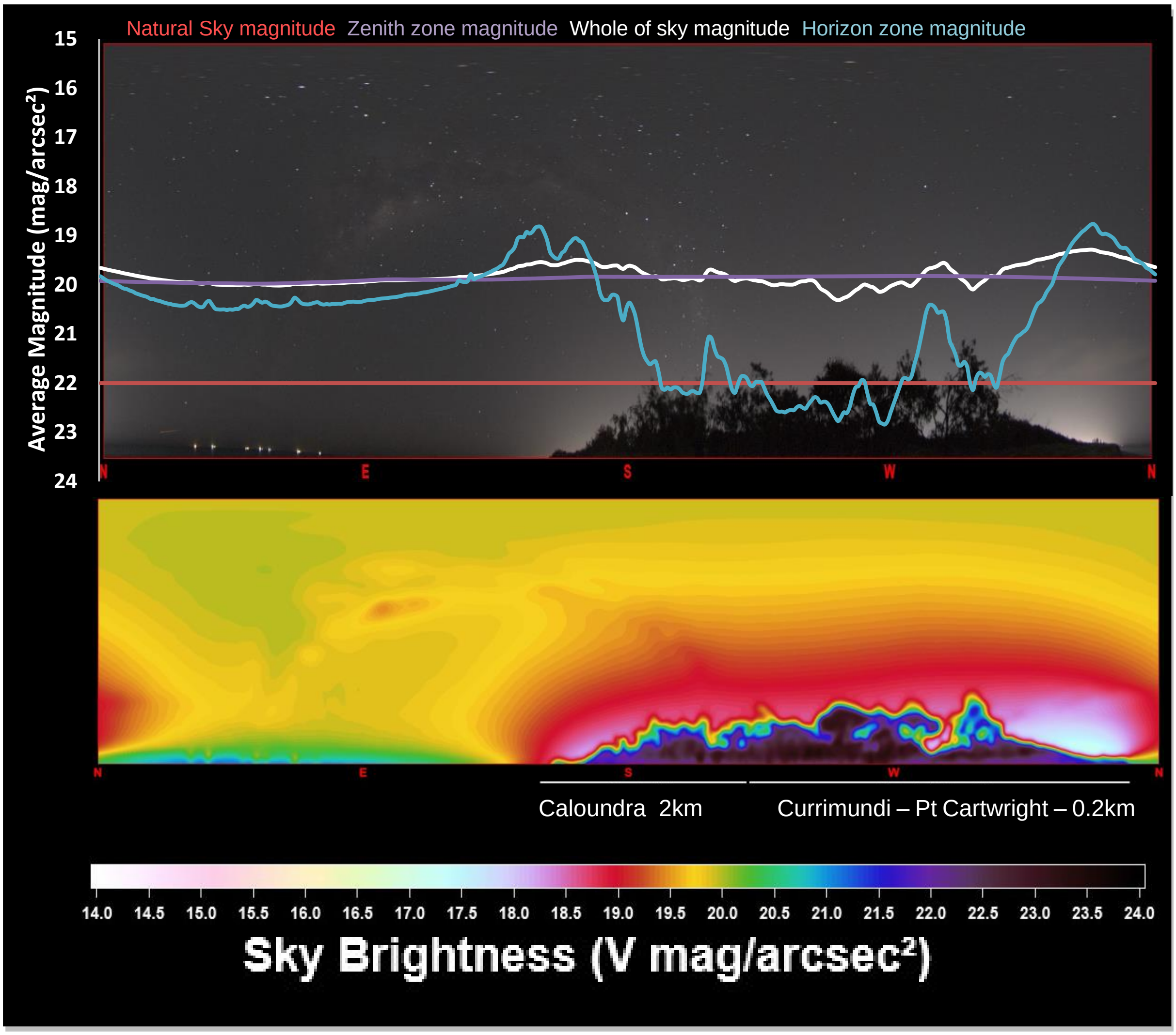


Figure 13: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Currimundi. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Currimundi	Zen	WoS	Hor
2017 (mag/arcsec²)	20.34	20.24	19.41
2022 (mag/arcsec²)	19.92	19.60	19.79
% increase since 2017	48	81	-30
x brighter in 2022 than 2017	1.5	1.8	0.70

Table 9: Average magnitude (mag/arcsec²) for Currimundi for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon zone magnitudes for Currimundi on a clear night were 19.92, 19.60 and 19.79 mag/arcsec² respectively. There was sky glow visible from Caloundra at the south, which increased towards the north-west due to lights from the coastline stretching towards Pt Cartwright.

The landward sky is brighter than the seaward horizon. The peak sky brightness was towards the north-west.

4.6 Bokarina South (Site 6)

Figure 14: Bokarina South measurement site map

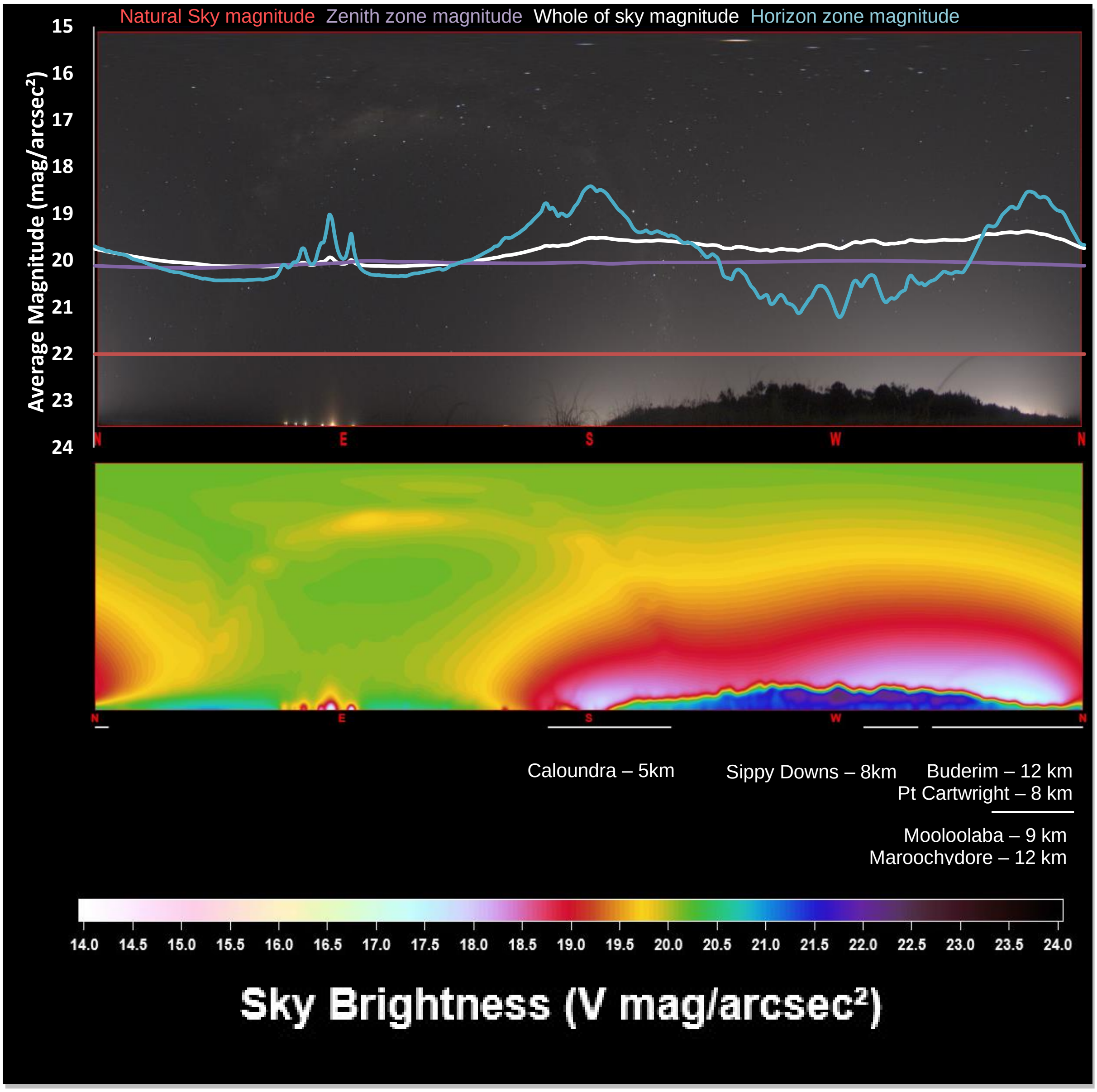


Figure 15*:* Bearing (°) and av magnitude in clear sky conditions, measured in June 2022 from Bokarina South. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Bokarina South	Zen	WoS	Hor
2022 (mag/arcsec²)	19.76	19.30	19.32
x brighter than natural skies (22 mag/arcsec²)	7.9	12.0	11.8

Table 10: Average magnitude (mag/arcsec²) for Bokarina South for June 2022, and the number of times brighter the location is than natural skies.

The average zenith, whole of sky and horizon zone magnitudes for Bokarina South on a clear night were 19.76, 19.30 and 19.32 mag/arcsec² respectively. There was sky glow visible to the south caused by Caloundra, and sky glow to the north caused by the coastline from Buderim to Pt Cartwright. The sky glow in the north-west direction was impacted by the stacking of light sources at different distances, from Birtinya Hospital and retail precinct, to the USC at Sippy Downs. The landward horizon is brighter than the seaward horizon.

The sky brightness for the zenith, whole of sky and horizon zones varied between 7.88 and 12 times brighter than natural, rural night skies.

4.7 Bokarina North (Site 7)

Figure 16: Bokarina North measurement site map

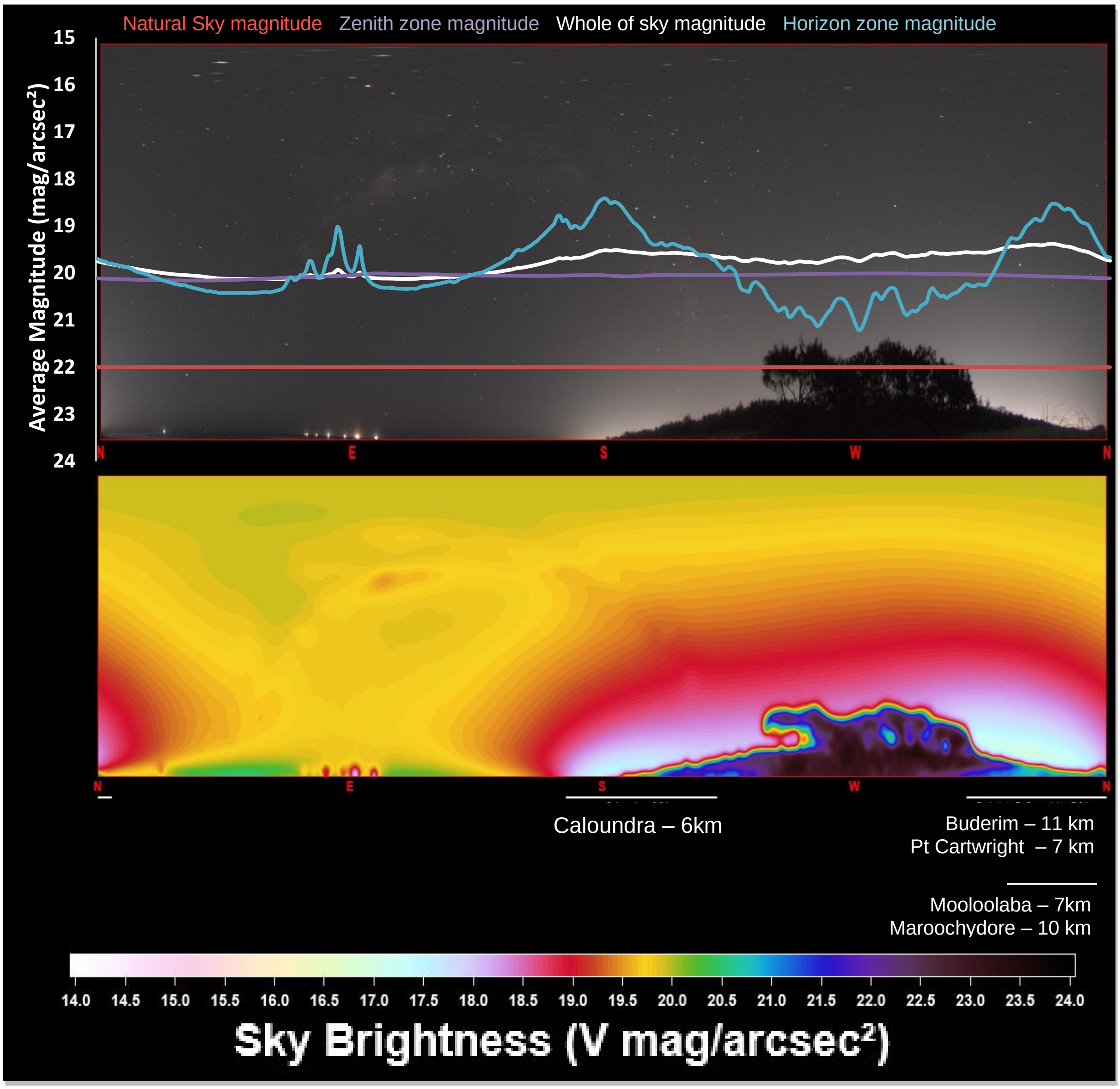


Figure 17*:* Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Bokarina North. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Bokarina North	Zen	WoS	Hor
2022 (mag/arcsec²)	19.65	19.24	19.16
x brighter than natural skies (22 mag/arcsec²)	8.74	12.8	13.7

Table 11: Average magnitude (mag/arcsec²) for Bokarina North for June 2022, and the number of times brighter the location is than the target magnitude of 22 mag/arcsec².

The average Zenith, Whole of Sky and Horizon zone magnitudes for Bokarina North on a clear night were 19.65, 19.24 and 19.16 mag/arcsec² respectively. The peak sky glow was visible to the south caused by lighting throughout Caloundra. Sky glow to the north is caused by lighting along the coastline from Buderim to Pt Cartwright, and to the north-west by Mooloolaba – Maroochydore.

The landward skies are brighter than the seaward horizon.

4.8 Buddina (Coopers Lookout) (Site 8)

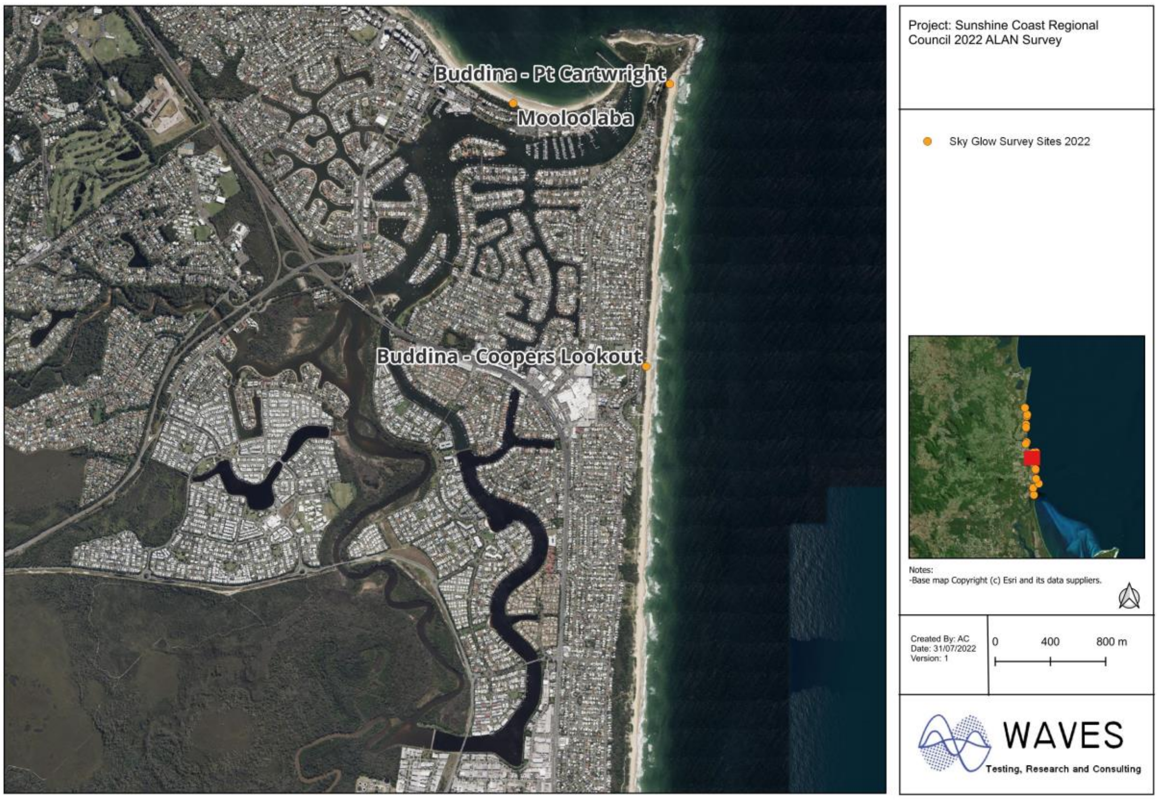


Figure 18: Buddina (Coopers Lookout) measurement site map

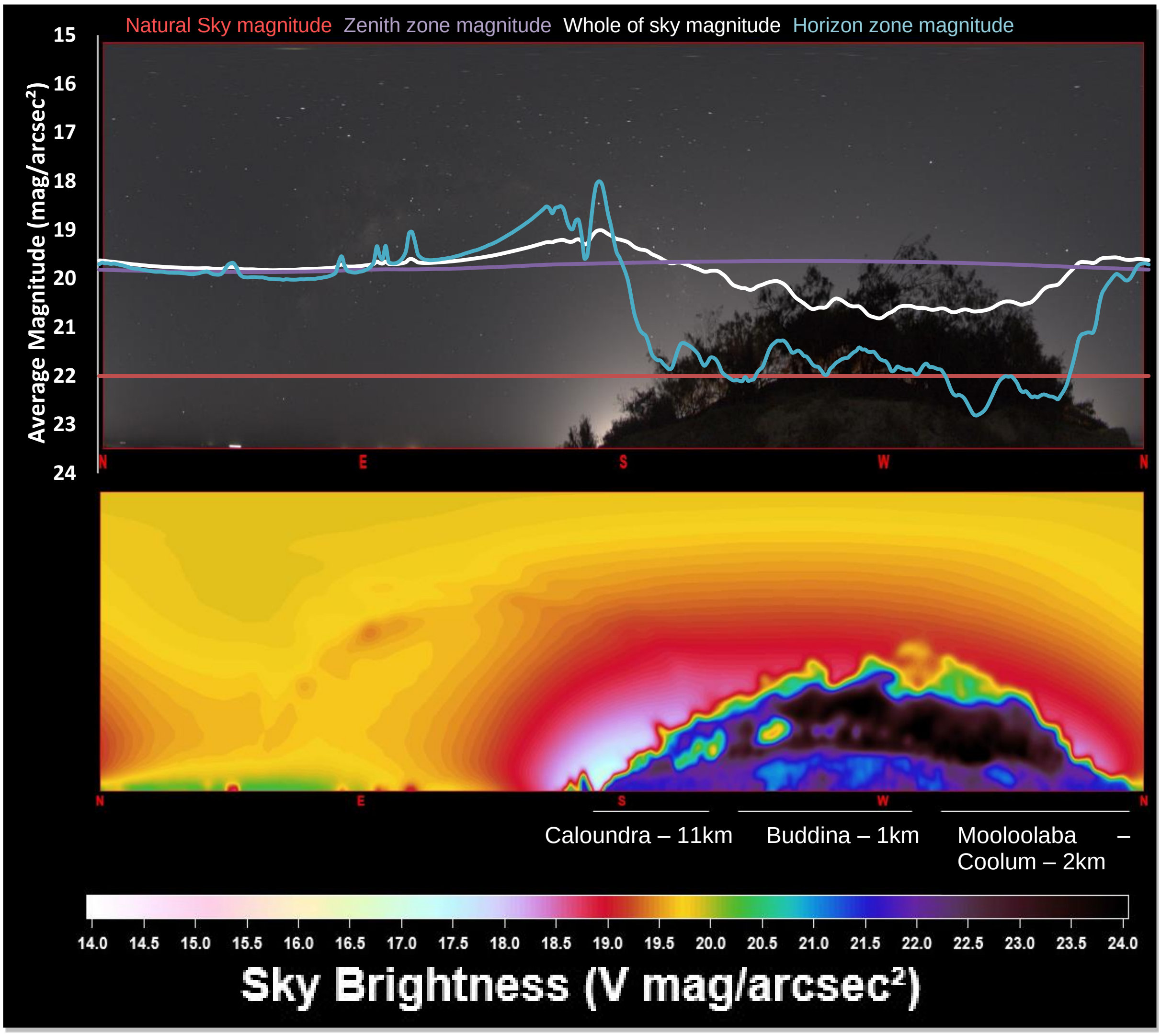


Figure 19: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Buddina – Coopers Lookout. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Buddina – Coopers Lookout	Zen	WoS	Hor
2017 (mag/arcsec²)	19.72	19.55	18.55
2022 (mag/arcsec²)	19.49	19.46	19.72
% increase since 2017	24	9.0	-66
x brighter in 2022 than 2017	1.24	1.09	0.34

Table 12: Average magnitude (mag/arcsec²) for Buddina – Coopers Lookout for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon magnitudes for Buddina – Coopers Lookout on a clear night were 19.49, 19.46 and 19.72 mag/arcsec² respectively. There was sky glow visible to the south caused by lighting from Bokarina to Caloundra, to the west from light sources throughout Buddina, and to the north from light sources throughout Mooloolaba and Coolum.

The landward Skies were brighter than the seaward horizon. The peak sky glow was towards the south.

4.9 Buddina (Pt. Cartwright) (Site 9)

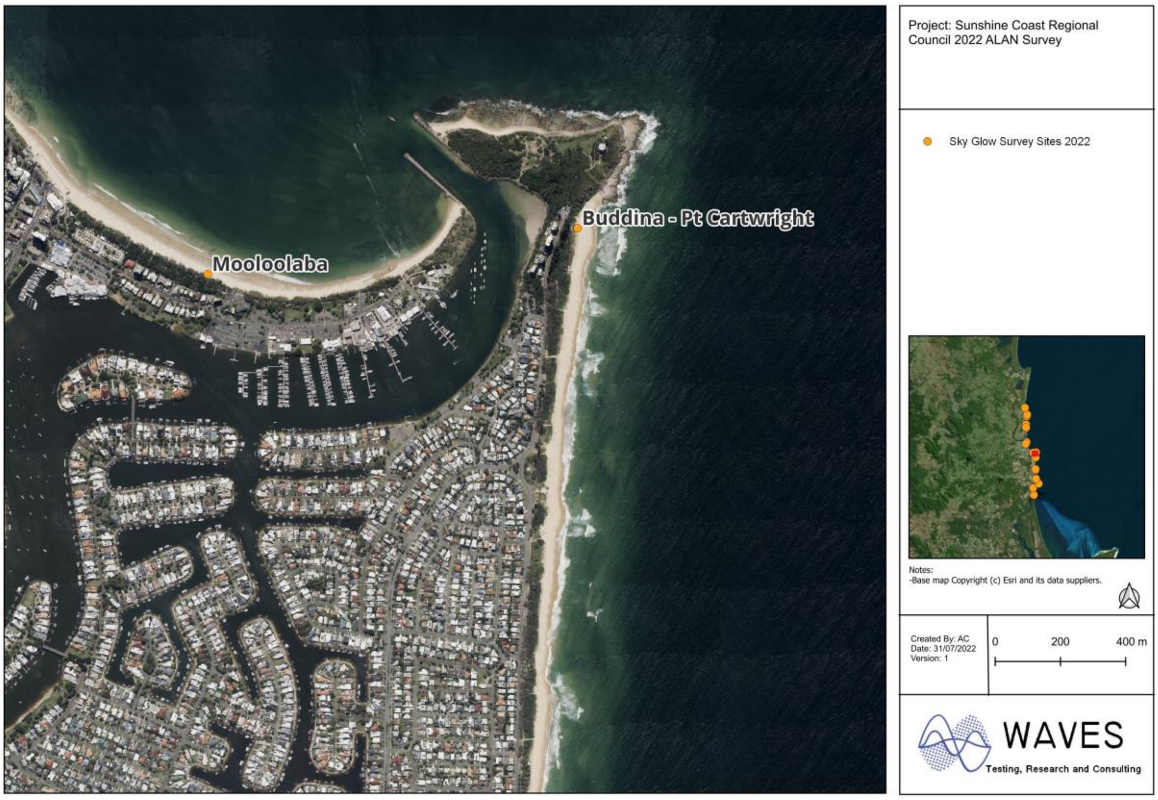


Figure 20: Buddina (Pt Cartwright) measurement site map

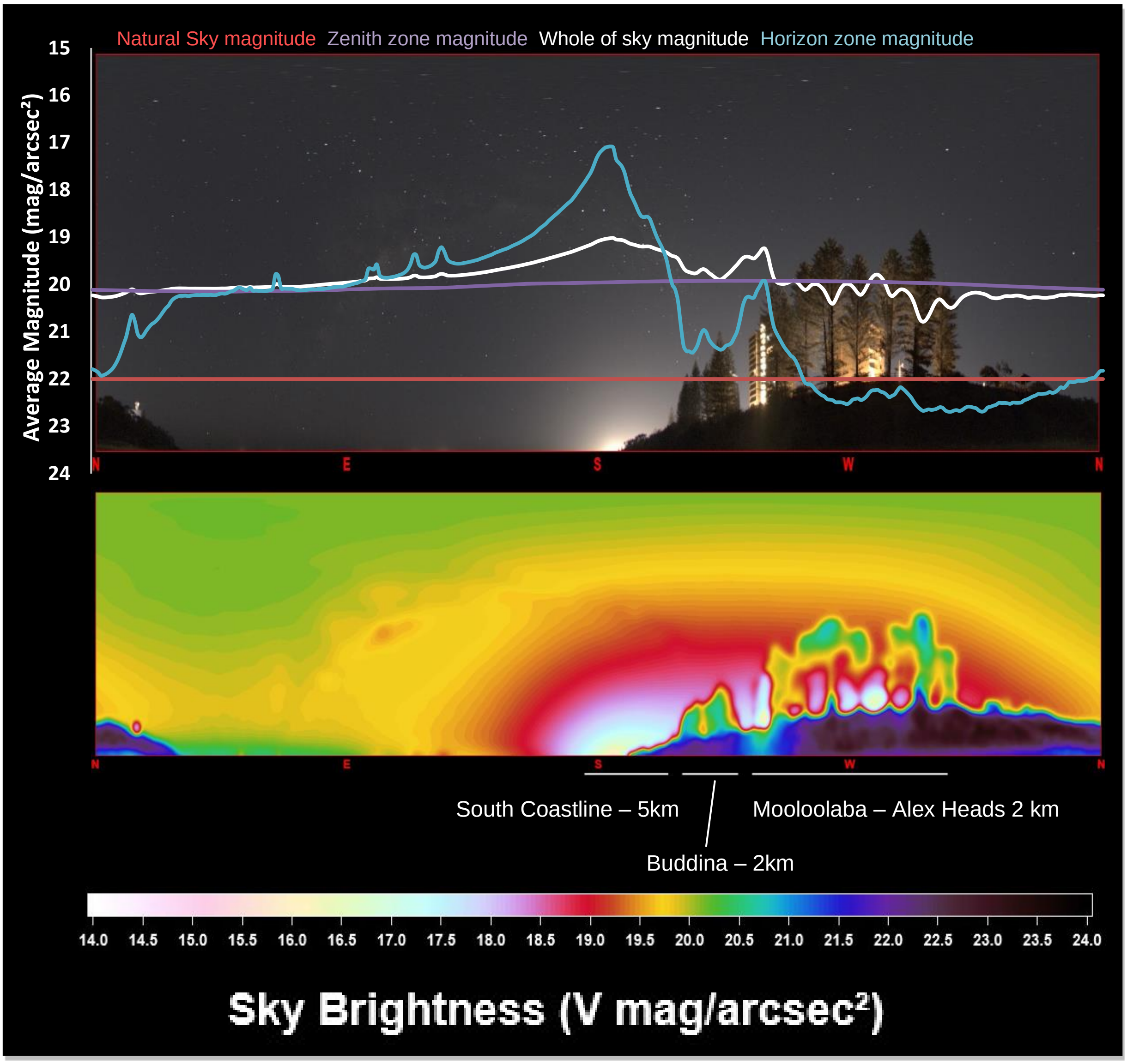


Figure 21: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Buddina (Pt Cartwright). X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Buddina – Pt Cartwright	Zen	WoS	Hor
2017 (mag/arcsec²)	20.19	20.09	19.05
2022 (mag/arcsec²)	19.85	19.49	19.45
% increase since 2017	37	74	-30.5
x brighter in 2022 than 2017	1.37	1.74	0.69

Table 13: Average magnitude (mag/arcsec²) for Buddina – Point Cartwright for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon magnitudes for Buddina (Pt Cartwright) on a clear night were 19.85, 19.49 and 19.45 mag/arcsec² respectively. The peak sky glow was visible to the south caused by light sources along the coastline towards Caloundra. Light sources used to illuminate the footpath and streets, and light from unit blocks atop the hill, were visible from the measurement location, and filtered by tall trees. The landward sky was brighter than the seaward horizon.

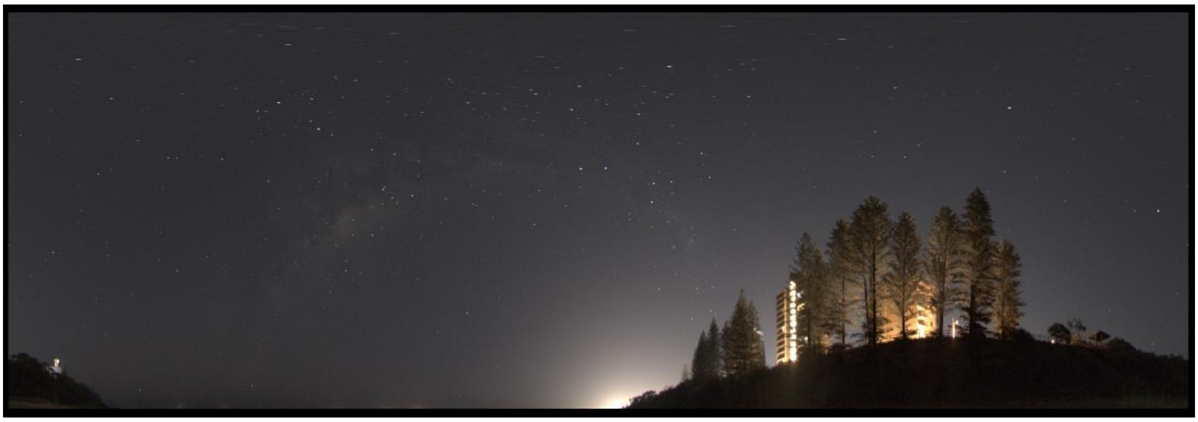


Image 2: Sky glow can be seen to the south and light sources from buildings and roads illuminate trees atop Point Cartwright.

4.10 Mooloolaba (Site 10)

Figure 22: Mooloolaba measurement site map

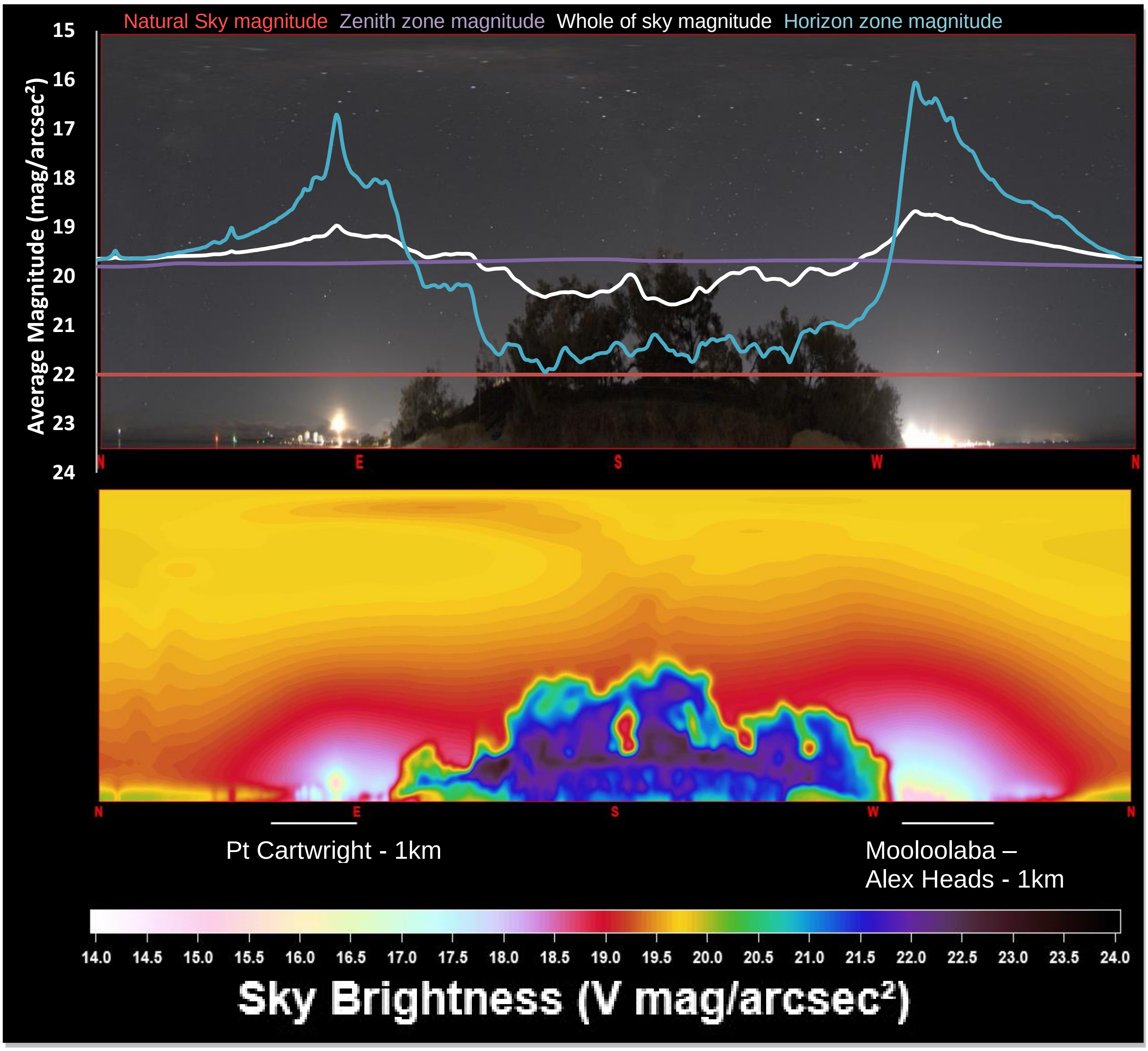


Figure 23: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Mooloolaba. X-axis: bearing from 0 – 360°, Y-axis: Average magnitude (mag/arcsec²).

Mooloolaba	Zen	WoS	Hor
2017 (mag/arcsec²)	19.77	19.67	18.79
2022 (mag/arcsec²)	19.49	19.05	18.12
% increase since 2017	29	76	86
x brighter in 2022 than 2017	1.29	1.76	1.86

Table 14: Average magnitude (mag/arcsec²) for Mooloolaba for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The average zenith, whole of sky and horizon magnitudes for Mooloolaba on a clear night were 19.49, 19.05 and 18.12 mag/arcsec² respectively. There was sky glow visible to the south caused by Port of Brisbane and Brisbane Airport. Light sources towards the Mooloolaba Spit to the east and Mooloolaba Foreshore Park to the west were visible from the measurement location.

The vegetation to the south created a silhouette and the seaward horizon towards the north was about the same brightness as the sky above the silhouette on the landward side towards the south. The brightest skies are along the beach to the east and west, which may cause loggerhead turtle hatchlings to orient along the beach rather than towards the ocean.

4.11 North Shore (Site 11) (Shorebird Site)

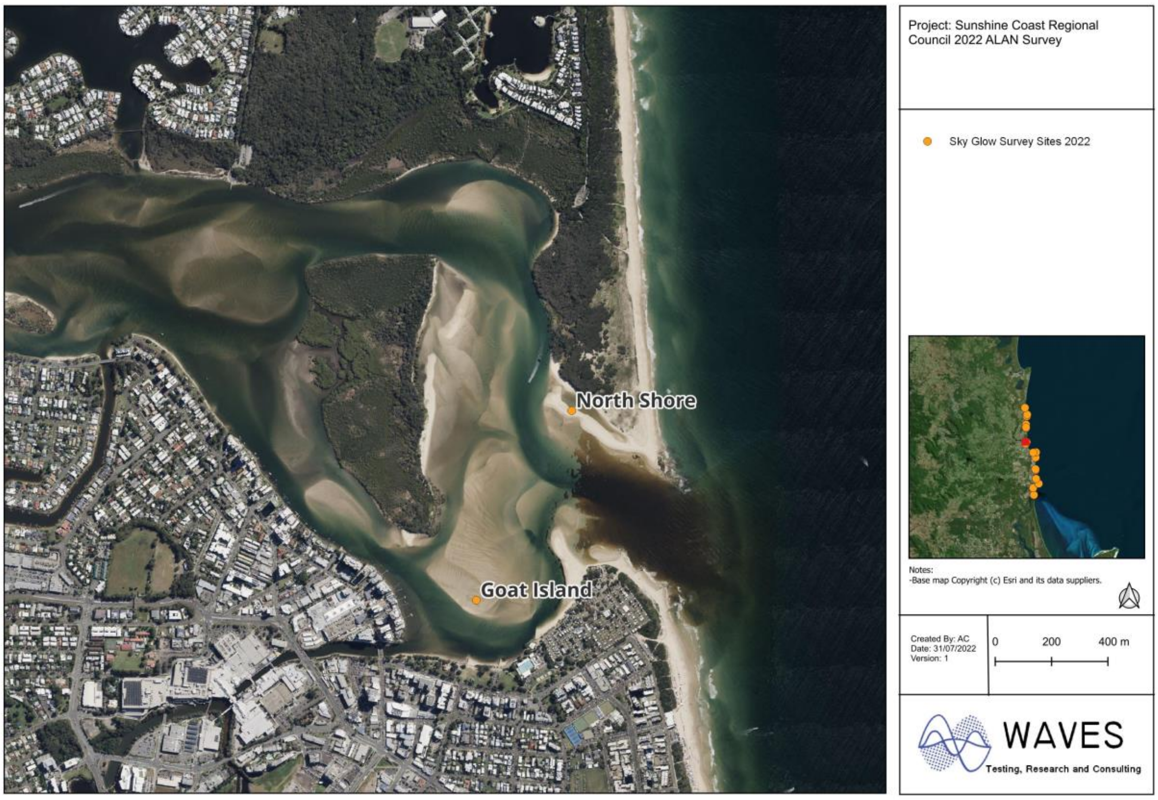


Figure 24: North Shore measurement site map

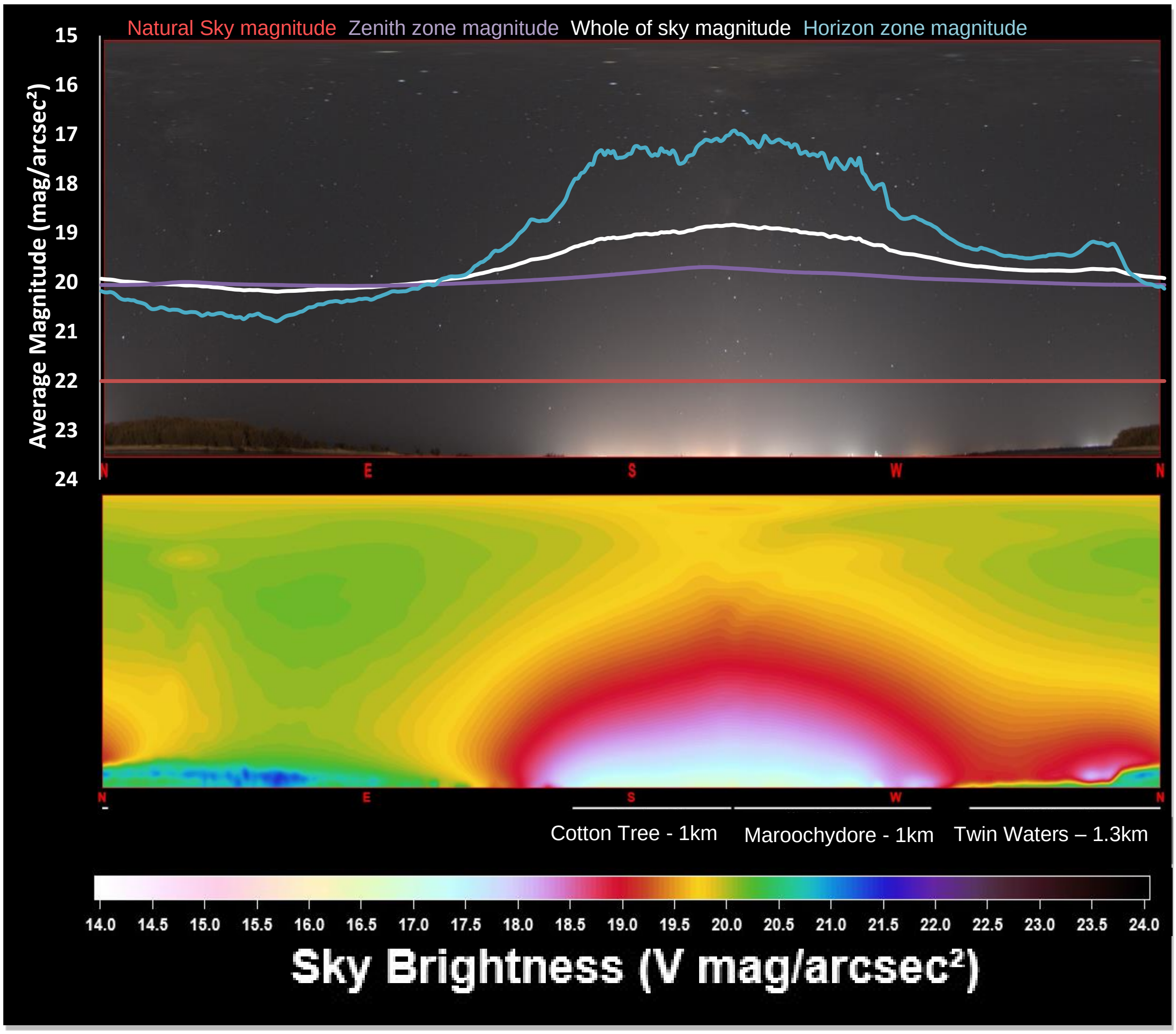


Figure 25*:* Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from North Shore. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec^2).

North Shore	Zen	WoS	Hor
2022 (mag/arcsec²)	19.75	19.06	18.31
x brighter than 22 mag/arcsec²	7.97	15.0	29.8

Table 15: Average magnitude (mag/arcsec²) for North Shore for June 2022, and the number of times brighter the location is than natural, rural skies with unaltered night sky horizon.

The Zenith, Whole of Sky and Horizon magnitudes for North Shore on a clear night were 19.75, 19.06 and 18.31 mag/arcsec² respectively. There is significant sky glow visible from south-east to north.

The sky towards Cotton Tree and Maroochydore, on the landward bank of the Maroochy River, is much brighter than the sky towards North Shore and the seaward side of the peninsula. The zenith, whole of sky and horizon zones vary between approximately 8 times and 30 times brighter than natural night sky brightness levels. The peak sky brightness was towards the commercial precinct of Maroochydore.

4.12 Goat Island (Site 12) (shorebird site)

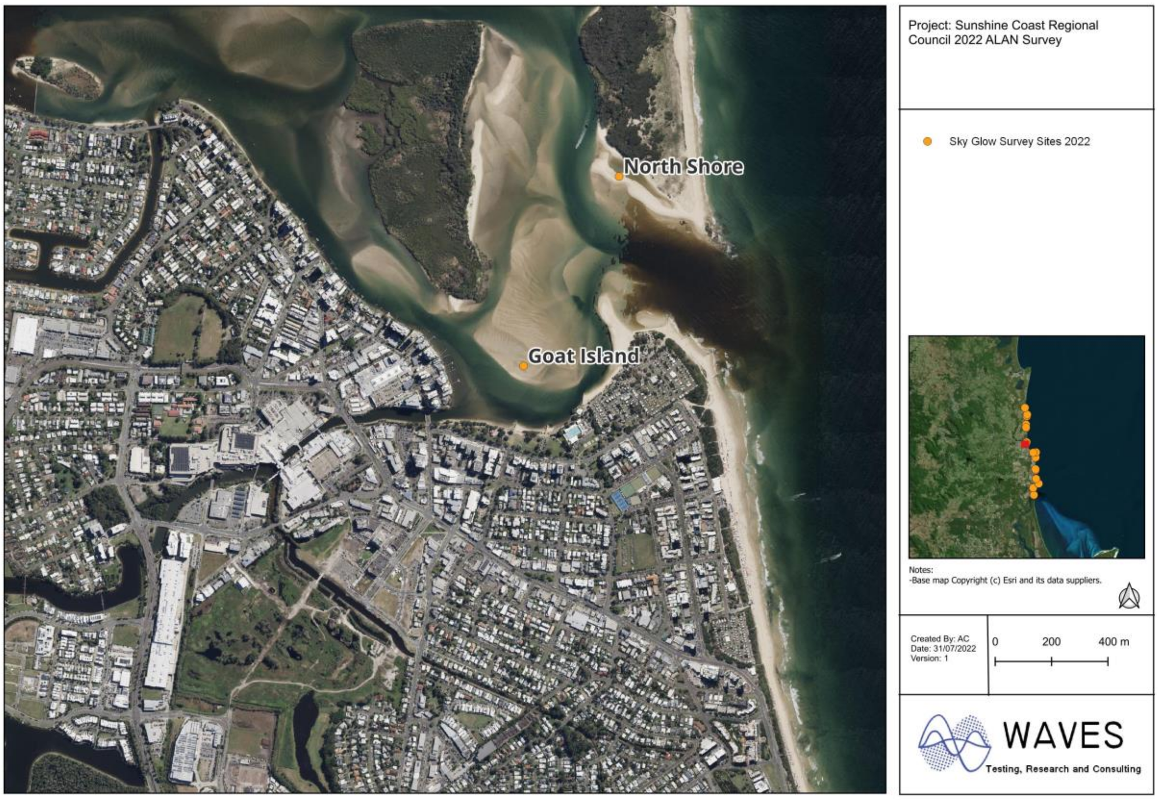


Figure 26: Goat Island measurement site map

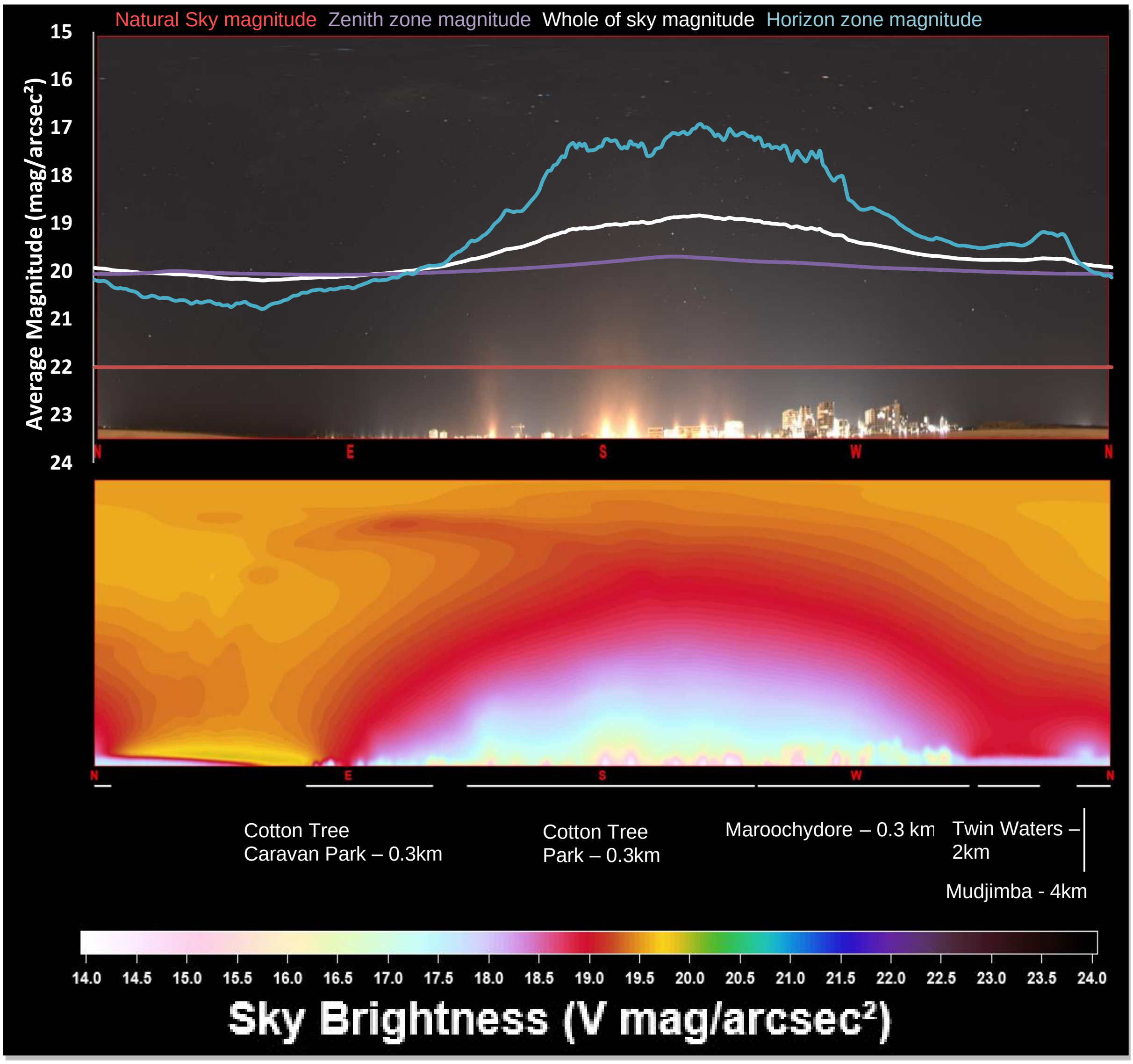


Figure 27: Bearing (°) and average magnitude in clear sky conditions, measured in June 2022 from Goat Island. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Goat Island – Maroochy River	Zen	WoS	Hor
2022 (mag/arcsec²)	19.19	18.04	16.67
x brighter than 22 mag/arcsec²	13.4	38.3	136

Table 16: Average magnitude (mag/arcsec²) for Bokarina North for June 2022, and the number of times brighter the location is than the target magnitude of 22 mag/arcsec².

The Zenith, Whole of Sky and Horizon magnitudes for Goat Island on a clear night were 19.19, 18.04 and 16.67 mag/arcsec² respectively. There are many visible light sources and significant sky glow from east to north. Many light sources are visible from the measurement site. The sky zones vary between approximately 13 times and 136 times brighter than natural night sky brightness levels.

The skies towards the mainland are significantly brighter than the skies towards the ocean and North Shore.

4.13 <u>Mudjimba South (Site 14)</u>

Figure 28: Mudjimba South measurement site map

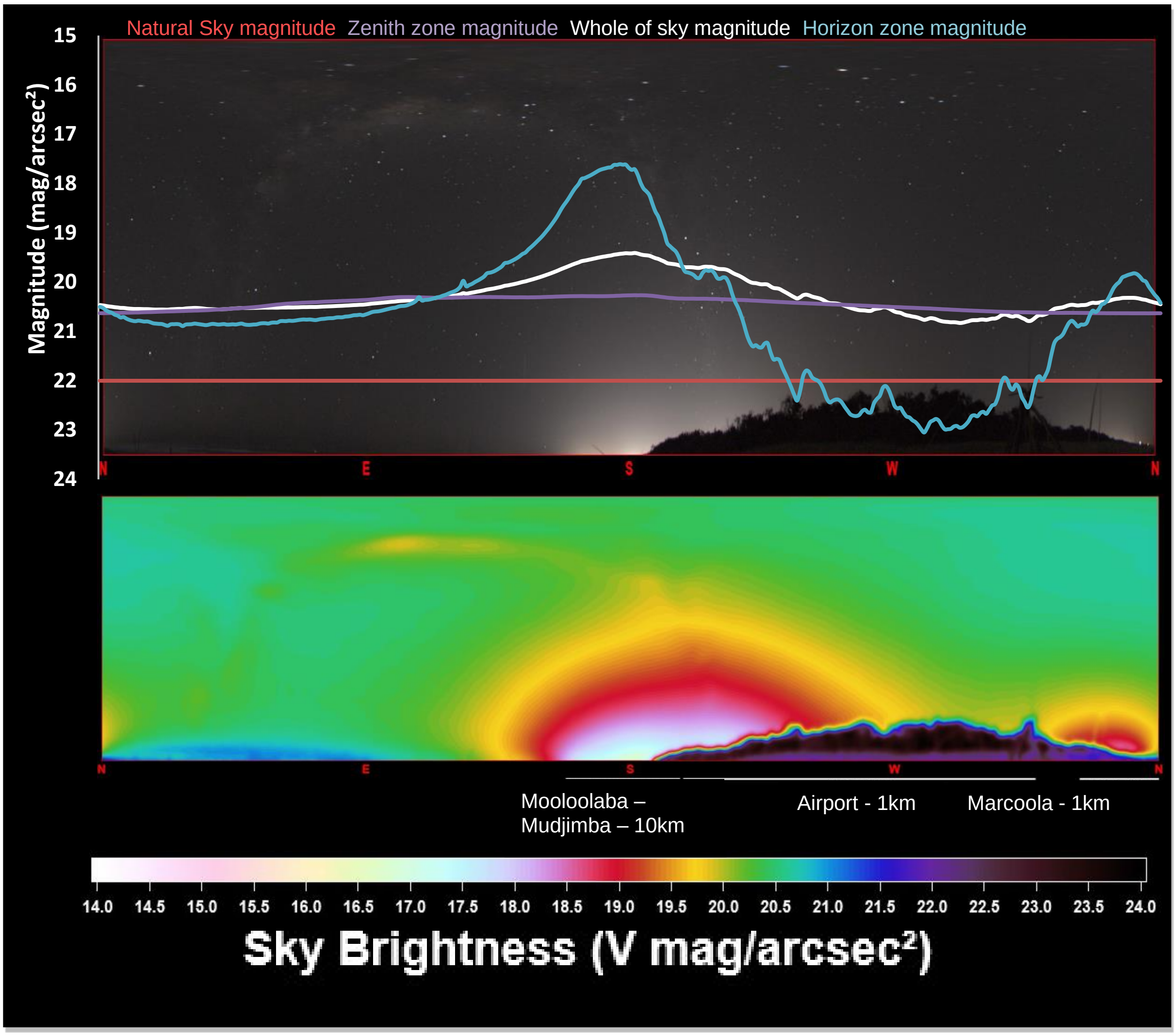


Figure 29*:* Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Mudjimba South. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Mudjimba South	Zen	WoS	Hor
2017 (mag/arcsec²)	20.51	20.37	18.52
2022 (mag/arcsec²)	20.20	19.76	19.44
% increase since 2017	33	76	-57
x brighter in 2022 than 2017	1.33	1.76	0.43

Table 17: Average magnitude (mag/arcsec²) for Mudjimba South for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The zenith, whole of sky and horizon magnitudes for Mudjimba South on a clear night were 20.20, 19.76 and 19.44 mag/arcsec² respectively. The horizon zone measured in the 2017 survey was approximately 57% brighter than in 2022, which may be due to a slight variation in measurement location required to account for changes in the landscape between surveys. The zenith and whole of sky zones are brighter now than measured in the 2017 survey, by 33% and 76% respectively. This indicates an increase in the sky brightness levels throughout the Sunshine Coast. The horizon zone is darker in 2022 than in 2017, which is likely due to a light source being visible in 2017 which was not visible in 2022.

There was sky glow visible over the headland to the south caused by light sources throughout Mooloolaba and Mudjimba, and north-north-east caused by light sources at Marcoola. The seaward horizon is generally darker than the landward horizon. However, the peak horizon brightness coincides seaward to the headland to the south.

4.14 <u>Mudjimba North (Site 15)</u>

Figure 30: Mudjimba North measurement site map

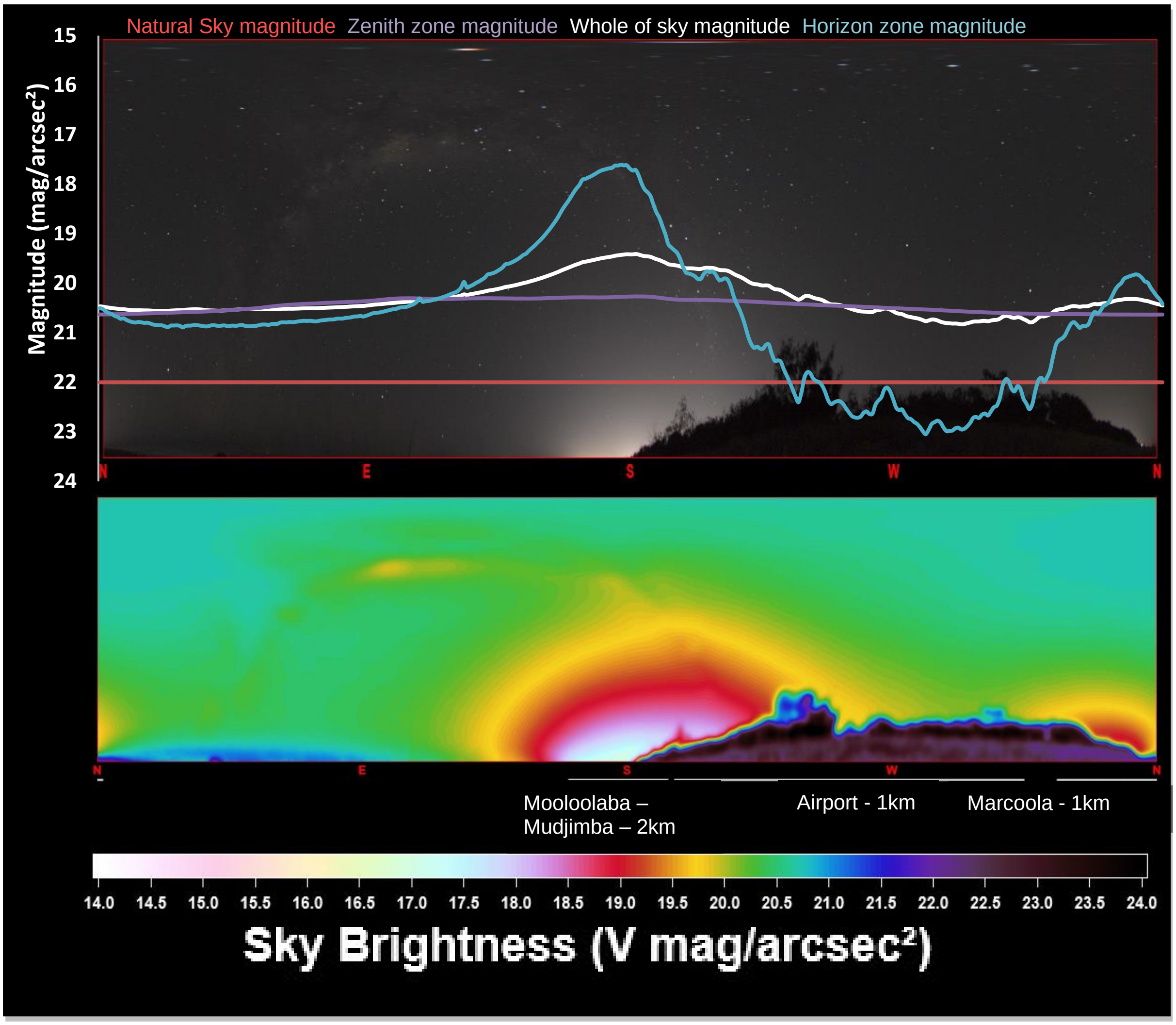


Figure 31*:* Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Mudjimba North. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec^2).

Mudjimba North	Zen	WoS	Hor
2017 (mag/arcsec²)	20.64	20.51	19.24
2022 (mag/arcsec²)	20.28	19.89	19.70
% increase since 2017	40	76	-35
x brighter in 2022 than 2017	1.40	1.76	0.65

Table 18: Average magnitude (mag/arcsec²) for Mudjimba North for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The zenith, whole of sky and horizon magnitudes for Mudjimba North on a clear night were 20.28, 19.89 and 19.70 mag/arcsec² respectively. Compared to 2017 survey results there was an increase in zenith and whole of sky magnitude of 40% and 76% respectively. The horizon zone sky brightness decreased by 35% between 2017 and 2022, due to a slight change in measurement location caused by changes in landscape over time. There was sky glow visible beyond the southern headland caused by light sources throughout the coast from Mooloolaba to Mudjimba, and from Yaroomba to the north. Light sources were not directly visible from the measurement location.

The peak in sky glow is in the southern direction, coinciding with both ocean and land.

4.15 Marcoola (Site 13)

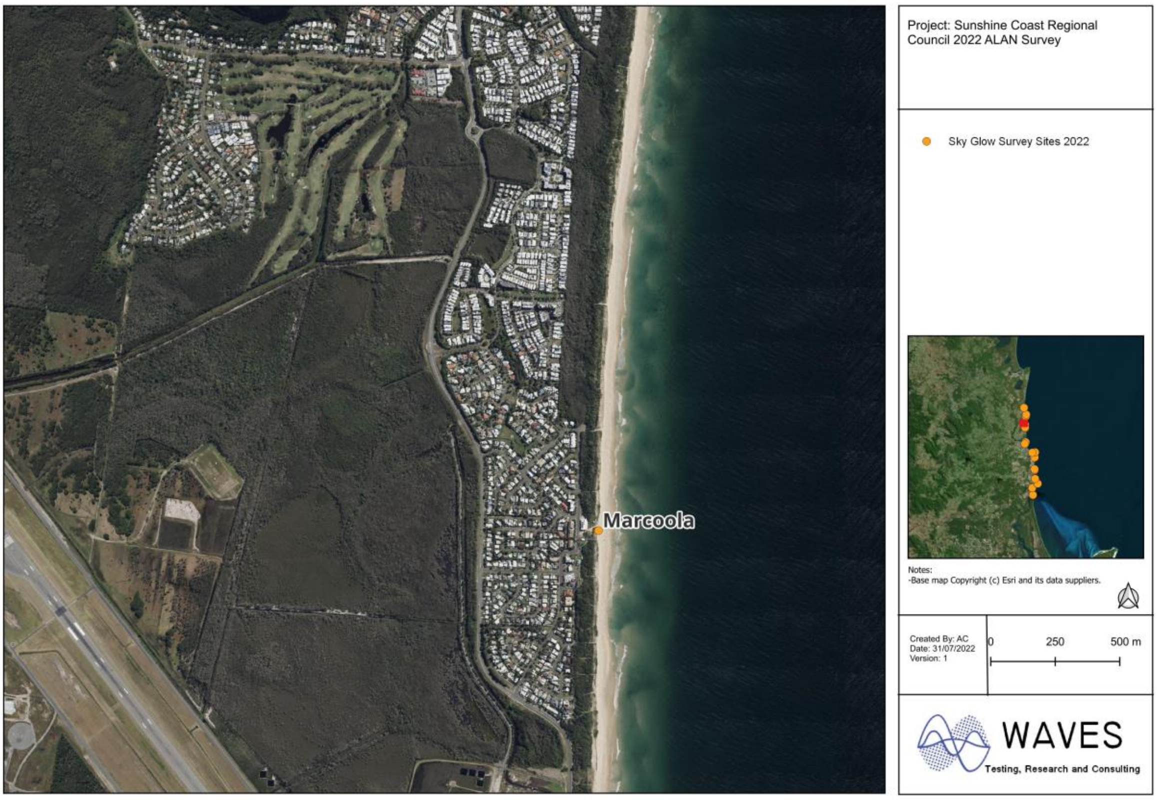


Figure 32: Marcoola measurement site map

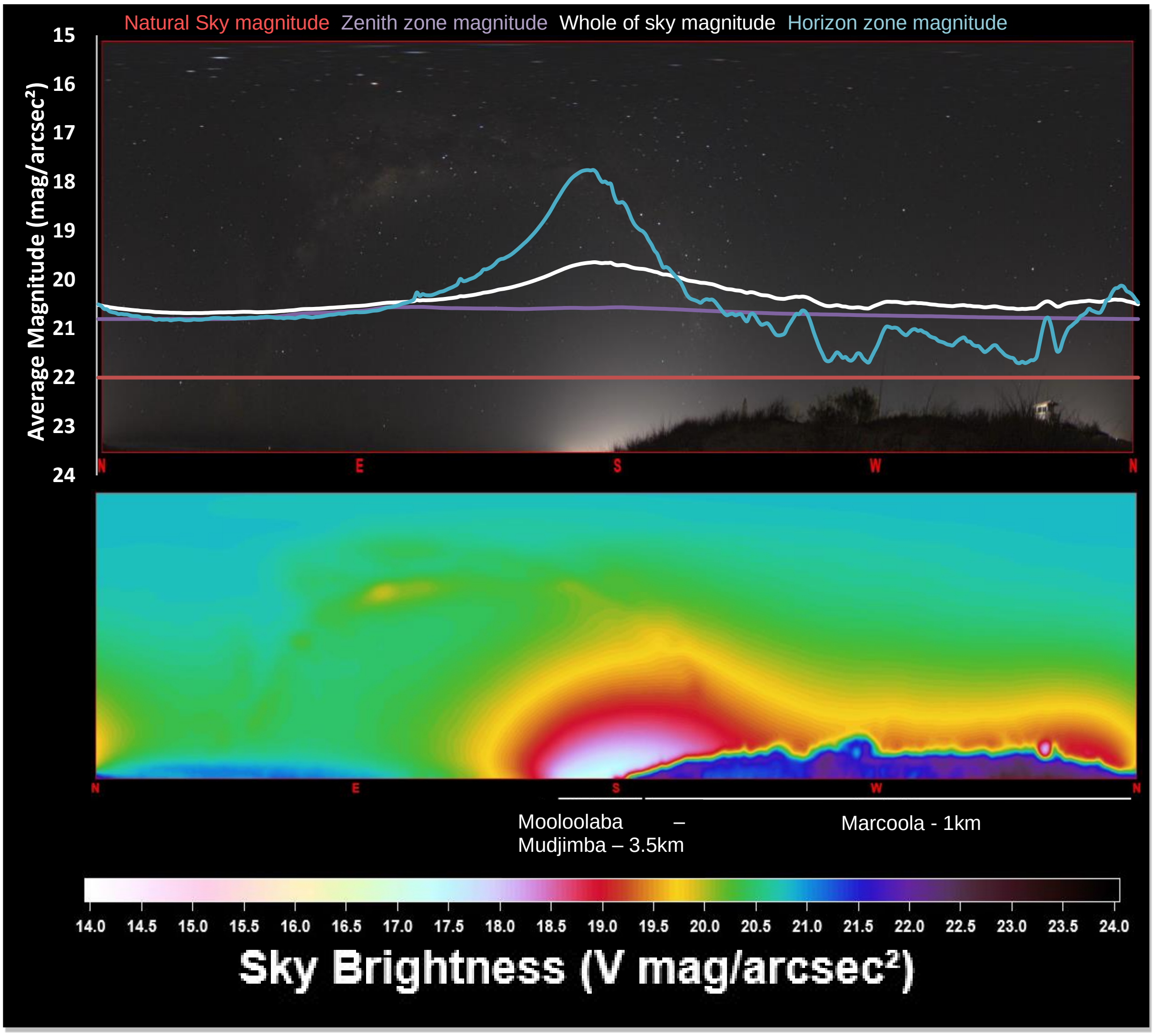


Figure 33*:* Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Marcoola**.** X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Marcoola	Zen	WoS	Hor
2022 (mag/arcsec²)	20.39	19.87	19.64
x brighter than target	4.42	7.08	8.83

Table 19: Average magnitude (mag/arcsec²) for Marcoola for June 2022, and the number of times brighter the location is than the target magnitude of 22 mag/arcsec².

The Zenith, Whole of Sky and Horizon magnitudes for Marcoola on a clear night were 20.39, 19.87 and 19.64 mag/arcsec² respectively. There was sky glow visible over the headland to the south caused by Mooloolaba and Mudjimba. No light sources were directly visible from the measurement site.

The zenith, whole of sky and horizon zones vary between approximately 4.4 times and 8.8 times brighter than natural night sky brightness levels.

The seaward horizon between the south-east direction and the southern headland is generally brighter than the landward horizon and horizon between south-east and north. The peak horizon brightness is south towards Mooloolaba and Maroochydore.

4.16 Yaroomba South (Site 16)

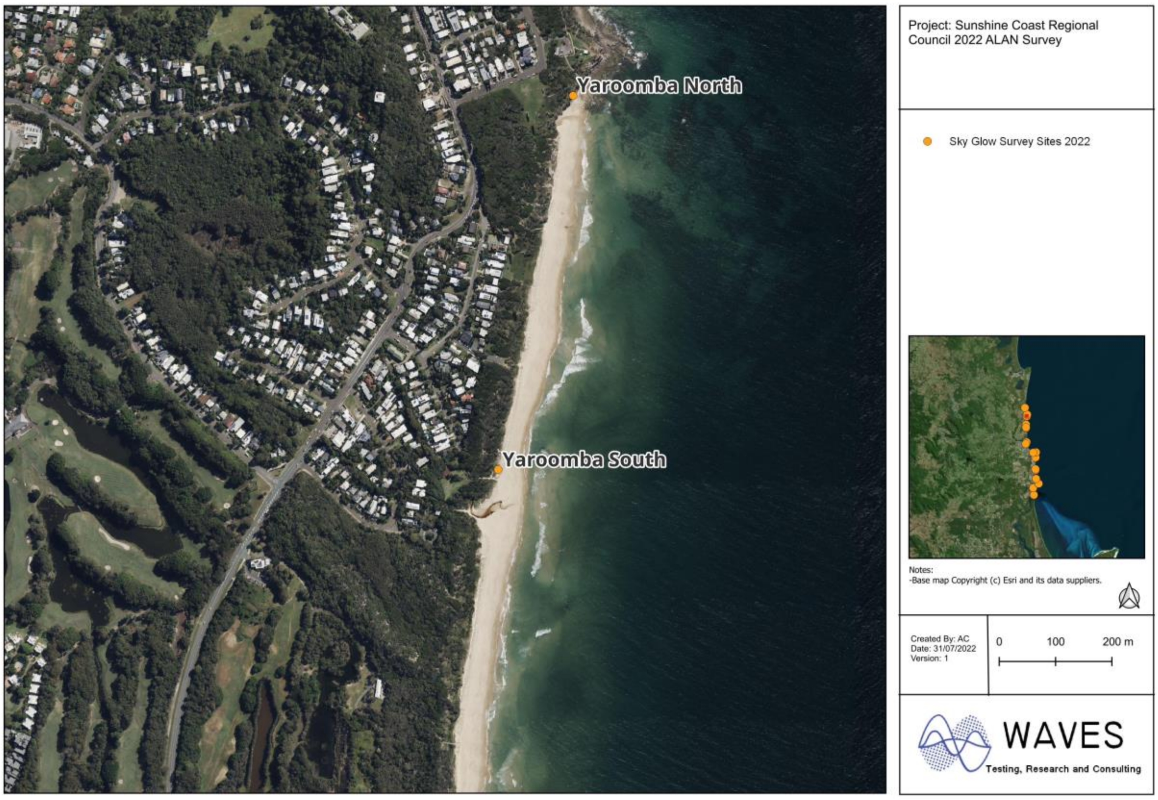


Figure 34: Yaroomba South measurement site map

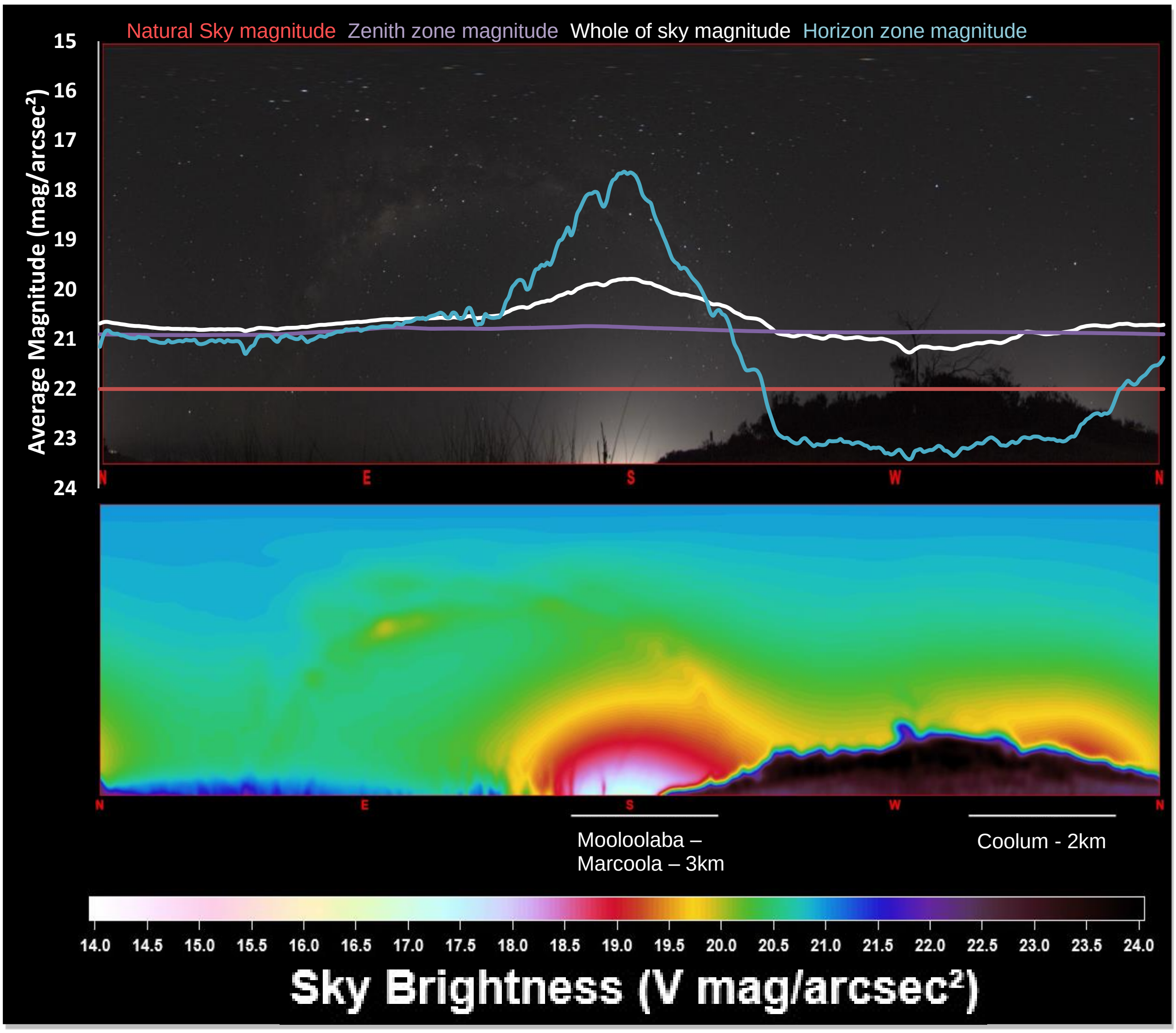


Figure 35*:* Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Yaroomba South. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Yaroomba South	Zen	WoS	Hor
2017 (mag/arcsec²)	20.86	20.74	19.75
2022 (mag/arcsec²)	20.53	20.09	19.84
% increase since 2017	35	82	-7.7
x brighter in 2022 than 2017	1.35	1.82	0.92

Table 20: Average magnitude (mag/arcsec²) for Yaroomba South for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The zenith, whole of sky and horizon magnitudes for Yaroomba South on a clear night were 20.53, 20.09 and 19.84 mag/arcsec², respectively. Compared to 2017 survey results there was an increase in zenith and whole of sky magnitude of 35% and 82% respectively, indicating a general increase in sky brightness between surveys. The horizon zone sky brightness decreased by 7.7% between 2017 and 2022.

There was sky glow visible beyond the southern headland caused by light sources throughout the coast from Mooloolaba to Marcoola, and from Coolum to the north-east. Light sources were not directly visible from the measurement location due to the measurement being taken at ground level and surrounding sand dunes blocking light sources towards the south.

The peak in sky glow is in the southern direction, coinciding with both ocean and land.

4.17 Yaroomba North (Site 17)

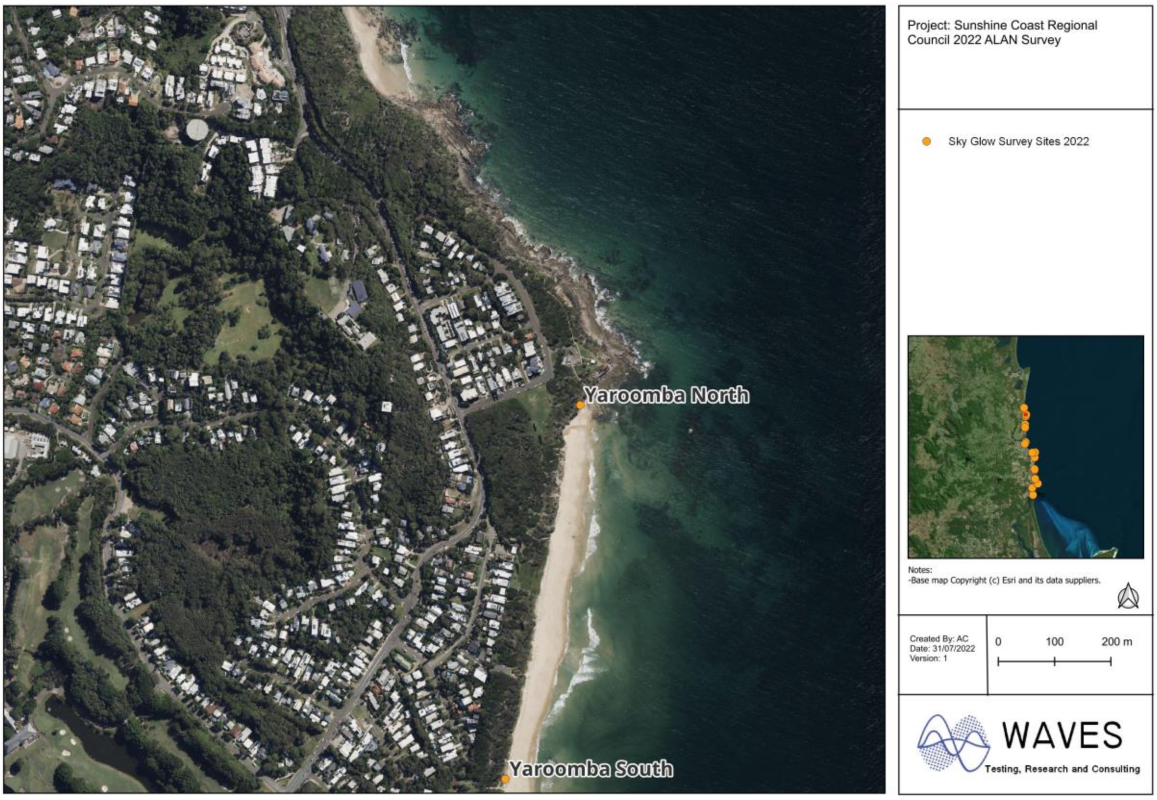


Figure 36: Yaroomba North measurement site map

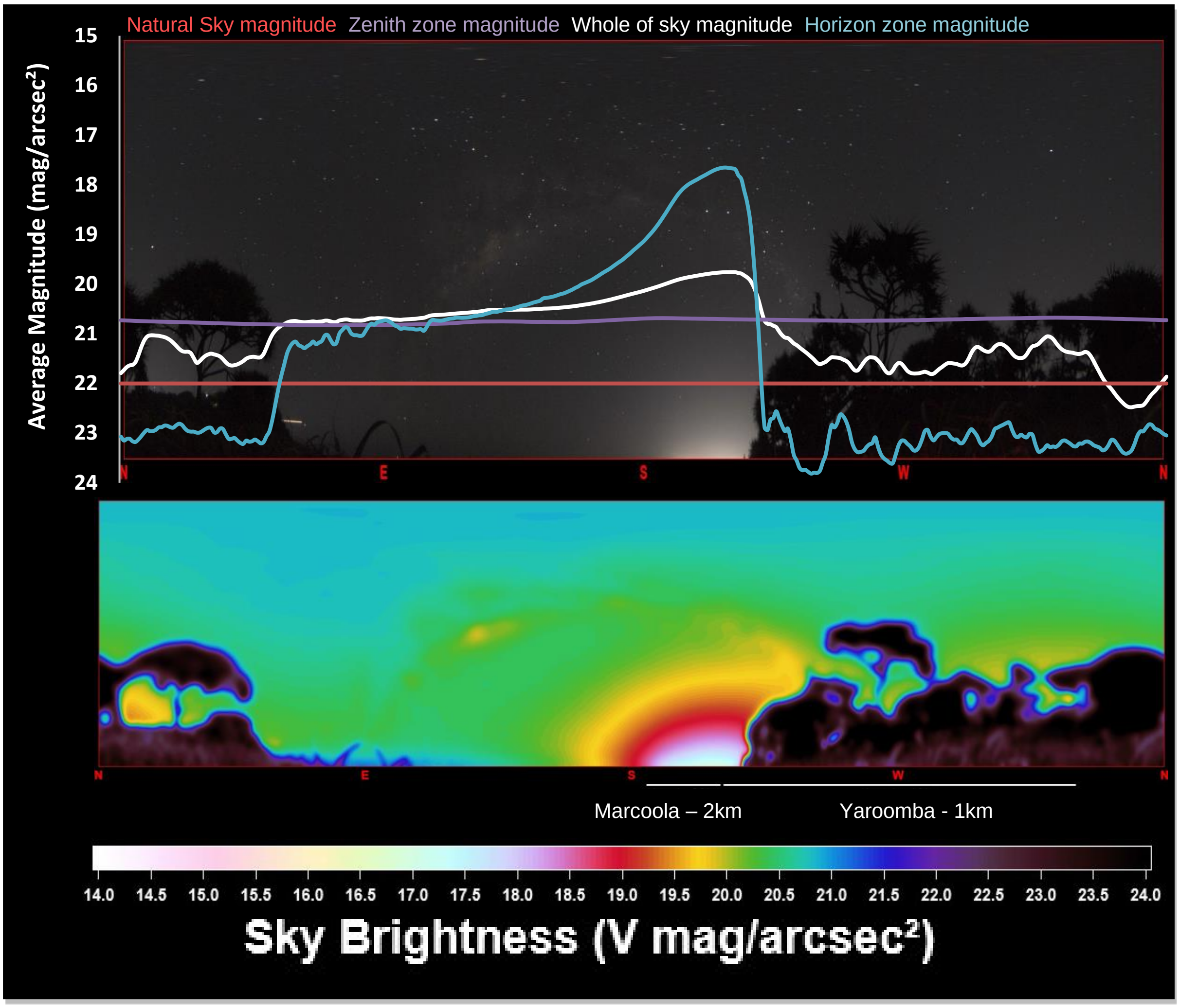


Figure 37*:* Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Yaroomba North. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Yaroomba North	Zen	WoS	Hor
2017 (mag/arcsec²)	20.85	20.76	20.02
2022 (mag/arcsec²)	20.46	20.33	20.00
% increase since 2017	43	49	1.4
x brighter in 2022 than 2017	1.43	1.49	1.01

Table 21: Average magnitude (mag/arcsec²) for Yaroomba North for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The zenith, whole of sky and horizon magnitudes for Yaroomba North on a clear night were 20.46, 20.33 and 20.00 mag/arcsec² respectively. Compared to 2017 survey results there was an increase in zenith and whole of sky magnitude of 43% and 49% respectively, indicating a general increase in sky brightness between surveys. The horizon zone sky brightness was about the same between 2017 and 2022 surveys.

There was sky glow visible to the south caused by light sources along the coastline from Marcoola to Mooloolaba. Light sources were not directly visible from the measurement location.

The peak sky glow is towards the south and coincides with the direction of the ocean, however there is more sky glow landward than directly east.

4.18 Coolum North (Site 18)

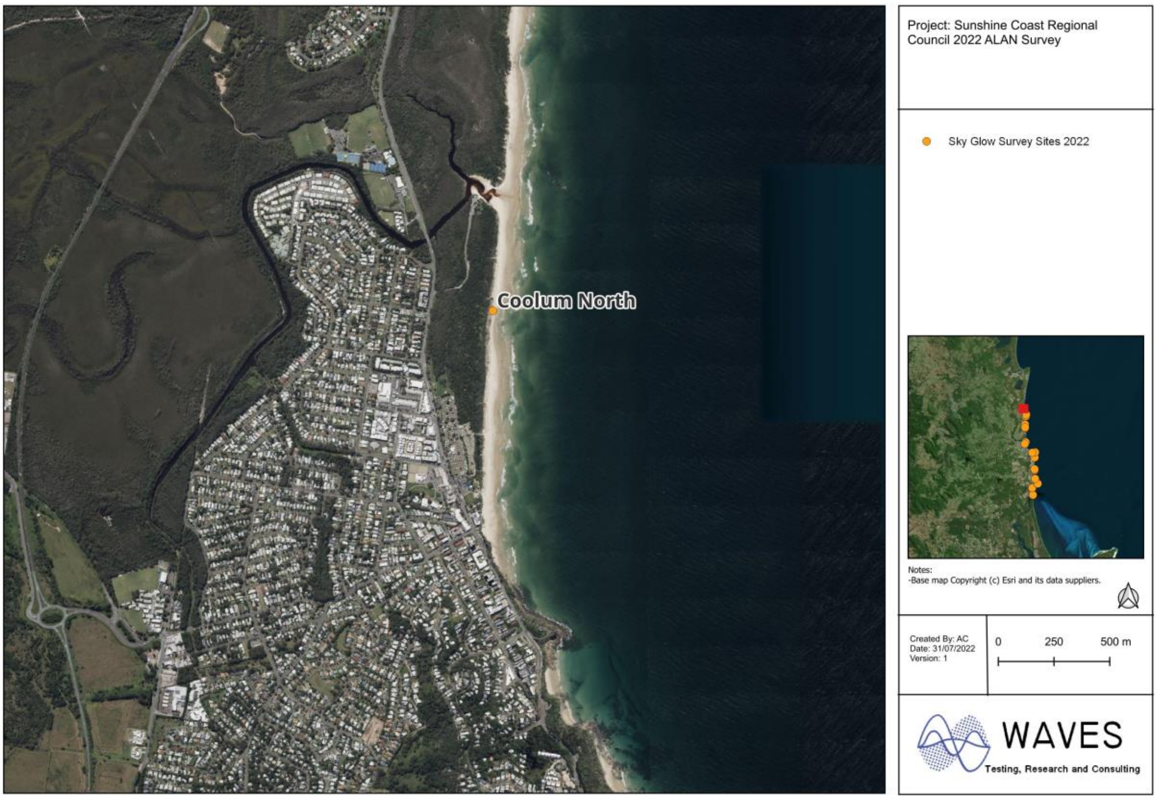


Figure 38: Coolum measurement site map

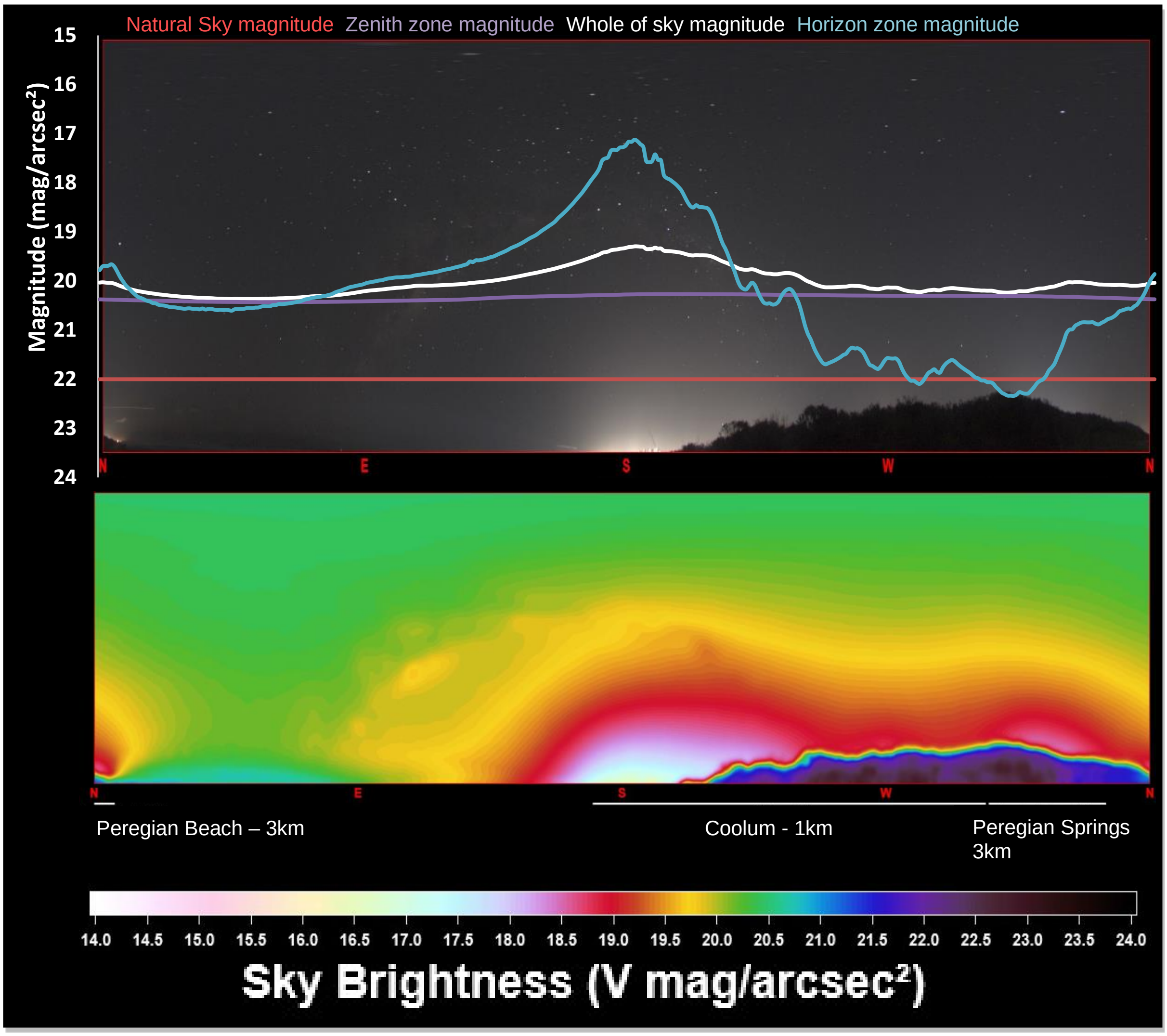


Figure 39: Bearing (°) and magnitude in clear sky conditions, measured in June 2022 from Coolum North. X-axis: bearing from 0 – 360°, Y-axis: Magnitude (mag/arcsec²).

Coolum	Zen	WoS	Hor
2017 (mag/arcsec²)	20.31	20.19	19.14
2022 (mag/arcsec²)	20.09	19.50	19.17
% increase since 2017	22	90	-2.3
x brighter in 2022 than 2017	1.22	1.90	0.98

Table 22: Average magnitude (mag/arcsec²) for Coolum for 2017 and 2022, the % increase between 2017 and 2022 surveys, and the number of times brighter the location is in 2022 than in 2017.

The zenith, whole of sky and horizon magnitudes for Coolum North on a clear night were 20.09, 19.50 and 19.17 mag/arcsec² respectively. Compared to 2017 survey results there was an increase in zenith and whole of sky magnitude of 22% and 90% respectively, indicating a general increase in sky brightness between surveys. The horizon zone sky brightness was about the same between 2017 and 2022.

There was sky glow visible from south-east to south-south-east above the ocean and from south-south-east to north above the land. Distant light sources were visible to the south.

The landward horizon is generally brighter than the seaward horizon. However, the peak horizon brightness coincides with the ocean that is seaward of the headland to the south.

5 ANALYSIS AND DISCUSSION

Yaroomba South had the darkest zenith zone with magnitude 20.53 mag/arcsec². Yaroomba North had the darkest whole of sky zone of magnitude 20.33 mag/arcsec², and Shelly Beach North had the darkest horizon zone with magnitude 20.07 mag/arcsec². Goat Island was exposed to multiple light sources which were directly visible from the measurement location and was the brightest location for all zones with magnitudes of 19.19, 18.04 and 16.67 mag/arcsec² for zenith, whole of sky and horizon zones. This is shown with yellow shading.

The zenith zone and whole of sky brightness has increased for all locations since 2017 (Figure 40 and Figure 41). The change in horizon zone magnitude has varied with some locations being brighter and some being darker compared to 2017 survey results (Figure 42). This random variation in horizon brightness throughout cities is expected due to human activity, changes in landscape, visibility or switching of light sources, and changes to lighting installations over time.

The zenith zones have increased by 0.22-0.62 mag/arcsec² since 2017, while the whole of sky has increased by 0.09-1.21 mag/arcsec² over the same period. The horizon zone has reduced by 1.17 mag/arcsec² at Buddina (Coopers Lookout) and increased by 0.73 mag/arcsec² at the ocean side of North Bribie Island. The magnitude for each zone was plotted to see the general pattern of sky glow along the Sunshine Coast coastline.

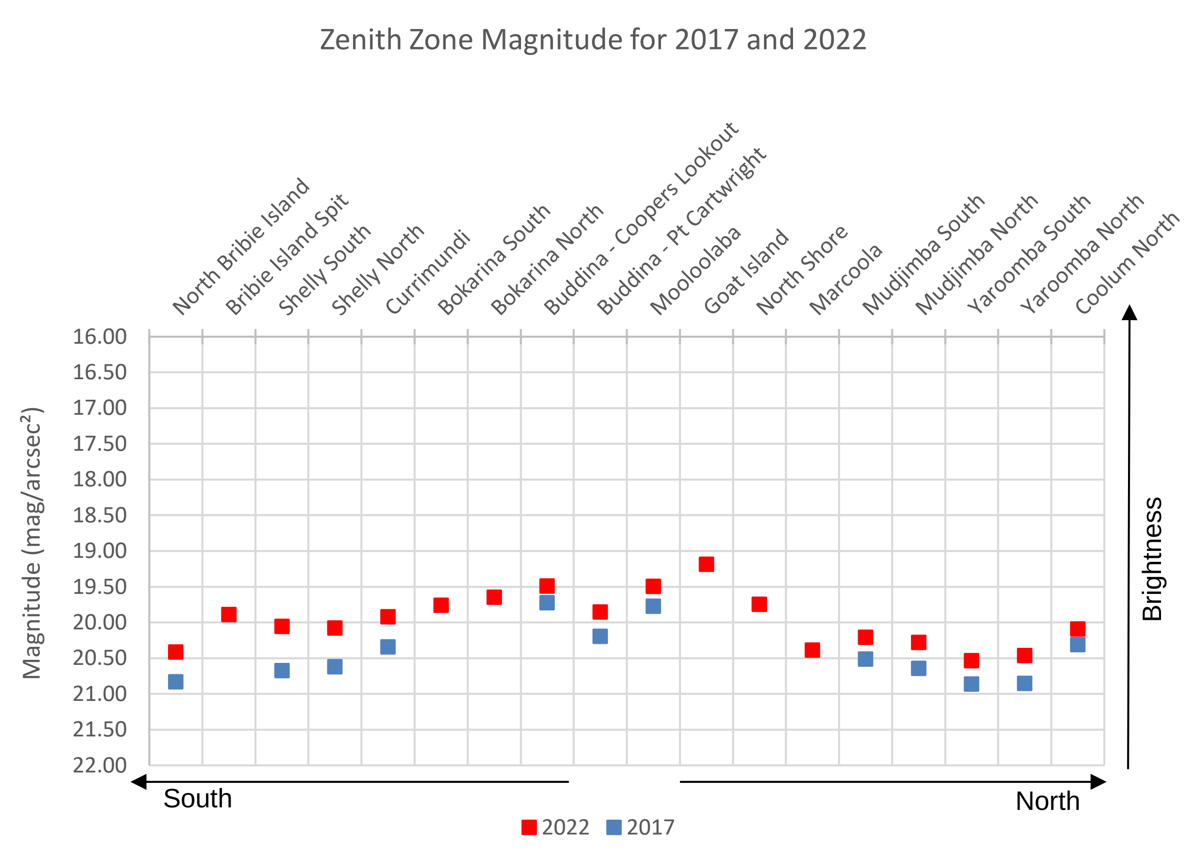


Figure 40: Magnitude (mag/arcsec²) of zenith zone throughout Sunshine Coast measurement locations, with y-axis reversed to represent sky brightness.

Locations to the north from Mudjimba to Coolum, and to the south from Bribie Island to Shelly Beach, demonstrated darker zenith zones, whereas locations in the centre of the coast, from Currimundi to North Shore are brighter. Sites located on sand flats, such as Goat Island and Bribie Island Spit, were exposed to many light sources located on the opposite side of the river or passage. Visibility of light sources increases the sky brightness. Vegetation on and beyond sand dunes shield beaches from artificial light. Sites surrounded by thick and tall vegetation receive the best protection.

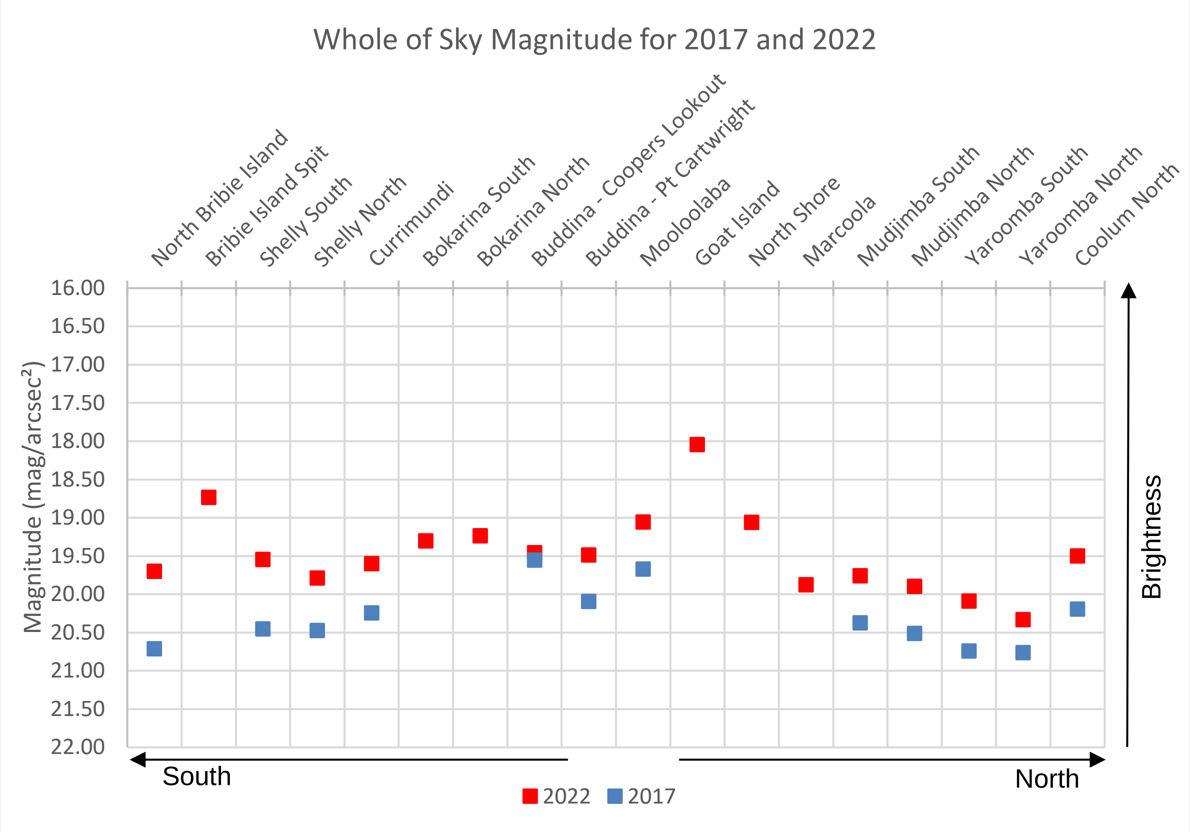


Figure 41: Magnitude (mag/arcsec²) of whole of sky throughout Sunshine Coast measurement locations, with y-axis reversed to represent sky brightness.

The whole of sky brightness increased from 2017 to 2022 for all locations. Locations where light sources are directly visible, such as Goat Island and the Bribie Island spit demonstrate the whole of sky is brighter than locations which do not have nearby light sources.

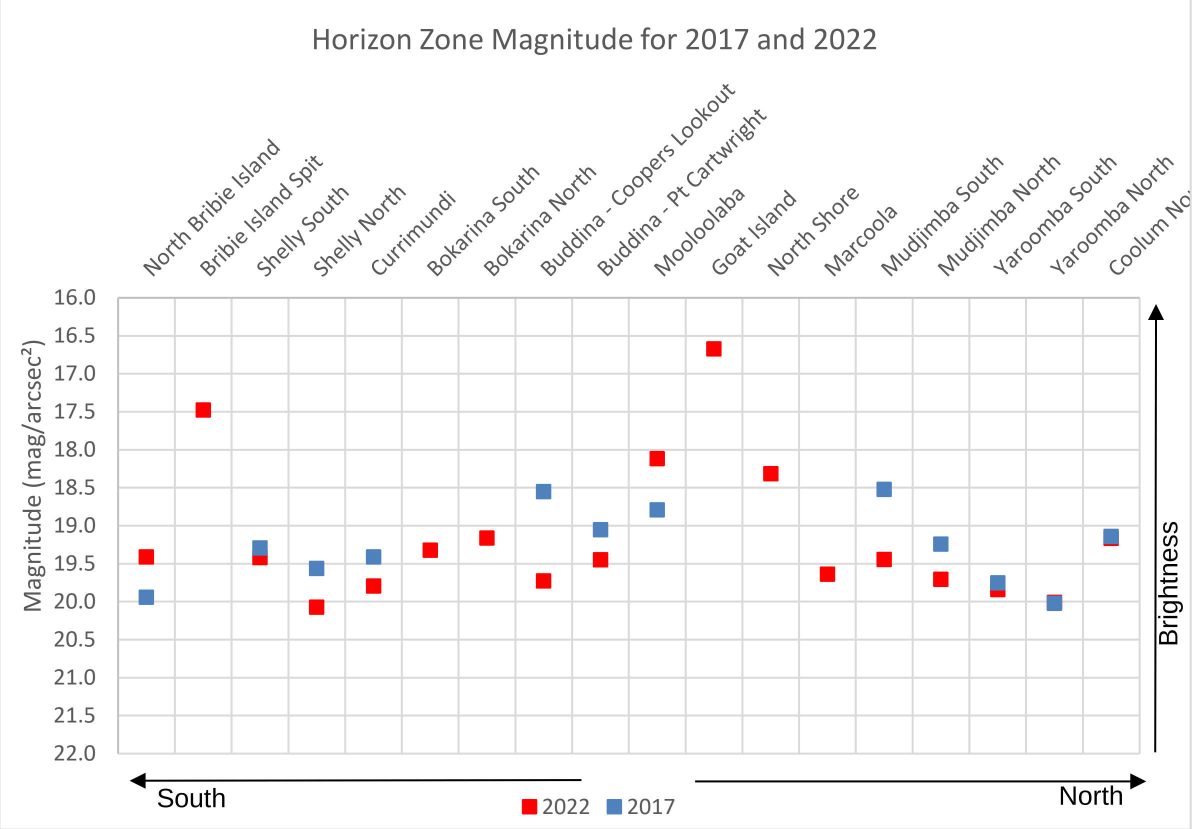


Figure 42: Magnitude (mag/arcsec^2) of horizon zone throughout Sunshine Coast measurement locations, with y-axis reversed to represent sky brightness.

The locations which were identified as migratory shorebird habitat – Bribie Island spit, Goat Island and North Shore – as well as Mooloolaba which has high intensity light sources illuminating the beach, have significantly brighter horizon zones due to the direct visibility of light sources. These light sources increase the overall sky glow in the area and provide less suitable conditions for both migratory shorebirds and turtles.

Beach	Site	% Change since 2017			x brighter than in 2017		
		Zen	WoS	Hor	Zen	WoS	Hor
North Bribie Island	Ocean Side	47	**154**	63	1.47	**2.54**	1.63
Shelly	South	**77**	131	-11	**1.77**	2.31	0.89
Shelly	North	65	88	-38	1.65	1.88	0.62
Currimundi	Currimundi	48	81	-30	1.48	1.81	0.70
Buddina	Coopers Lookout	24	9	-66	1.24	1.09	0.34
Buddina	Pt Cartwright	37	74	-31	1.37	1.74	0.69
Mooloolaba	Mooloolaba	29	76	**86**	1.29	1.76	**1.86**
Mudjimba	South	33	76	-57	1.33	1.76	0.43
Mudjimba	North	40	76	-35	1.40	1.76	0.65
Yaroomba	South	35	82	-7.7	1.35	1.82	0.92
Yaroomba	North	43	49	1.4	1.43	1.49	1.01
Coolum	North	22	90	-2.3	1.22	1.90	0.98

Table 23: The percentage change in sky brightness between 2017 and 2022 and the number of times brighter the locations were in 2022 than in 2017, for Zenith, Whole of Sky and Horizon zones.

The greatest increase in magnitude has been displayed using bold font. Increases in sky brightness have been shaded pink and decreases in sky brightness have been shaded green.

Shelly Beach South demonstrated the greatest increase in zenith zone brightness, and North Bribie Island (ocean side) demonstrated the greatest increase in whole of sky brightness since 2017. Coolum North demonstrated the least increase in zenith zone brightness since 2017 and Buddina (Coopers Lookout) demonstrated the least increase in whole of sky brightness, and the greatest reduction in horizon zone brightness since 2017.

The change in zenith magnitude since 2017 was demonstrated in Table 23. It is also important to compare the locations throughout Sunshine Coast within themselves. Table 24 demonstrates the number of times brighter different magnitudes measured across the Sunshine Coast are compared to the darkest Sunshine Coast location, Yaroomba South, and to naturally dark skies with magnitude greater than 22 mag/arcsec².

Description	Visual Mag (mag/arcsec²)	x brighter than darkest measurement site	x brighter than 22 mag/arcsec²
Naturally dark skies	22.00	-	1.0
Darkest Measurement Site (Yaroomba South)	20.53	1.0	3.9
	20.25	1.3	5.0
	20.00	1.6	6.3
	19.75	2.1	7.9
	19.50	2.6	10.0
Brightest Measurement Site (Goat Island)	19.19	3.4	13.3

Table 24: Comparison of the magnitude of naturally dark rural skies, the darkest and brightest Sunshine Coast locations, and a range of magnitudes between these extents.

The darkest location, Yaroomba South, is 3.9 times brighter than naturally dark skies. The brightest location, Goat Island, is 3.4 times brighter than Yaroomba South and 13.3 times brighter than naturally dark skies.

Light sources which illuminate migratory shorebird foraging sites may extend foraging times for birds, push birds to relocate to other sites for nesting, expose birds to greater levels of predation and disrupt migration patterns. Bribie Island Spit, Goat Island and North Shore measurement locations are exposed to light sources which illuminate the beach. Low-mounted, low intensity sources which are aimed away from the river or ocean and only illuminate the intended footpath would significantly reduce light pollution and energy consumption while providing a more natural habitat for migratory shorebirds.

5.1 Visual Appraisal of Sky Glow Images

In natural areas, free from the influence of artificial light, vegetation on the landward side of the beach creates a silhouette which is darker than the sky above it, and darker than the sky over the horizon on the seaward side of the beach. Because turtles lay their nest above the high tide mark usually on sand dunes and elevated foreshores, the seaward horizon is lower and brighter than the landward sky which meets the vegetation silhouette. Turtles orientate to this lower, brighter horizon to find their way to the ocean. When sky glow over the land creates the situation where the sky above the vegetation silhouette is brighter than the sky above the seaward horizon, loggerhead turtle hatchlings may become disorientated and move inland instead of seaward leading to greater risk of mortality due to exhaustion, being run over by vehicles, and increased risk of prey by wild and domestic animals.

A visual analysis (Table 25) of the sky glow images was undertaken to identify correlation between possible turtle orientation cues and magnitude. A comparison of the horizon brightness for the seaward, landward and zenith directions, direction of peak horizon brightness, and presence of man-made obstructions was tabulated against turtle nesting data.

Cells have been shaded green for positive events such as turtle nesting site and seaward horizon being brighter than landward horizon; pink shading for negative events which may hinder turtle option or chance to nest such as man-made obstructions or sky glow which may cause disorientation in nesting or hatchling turtles – such as the landward horizon being brighter than the seaward horizon; and orange shading for mixed outcomes such as an alternation of bright horizon between seaward and landward directions, or partial outcomes.

Table 25: Comparison of the horizon brightness for the seaward, landward and zenith directions. Sites within river system or the passage were omitted.

Site	Measurement site shielded from high intensity light sources	Which is brighter?			Is peak horizon brightness seaward?
		Seaward Vs Landward Sky	Seaward Sky vs Zenith	Landward Sky vs Zenith	
North Bribie Island	No	Land	Similar NE – SE	Land	No
Shelly Beach South	No	Land	Equal	Land	No
Shelly Beach North	No, due to residential lights	Land	Zenith	Land	No
Currimundi	Yes	Land	Zenith	Land	No
Bokarina South	Yes	Land	Zenith	Land	No
Bokarina North	Yes	Land	Zenith	Land	No
Buddina – Coopers Lookout	Yes	Land	Zenith	Land	No
Buddina – Pt Cartwright	No	Land	Seaward	Land	No
Mooloolaba	No	Brightest along the beach	Zenith	Zenith	Partially: some water in direction of peak brightness, depending on tides.
North Shore	No	Seaward, towards Maroochy River	Seaward, towards Maroochy River	Landward, on opposite bank of Maroochy River	Peak is beyond opposite river bank.
Marcoola	Yes	Land	Zenith	Land	Yes, along beach adjacent southern headland

Site	Measurement site shielded from high intensity light sources	Which is brighter?			Is peak horizon brightness seaward?
		Seaward Vs Landward Sky	Seaward Sky vs Zenith	Landward Sky vs Zenith	
Mudjimba South	Yes	Land	Zenith	Land	Yes, along beach adjacent southern headland
Mudjimba North	Yes	Land	Zenith	Land	Yes, along beach adjacent southern headland
Yaroomba South	Yes	Land	Seaward	Land	Yes, along beach adjacent southern headland
Yaroomba North	Yes	Similar	Seaward	Land	Yes, along beach adjacent southern headland
Coolum	Yes	Land	Seaward, due to sky glow adjacent headland to south	Land	Yes, along beach adjacent southern headland

The sites which have the most ideal conditions for turtle nesting and hatching are Yaroomba north and south. These sites have a brighter, lower seaward horizon, and are free of man-made obstructions (such as rock/retaining walls, board-walks and footpaths) which may hinder turtle nesting. However, the peak horizon brightness is towards the south, adjacent the headland, and this may cause some hatchling turtles to orientate in that direction instead of towards the open ocean.

Overall, throughout the study area, the landward skies are brighter than the seaward skies, and the potential for turtle disorientation is present. The artificial light created on land should be managed and reduced to prevent disorientation.

The locations from Marcoola to Coolum demonstrate peak horizon brightness which is over the sea, yet along the beach. The main cause of the sky glow is light sources along the coastline between Mooloolaba and Marcoola.

6 LIGHT AUDIT Of SUNSHINE COAST ALAN SURVEY SITES

6.1 Light Audit Methodology

Artificial light impacts turtles in a number of ways: via visible light sources, reflected light, sky glow and spectral content of light sources. A light audit was conducted to record the locations and details of light sources which are directly visible or contribute to sky glow in the vicinity of the ALAN measurement locations. Data was recorded using GIS mapping and shapefiles are provided supplementary to this report. Recorded data for each light include GPS coordinates, type of source, colour of the source, mounting height, spectral output of the source, correlated colour temperature and image(s) of the source or installation.

Spectral irradiance measurements were taken using an Everfine SPIC-200BW spectral irradiance colorimeter (SN M1361118). The relative spectral irradiance for sources measured are included in Appendix 3.

6.2 Light Audit Locations

Starting from the most southern measurement location and moving north, the following maps were produced for the light sources.

Figure 43: Map of light sources visible from Ocean side of Bribie Island North (Site 1), Bribie Island Spit (Site 2), Shelly Beach South (Site 3), and Shelly Beach North (Site 4).

Light sources installed at Lion's Park and along the Kings Beach foreshore and roads are visible from the measurement site on the ocean side of Bribie Island (site 1). There are many light sources at Bulcock Beach and Golden Beach which are visible from site 2. Many road lights shine light towards the measurement site. The fitting of light screens to luminaires to prevent light spill in the direction of the measurement sites would decrease visibility and sky glow. Many pedestrian crossings have 3-4 light sources which provide excessive illumination and emit light towards the migratory shorebird habitat. Commercial and residential lighting contribute to the sky glow as they are not shielded or are omnidirectional.

There were no significant light sources visible from Currimundi (Site 5), Bokarina North (Site 6), Bokarina South (Site 7), and Buddina – Coopers Lookout (Site 8) measurement sites.

Figure 44: Map of light sources visible from Point Cartwright (Site 9) and Mooloolaba (Site 10) measurement locations.

The light sources on the hilltop above the Pt Cartwright measurement location were mainly from common areas of unit blocks, and road lighting. Lighting of common areas could be controlled by motion sensors to reduce the light pollution and reduce energy consumption.

Light sources from the Mooloolaba Surf Lifesaving Club and adjacent park and the Mooloolaba Spit were visible from site 10. The light sources included floodlights, footpath and playground lights, exterior building lights and spotlights on lifeguard towers. Most sources were neutral white or cool white and aimed towards the beach. A review of the lighting in the area is recommended to reduce impact on nearby suitable turtle nesting habitat and to promote nesting activity in the area.

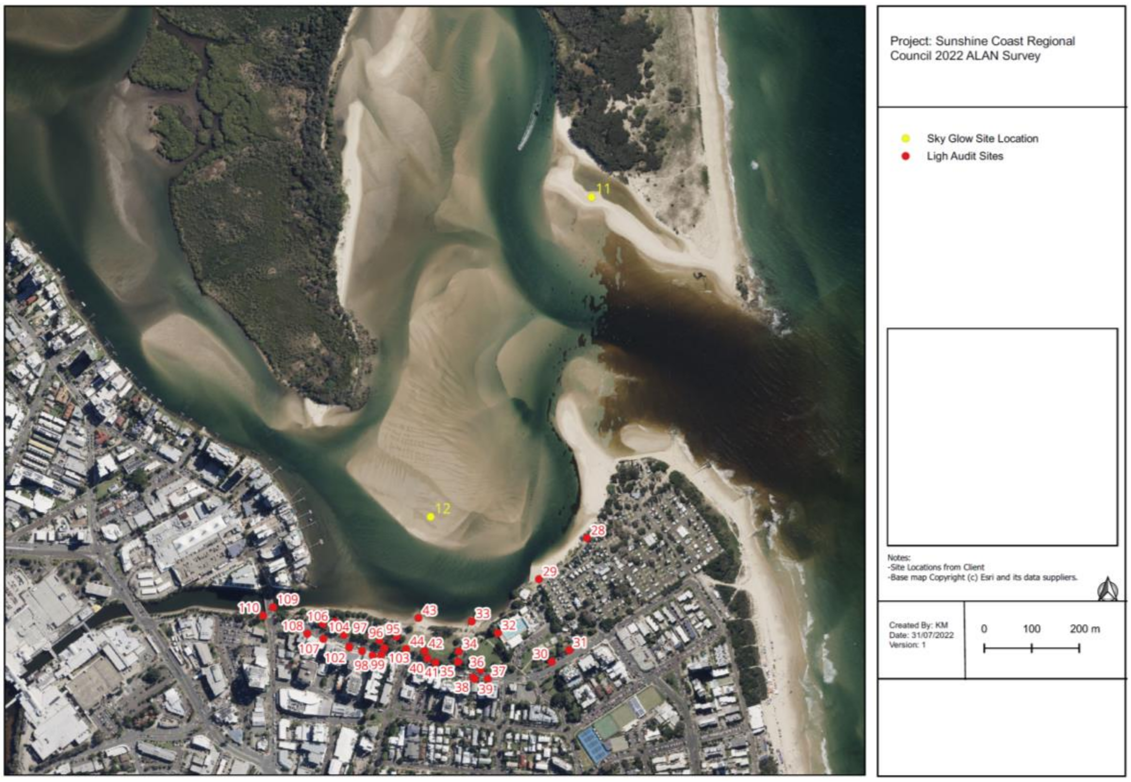


Figure 45: Map of light sources contributing to sky glow or visible from North Shore (11) and Goat Island (12) measurement sites.

Sites 11 and 12 are located on the Maroochy River and are considered for turtle nesting and migratory shorebird habitat. There are many light sources visible from measurement sites 11 and 12, ranging from multiple omnidirectional sources atop poles at Cotton Tree Caravan Park, lighting of the pool and viewing platforms, high intensity park lighting, commercial signage, interior commercial lights, and road lighting. Many park lights illuminate vegetation and provide minimal usable light for safe access of pedestrians. Pedestrian crossings are illuminated by multiple lights and some emit light in the direction of the measurement sites.

The lights remain on throughout the night despite minimal observed use by the community. The light audit of the area took from 11:40 p.m. on a Tuesday night until 1:30 a.m. Wednesday, and only one pedestrian – a fisherman avoiding the light, standing in the shadows produced by trees – was seen at the park or foreshore area.

There were no significant light sources visible from Mudjimba south (Site 13) and Mudjimba north (Site 14) measurement sites.

Figure 46: Map of light sources visible from Marcoola (15) survey site.

Site 15 is located near the Marcoola Surf Lifesaving Club. This clubhouse contained many TV screens and interior light sources which remained switched on throughout the night, despite the venue being closed. The light sources varied in colour (TVs) or were neutral-cool white LED and fluorescent sources. There were also cool white compact fluorescent park lights and omnidirectional (light diffusely emitted in all or most directions) wall and exterior lights attached to unit blocks across the road.

There were no significant light sources visible from Yaroomba south, measurement site 16.

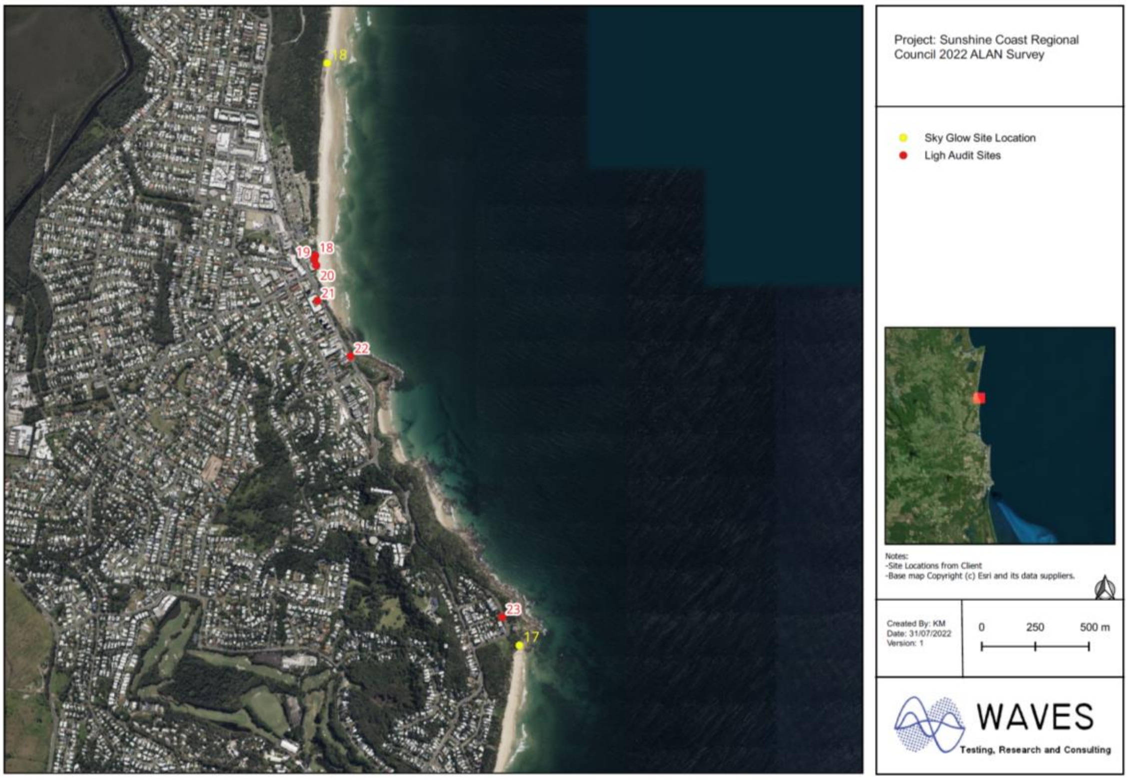


Figure 47: Light sources visible from Yaroomba north (17) and Coolum north (18) measurement sites.

The light sources visible or contributing to sky glow in the immediate vicinity of sites 17 and 18 were mainly cool white LED lights mounted to the lifeguard tower and fascia and spotlights affixed to the Coolum surf club. Blue LEDs were floodlighting a pool at point 22 which were visible from the measurement location.

Short wavelength light, such as white and blue light sources, scatter more in the atmosphere than longer wavelength lights, and turtles are more sensitive to short wavelength light than long wavelength light, making them unsuitable for use near turtle nesting beaches. Low pressure sodium road lights were illuminating the road along David Low Way and visible from the measurement location. The sources would not be visible if light shields were installed in the direction of the beaches.

6.3 Light Audit Results

The results for all ALAN survey locations are provided in the supplementary GIS Shapefile, and discussion and photographs are provided in Appendix 2 for the more concerning lighting installations.

7 REVIEW OF PRE- AND POST-DEVELOPMENT ALAN SURVEYS

Two pre- and post-development ALAN surveys were reviewed and compared to results of the 2017 and 2022 ALAN surveys, where possible.

2019 ALAN survey – Seanna Apartments

An ALAN survey was completed to support the development of a residential apartment complex in 2019 by an external consultant. The locations 'Cross section A', 'Cross section B' and 'South' were measured in the 2019 survey. These locations are located near Bokarina North and Bokarina South site locations measured in the 2022 survey. Measurements of zenith zone (0° - 30° altitude) and whole of sky (0° - 90°) are comparable to the same zones measured in the 2022 survey. Table 26 shows the 2019 values in orange shading and the 2022 values in green shading.

Site	Magnitude (mag/arcsec²)	
	Zen	WoS
Cross section A 2019	19.88	19.32
Bokarina North 2022	19.65	19.24
Cross Section B 2019	19.92	19.32
Bokarina South 2022	19.76	19.30
South 2019	19.93	19.39

Table 26: The zenith and whole of sky magnitude nearby residential apartment development in 2019 compared to Bokarina north and south ALAN results for 2022.

The results of this comparison demonstrate the zenith and whole of sky magnitudes have decreased between 2019 and 2022, indicating an increase in sky brightness. This is consistent with the comparison of the 2022 ALAN survey compared to the 2017 ALAN survey for nearby locations.

2021 ALAN survey – First Bay, Coolum

A survey was completed by an external consultant to support the construction of a dwelling at First Bay, Coolum which involved an ON/OFF assessment of the sky glow in the zenith zone (0° - 30° azimuth), whole of sky (0° - 90° azimuth) and horizon zone (80° - 90° azimuth).

The development site is located approximately mid-way between Coolum North and Yaroomba North ALAN measurement sites. The 2021 First Bay sky brightness was compared to the sky brightness of Coolum and Yaroomba in 2017 and 2022 (Table 27).

Site	Magnitude ($mag/arcsec^2$)		
	Zen	WoS	Horizon
Coolum North 2017	20.31	20.19	19.14
Coolum North 2022	20.09	19.50	19.17
Coolum South 2017	19.62	19.48	17.90
First Bay, 2021 lights ON	19.92	19.03	19.97
First Bay, 2021 lights OFF	20.11	19.64	20.30
Yaroomba North 2017	20.85	20.76	20.02
Yaroomba North 2022	20.46	20.33	20.00

Table 27: A comparison of the zenith, whole of sky and horizon zone magnitudes at the First Bay development in 2021 and Coolum and Yaroomba ALAN survey sites in 2017 and 2022.

The increase in zenith zone, whole of sky and horizon zone sky brightness caused by switching the dwelling lights on was estimated by the external consultant to be 0.19, 0.61 and 0.33 $mag/arcsec^2$, respectively.

The magnitude estimates for First Bay in 2021 are similar to values measured in 2022 at Coolum North and Yaroomba North.

8 OPTIONS FOR MINISING LIGHT POLLUTION

The following issues will be addressed by providing options for mitigating the problems:

- Bright light sources may deter adult turtles from nesting in the area and misorientate loggerhead turtle hatchlings from nearby nests.
- Sky glow from light sources, near and far, disorientate hatchling turtles.
- Turtles are more sensitive to shorter wavelength (purple-blue) light than longer wavelength (yellow-red) light.

Options have been provided for reducing the light pollution, including Best Practice Principles for Lighting Design from the National Light Pollution Guidelines for Wildlife, Commonwealth of Australia 2020. Examples of best practices that can be implemented to reduce the light pollution near turtle nesting and hatching beaches include but are not limited to:

- Ensuring luminaires only illuminate the required area, and taking action to prevent spill light outside the required area;
- Prohibit the use of light sources which are visible from the beach or ocean;
- Prohibit use of wall-washing and floodlight luminaires;
- Prohibit lighting of vegetation, fences and other facades visible from potential turtle nesting beaches;
- Omnidirectional sources produce a significant amount of light pollution and minimal usable light for safe access and movement, and their use should be prohibited.
- Remotely managing lights (computer controls);
- Use lights with reduced or filtered out blue, violet and ultraviolet wavelengths;
- Use technology such as dimming, timers, flashing rate, motion sensors and well-defined directivity of light where possible;
- Lighting that is as close to the ground as possible, directional and shielded can be extremely effective;
- Artificial light can be prevented from shining above the horizontal plane by ensuring luminaires, especially road lighting luminaires, are mounted horizontally relative to the ground and not at

an angle. Alternatively, mounting luminaires on a building so that the structure prevents the light shining above the horizontal plane, for example light sources recessed into an overhanging roof eave, will prevent light shining above the horizontal plane;

- Light levels should be appropriate for the activity, and level limits may be placed on certain areas (such as decks/verandas) to restrict the amount of light permitted for the area (ie maximum lumens/m² limit);
- The amount of light produced, rather than the amount of energy used (Watt) is the most important consideration in ensuring that an area is not over lit;
- High quality, low glare lighting should always be used. Low glare lighting enhances visibility for the user at night, reduces eye fatigue, improves night vision and delivers light where it is needed;
- Specify non-reflective, dark coloured surfaces for buildings or infrastructure (white painted infrastructure, polished marble or white sand can contribute to reflection and increase sky glow);
- Tinting windows on the seaward and sides of buildings is effective for reducing the amount of light emitted from the building;
- Opaque balustrades on decks and verandas visible from the beach or ocean will reduce the light pollution from the building;
- Light on decks shall be narrow beam angle and installed, directed, aimed and shieled to produce appropriate light cut-off so that light produced is contained within the deck footprint and shall not spill beyond the top of balustrades; and,
- Seaward facing lighting from commercial properties is switched off during turtle nesting and hatching season.

When Council seeks a Contractor to install or design lighting, we suggest the tender requirements for lighting installations should include the following:

- Council to define the footprint (length and width or diameter) to be illuminated;
- Council to define lighting exclusion zone(s), ie areas that are not to receive light from the installation; such as beaches, vegetation, grassy areas beyond 2m from footpaths, beyond road verges, property boundaries, etc. Light sources from the installation shall not be visible from exclusion zones.
  This reduces long-term costs as there will be less requirements to engage consultants to perform assessments of obtrusive light for residents or environmentally sensitive areas.
- Set a maximum mounting height for luminaires to minimise sky glow (eg 1.2m for bollard lights or 4m for Category P streetlights). Note, light obeys an inverse square law for illumination – such that, for a particular luminaire, doubling the mounting height requires four times the amount of light output (and approx. 4 times the energy consumption) to achieve the same illumination; tripling the mounting height requires nine times the light output (and approx. 9 times the energy consumption) to achieve the same illumination, and so on – whereas halving the mounting height requires one quarter the light output to achieve the same illumination.
  Higher mounting heights incur additional costs due to increased steel requirements for longer and thicker poles, larger footings, switchboards capable of greater capacities, potentially thicker wires, and additional resources and safety measures for installation and maintenance.
- Define spectral output of luminaires being installed near turtle nesting beaches: shorter wavelength light (ie blue light) scatters more in the atmosphere than longer wavelength light (ie yellow and red light). Council could set a maximum limit permitted (ie 5%) for the spectral output below 500 nm, or define a wavelength cut-off so that lights do not emit light of wavelength shorter than 500 nm.
- Forward light screens and backward light screens should be fitted to all road and footpath lighting luminaires at the time of installation, and fitted to already installed luminaires.
  This helps minimise sky glow and the impact of light source visibility on wildlife, and also prevents complaints from residents regarding glare from streetlights entering their home, and the associated cost to engage consultants to perform assessments.
- Amenity blocks should utilise recessed fittings with sufficient cut-off to only illuminate the intended footprint. Diffuse, surface mounted battens should be avoided. Motion sensors,

dimmers and timers can be used to minimise the cumulative light output and energy consumption over time while providing safe access and movement when required.
- Aesthetic lighting should consider environmentally sensitive areas and direct light away from the beach.

9 CONCLUSION

Data was collected at locations used in the 2017 ALAN survey for Sunshine Coast to assess the change in average magnitude over a 5-years period, and at additional turtle nesting or shorebird habitat. The results show the zenith magnitude has increased by between 22% and 77% over the 5-years period, with Shelly Beach South experiencing the greatest increase in sky brightness and Coolum north experiencing the least increase in sky brightness since 2017.

Goat Island demonstrated the brightest skies due to a large number of sources along the foreshore and beyond, from the caravan park to Maroochydore. Bribie Island Spit also experienced illumination due to light sources along the Esplanade from Kings Beach to Golden Beach, and sky glow from Caloundra beyond. These sites do not have elevated, vegetated dune systems to block the light at horizon level. These sources illuminate shorebird habitat, altering natural feeding, sleeping and migratory cycles. Removing, obscuring, or controlling lights sources visible from shorebird habitat will promote natural behaviours.

The peak horizon brightness was located landward for eleven of the 18 ALAN survey sites.

A light audit was conducted around the ALAN survey locations to record and GPS light sources which are directly visible from the measurement site, or contribute significantly to sky glow in the area. The attached shapefile contains the results of the light audit with supporting photos. Recommendations were provided to reduce the number of light sources visible from the ALAN survey locations or contributing to sky glow in the area.

Light sources were visible from eight of the 18 sky glow survey sites. Visibility of light sources can be prevented by shielding light sources and aiming them away from the beach, or by providing vegetation buffers along the foreshore and beyond.

The amount of wasted, spill light needs to be reduced significantly throughout the area, not just at the immediate foreshores and streets surrounding the nests.

Some specific examples for reducing spill light across the region include:
- Street lights should be shielded to reduce spill light illuminating beyond the required footprint;
- Spill light from BBQ shelters and amenity blocks should be minimised beyond the concreted area;
- Low mounted luminaires should be used instead of high mounted luminaires to reduce the total amount of light required to illuminate the area and to reduce the spill light beyond the required footprint;
- Commercial properties should avoid the use of advertising screens, and lights should be controlled by timers or motions sensors so they are switched off when not in use;
- Motion sensors and surveillance cameras should be used for security instead of luminaires remaining illuminated throughout the night; and,
- Floodlights and wall mounted luminaires should be avoided to reduce the horizontal spill light emitting into the atmosphere.

In areas that may impact turtle nesting, it should be prohibited to have light sources directly visible from the beach, and limitations should be placed on spectral content of light sources, reflectivity of building materials, transmittance of glazing, and building design.

Currently, there is no clear and defined way to assess the contribution light from a development makes to cumulative sky glow. A standard testing methodology should be defined to assess the impact developments have on potential turtle nesting beaches, and data should be collated over time for comparison purposes.

Recommendations were made for minimising light pollution and can form the basis of more detailed planning scheme policies and community engagement activities.

10 REFERENCES

1 National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia 2020

2 Stanley TR et. al. (2020) Brightness of the Night Sky Affects Loggerhead (Caretta caretta) Sea Turtle Hatchling Misorientation but Not Site Selection. Frontiers in Marine Science Vol 7 Article 221

3 Witherington B & Martin RE (2003) Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches Florida Fish and Wildlife Conservation Commission FMRI Technical Report TR-2: Jensen Beach, Florida. 84p.

4 Witherington, B. E. (1992) Behavioural responses of nesting sea turtles to artificial lighting. *Herpetologica*, *48*, 31–39

5 Pendoley Environmental (2017) Sunshine Coast and Moreton Bay Regional Council Benchmark Artificial Light at Night (ALAN) Survey 2017

Appendix 1
Supplementary images (full hemisphere)

Bribie Island North Site (Ocean side of Lion's Park) Site

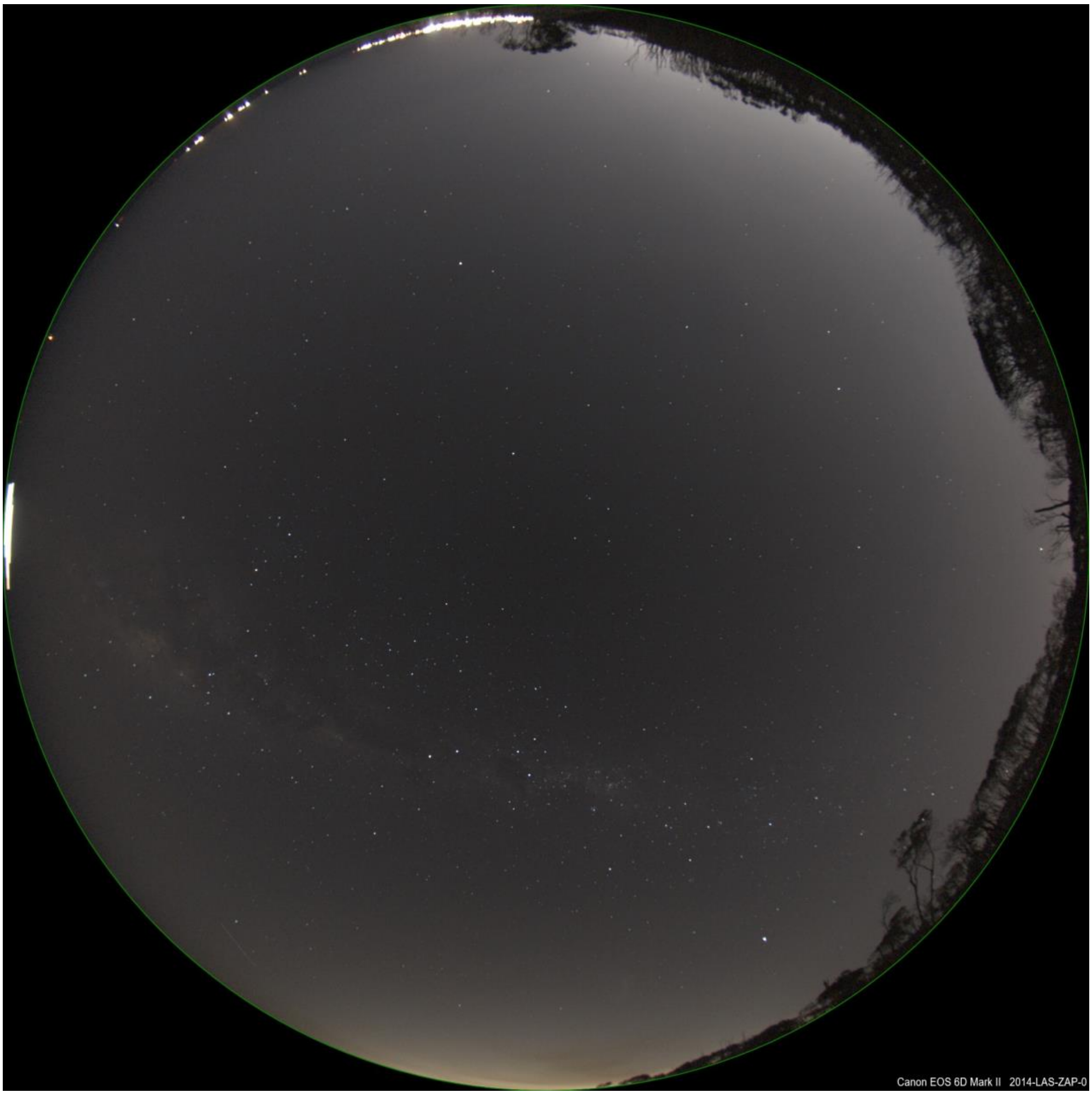


Image 3: Hemispherical image of North Bribie Island (ocean side of Lion's Park) Site

Bribie Island Spit Site

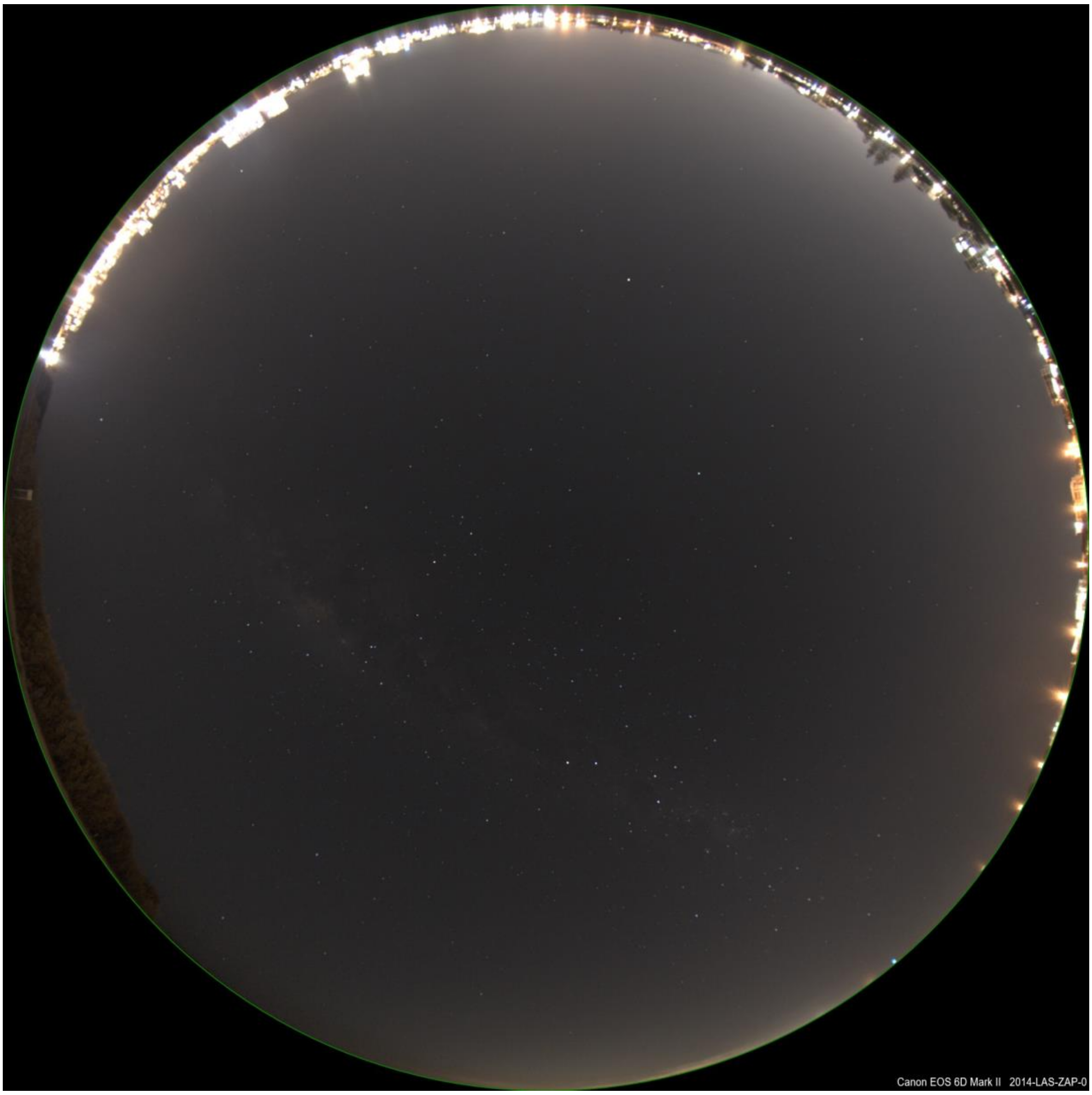


Image 4: Hemispherical image of Bribie Island Spit Site

Shelly Beach South Site – Minimal residential lighting switched on.

Image 5: Hemispherical image of Shelly Beach South Site (minimal residential lighting switched on)

Shelly Beach South Site – bright residential lighting switched on

Image 6: Hemispherical image of Shelly Beach South Site (bright residential lighting switched on)

Shelly Beach North Site

Image 7: Hemispherical image of Shelly Beach North Site

Currimundi Site

Image 8: Hemispherical image of Currimundi Site

Bokarina South Site

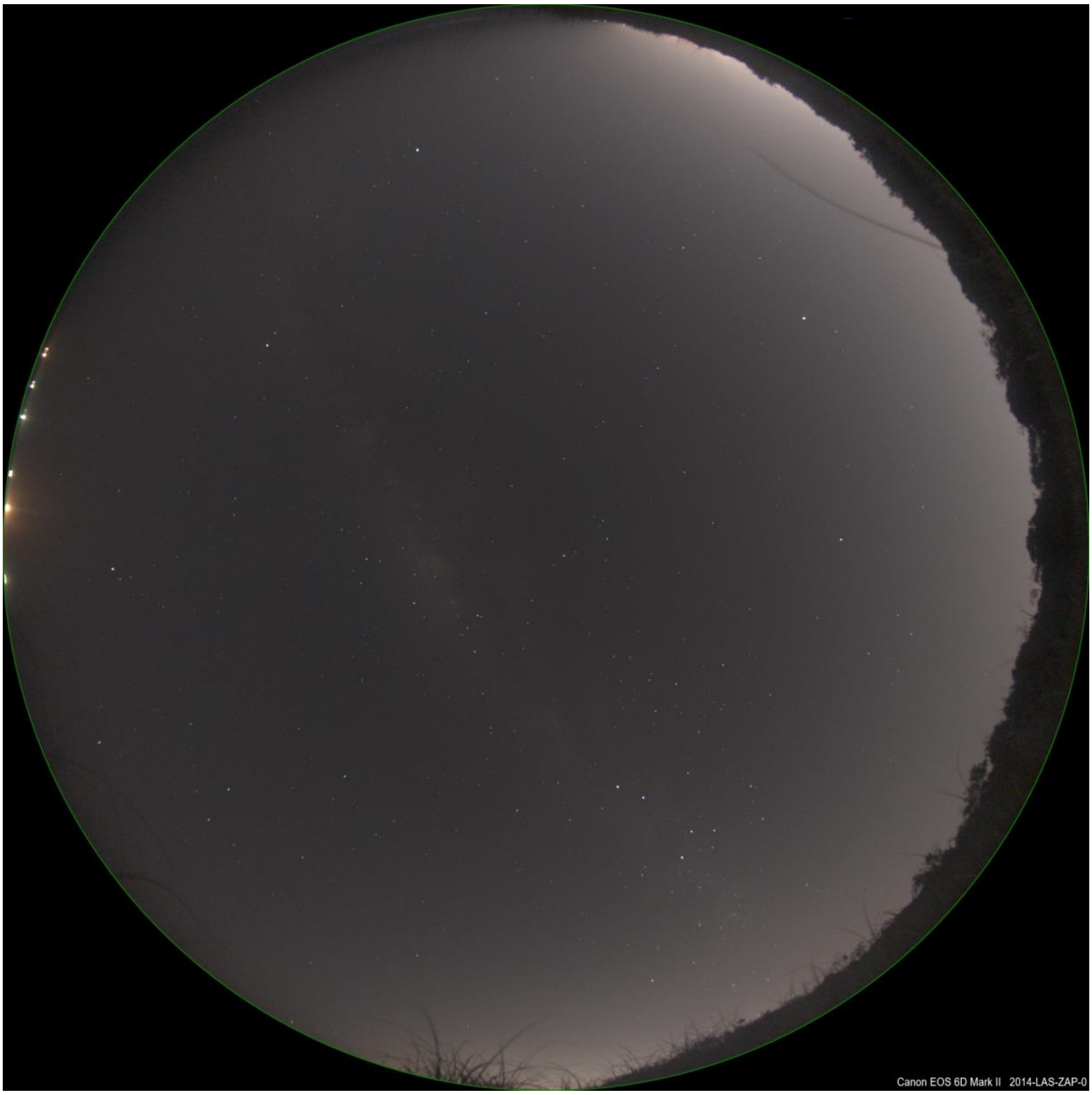


Image 9: Hemispherical image of Bokarina South Site

Bokarina North Site

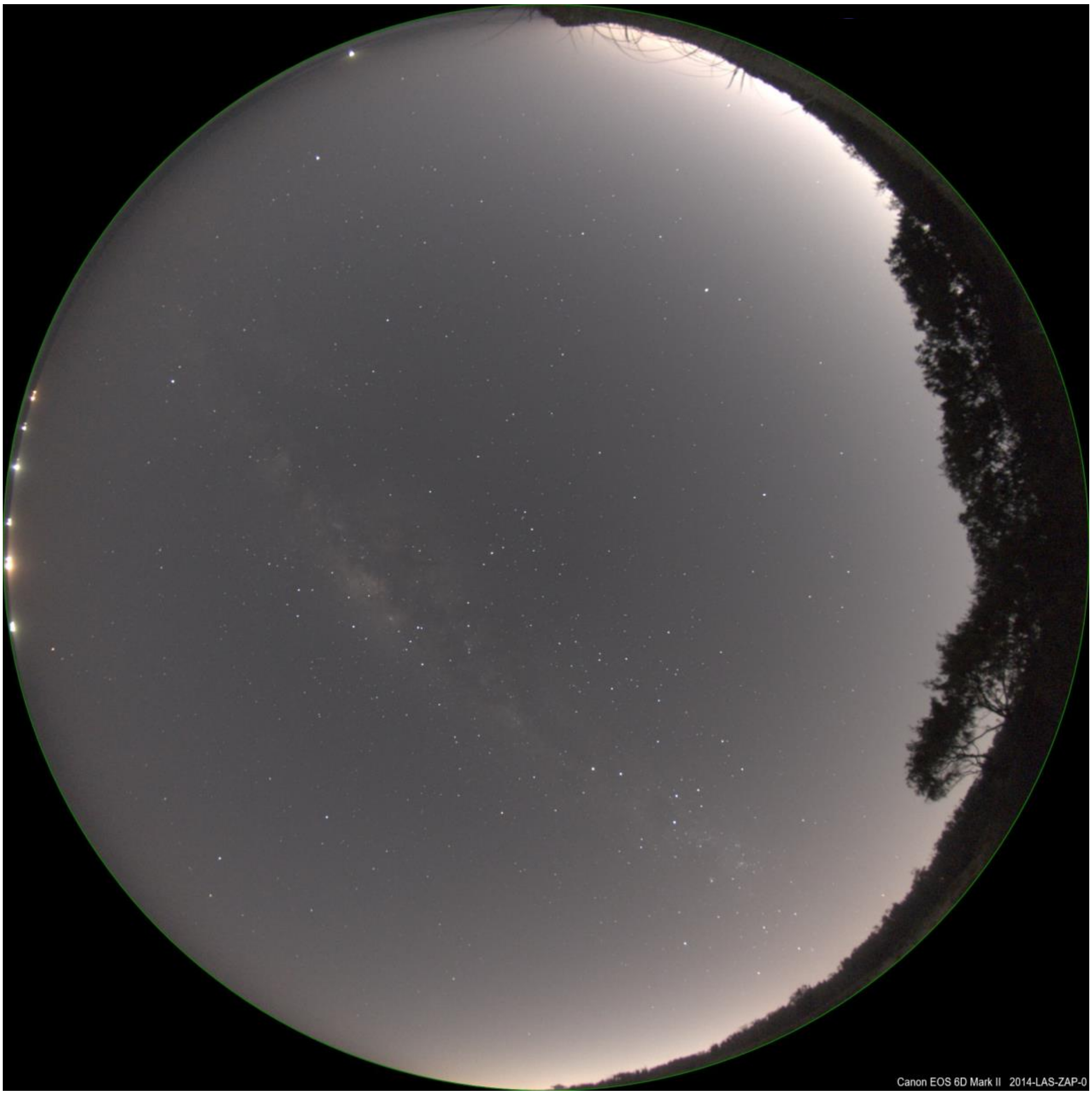


Image 10: Hemispherical image of Bokarina North Site

Buddina (Coopers Lookout) Site

Image 11: Hemispherical image of Buddina (Coopers Lookout) Site

Buddina (Pt Cartwright) Site

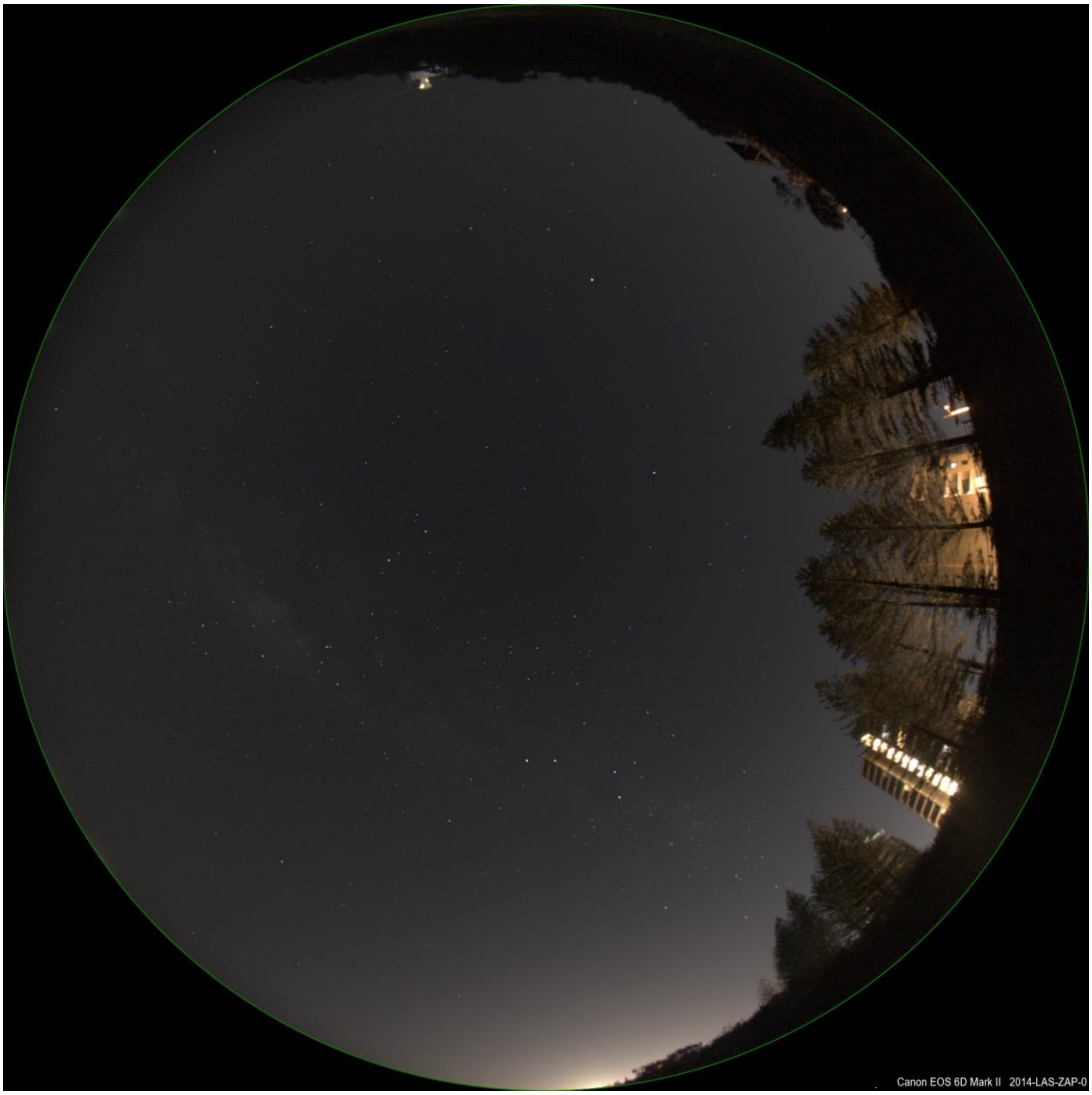


Image 12: Hemispherical image of Buddina (Pt Cartwright) Site

Mooloolaba Site

Image 13: Hemispherical image of Mooloolaba Site

North Shore Site

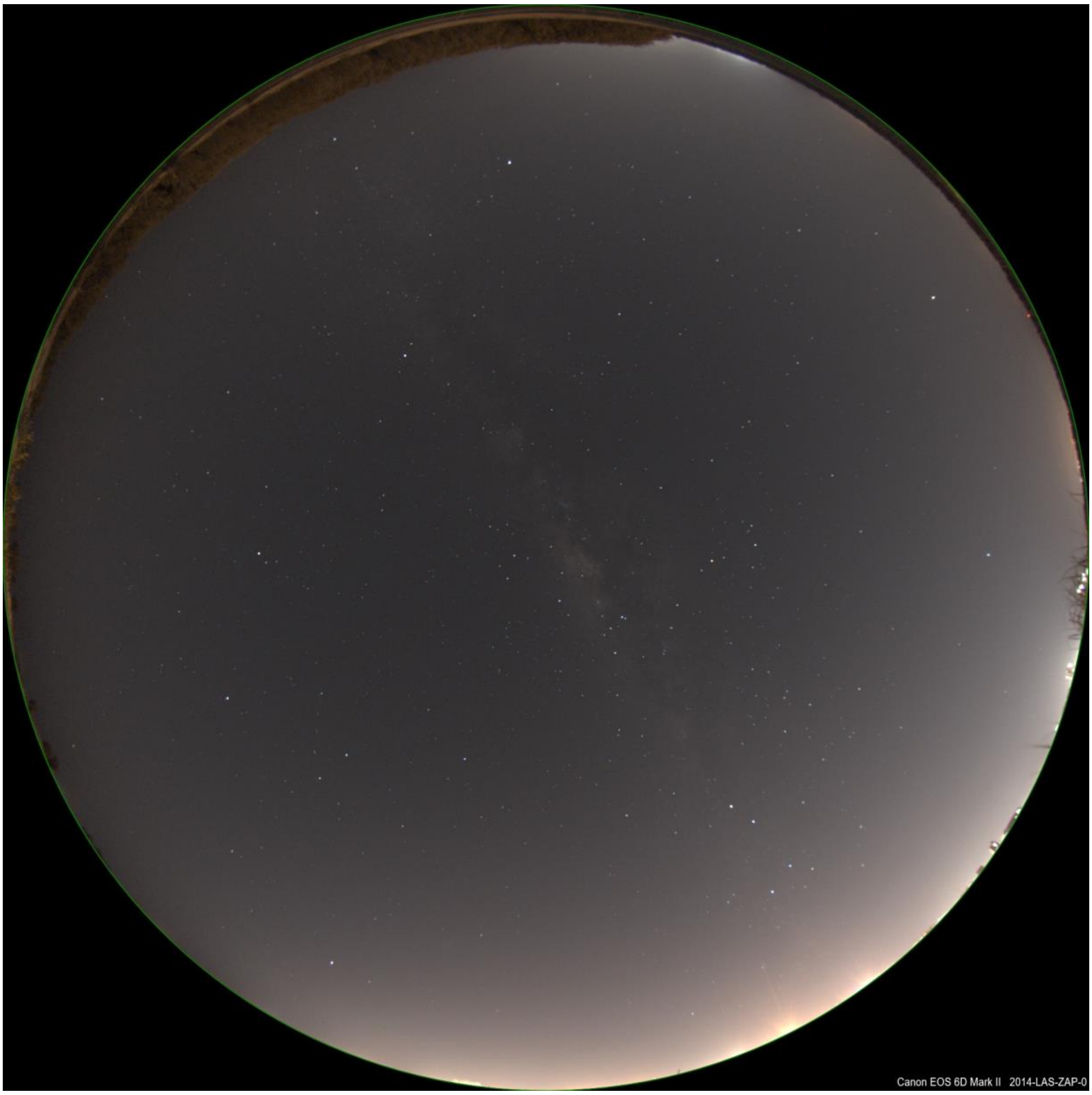


Image 14: Hemispherical image of North Shore Site

Goat Island Site – Maroochy River Site

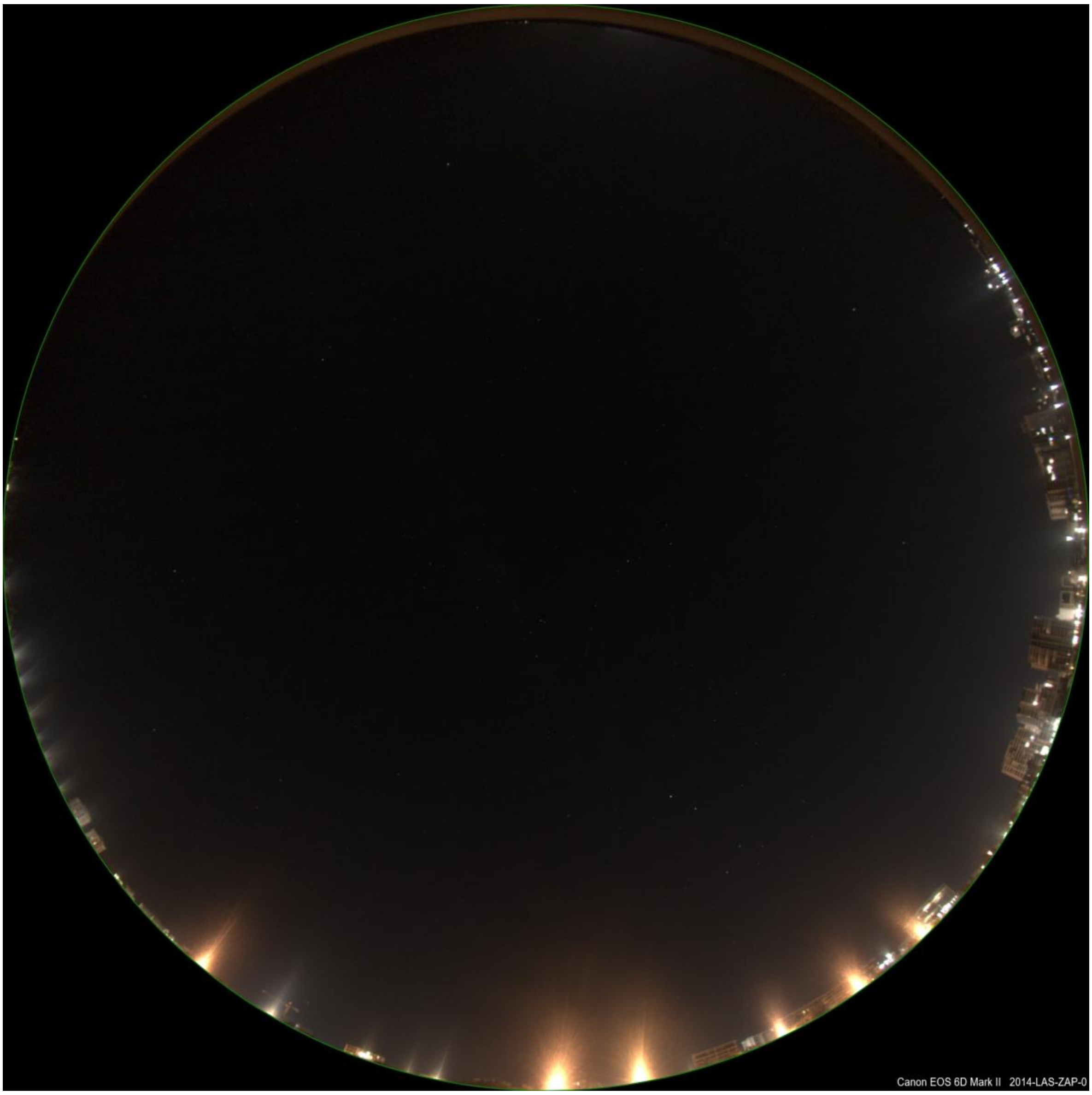


Image 15: Hemispherical image of Goat Island Site

Marcoola Site

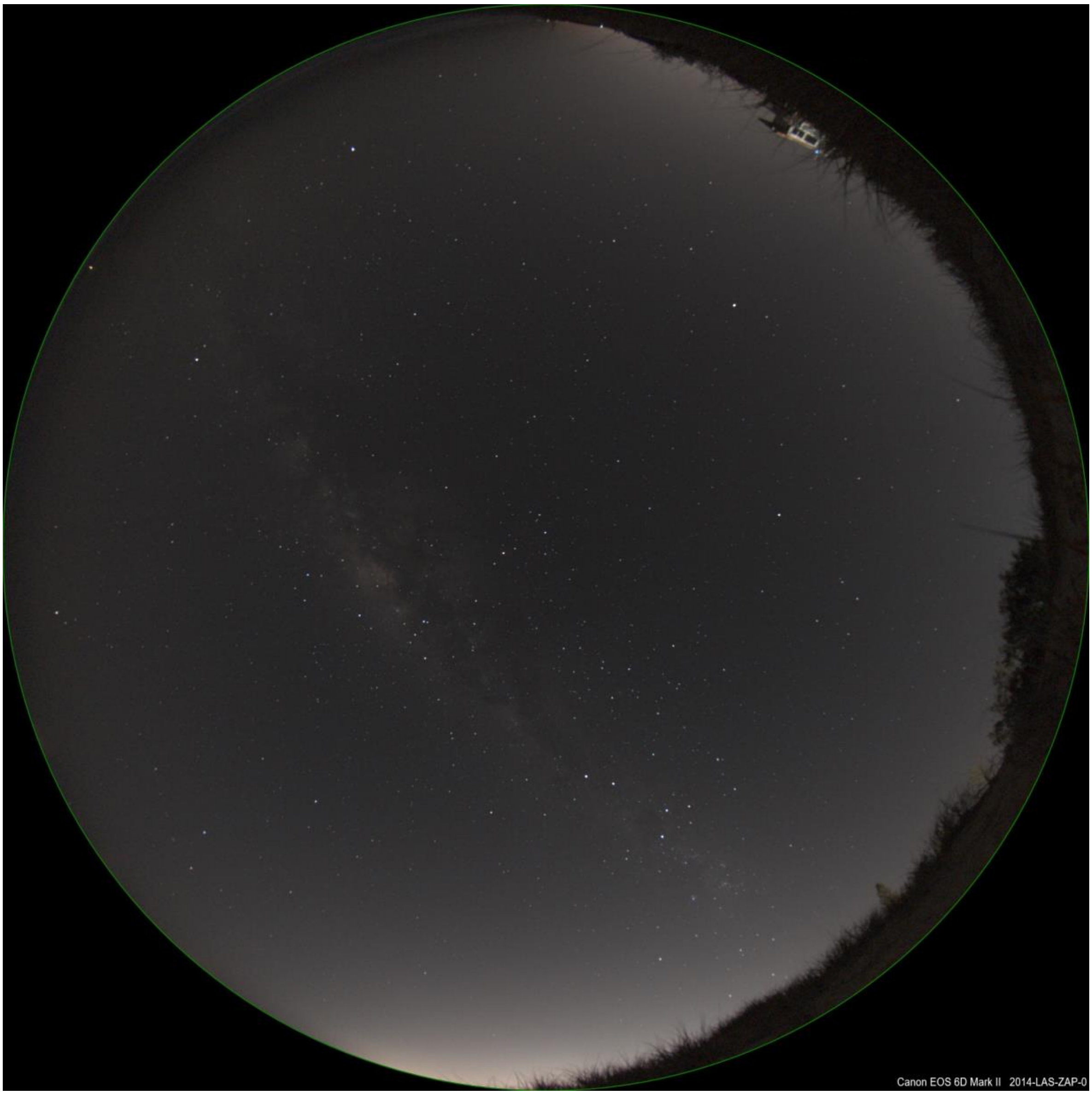


Image 16: Hemispherical image of Marcoola Site

Mudjimba South Site

Image 17: Hemispherical image of Mudjimba South Site

WAVES Testing, Research and Consulting

Mudjimba North Site

Image 18: Hemispherical image of Mudjimba North Site

Yaroomba South Site

Image 19: Hemispherical image of Yaroomba South Site

Yaroomba North Site

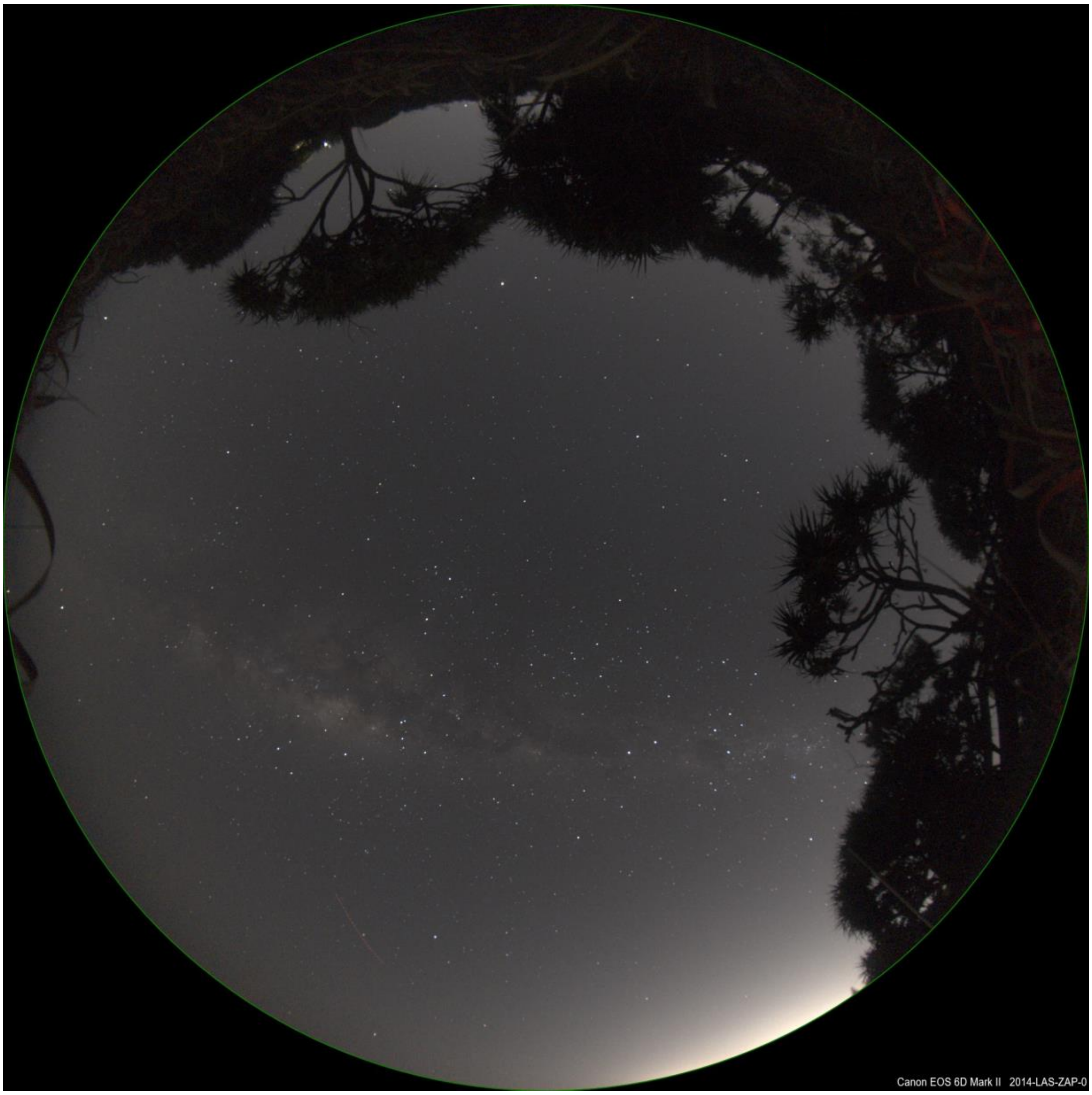


Image 20: Hemispherical image of Yaroomba North Site

Coolum North Site

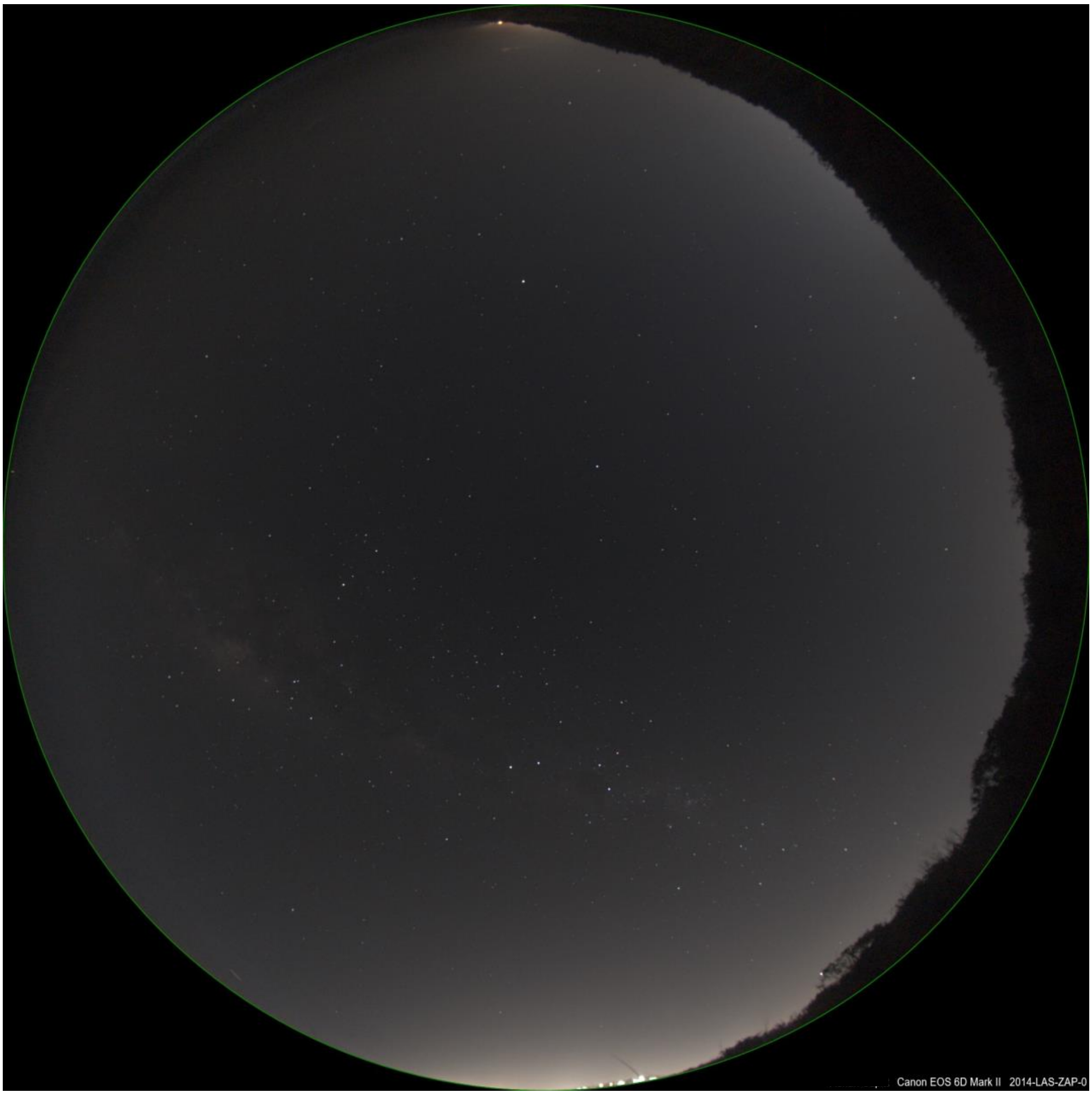


Image 21: Hemispherical image of Coolum North Site

Appendix 2
Problematic Light Sources Identified in Light Audit

a) Bribie Island Spit (Shorebird Habitat)

Pedestrian crossings along the Esplanade use multiple, high-mounted light sources with reflectors, some of which are aimed such that light emits in the direction of the measurement site. A review of the light levels on pedestrian crossings may show some sources are not required and can be dimmed, switched off or removed.

Some light sources are mounted above trees and illuminate the vegetation without providing useful illumination of the intended area below the canopy. Lighting of vegetation reduces the spread of light and hence sky glow, however low-mounted lights which only illuminate the intended area would be a better solution and reduce energy consumption. Ideally, luminaires should be mounted below the vegetation canopy, aimed away from environmentally sensitive areas, and without any upward illumination.

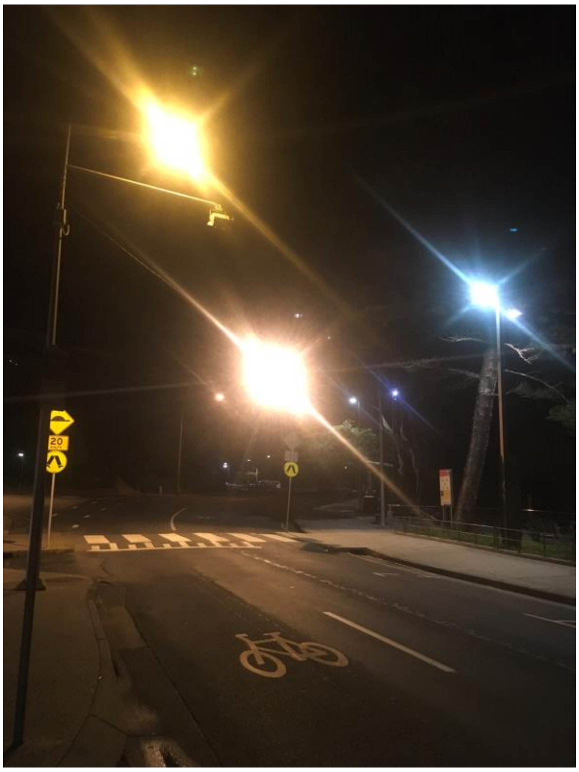


Image 22: Multiple high-mounted luminaires at pedestrian crossing providing excessive light for the intended area - contributing to sky glow and being directly visible from the measurement site.

Image 23*:* Multiple light sources illuminating vegetation and casting shadows on a pedestrian crossing, road and carpark – the areas intended for illumination. Light sources mounted below the tree line that illuminate only the intended area would reduce energy consumption and sky glow.

Image 24: High mounted luminaires illuminating vegetation canopies produce shadows on the ground. Vegetation is useful for screening light and reducing sky glow. Light sources mounted below the vegetation canopy will illuminate the required area using less light output and, hence, consume less energy.

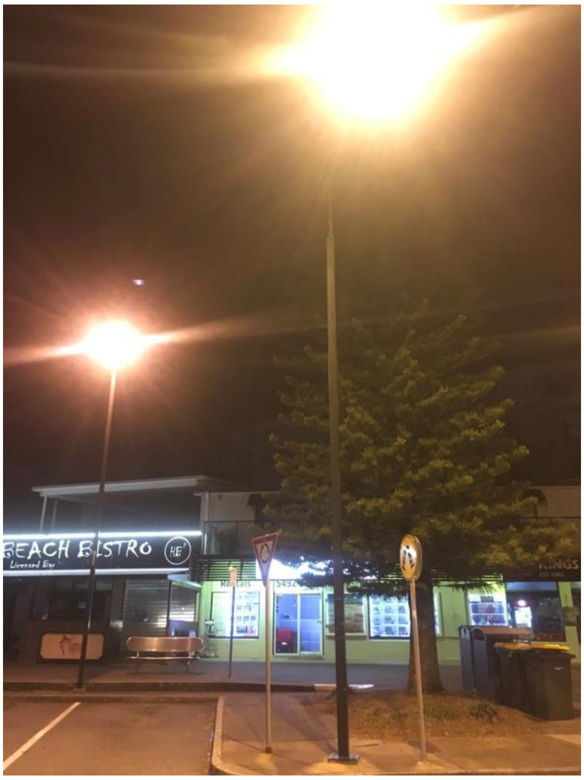


Image 25: Light sources from commercial properties and street lights remain on throughout the night despite minimal or no use by the community. The light sources are visible from turtles nesting locations on the ocean side of Bribie Island.

Image 26: Light sources mounted on poles of picnic shelters produce significant spill light and only a small portion of the light output is used for the intended purpose. Recessed light fittings, or light fittings with cut-off reflectors or sides, are useful to reduce spill light and its contribution to sky glow.

Image 27: Board walks along the coastline illuminate the beach and ocean, while only producing limited light for the intended purpose. Light sources should be shielded to only illuminate the intended area, and the use of low intensity, shielded sources directed away from the beach at a low mounting height (such as railings or bollards) are best for the application.

Image 28: Amenity blocks produce significant spill light, including at times when they are locked and not in use. Amenity blocks often utilise surface mounted, diffuse, linear battens which produce light beyond the intended area. Dimmers, motion sensors, and timers are useful for only illuminating the area when required and to the level required.

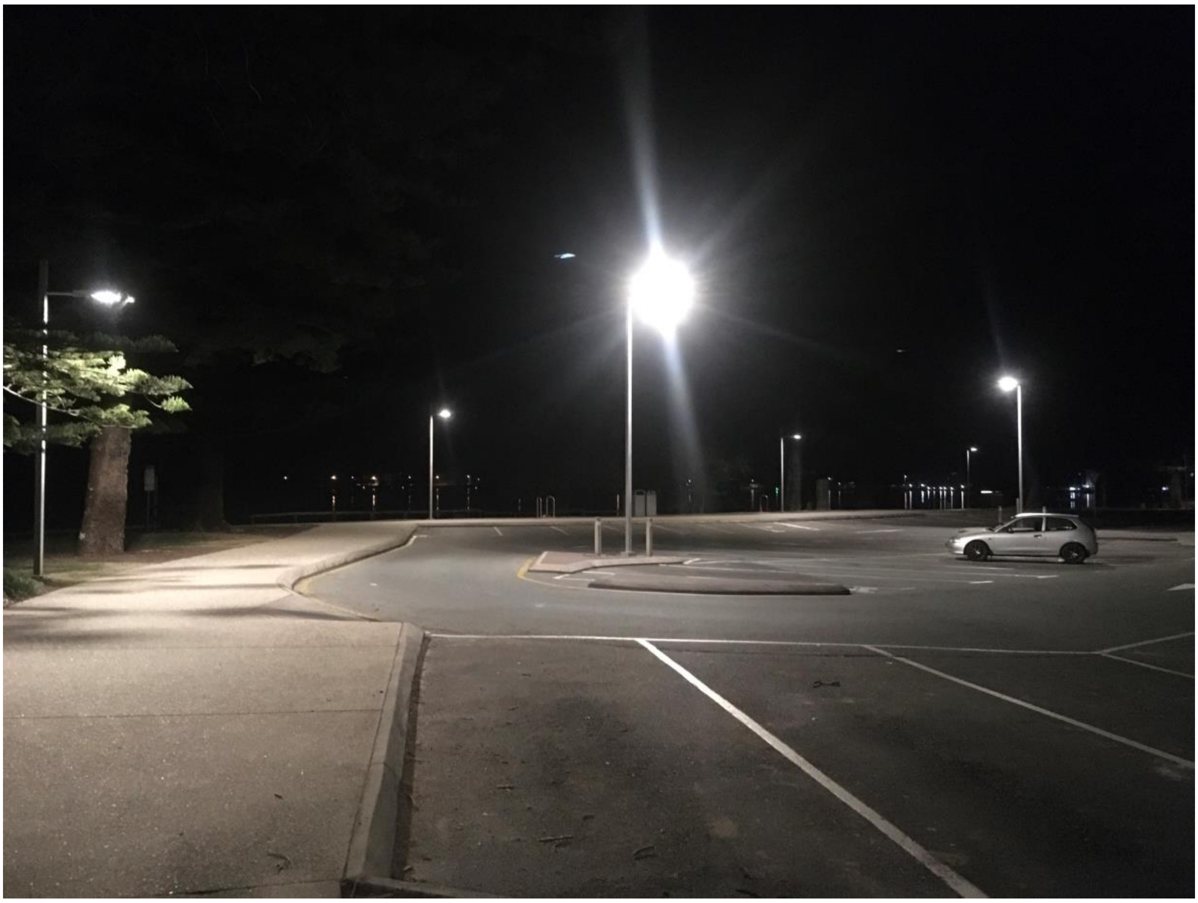


Image 29: Lighting installations for carparks use high mounted luminaires which spill light beyond the intended area

For this location, considering the footpaths have lights, the limit of illumination required for the carpark is the edge between the bitumen and the footpaths. Lower mounted luminaires with shielding can be used to minimise spill light beyond the intended area, and prevent the light sources from being visible from the beach – as seen in the following image.

Image 30: High intensity carpark, road and footpath light sources visible from the beach due to high mounting heights and insufficient shielding.

Image 31: High mounted park lighting illuminate properties beyond the intended area, and are visible from the beach.

b) Mooloolaba

The main sources of light pollution in the area are floodlights and spotlights at the Mooloolaba Surf Club (Images 33 and 34) and light sources in the Mooloolaba Foreshore Park (Images 35 and 36). Multiple high intensity, high-mounted light sources directly illuminate the beach and ocean, and provide minimal usable light for pedestrian access and safety.

Image 32: The view towards Mooloolaba Surf Club and Park from adjacent the Mooloolaba sky glow survey location showing high intensity, high mounted lights aimed towards the beach.

Image 33: Floodlights and linear fluorescent luminaires mounted on the Mooloolaba Surf Club, aimed towards the ocean. The floodlights are visible from the Mooloolaba measurement site.

Image 34: Photograph captured at 12:08 a.m. – Floodlights mounted on Mooloolaba Surf Club illuminate the beach and ocean, and provide minimal usable light (compared to the amount of light produced) for pedestrian access and safety.

The lights remain switched on throughout the night despite the area experiencing minimal use by the community.

Image 35: High intensity, high-mounted lighting in the park directly illuminates the beach and are visible from the measurement site.

Image 36: Footpath lighting in Mooloolaba Foreshore Park illuminates larger areas than required and spills light onto the beach.

The lights remain on throughout the night despite the area not being used for pedestrian access or safety.

The lighting is excessive and consumes more energy than required for the purpose. Low, bollard lights which are directed away from the beach would provide sufficient illumination for safe movement and significantly reduce light pollution and energy consumption.

c) Goat Island (Shorebird Habitat)

There are a large number of omni-directional light sources mounted atop poles throughout the Cotton Tree Caravan Park which contribute to sky glow yet only a small portion of the light produced is usable light for safe access by pedestrians and guests.

Very high intensity, high-mounted luminaires are scattered throughout Cotton Tree Park which are aimed in the direction of the Maroochy River. Many of the park lights illuminate vegetation or beyond the intended area and do not serve a purpose for park user access or safety.

Image 37: Bridge lighting uses diffuse sources which spread the light beyond the intended area and into the waters below.

Sources such as these, beyond the immediate foreshore of Maroochy River, contribute to sky glow in the area. Shielding of sources or installation of directed railing lights may reduce light spill beyond the bridge area while providing sufficient light for safe access and movement of pedestrians.

Appendix 3
Spectral Output of Light Sources

Turtles are sensitive to blue light (Witherington, B. E. 1992), therefore light sources which have a large short wavelength (purple-blue light) component cause the greatest impact on turtle behaviour. High intensity light sources of any spectral content are also disruptive to turtle behaviour. Hence, the intensity of the sources and the spectral content need to be considered when assessing the suitability of a light source for use in a sea turtle sensitive area. The spectral power distribution (SPD) of visible light sources mentioned in this report were measured to understand the wavelength component of the sources. The spectral irradiance measurements were normalised to the maximum spectral irradiance value.

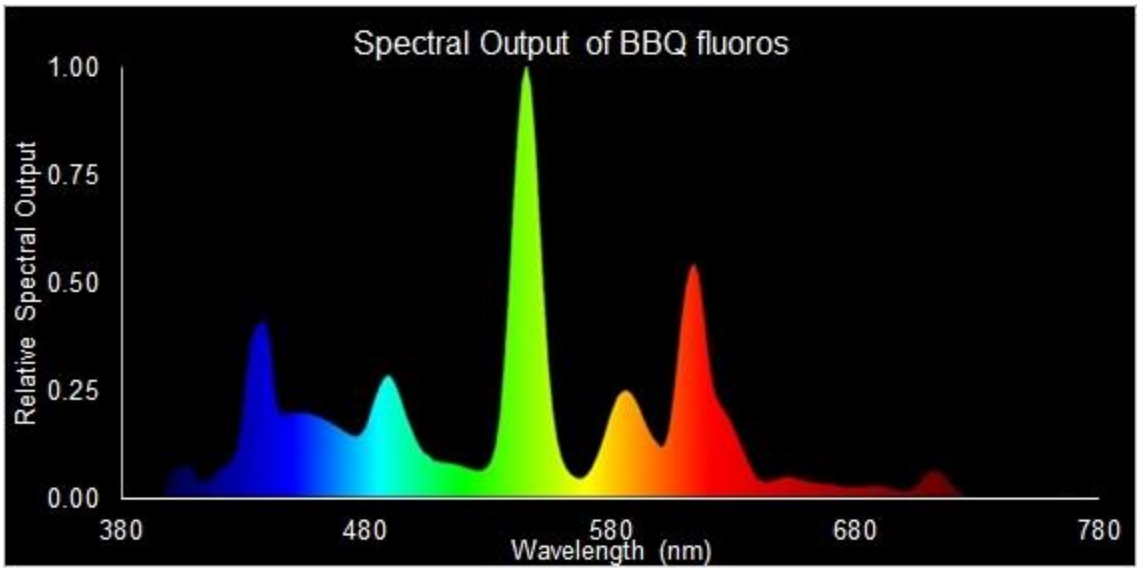


Figure 48: SPD of cool white linear fluorescent typical for many BBQ shelters and amenity blocks

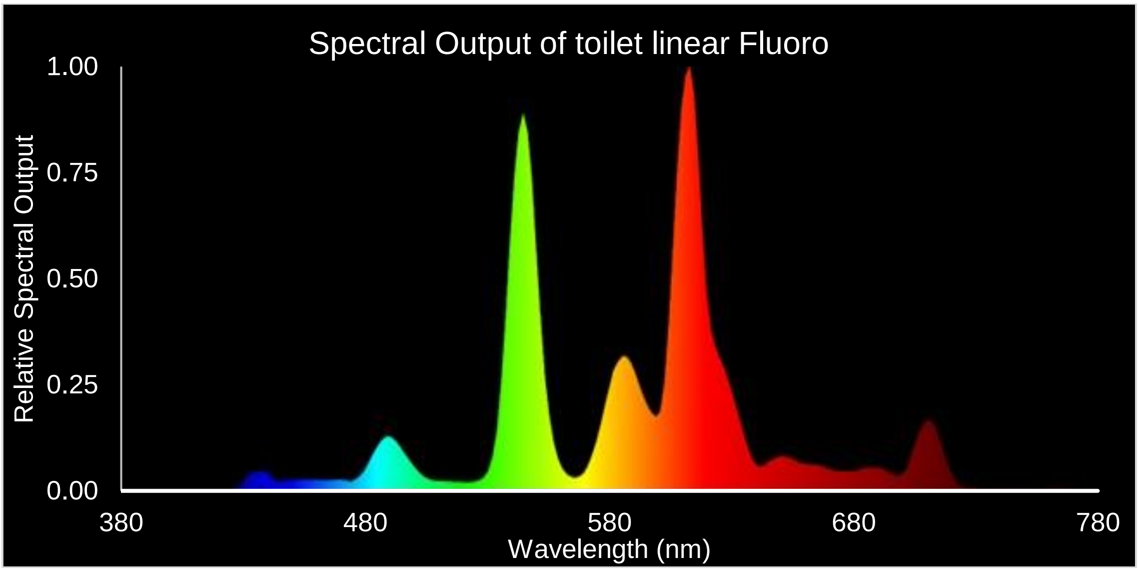


Figure 49: SPD of warm white linear fluorescent typical for many amenity blocks

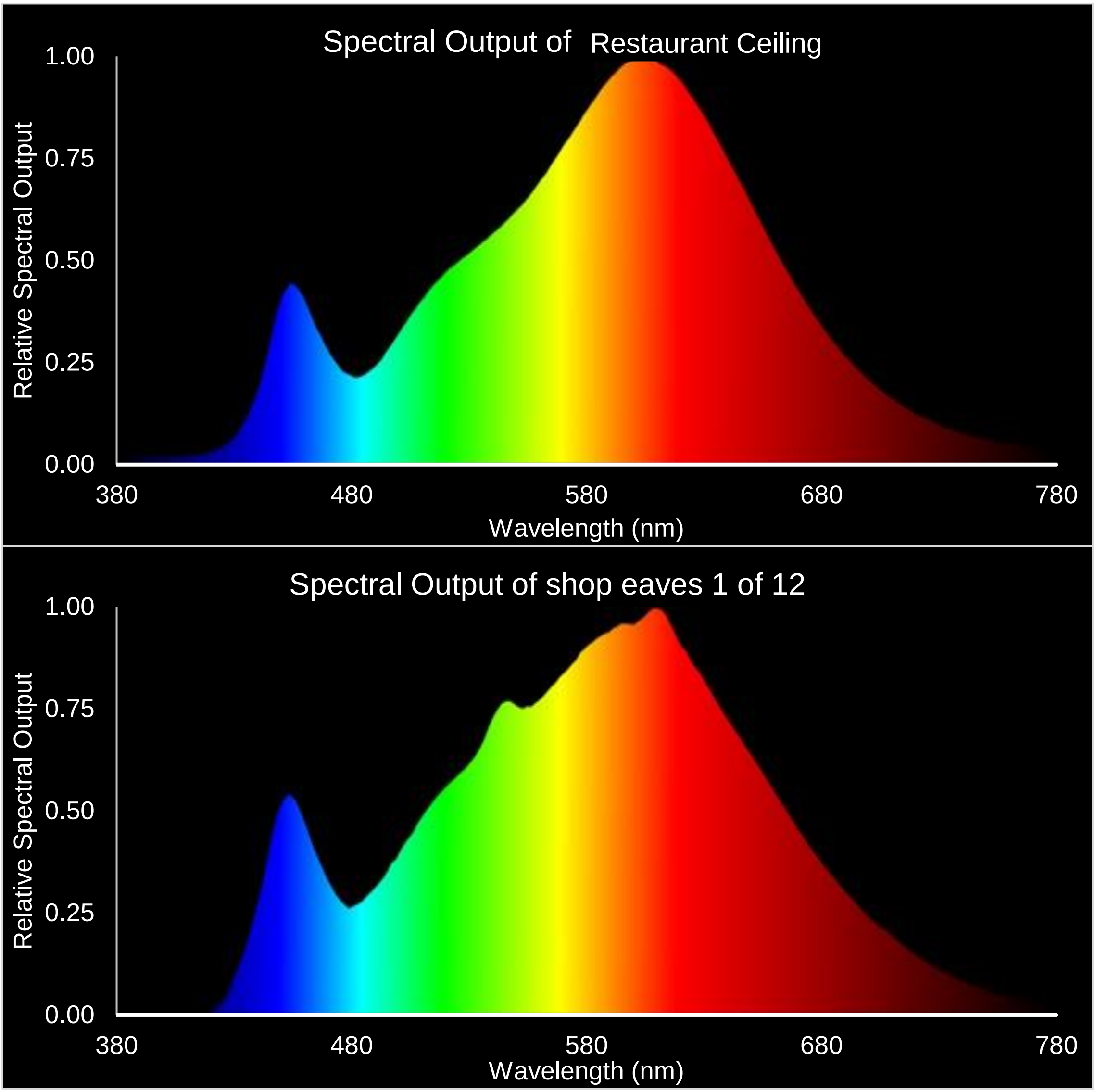


Figure 50: SPD of approx. 3000K LED typical for commercial buildings, amenity blocks, park/BBQ shelters, carparks and residential lighting

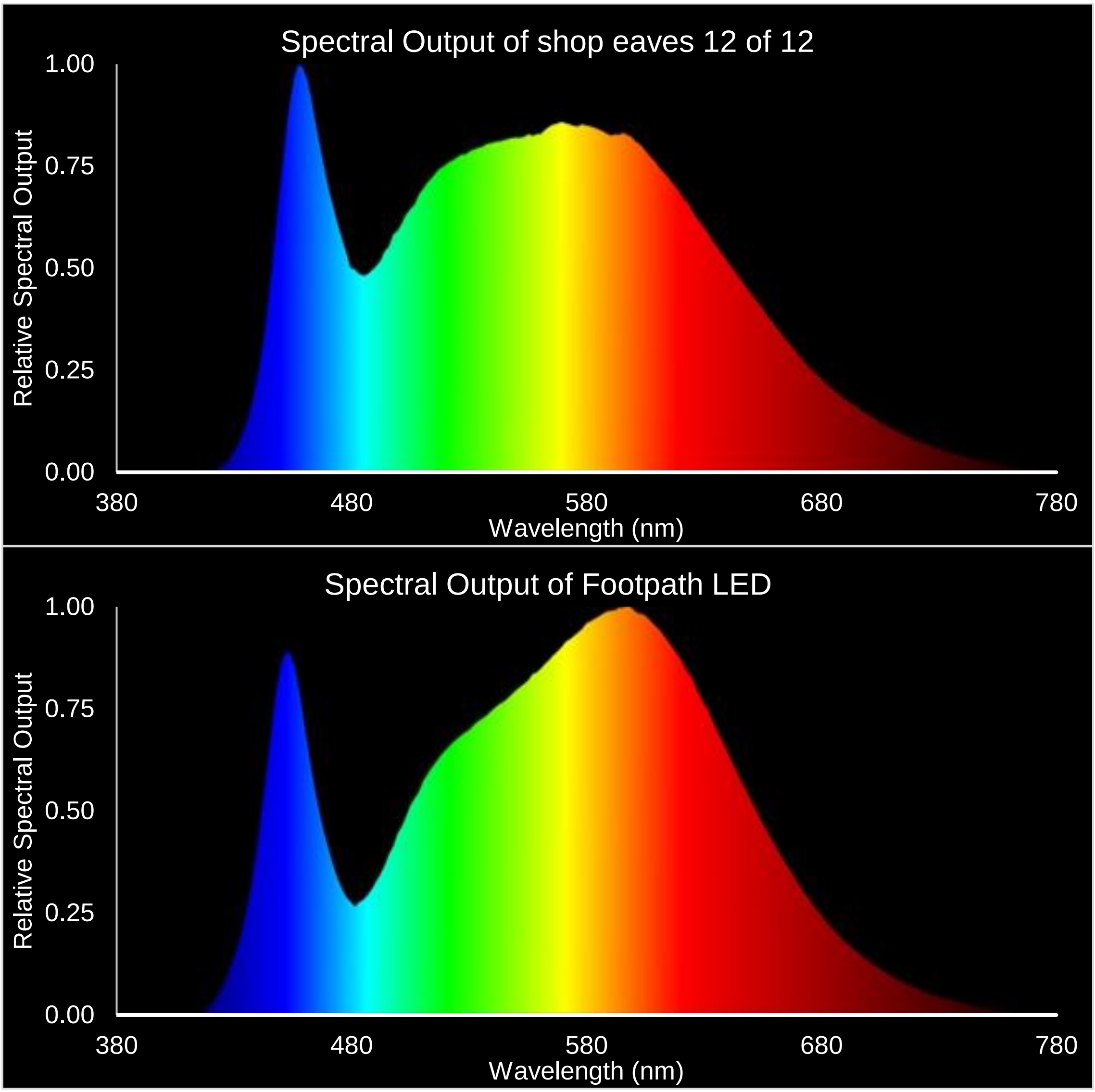


Figure 51: SPD of approx. 4000K LED typical for commercial buildings, footpath and park lighting, BBQ shelters, and carparks

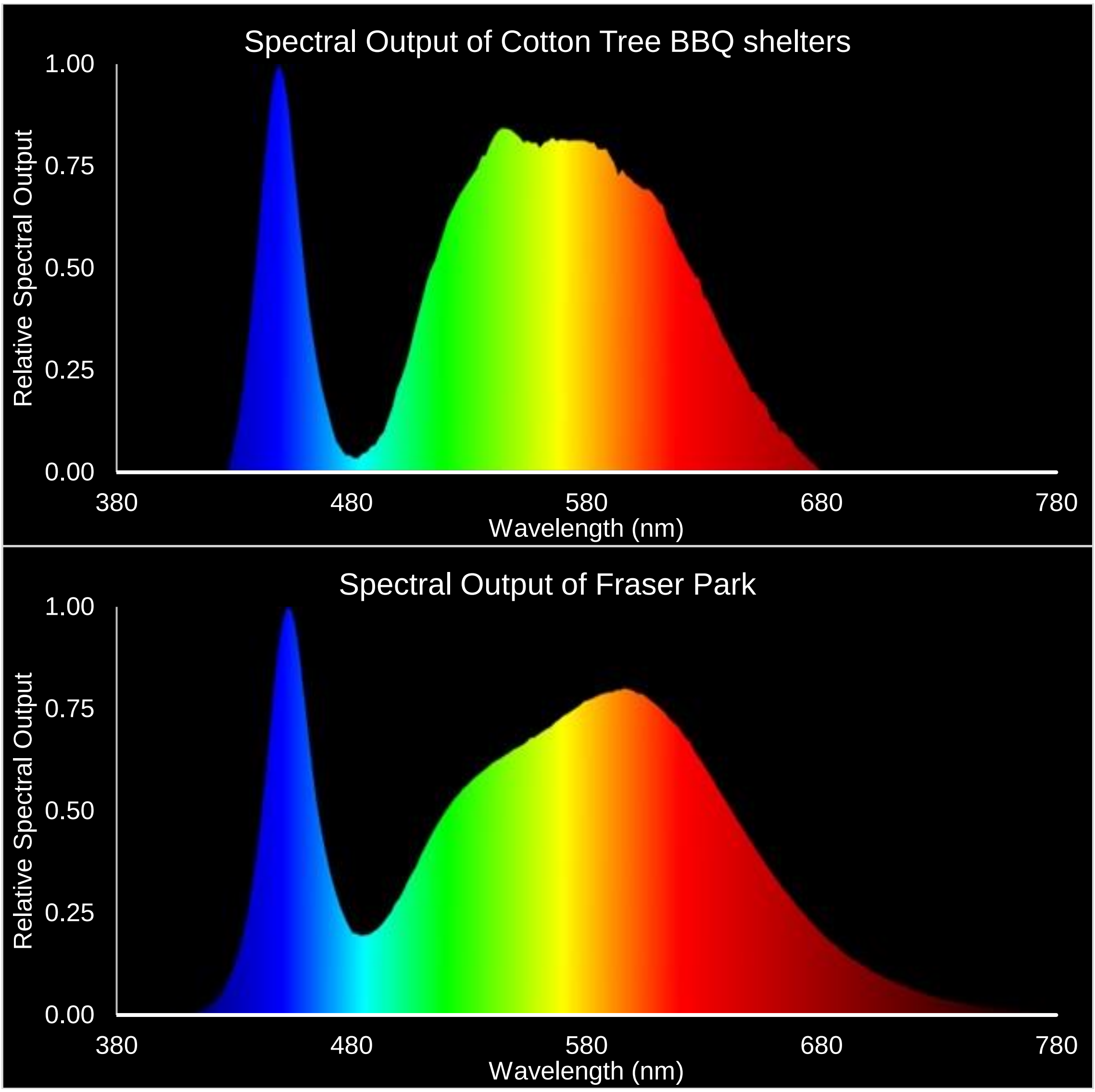
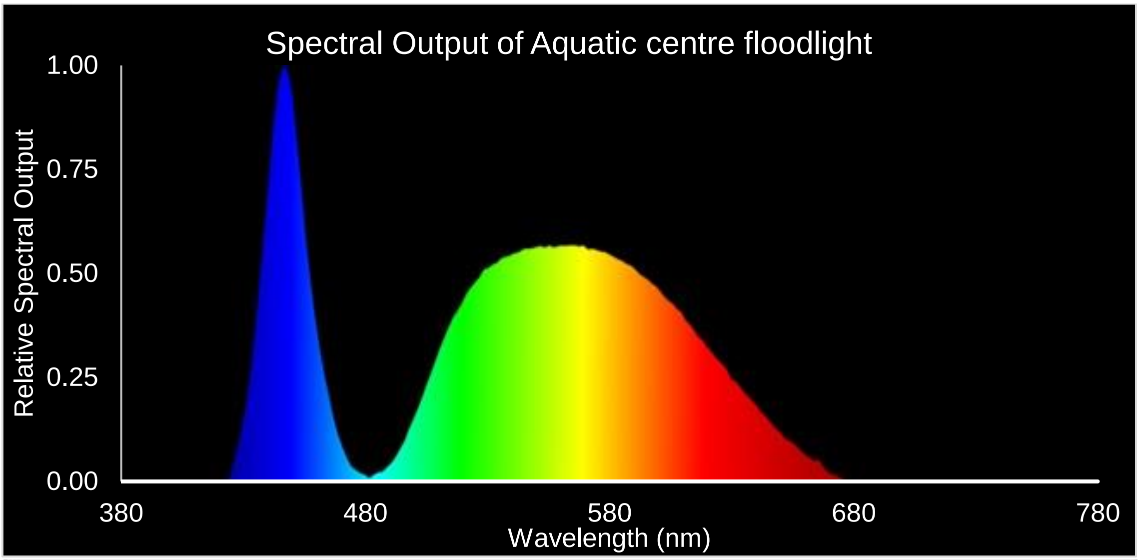


Figure 52: SPD of approx. 4000K (neutral white) linear LED typical of BBQ shelters of Cotton Tree, parks such as Fraser Park, amenity blocks, and commercial properties.



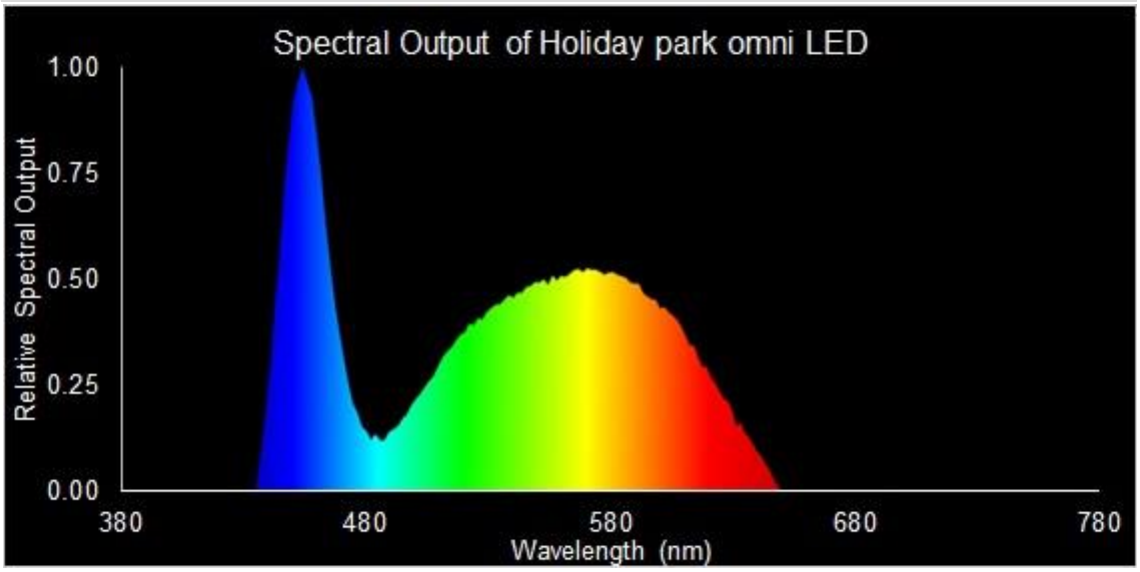


Figure 53: SPD of approx. 5000K (cool white) LED floodlight measured at an aquatic centre and a holiday park.

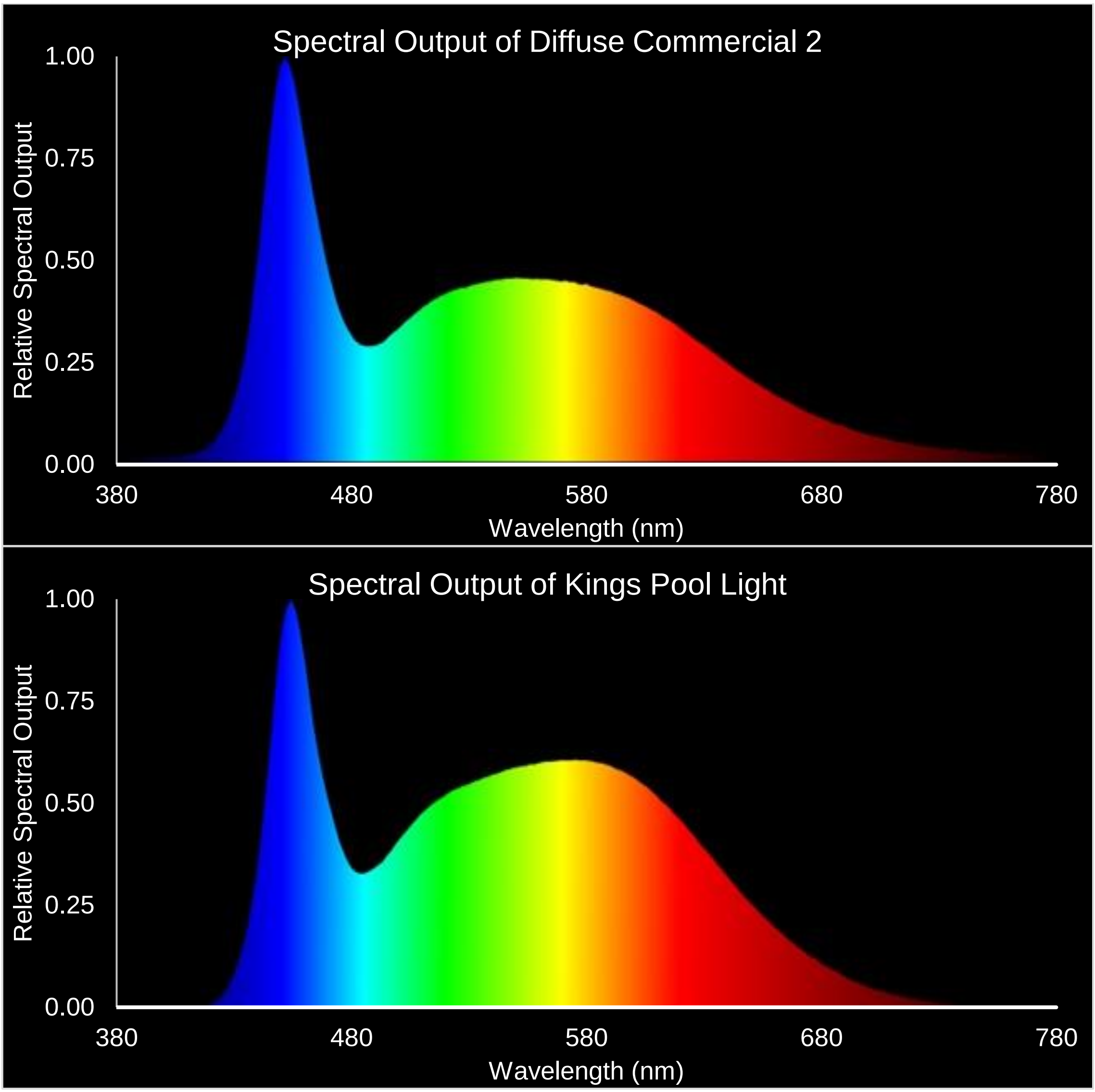


Figure 54: SPD of approx. 5000K (cool white) LED floodlight measured at a commercial property and at the Kings Park Pool.

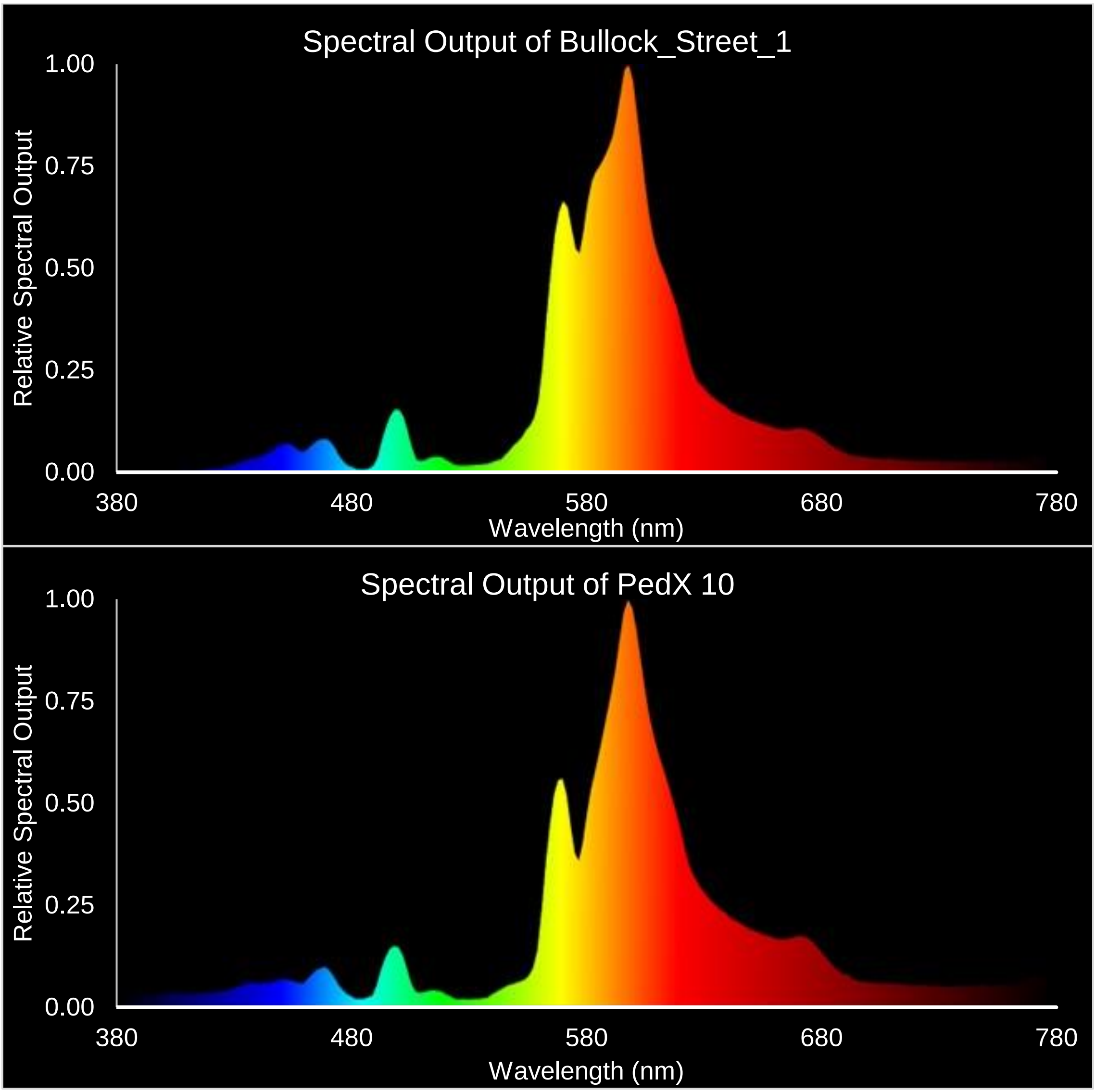


Figure 55: SPD of high-pressure sodium source typical of street lights, pedestrian crossings, carparks and footpaths

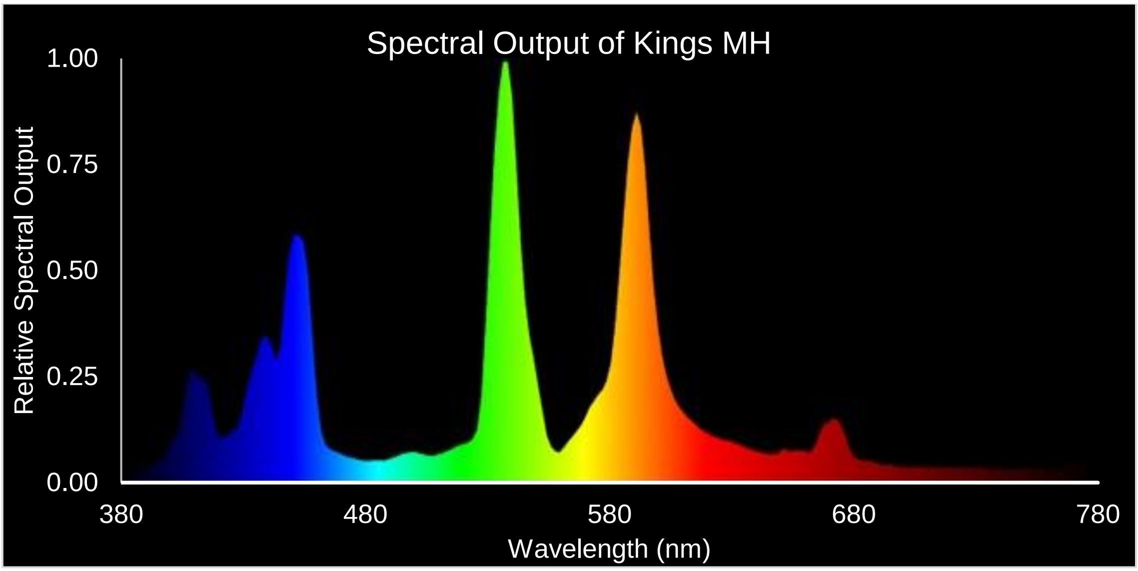


Figure 56: SPD of metal halide streetlight at Kings Beach

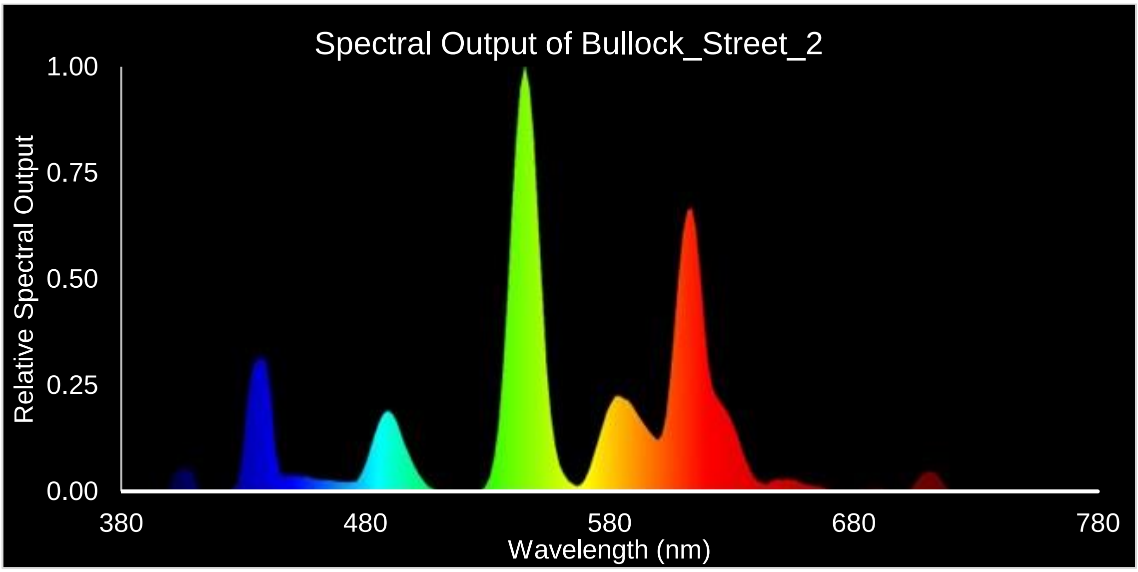


Figure 57: SPD of compact fluorescent source typical of streetlight and park lighting luminaires

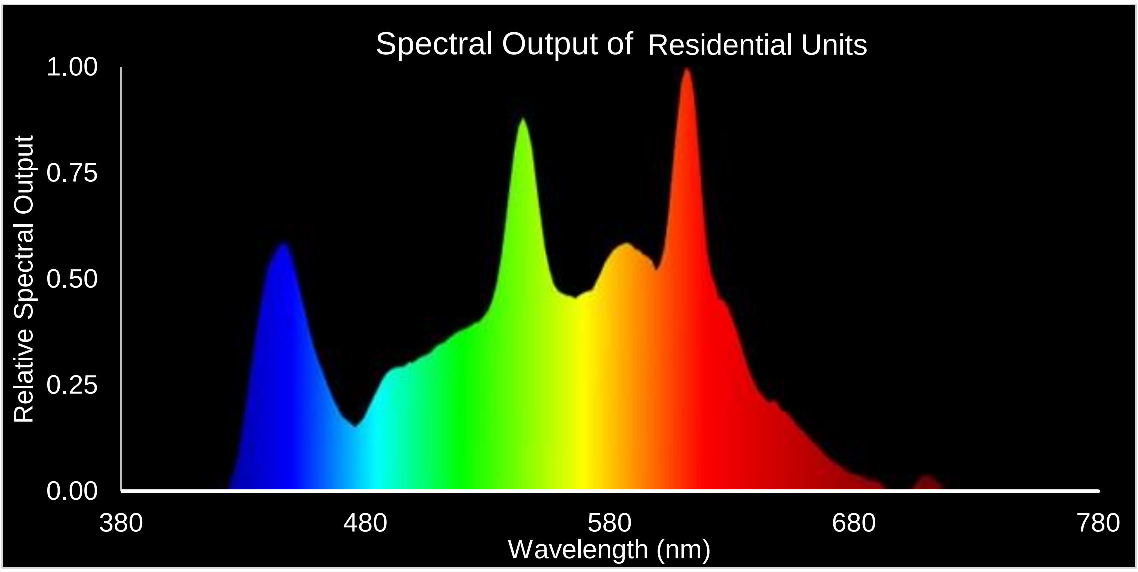


Figure 58: SPD of a combination of LED and fluorescent typical of residential dwellings and unit blocks

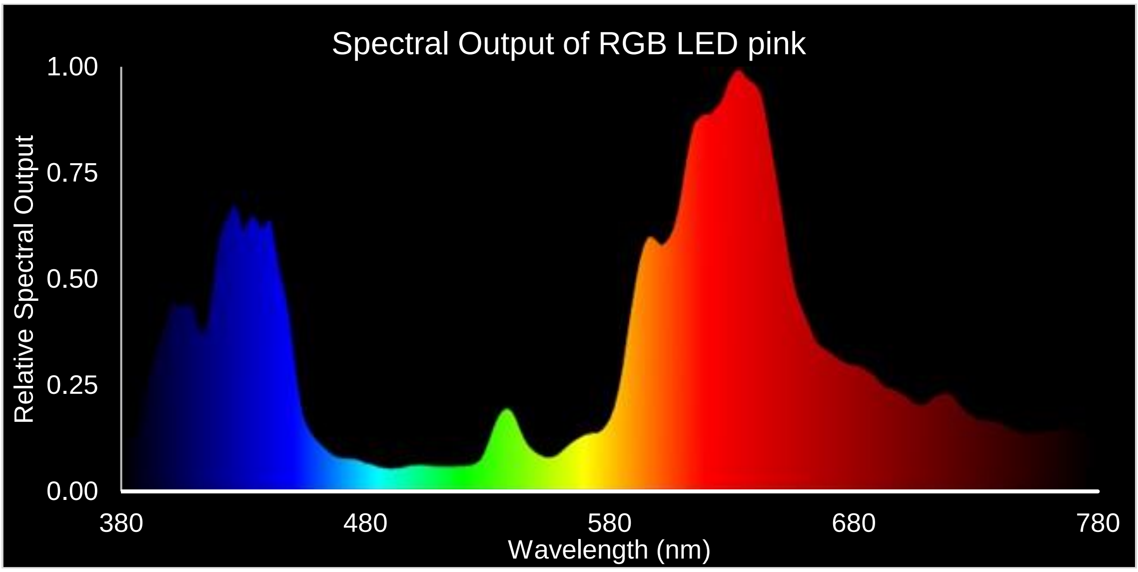


Figure 59: SPD of RGB LED in ‘pink’ colour at Golden Beach foreshore

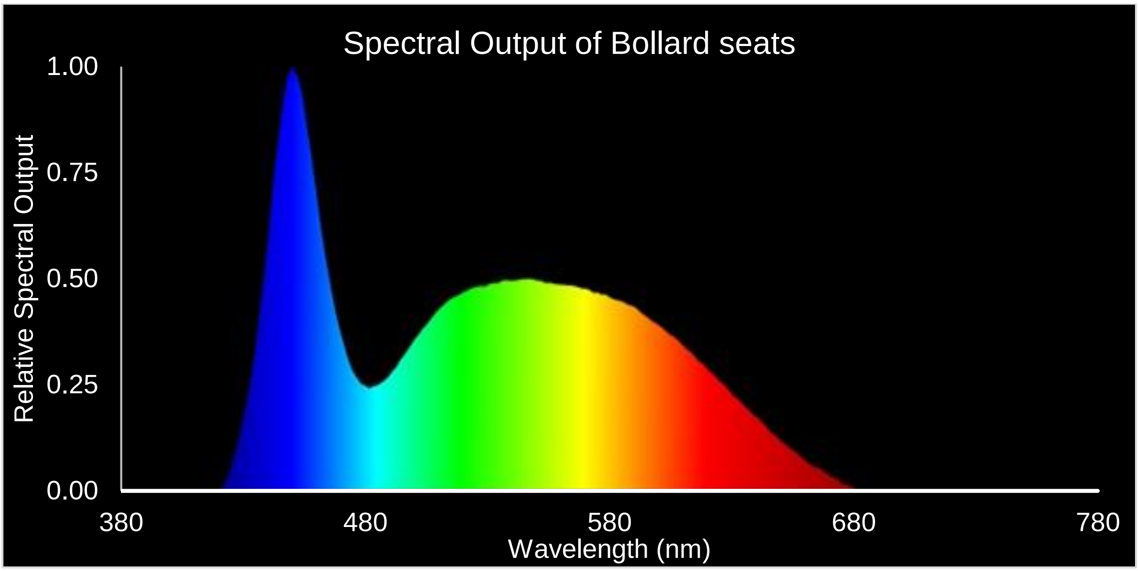


Figure 60: SPD of cool white LED sources installed in bollard seats at Mooloolaba foreshore

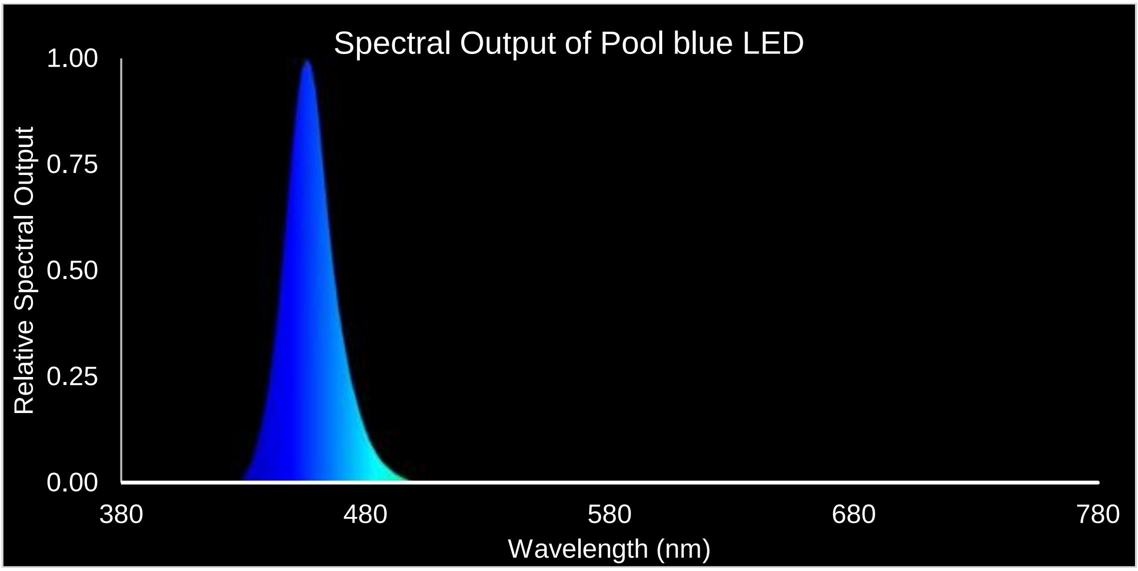


Figure 61: SPD of blue LED lights in pool

As illustrated by the above figures, the spectral output of white LEDs (ie, non-RGB) will usually contain a 'spike' in the blue region and a 'hump' in the green-red region. When assessing the blue content of a white LED it is important to compare the relative size of the spike and the hump. The 3000K LEDs show the spike in the blue region to be far less than the hump in the green-red region. The 5000K LED shows the spike in the blue region to be far greater than the hump in the green-red region. Sources with large blue content such as white LEDs are disruptive to turtle behaviour.

Low pressure sodium and amber LED luminaires have the least blue content of the luminaires measured. White LEDs (warm white, 3000K to cool white, 6500+K), metal-halide, mercury vapour and cool white fluorescent tubes contain relatively large amounts of blue wavelength light. Due to the sensitivity of turtles to blue light, these lights would appear brighter to turtles than they would humans.