Appendix K - Lighting Management Plan

NORTHWEST RESORTS

NINGALOO LIGHTHOUSE RESORT DEVELOPMENT: ARTIFICIAL LIGHT ASSESSMENT AND MANAGEMENT PLAN

Prepared by

Pendoley Environmental Pty Ltd

For

Northwest Resorts

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1 INTRODUCTION

1.1 Background

The Ningaloo Lighthouse Resort Development (the project) involves the construction and operation of a tourist resort on the footprint of 30+ year old campground and caravan park on north western Cape Range, Western Australia. The project proponent is Northwest Resorts Pty Ltd (NWR).

The project and its aims have been described in the Ningaloo Lighthouse Resort Development Application Report (Element 2020). The development will provide world class accommodation types to appeal to a broad range of travellers and is divided into two main areas: the resort village and the caravan park. These areas comprise heritage buildings, administration and village buildings (including a restaurant, bar, spa, recreation centre, pool and pavilion), accommodation buildings (including a hotel, caravan park, lodge style units, villas, high end villas, staff accommodation, eco tents, and a camping ground), and service buildings.

The resort village is located adjacent to a beach. The caravan park is situated in a small valley to the south of the resort village and contains the infrastructure, logistics, and boat storage buildings that support the village, including a fuel station (**Figure 1**).

The project is situated in the vicinity of known nesting habitat for marine turtles. Under both State and Federal legislation, marine turtle species are protected by various regulatory instruments and consequently, any action that has the potential to impact on the populations or their habitat must be assessed and managed to the satisfaction of the regulators. The project is recognised as potentially impacting on these biological receptors and hence a formal assessment and management plan is required.

In addition to the recognised biological receptors, socioeconomic receptors, primarily the US owned, and Department of Defence (DoD) operated, Space Surveillance Telescope (SST), may also be impacted by artificial light from the project. The SST detects and tracks orbital debris in addition to near Earth asteroids and is an important contributor to the US Global Space Surveillance network (DoD 2014).

In early 2020, NWR requested Pendoley Environmental (PENV) to undertake a preliminary Lighting Impact Assessment and Artificial Light Management Plan (ALMP) for the Development Approval submission to the Shire of Exmouth (Rev A).

In December 2020, a preliminary ALMP was prepared prior to planned field work programs that occurred in February 2021 (J86001 Rev A). The field surveys conducted in February 2021 included the collection of:

- benchmark marine turtle hatchling orientation data at potentially impacted nesting beaches.
- in-situ benchmark light monitoring data from nesting beaches and the SST.

The preliminary ALMP has been updated with results from the field surveys listed above and the lighting impact risk assessment has been revised to include those new data. This report contains those updates. The February 2021 marine turtle hatching orientation and light monitoring surveys also provide essential benchmark data for ongoing monitoring of light and hatchling orientation.

This ALMP complies with the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia 2020) (the guidelines) and the NSW Dark Sky Planning Guidelines (NSW 2016) and identifies the potential impact of the project related artificial light on marine turtles and the SST. The ALMP uses the results of the assessment to address the requirement of the guidelines. It outlines best practice lighting design by including a consolidated list of mitigation measures that could prevent or minimise project related lighting impacts to relevant receptors. The ALMP builds on early work undertaken by Arup (Arup 2020).

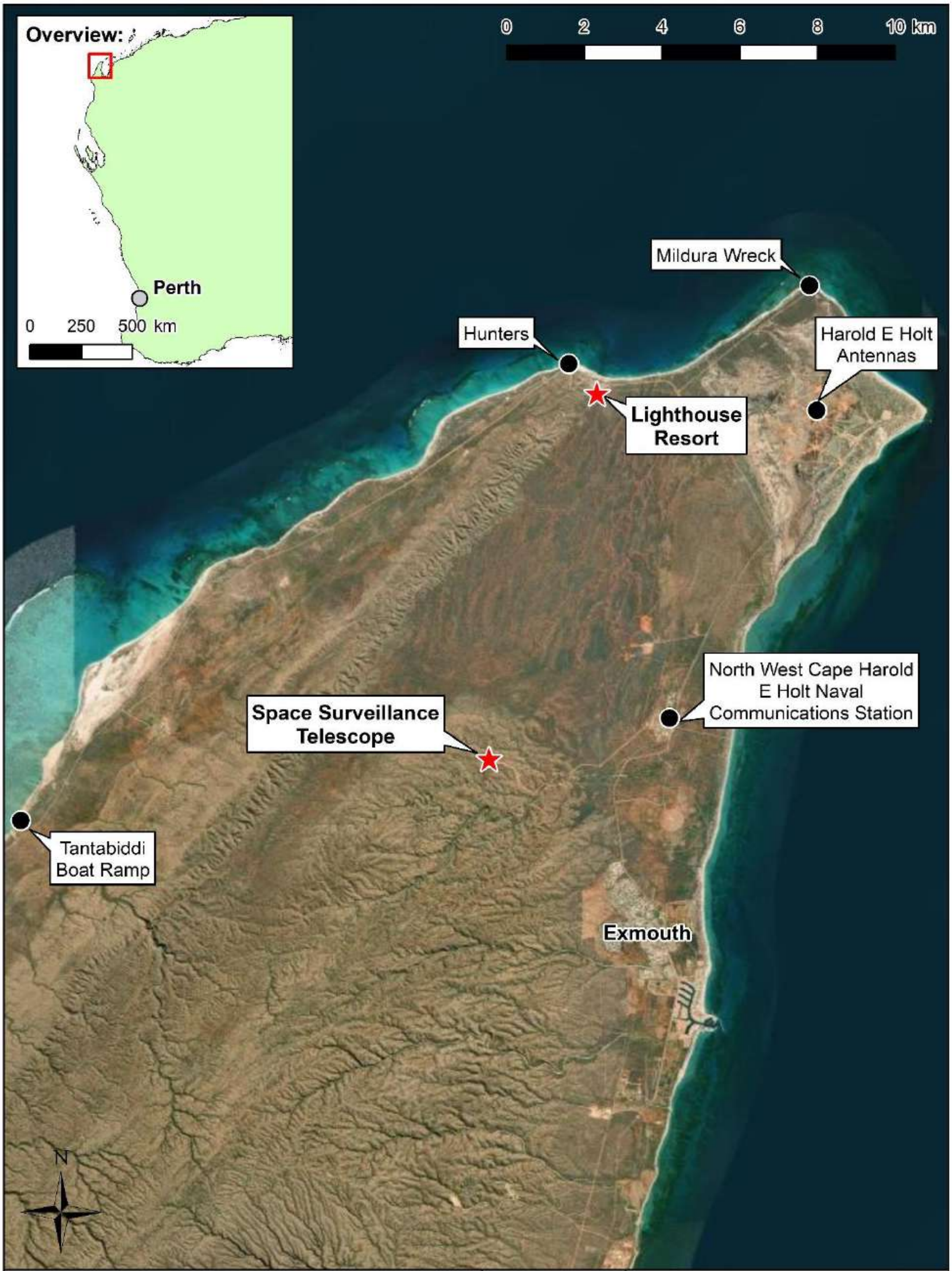
Future light modelling will be used to refine and confirm the lighting design suitability for dark sky conservation.

1.2 Scope and Objectives

For this project, there is a recognised potential impact pathway from project related artificial lighting to sensitive biological and socioeconomic receptors, specifically marine turtles and the SST. Accordingly, this ALMP includes:

- A description of the SST and the marine turtle species nesting within 20 km of the project (distance at which a potential impact to marine turtles could occur; Commonwealth of Australia 2020).
- A viewshed analysis indicating the visibility of project related light sources at marine turtle nesting habitat and the SST.
- A description of light sources associated with the project.
- Results of benchmark marine turtle hatchling orientation and artificial light monitoring surveys
- An impact assessment of identified light sources on marine turtles and the SST.
- Details of best practice lighting design principles and mitigation measures that could be applied to eliminate or minimise project related lighting impacts to marine turtles and the SST.
- Recommendations for marine turtle and light monitoring for pre-construction, construction, and operations phases of the project.

In-water habitat use by foraging and inter-nesting marine turtles was considered out of scope and is not discussed further. Similarly, artificial light sources associated with the Exmouth town site and the Naval Communication Station Harold E Holt are considered out of scope and not considered further in the risk assessment.



J86001 Preliminary Lighting Impact Assessment and ALMP

Drawn: P. Whittock
Date: 18/12/2020
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PENV-J86001-1039-A

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Figure 1: Project location.

2 LEGISLATIVE AND GUIDANCE INSTRUMENTS

2.1 National

2.1.1 Marine Turtles

The Australian Government's key piece of environmental legislation is the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The EPBC Act protects and manages matters of national environmental significance (MNES) which include nationally and internationally important flora, fauna, ecological communities, and heritage places. This act protects species that are listed threatened, migratory, or marine. The North West Cape and Ningaloo region on which the project is situated supports nesting for four listed species of marine turtle (**Table 1**).

Table 1: EPBC Act listed marine turtle species in the project area.

Common name	Scientific name	Conservation Status
Loggerhead	*Caretta caretta*	Endangered
Green	*Chelonia mydas*	Vulnerable
Hawksbill	*Eretmochelys imbricata*	Vulnerable
Flatback	*Natator depressus*	Vulnerable

Additional protection of Australian marine turtles is provided by the *Recovery Plan for Marine Turtles in Australia* (Commonwealth of Australia 2017). This plan lists specific anthropogenic threats to the conservation and recovery of marine turtle species in Australia. The Recovery Plan lists the NW Cape/Ningaloo coast as habitat critical for the survival of green and loggerhead turtles and recognises light pollution as a key threat to the recovery of marine turtles in Australia.

The Commonwealth Government is also the signatory to a range of international conventions and agreements that provide additional protection to marine turtles globally including but not limited to:

- Convention on the conservation of Migratory Species of Wild Animals (CMS);
- Convention on Biological Diversity, the Convention Concerning the Protection of the World Cultural and Natural Heritage;
- Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES); and
- International Union for the Conservation of Nature (IUCN) Red List of Threatened Species.

Australia's obligations under these agreements are met through the EPBC Act.

2.1.2 Astronomical Observing

There are no Commonwealth laws that protect the quality of the night sky in the vicinity of Australian observatories.

2.2 State

2.2.1 Marine Turtles

The *Environmental Protection Act 1986* (EP Act) provides for the "*prevention, control and abatement of pollution and environmental harm, for the conservation, preservation, protection, enhancement and management of the environment and for matters incidental to or connected with the foregoing*".

The Biodiversity Conservation Act 2016 (BC Act) and Biodiversity Conservation Regulations 2018 brought into law on 1st January 2019 replaced the Wildlife Conservation Act 1950. The BC Act aims to conserve and protect biodiversity, and provides protection to, and establishes recovery plans for, listed species, threatened ecological communities, and critical habitat. The BC Act lists threatened and priority fauna under the Wildlife Conservation (Specially Protected Fauna) Notice 2018; these listings reflect the EPBC Act marine turtle species and listing status (**Table 1**).

2.2.2 Astronomical Observing

There are no State laws that protect the quality of the night sky in the vicinity of Western Australian observatories.

2.3 Local

2.3.1 Marine Turtles

The protection of marine turtles from light is recognised at a local level i.e. a variation to the Shire of Exmouth Local Planning Scheme No. 4 *Ningaloo Lighthouse Holiday Park Local Development Plan,* Clause *13,* requires "*The DA requires a lighting impact assessment, addressing the lighting impacts on nesting turtle habitat."* which is consistent with the Vlamingh Head Master Plan, Planning and Sustainability Guidelines, which specify that "*Lighting must not affect nocturnal or breeding animals".*

2.3.2 Astronomical Observing

While not specific to the Observatory, the Exmouth Shire Local Planning Scheme refers to Floodlighting (Part 4.14), and states that *"no person shall erect, install or maintain any floodlighting, spotlight or other forms of lighting for any purpose, unless the emission of light from such devices is oriented or controlled so as not to interfere with the amenity of any adjacent locality, nor cause a traffic hazard in the nearby street system"*.

2.4 Guidelines and Standards

2.4.1 Marine Turtles

Under the recently published *National Light Pollution Guidelines for Wildlife* (Commonwealth of Australia 2020), any action or activity that includes externally visible artificial lighting should use best practice lighting design and assess the potential impact on listed species and their important habitat(s) if they are present within a 20 km radius. Consequently, for this project there is a recognised pathway for a potential impact from artificial lighting to listed threatened and migratory marine turtles that nest on the North West Cape.

The guidelines are consistent with, and build upon, the Western Australian *Environmental Assessment Guideline No. 5 Protecting Marine Turtles from Light Impacts* (EPA 2010). The guidelines also outline the minimum requirement for protection of marine sea turtles from light exposure and addresses the approach to project design, management, and mitigation from the adverse impacts of light. The 2010 EPA guidelines, written before the recent and rapid evolution in light emitting diode (LED) technology, do not address the very particular biological impacts emerging as a result of exposure to LED lights.

2.4.2 Astronomical Observing

The management of light in the vicinity of the SST is important because telescopes require clear dark nights to operate effectively. In the absence of any State or Federal regulatory framework for dark sky protection in the vicinity of the SST, the *NSW Department of Planning and Environment, Dark Sky Planning Guideline, Protecting the observing conditions at Siding Spring* (NSW 2016) will be used to provide a basis for the management of light with respect to the SST at Exmouth.

Additional guidance for control and management of excess outdoor lighting will also be obtained through *AS/NZS 4282:2019 Control of the obtrusive effects of outdoor lightings.* This Standard specifically refers to the potentially adverse effects of outdoor lighting on nearby residents (e.g. dwellings such as houses, hotels, hospitals), users of adjacent roads (e.g. vehicle drivers, pedestrians, cyclists), transport signalling systems (e.g. air, marine, rail) and on **astronomical observations**. The Standard provides guidance on design and operation of lighting to mitigate the adverse effects of light falling directly onto the optical surface of the SST as well as sky glow.

The Astronomical Society of Australia acknowledges the guidance AS4282 provides to planning authorities to ameliorate the effects of light pollution in the vicinity of observatories.

2.5 International

While the focus of this project is on minimising the impact of light on marine turtles and the SST, the approach taken will also be consistent with the principles of dark sky protection promoted by locally based Australasian Dark Sky Alliance (ADSA) and by the International Dark Sky Association (IDA), the global authority on dark sky conservation and the certifying body for International Dark Sky Places.

Light pollution is growing at a rate of 2% per year (Kyba et al 2016). Reducing light pollution and conserving the dark sky is important for a range of values including;

- Astronomy and Astrotourism,
- Wildlife, ecology and environment
- Human health
- Heritage including both European and indigenous astronomy and navigation
- Reduced energy consumption, and
- Reducing greenhouse gas emissions.

3 DESCRIPTION OF WILDLIFE

3.1 Marine Turtles

Marine turtles are known to utilise onshore and offshore areas of habitat situated within 20 km of the project site.

Three species of marine turtle have been recorded utilising nesting habitat within 20 km of the project site, these include green (*Chelonia mydas*), loggerhead (*Caretta caretta*), and hawksbill (*Eretmochelys imbricata*), turtles (DBCA 2020; Whiting 2016; **Table 2**). The *Recovery Plan for Marine Turtles in Australia, 2017 – 2027* (Commonwealth of Australia 2017) lists the NW Cape/Ningaloo coast as habitat critical for the survival of green and loggerhead turtle and recognises light pollution as a moderate to high threat for all three genetic stocks shown in **Table 2**.

Table 2: Conservation status (Australian Commonwealth and state legislation) and genetic stock status of marine turtles found onshore within 20 km of the project.

Marine turtle species	Protection status		Genetic stock	
	Commonwealth *EPBC Act 1999*	Wildlife *Conservation Act 1950*	Name	Recovery status
Green	Vulnerable	Vulnerable	Northwest Shelf	Stable
Hawksbill	Vulnerable	Vulnerable	Western Australia	Stable
Loggerhead	Endangered	Endangered	Western Australia	Stable

The reported nesting and hatching season for the genetic stocks of the three marine turtle species is shown in **Table 3**. The nesting period is in late spring/early summer for hawksbill turtles, and summer for green and loggerhead turtles. A 2016 trend analysis of local (North West Cape and Ningaloo) turtle monitoring data found the nesting period was centred on the first week in January for all three species (Whiting 2016), recognising that the intensive monitoring program is focussed around the peak summer nesting months (December – January) and may miss the peak in hawksbill nesting.

Interannual variation in nesting activity of green turtles is widely reported and can exhibit large fluctuations. The variation is thought to be linked to the impact of the El Niño Southern Oscillation (ENSO) on food resources at their foraging grounds (Limpus & Nicholls 2000). Standardised analysis of the 2002/03 to 2018/19 Ningaloo Turtle Program (NTP) monitoring data found a peak in activity in 2011/12 which was followed by one of the least active years ever recorded in the following season (2012/13). Less variation is evident in hawksbill and loggerhead nesting activity (NTP 2020). Anecdotal evidence from regional monitoring programs indicated the 2020/21 season was a very active season for green turtles.

Table 3: Nesting and hatching season for green, loggerhead, and hawksbill genetic stocks (Commonwealth of Australia 2017).

Species (genetic stock)	Nesting period	Hatching period
Hawksbill (H-WA)	Year round, (Oct – Jan peak)	Year round (Dec – Feb peak)
Loggerhead (L-WA)	Nov – Mar (Jan peak)	Jan – May (Feb – Mar peak)
Green (G-NWS)	Nov – Mar (Dec – Jan peak)	Dec – Mar (Feb – Mar peak)

3.2 Ningaloo Turtle Program

3.2.1 Regional Activity: North West Cape and Cape Range Divisions

Onshore, annual marine turtle track census surveys have been conducted by the NTP at beaches near the project site during the peak of nesting activity since 2002. The surveys are managed by the Exmouth office of the Department of Biodiversity, Conservation and Attractions (DBCA). The programs aim is to predict long-term trends in marine turtle populations along the Ningaloo coast. The survey results are used by DBCA to inform management and conservation; reducing disturbance to nesting turtles, management of introduced predators and managing coastal access and visitation to support effective conservation of sea turtles on the Ningaloo coast (DBCA 2020). All annual reports and other supplemental materials from this program can be found at www.ningalooturtles.org.au.

Details regarding monitoring methods, demographic parameters and effort are provided in the annual reports. Historically, the program has focussed on the nesting activity in the northern half of Cape Range (e.g. Bangalup northwards) and consequently this is the data used in this assessment. Here we summarise those results to put the rookeries located withing 20 km of the project site into context.

The NTP monitoring sites that fall within a 20 km radius of the project site are within the North West Cape Division, encompassing Lighthouse Bay, Hunters, Graveyard and Tantabiddi (**Figures 1** and **2**). The NTP also monitoring the Cape Range Division encompassing Neils, Bungelup and Rolly (**Figure 3**) and located 57 km south west of the project location.

During the 2018/19 season, nesting activity across these Divisions varied with green turtles dominating in the North West Cape Division and loggerhead turtles dominating the more southerly Cape Range Division (**Table 4**).

Table 4: Proportion of nesting activity (nests and false crawls) by species across the North West Cape and Cape Range Divisions recorded during the 2018/19 monitoring season.

Division	Marine Turtle Species				
	Green	Hawksbill	Loggerhead	Flatback	Unidentified
North West Cape	95.5 %	1.3 %	3 %	0.1 %	0.1 %
Cape Range	15.9 %	2 %	81.7 %	0.1 %	0.3 %

These results are broadly consistent with the long-term nesting species results; since the commencement of monitoring (2002) the North West Cape and Cape Range Divisions combined are dominated by green turtles (87 % of all activity) followed by loggerhead (10.7 %), hawksbill (2 %), and unidentified (0.4 %) activity from a total of 57,229 “suspected” nests and 134,441 false crawls (no nesting attempt) (NTP 2020).

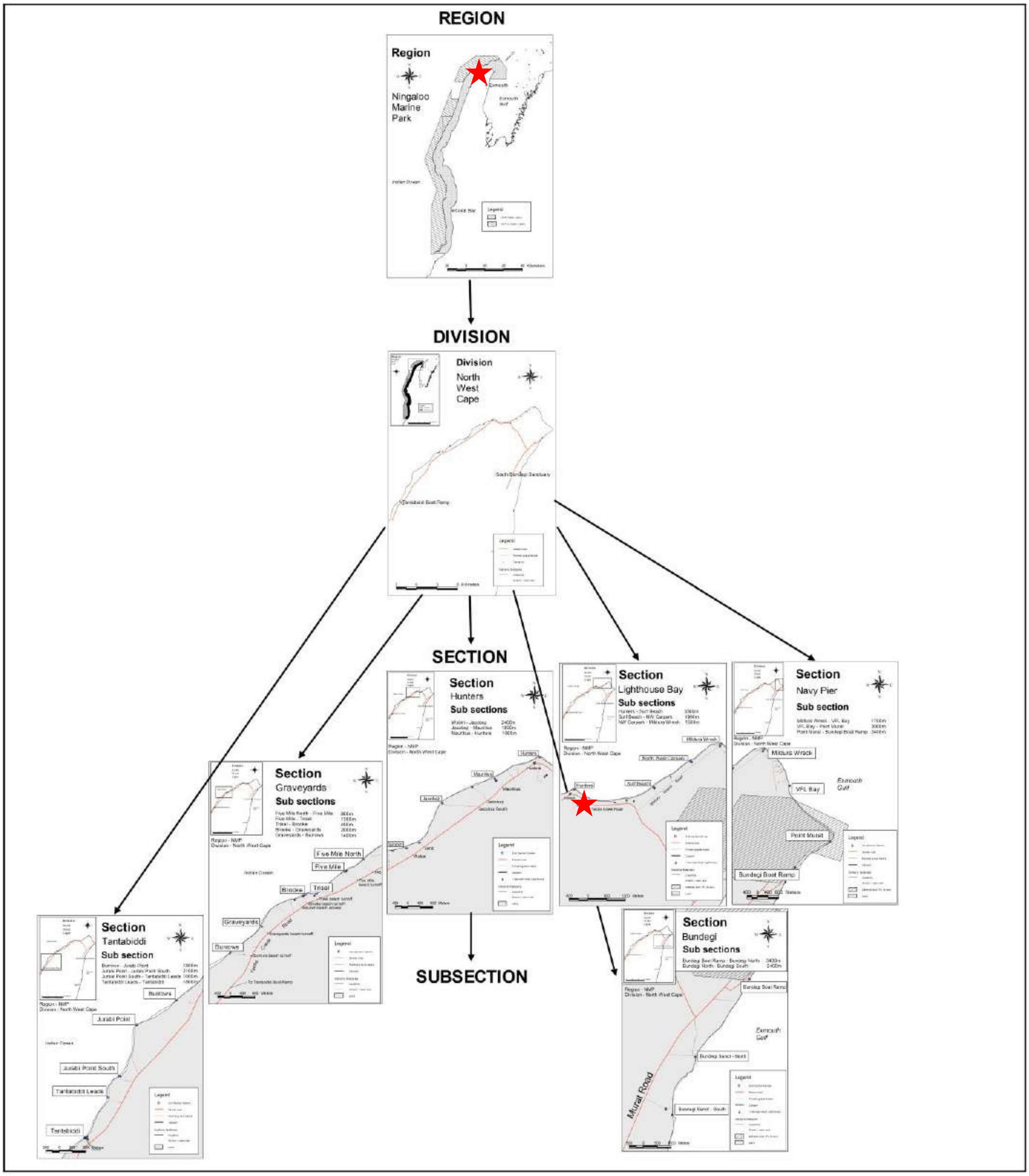


Figure 2: Ningaloo Turtle Program – Sections of the North West Cape Division located within 20 km of project site; Tantabiddi, Graveyards, Hunters, Lighthouse Bay, Navy Pier, Bundegi. Red star denotes project location (Source: NTP 2020).

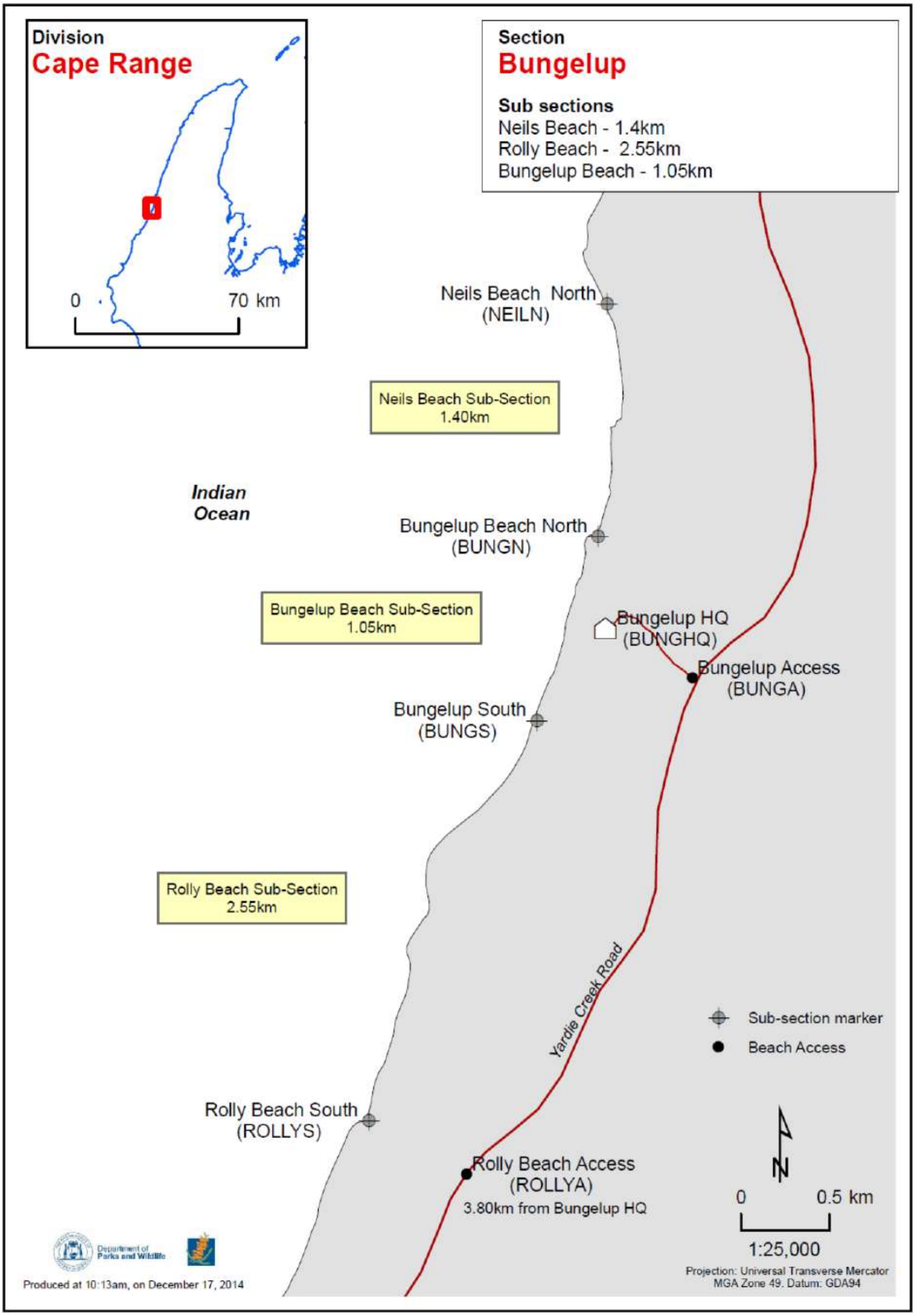


Figure 3: Ningaloo Turtle Program – Sections of the Cape Range Division; Neils, Bungelup, Rolly, located 57 km south west of project site (Source: NTP 2020).

The percentage of nesting activity that resulted in a suspected nest across both the North West Cape and Cape Range Divisions combined in 2018/19 is shown in **Table 5**. The results show that despite a high level of nesting activity by green turtles (10,815 tracks), only 25.3 % of these successfully resulted in egg laying. These results were consistent with previous seasons, with this result within the range reported for the 2002/03 to 2018/19 seasons. This contrasts with hawksbills and loggerheads which had a higher nesting success in 2018/19 (**Table 5**). These results are consistent with the results of the 2016 trend analysis of multiyear data which reported a mean nesting success of 28.5 % for green turtles, 44.9 % for loggerhead turtles, and 50.4 % for hawksbill turtles (Whiting 2016).

Table 5: Percentage of nesting activity which resulted in successful egg laying in 2018/19 season compared with the seasonal range 2002/03 – 2018/19.

Marine turtle species	False crawls (*n*)	Nests (*n*)	Nesting Success	Range (2002/03 to 2018/19)
Green	8,082	2,733	25.3 %	21.7 – 37.3 %
Hawksbill	104	63	37.7 %	38.4 – 61.9 %
Loggerhead	730	481	39.7 %	26.5 – 59.5 %

The 2016 trend analysis on the NTP data (Whiting 2016) for the North West Cape and Cape Range data concluded that:

- Green, loggerhead, and hawksbill nesting activity remained stable with no positive or negative trends in nesting abundance for any species.
- There was little variation in the spatial distribution of annual nesting activity for green and loggerhead turtles (between 2005/06 and 2015/16 seasons).
- An estimated annual average of 17,500 green turtle tracks, 2,200 loggerhead turtle tracks, and 470 hawkbill turtle tracks were recorded withing the two Divisions.
- The estimated size of the breeding populations withing the two Divisions was:
  - Green turtles: 15,104 – 33,721
  - Loggerhead turtles: 991 – 2,763
  - Hawksbill turtles: 351 – 791
- The estimated population sizes represent globally significant populations for all species.

3.2.2 North West Cape Division

Local scale nesting within the North West Cape Division has been analysed by Whiting (2016). The spatial distribution of nesting in the vicinity of the project site shows the nesting is dominated by green turtles and of all the sections in this Division, the Lighthouse section immediately adjacent to the project site supports less nesting effort than Hunters (1 – 6 km west) and Graveyards (~6 – 12 km west) (**Figures 2 and 4**).

Within the Lighthouse section, loggerhead and hawksbill activity is concentrated in the northern subsections while green activity dominates the southern subsections close to the project site (NTP 2020; Whiting 2016).

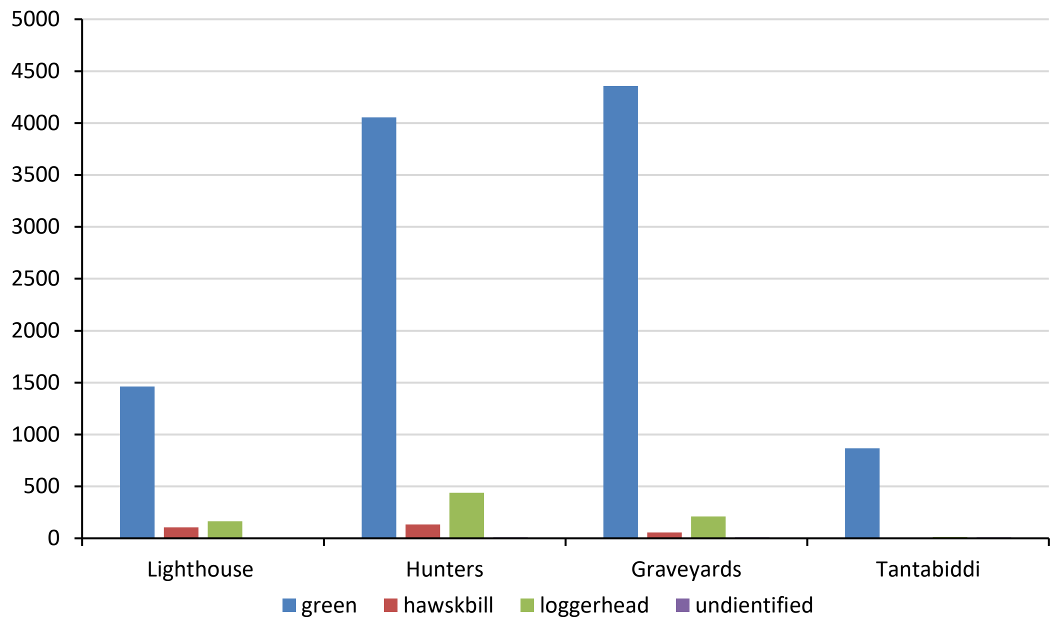


Figure 4: Total track counts in each Section of the North West Cape Division.

3.3 Benchmark Regional Marine Turtle Orientation

No systematic surveys of hatchling or adult nesting female orientation behaviour on regional North West Cape beaches has been carried out. Anecdotal evidence suggests that hatchling sea turtles have been found in the existing campground pool suggesting that they had crawled up the beach and over the dunes, attracted to the lights from the beach (pers. comm. D. Rob, DBCA). An alternative explanation is that the hatchlings were carried inland and dropped by seabirds. In the absence of any data on hatchling behaviour on nearby beaches, it is not possible to confirm the cause of this behaviour.

Similarly, anecdotal evidence suggests that adult females are occasionally observed crawling along Yardie Creek Road, presumably lost after crawling across the dunes (pers. comm. D. Rob, DBCA). This is not uncommon in naturally dark areas characterised by large or complex dune systems; however, the presence of inland light could potentially confuse a female trying to return to the ocean, making it difficult for them to orient themselves seaward.

To understand the behaviour of marine turtle hatchlings on beaches within 20 km of the project site, a field survey was conducted in February 2021 to collect hatchling orientation data under existing lighting conditions. This data will be used as a benchmark for monitoring hatchling behaviour during construction and ongoing operations and assess if the project has caused any changes in hatchling behaviour. The report is attached as Appendix A.

3.3.1 Hatchling Orientation Survey

PENV conducted eight days of hatchling orientation monitoring during the peak green turtle hatching period in February 2021. This survey timing ensured sufficient data was collected to provide a robust benchmark picture of turtle orientation on beaches under existing lighting conditions. The February 2021 timing of this survey was critical due to the highly cyclic nature of green turtle nesting, i.e. the green turtle nesting effort this season was at a peak which ensured the best opportunity to capture sufficient benchmark turtle hatchling orientation data.

3.3.1.1 Methodology

The most common method to monitor the influence of existing artificial light on the dispersal behaviour of hatchling turtles is to record the angles of their tracks left on the beach (Pendoley 2005).

During each morning survey the field team located any recently emerged nests by following sighted hatchling tracks to the emergence point. The emergence point is indicated by a depression (the 'nest cone') in the sand from where the hatchlings emerged. The field team used a sighting compass to measure angles of the fan of tracks from the emergence point to where the tracks cross the high tide line on a flat beach surface (removes variation caused by undulating nesting landscapes i.e. from body pits made by nesting turtles), or at a distance of 5 m, whichever was greater. Angles measured include the outer tracks that form the outside arms of the fan (A and B angles) and the most direct line to the ocean (X) (Error! Reference source not found.**5**). The approach allows for determination of both the r ange of dispersion or 'spread' angle of emergent hatchlings and the degree of deflection or 'offset' angle from the most direct route toward the ocean. The work scope was undertaken in accordance with PENV's Hatchling Orientation Standard Operating Procedure (SOP) (PIMS-SOP04; provided upon request).

Beaches located up to 10 km on either side of the project site were monitored daily during the survey (please see **Figure 1 in Appendix A**). Factors impacting survey effort and coverage included track access (2WD only), wind and rain erasing hatchling tracks, driving restrictions (rental contract restricted vehicle use too day light only) and heat stress risk for field team members.

Beaches with most direct line-of-sight to the project and located within five km of the project site (Lighthouse Bay Area) were surveyed over five separate days. Beaches between Hunters and Jacobsz (Ningaloo Coast North) 0.5 km – 2.7 km due west of the project were surveyed over four separate days, while Wobiri to Jacobsz (Ningaloo Coast North) 2.7 – 5 km south west and the beaches 7 – 9 km south west (Ningaloo Coast South), were surveyed twice.

This data has been integrated with the artificial light monitoring data (see **Section 6.5**) to determine the directionality of identified light sources in relation to hatchling orientation.

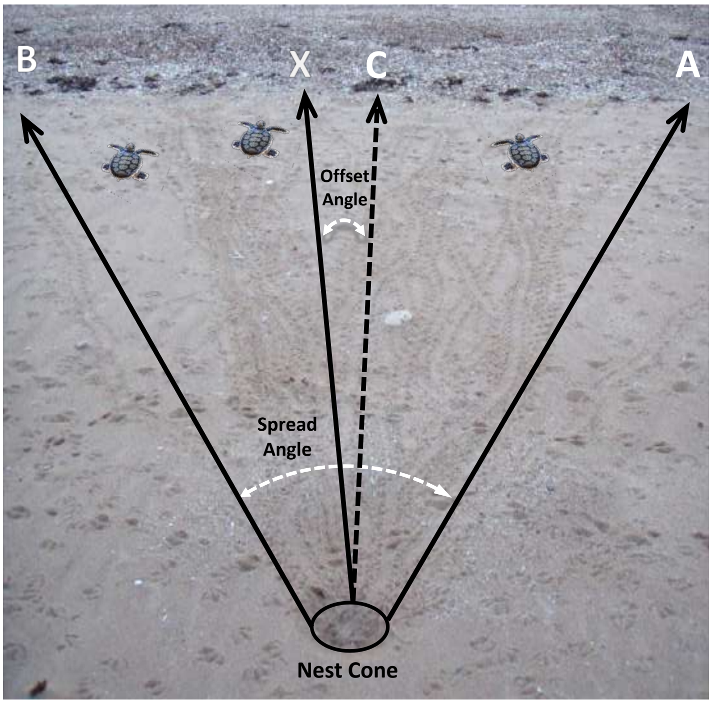


Figure 5: Hatchling orientation angles recorded for a nest fan and associated spread and offset angles. Black arrows indicate metrics that are captured in the field. Dashed black arrow indicates middle indices between A and B that is used to calculate the offset.

3.3.1.2 Data Analysis

Hatchling orientation data was analysed to provide:

- **The range of dispersion (spread angle) of tracks from the emergence point:** describing the degree of dispersion of all hatchling pathways toward the ocean. A larger value indicates greater dispersion or variation in ocean finding bearings and may indicate disruption to natural hatchling sea finding ability.
- **The degree of deflection (offset angle) of tracks from the most direct route to the ocean**: A smaller value indicates a more direct route (i.e. less deviation from the most direct route) and a larger value demonstrates greater deviation from the most direct route which may indicate disruption to natural hatchling sea finding ability.

Hatchling orientation data was grouped into separate datasets based on proximity to the project location and the line-of-site visibility to the project location. This allowed a comparison of fan metrics recorded on nesting habitat with no line-of-sight to the project location with fan metrics recorded on nesting habitat with potential for direct line-of-sight or greater exposure to project related light glow. A Wilcox Mann-Whitney test was used to assess if there was any statistical difference between the two datasets (Appendix A).

3.3.1.3 Survey results

Nest fan metrics were collected from 257 nests (green turtle = 196; hawksbill/loggerhead turtle = 22; and unknown species = 39) and grouped into four regional beach sections. The largest mean spread angle was recorded for those nest fans situated within the Hunters to Lighthouse Bay Parking section (53.6 ± 17.1°; n = 10) and the smallest mean spread angle on Surf Beach South to Mildura Wreck section (36.2 ± 17.3°; n = 62). The largest mean offset angle was recorded for those nest fans situated within the Ningaloo Coast West section (9.6 ± 8.9°; n = 180) and the smallest mean offset angle on Mildura Wreck to Mildura Wreck East section (3.8 ± 2.6°; n = 7). The overall spread and offset angles were 40.7 ± 17.3° and 8.6 ± 8.2 (n = 257), respectively.

The spread and offset angles indicate the hatchlings across the region are orienting normally and are successful in sea finding. Further statistical analyses investigated the difference between beach sections based on the line-of-sight visibility to the project location (i.e. beaches with no line-of-sight vs beaches with line-of-sight) and found that there was no significant difference in fan spread between the two habitat groupings ($p = 0.86$) however there was a significant difference in fan offset ($p = 0.015$), likely related to the impact of a high density of adult body pit craters affecting hatchling orientation in some beach sections.

Regionally, hatchlings were successful in sea finding despite the wide-spread visibility of existing light sources including Exmouth, the HEH base, and antenna array situated onshore, and the oil and gas facilities situated offshore.

3.4 Orientation of Hatchlings in Nearshore Waters

Once in the marine environment, hatchling marine turtles are known to undertake an initial swimming frenzy within the nearshore area adjacent to their nesting habitat (Wyneken & Salmon 1992). Green, hawksbill, and loggerhead turtle hatchlings are therefore likely to be present in nearshore waters adjacent to the project site as they move away from the beach during the hatching period.

Green hatchlings tracked through shallow nearshore waters at Wobiri Beach (Hunter Division, North West Cape) in 2014 dispersed straight offshore under ambient (no artificial light) conditions and under highly variable current speed and direction. However, when artificial light was present offshore, 88 % of hatchlings tested oriented towards the light and spent 23 % more time in the tracking array than under ambient light conditions (Thums et al. 2016).

Green hatchlings swimming offshore have also been recorded misoriented and attracted back to shore by onshore lights in trials conducted during moonless nights at Heron Island, Queensland (Truscott et al. 2017).

There are no published or anecdotal reports on hatchlings crawling back out of the water in the vicinity of the project site.

4 DESCRIPTION OF SPACE SURVEILLANCE TELESCOPE

The most sensitive socioeconomic receptor in the region that could be impacted by artificial light from the proposed development has been identified as the DoD SST (**Figure 1**). This telescope detects and tracks orbital debris in addition to near Earth asteroids and is an important contributor to the US Global Space Surveillance network (DoD 2014).

The SST detects, tracks, and can discern small, obscure objects, in deep space with a "wide field of view system". It is a single telescope with the dual abilities; the telescope is sensitive enough to allow for detection of small, dimly lit objects as well as being capable of quickly searching the visible sky, a combination that is difficult to achieve in a single telescope design (Pike 2010).

The telescope design has an F/1.0 aperture and a 3.5 meter primary mirror. It uses an array of charge-coupled device (CCD) sensors, arranged on a curved focal plane array. The SST mount uses an advanced servo-control technology, that makes it one of the quickest and most agile telescopes of its size. It has a field of view of six square degrees and can scan the visible sky down to an apparent magnitude of 20.5.

The SST is located three km north west of Exmouth, 2.7 km south west of the Harold E Holt Naval Communications Station and 15km south of the project site. The location of current (2019) light sources in the vicinity of the SST is shown in **Figure 6.**

5 DESCRIPTION OF REGIONAL LIGHTING

The existing regional light sources present within 20 km of the project site are shown as an output of an online mapping application (www.lightpollutiomap.info) in **Figure 6** and includes light emissions from the Exmouth town site, the North West Cape Harold E Holt Communications base, and the Harold E Holt antenna field.

Although **Figure 6** presents radiometric measurements of light intensity, it should be noted that these measurements are generated using a Visible Infrared Imaging Radiometer Suite (VIIRS) satellite sensor data. The VIIRS sensor measures upward light in the spectral range of approximately 500 – 900 nm. This is not the same as human vision (400 – 700 nm), or other animal species including marine turtles (<400 – 700 nm; see Commonwealth of Australia (2020) for review) thus there is less sensitivity to the short-wavelength blue region of the spectrum, and more sensitivity to infra-red (heat) sources, such as bushfires and flares. Furthermore, because night-time lighting is dynamic and may contain environmental effects (clouds and aerosols) and natural sources (moonlight, fires, lightning, and aurora), the data for each grid cell is processed into a monthly composite, after filtering out data affected by moonlight and clouds (Falchi et al. 2016). Accordingly, results may be biased where light sources contain large amounts of short wavelength light or the long wavelength radiation that are associated with significant heat sources. Another limitation is that since light emissions observed over a monthly basis can vary due to a variety of factors including the imaging angle, seasonal changes in ground reflection, and seasonal changes in atmospheric particle density, averaging over the month is unlikely to present the worst-case scenario in light emissions.

Therefore, it is not possible to interpret the radiance values presented in Error! Reference source not f ound.**6** as an accurate measurement of light intensity. Nevertheless, the figure provides the best available regional scale representation of light emissions and is used here to identify notable areas of light emissions.

Light emissions in the Exmouth townsite are associated with recreation/sports ground flood lighting, street lighting, residential and tourist accommodation, commercial and entertainment facilities. The North West Cape Harold E Holt Communications base and security lighting around the Harold E Holt antenna field lighting is likely to include lighting for streets and walkways, laydown and work areas, security, administration and service facilities, and aircraft navigation lighting to illuminate the antenna's. The base facilities and antenna field were constructed by the US Navy in the late 1960s, consequently the lighting design dating from that time is unlikely to be consistent with current technology and light management policy and guidance.

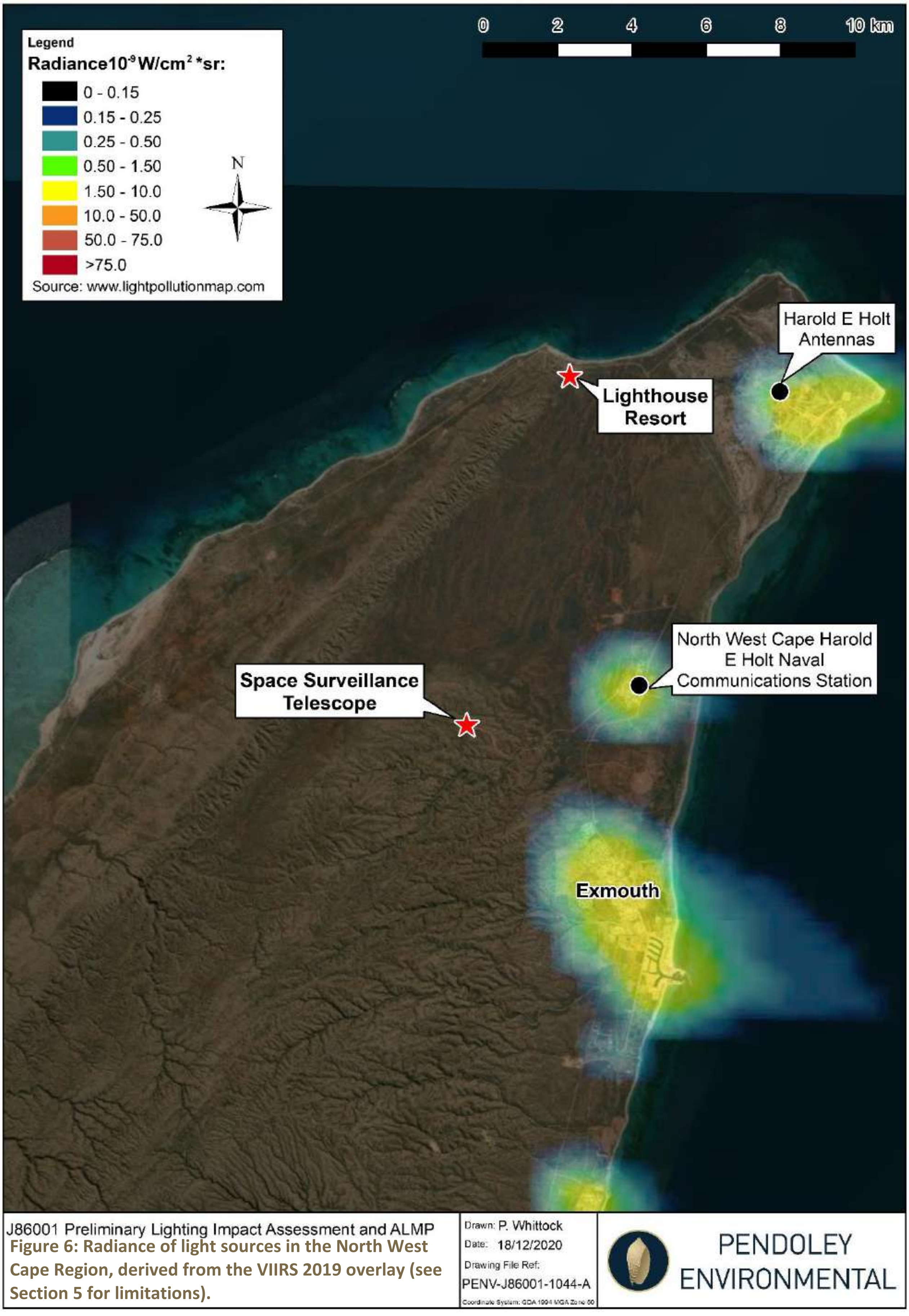


Figure 6: Radiance of light sources in the North West Cape Region, derived from the VIIRS 2019 overlay (see Section 5 for limitations).

6 PROJECT LIGHTING

6.1 Appearance of Light

Light may appear as either a direct light source from an unshielded lamp with direct line of sight to the observer or through sky glow. Where direct light falls upon a surface, be it land or ocean, this area of light is referred to as light spill.

Sky glow is the diffuse glow caused by light that is screened from view but through reflection and refraction, creates a glow in the atmosphere. Scattering of light by dust, salt and other atmospheric aerosols increases the visibility of light as sky glow, while the presence of clouds reflecting light back to earth can substantially illuminate broad areas the landscape (Kyba et al. 2011). White-blue light scatters more easily and further in the atmosphere compared to yellow-orange light (Kyba et al. 2011). Therefore, the distance at which direct light and sky glow may be visible from the source is dependent on the number, intensity, and types of lights, and how such lights are orientated or shielded, in addition to environmental conditions such as topography, vegetation, and cloud cover.

6.2 Description of Project Lighting – existing campground

The existing campground was designed and operated with traditional 18 – 36 Watt fluorescent and 12 - 60 Watt incandescent outdoor lighting (**Table 6** and **Figure 7**). As was typical for the time, the campground lighting did not take dark sky conservation into account and consequently there was no plan for managing or mitigating the lighting. Examples of the unmanaged lights are shown in **Figures 8** to **10**; bare unshielded decorative bulbs (**Figure 8**), unshielded bulkhead lights (**Figure 9**) that were directly visible from the turtle nesting beaches (**Figure 10**). These historical lighting design features are no longer considered acceptable and consequently the new resort development will feature a modern lighting design that will take conservation of dark sky values into consideration.

Figure 7: Existing campground and caravan park. Note cottages high on the hill with direct visibility from the nesting beaches.

Table 6: Inventory of campground lights.

Location	36-Watt 4000K fluorescent	18-Watt 4000K fluorescent	12 – 60 W, 2700 – 6500 K Compact fluorescent lamp and incandescent globes	LED	White street/ floodlights
East End	3	9	4		3
Overflow area	5		3		
Staff quarters	12	3	9		
Bungalows		7	35		
Cabins			35		
Fishermen's bungalows		2	8		
Shed				16	
Storeroom	4	3			
Lookout laundry	1				
Lookout chalets		14	49		
Lighthouse chalets	4	8	8		
West End	20	6	3		3
Swimming pool	2		1		2
Office	14	2	6		
Homestead	2	3	42		
Middle	23	6	2		
Café	2	1	25		

Figure 8: Unshielded bare white decorative light bulbs contribute sky glow and are potentially visible from nesting beaches.

Figure 9: Unshielded bulkhead lights.

Figure 10: Unshielded bulkhead lights in elevated cabins are directly visible from nearby nesting beaches and contribute to sky glow.

6.3 Description of Project Lighting: Proposed Resort

6.3.1 LED Technology

The characteristics of light emissions from the proposed project will depend upon the number, intensity, spectral output, and type of light fittings used. Over the past decade there has been major technological advances in light design and manufacture with LED technology replacing traditional light types such as fluorescent, halogen, metal halide, high pressure sodium etc. The advantages of LEDs over traditional light types include superior energy efficiency (i.e. it takes less electricity for the same light output compared to traditional lights), they are more robust and operate for a longer lifetime (reduced maintenance and replacement costs), they are smaller in size and have a reduced warm up and cool down time allowing for instant switching (on/off), they can be operated with smart controls (dimmable, timers), they can operate efficiently in hot climates, and are available in a wide range of colours. The disadvantages of LEDs are they can over light an area because of their improved efficiency i.e. for the same energy input, a LED is much brighter and whiter than an incandescent or a gas discharge lamp.

6.3.2 Project Lighting

Project related light sources would be associated with the key components of the resort village and the caravan park, including accommodation buildings, administration buildings, commercial services buildings, function centre, pools, tennis court, service station, outdoor public space, outdoor movie theatre, outdoor decks, and seating and recreation zones (**Figures 11** - **13**).

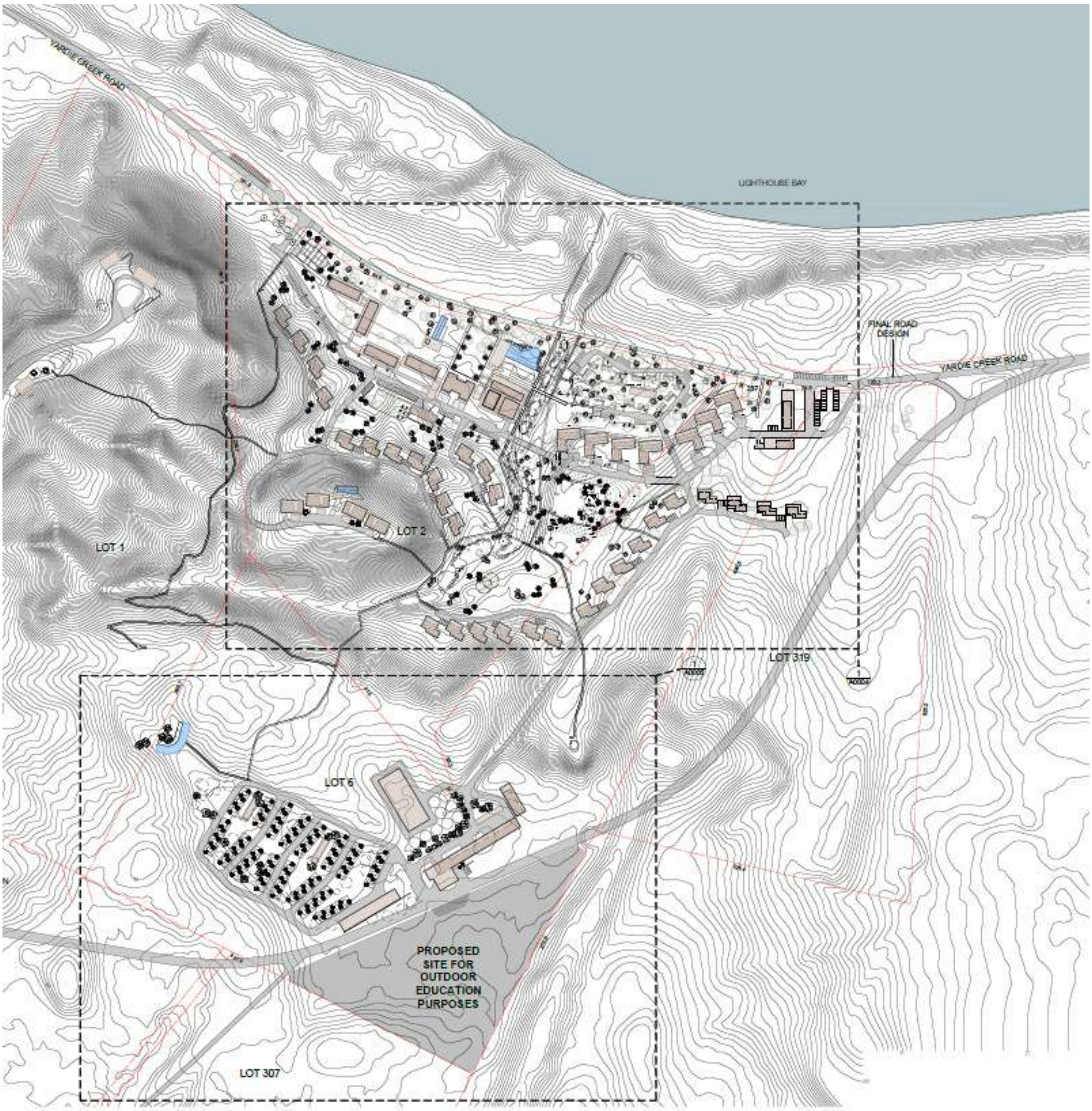


Figure 11: Project layout and footprints, resort (top) and campground (bottom) (Kerry Hill Architects, Site Master Plan).

Figure 12: Resort facilities (McGregor Coxall, Landscape Master Plan).

Figure 13: Campground facilities (McGregor Coxall, Landscape Master Plan).

6.4 Viewshed Analysis

A viewshed analysis was used to determine the line-of-sight visibility of different light sources associated with the proposed resort in relation to nearby marine turtle nesting habitat.

In the absence of a lighting design, the viewshed analysis for the project was carried out based on the following assumptions:

1. Only external lights are accounted for (i.e. light from inside rooms and visible through windows and doors not included).
2. As details on exact fixture locations are not known at this stage, all lights are assumed to be spaced evenly, 15 m apart within each specified zone.
3. All lights were assumed to be no higher than 1.5 m above floor/ground level i.e. no tall mast or street lighting was included (preliminary light height provided by the project electrical engineers).
4. Analysis was carried out for the following light groupings:
    a. Resort village on flat land adjacent to the Yardie Creek Road
    b. Sunset Villas located at ~30 m elevation on a ridge behind the resort
    c. Campground and caravan park located in valley behind the Sunset Villas ridge
5. Topography was based on ~30 m resolution NASA Shuttle Radar Topography Mission (SRTM) satellite data.
6. Nesting habitat area was derived from the location of known nesting sites identified in the 2018/19 NTP report (DBCA 2020) and covered the beach area seaward of the vegetation line (shown as pink polygon in **Figure 14**).
7. Viewshed analysis was undertaken for three zones:
    a. Beaches in the Lighthouse Bay region (between north and north-east of the project site; **Figure 15 - 17**).
    b. Beaches along the Ningaloo reef coast and extending from Hunters to Tantabiddi.
    c. The SST.

The analysis was undertaken using the Viewshed Analysis tool in QGIS 3.8.2.

The output of the analysis was a two-coloured raster at a 10 m^2 pixel resolution across the nesting habitat area, where yellow indicates areas where light was 'visible' and pink indicates areas where light was 'not visible' (note that the 10 m^2 resolution results in a pixilation across the nesting habitat area within the resulting map output).

Note that the viewshed analysis does not consider factors such as the directionality and intensity of the light or the shielding of the light from buildings or nearby vegetation. The viewshed analysis consequently presents a worst-case, unmitigated result based on the listed assumptions and is provided to gain an understanding of the extent to which light would be visible in the absence of mitigation measures.

6.4.1 Results

This results of this viewshed analysis indicate:

- Resort village lighting would be intermittently visible within the nesting habitat between Mildura wreck to the north and Hunters to the west (**Figure 15** and **Table 7**).
- Sunset villas lighting is more consistently visible along the north east shoreline of Lighthouse Bay in addition to a small section of beach north west (**Figure 16** and **Table 7**).
- Campground lighting will be visible along the nesting habitat extending east and north east of the project site (**Figure 17** and **Table 7**).

Resort lighting appears to be shielded from view by the well-developed sand dunes (10 – 12 m tall) in the area of nesting habitat directly north of the resort site. The resort village will be visible to the nesting habitat situated north-west of the site (**Figure 15**) due to a reduction in dune height moving east and north, and the curving nature of the nesting beach to the north-east of the site which changes the orientation of the beach in relation to the resort resulting in reduced shielding by the dunes. Nesting habitat along the Ningaloo coastline west of the project site is completely shielded from direct visibility of light by the 60 – 100 m Cape Ranges.

Sunset villas lighting is shielded from view by the sand dunes in front of the project site on Lighthouse Bay, with light visible from only a small section of beach north-west of the project site (**Figure 16**). Visibility of light along the east and north eastern beaches is similar to the resort viewshed with visibility mediated by dune structure, height, and coastline orientation relative to the Sunset villa location and elevation. Nesting habitat along the Ningaloo coastline west of the project site is completely shielded from direct visibility from the Sunset villas by the Cape Ranges.

The location of the campground area in a small valley, well inland and behind an elevated ridge to the north, substantially reduced the visibility of lighting from the nesting habitat immediately adjacent to the resort. Light is most visible from the campground on beach sections that are aligned and oriented north-east, with the campground situated at the south-west end of the line between the project site and the nesting beaches (**Figure 17**). The elevated topography of the Cape Range shields the western Ningaloo coast nesting habitat from direct visibility of campground light.

The line-of-sight analysis of the three light groupings relative to the SST located ~15 km to the south found that light was directly visible from all three light groupings in the resort.

Table 7: Area of nesting habitat that has visibility of light.

Light grouping	Visibility Lighthouse Bay coastline	Visibility Ningaloo coastline	Space Surveillance Telescope
Resort village resort	Yes	No	Yes
Sunset villas	Yes	No	Yes
Campground	Yes	No	Yes

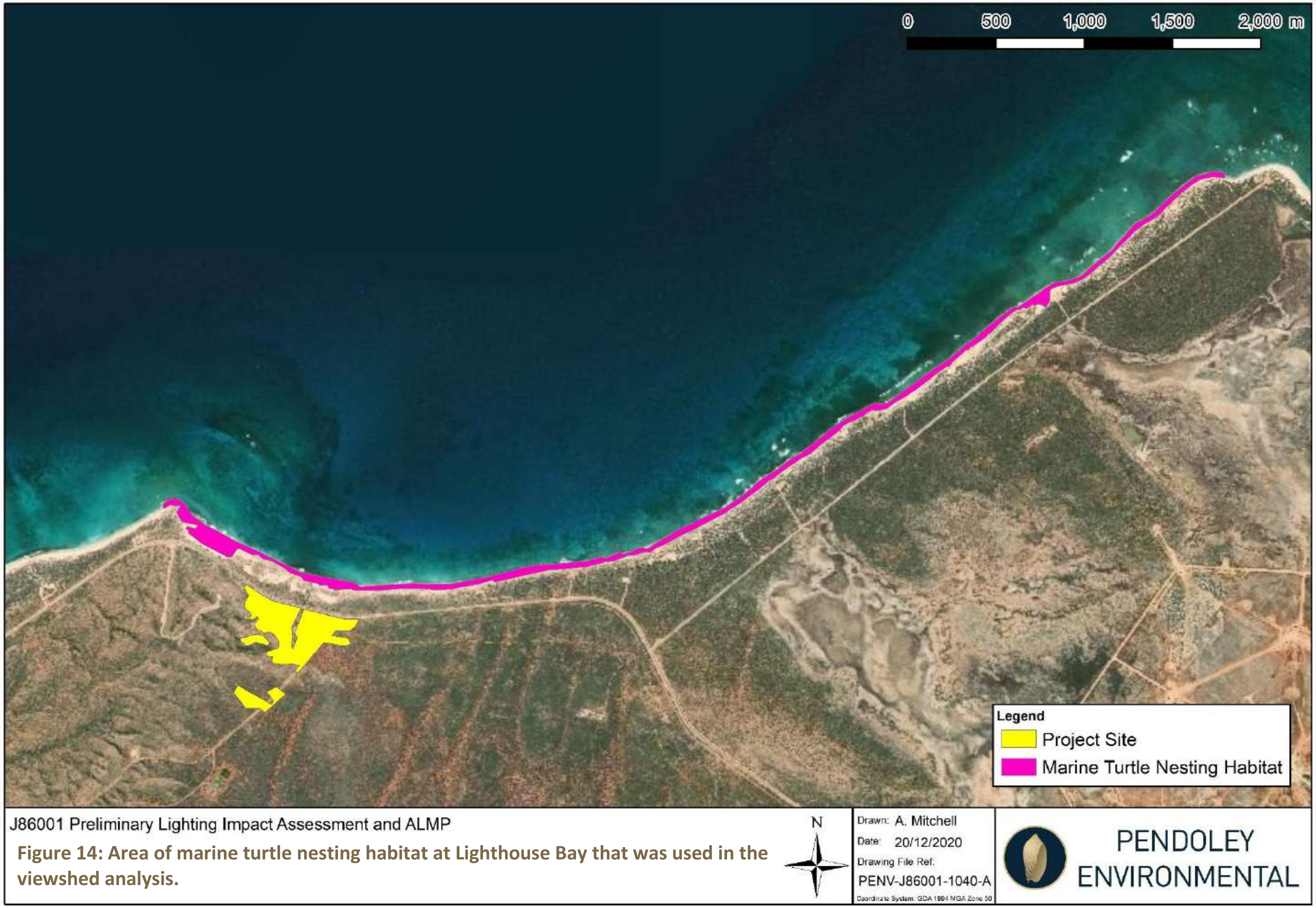
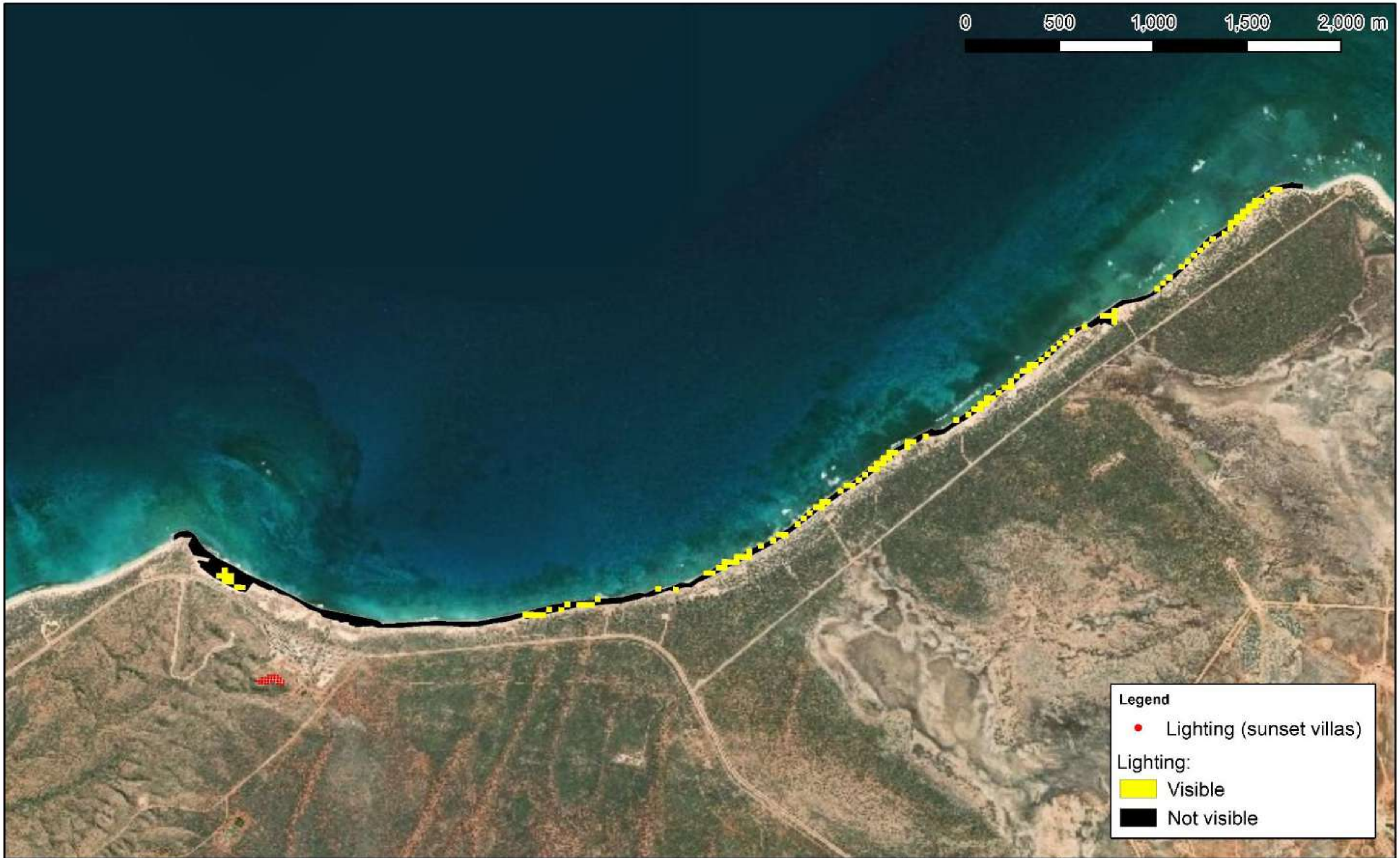


Figure 14: Area of marine turtle nesting habitat at Lighthouse Bay that was used in the viewshed analysis.

Figure 15: Area of marine turtle nesting habitat at Lighthouse Bay where Resort Village lighting was visible.



J86001 Preliminary Lighting Impact Assessment and ALMP

Figure 16: Area of marine turtle nesting habitat at Lighthouse Bay where Sunset villa lighting was visible.

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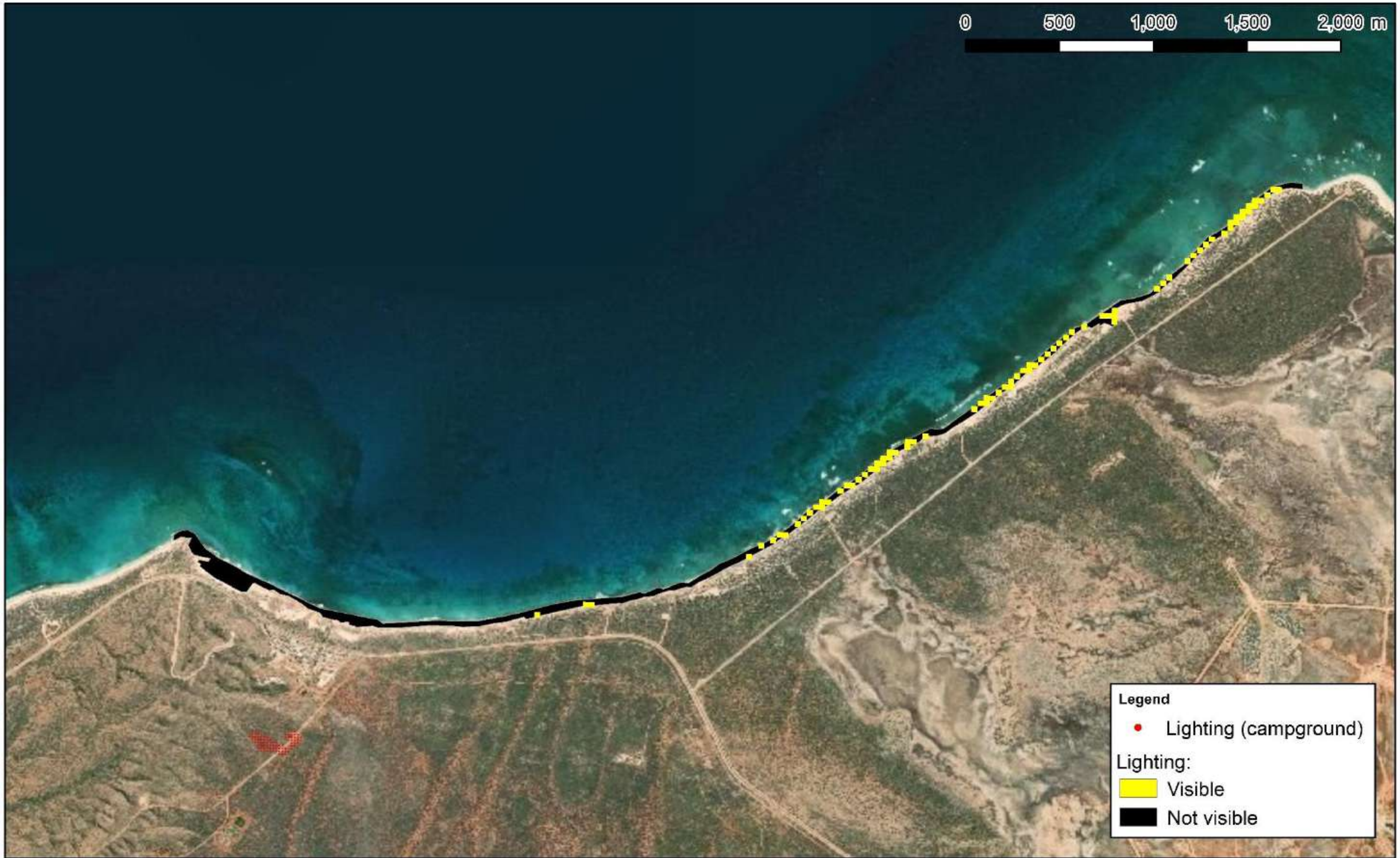
Drawn: A. Mitchell
Date: 20/12/2020
Drawing File Ref:
PENV-J86001-1042-A
Coordinate System: GDA 1994 MGA Zone 50

PENDOLEY ENVIRONMENTAL



J86001 Preliminary Lighting Impact Assessment and ALMP

Figure 17: Area of marine turtle nesting habitat at Lighthouse Bay where campground lighting was visible.

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Drawing File Ref:
PENV-J86001-1043-A
Coordinate System: GDA 1994 MGA Zone 50

PENDOLEY ENVIRONMENTAL

6.5 Benchmark Artificial Light Levels

Information on existing light and its visibility from the marine turtle nesting beaches and from the SST is necessary so that any additional light from the project during construction and operation of the resort facility can be compared with the benchmark data and monitored long term.

The benchmark images also allow for:

- All visible, individual light sources to be identified and monitored across a complete night-time period; and
- Suitable comparison against future monitoring seasons; and the effectiveness of any implemented light management controls to be quantified.

A benchmark artificial light at night (ALAN) survey was carried out on the new moon between 11th and 17th February 2021 and consecutively with the hatchling monitoring program. Sky42 light monitoring equipment was deployed on marine turtle nesting beaches and at the SST to capture artificial light data during new moon conditions.

6.5.1 Methodology

The equipment used to collect ambient night time light emissions is a custom built instrument (Sky42™ Digital SLR camera) The Sky42™ camera measures light on a landscape scale including the light at the horizon which is most pertinent to hatchlings orienting on the beach. The Sky42™ cameras are stand-alone, ruggedized within all-weather housing, and can be transported by hand in the field.

Sky42 cameras were deployed on tripods (set at a height above nearest vegetation) by the field team each afternoon and left unattended until their retrieval by the field team the next morning. The cameras automatically captured images of night-time light emissions on a 360° horizon at 15-minute intervals between sunset and sunrise. The captured imagery was downloaded, cameras charged and cleaned, and redeployed each afternoon.

Artificial light monitoring was completed over eight survey nights and involved the deployment of Sky42 cameras. The deployment locations were selected based on nesting effort recorded by the Ningaloo Turtle Program (DBCA 2020), distribution of observed hatched nests and the proximity to the project site (**Table 1** and **Figure 1 in Appendix A**). The SST was surveyed over three nights from two different camera locations, one immediately adjacent to the facility and one 200 m away, both with line-of-sight visibility to the project location, the Town of Exmouth and the Harold E Holt (HEH) facilities. The light monitoring work scope were undertaken in accordance with PENV's Light Monitoring SOP (PIMS-SOP14; provided upon request).

6.5.2 Data Analysis

The quality of an image captured by a Sky42 light monitoring camera can be influenced by atmospheric factors such as the presence of the moon, twilight, rain, dust, humidity, or physical factors such as accumulation of sand on the lens. Any images that were affected by these factors were removed from the analysis.

All remaining images were batch processed using specialised software (Sky Quality Camera, Euromix Pty Ltd). The processing involved converting each image into a false-colour map and calculating three sky brightness metrics in units of Vmag/arcsec^2:

- Zenith (directly overhead, 0 – 30° field of view);
- Whole of sky (0 – 90° field of view); and
- Horizon (60 – 90° field of view).

For each monitoring site, the clearest night was selected and all images recorded on that night were processed. The image with the median whole-of-sky brightness image was then used to represent light levels at that location.

Note that the colours used in the false-colour map represent the scale of intensity of light and is not representative of the colour of light as perceived by a human/turtle eye or Sky42 camera. Furthermore, the units of sky brightness (Vmag/arcsec^2) are on an inverted logarithmic scale, i.e. higher values represent lower intensity light, while lower values represent higher intensity light. The zenith brightness values can be interpreted using the Bortle scale sky quality guide shown in **Table 3 in Appendix A**.

The processed median image was subdivided into 1° segments within the horizon field of view (60 – 90°), (the area most relevant to hatchlings). The mean light intensity value within each segment was calculated and plotted on a line graph. The line graph is used to identify the areas of highest light intensity along the horizon, with comparisons over subsequent seasons allowing for changes in light intensity and its location to be identified (if required). The graph is also integrated with hatchling fan data and allows the orientation of the hatchlings to be compared with the direction of light at the nesting beach.

6.5.3 Survey results

The survey results show that glow from the regional light sources, including Exmouth, Harold E Holt base, and the antenna array are visible from all monitored sites (including the SST), while offshore oil and gas facilities (due north of the NW Cape) were also visible from monitoring sites on north facing beaches (directly visible plus sky glow) (**Appendix A**). The results suggest the current sky quality across all sites is equivalent to a *rural sky* on the Bortle scale (approx. 21.69 – 21.89 Vmag/arcsec2), declining to *rural/suburban transition* quality (20.49 – 21.69 Vmag/arcsec2) when cloud cover reflects the local light sources across the landscape.

The location of the project site relative to the SST means that any light from the project will introduce sky glow into a region of the SST monitoring horizon that is currently dark.

6.5.4 Integration of benchmark hatchling and light results

The integrated hatchling fan metrics and light data are shown in **Appendix A.**

The results from Wobiri on the west coast of the Cape Range show the nest fans within one km of the monitoring site had a moderate spread angle and were highly oriented seaward in a north westerly direction and did not orient towards the peak sky glow over the antenna array in the east, nor the south easterly glow from the Exmouth and HEH base.

The results from Tamarisk site immediately adjacent to the project site show the nest fans within one km of the monitoring site had a large spread angle but oriented seaward in an overall northerly direction and did not orient towards the peak sky glow over the antenna array in the east, nor the southerly glow from the Exmouth and HEH base.

The results from Surf Beach north east of the project stie show the nest fans within one km of the monitoring site had the smallest spread angle compared to the other two sites (Wobiri and Tamarisk) and were highly oriented seaward in a westerly direction. They did not orient towards the peak sky glow over the antenna array visible in the east.

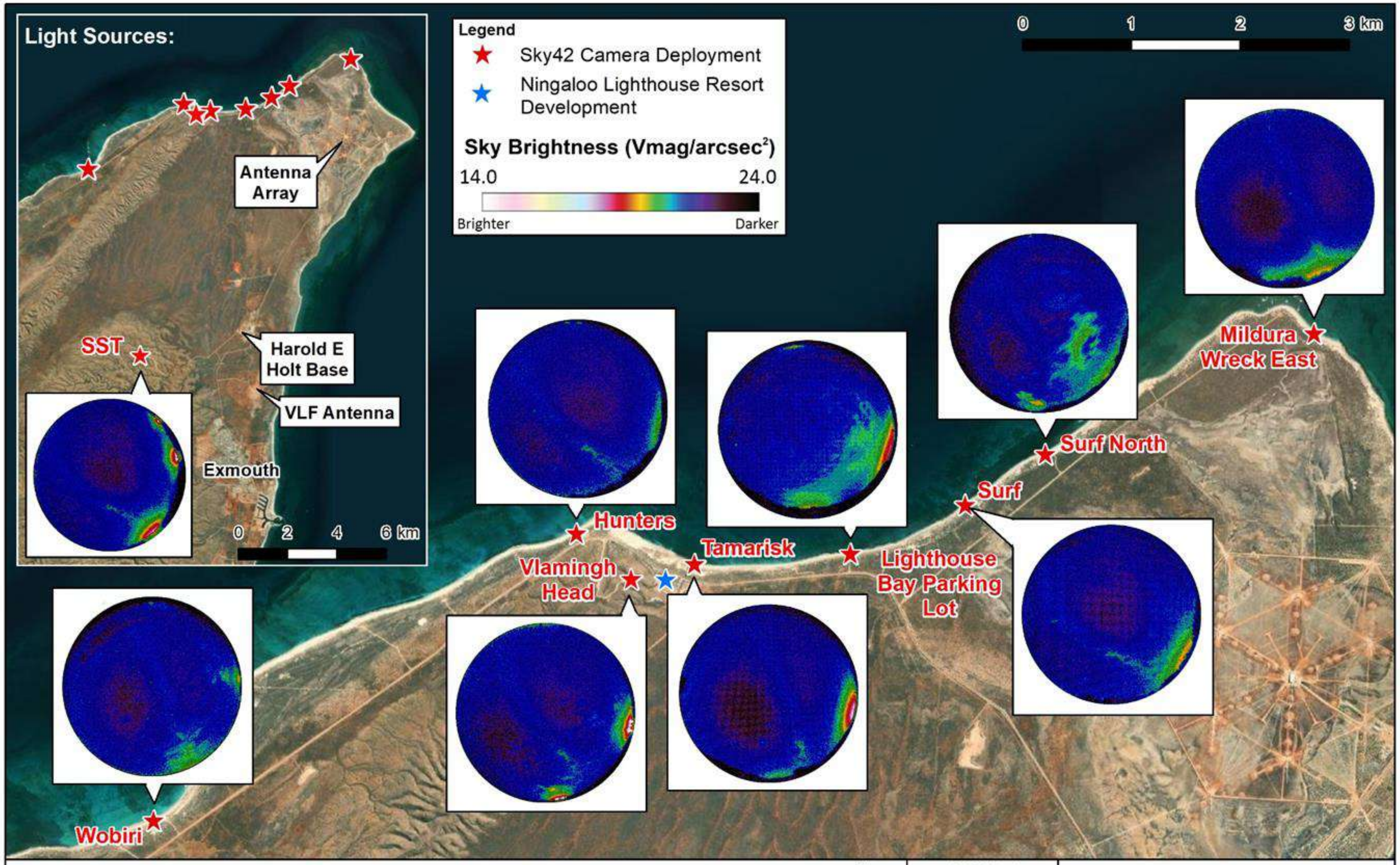

Figure 18: Sky brightness at each artificial light monitoring site. Brightness scale in images ranges from very bright (white/red) to very dark (black). See Appendix A for complete set of images.

6.6 Artificial Light at Night Modelling

The lighting design for the project is yet to be completed. Once the design isfinalised, it will be tested for the project's overall contribution to sky glow and visibility to turtle nesting beaches and the SST, using a landscape scale light model. The model will be built and run once the lighting design is completed and reported in a stand alone report . Model output will be used to refine the project light design and to confirm the appropriateness of the design in conserving the dark sky and minimising light pollution.

7 LIGHTING IMPACT ASSESSMENT

7.1 Impact Assessment Methodology

The potential impacts of lighting associated with the project during both construction and operational phases are assessed utilising an impact assessment matrix. The impact assessment process is modified from the Great Barrier Reef Marine Park Authority Environmental Assessment and Management Risk Management Framework (GBRMPA 2009). The impact assessment process is described in **Table 8** with descriptions of the likelihood and consequence definitions provided in **Table 9** and **Table 10**, respectively. In this section we assess the impacts before (inherent) and after (residual) mitigation measures outlined in the ALMP (see **Section 9**) are applied.

Table 8: Impact Assessment Matrix.

Likelihood (see **Table 9** for definition)		**Consequence** (see **Table 10** for definition)				
		Insignificant 1	*Minor* 2	*Moderate* 3	*Major* 4	*Catastrophic* 5
Almost certain *(96 – 100 %)*	5	**Medium** 5	**High** 10	**High** 15	**Extreme** 20	**Extreme** 25
Likely *(71 – 95 %)*	4	**Medium** 4	**Medium** 8	**High** 12	**High** 16	**Extreme** 20
Possible *(31 – 70 %)*	3	**Low** 3	**Medium** 6	**Medium** 9	**High** 12	**High** 15
Unlikely *(5 – 30 %)*	2	**Low** 2	**Low** 4	**Medium** 6	**Medium** 8	**High** 10
Rare *(0 – 5 %)*	1	**Low** 1	**Low** 2	**Low** 3	**Medium** 4	**Medium** 5

Table 9: Definition of likelihood.

Description	**Frequency**	**Probability**
Almost certain	Expected to occur continuously throughout a year (e.g. more than 250 days per year)	96 – 100 %
Likely	Expected to occur once or many times in a year (e.g. 1 to 250 days per year)	71 – 95 %
Possible	Expected to occur once or more in the period of 1 to 10 years	31 – 70 %
Unlikely	Expected to occur more than once in the period of 10 or more years	5 – 30 %
Rare	Expected to occur once or less over project life	0 – 5 %

Table 10: Definition of consequence.

Description	Definition
Insignificant	Little to no impact on the overall ecosystem. Very small levels of impact on turtles, and their habitats. Only occasional injury to, or mortality of, turtles.
Minor	Impacts are present, but not to the extent that the overall condition of turtle populations or their habitats are impaired in the long term. Low levels of mortality of turtles and their habitats. Recovery would generally be measured in years for habitats.
Moderate	Turtles and their habitats are significantly affected, as outlined in the Significant Impact Guidelines (Commonwealth of Australia 2013). Recovery at habitat level would take at least a decade, with recovery of turtle populations taking several decades.
Major	Significant impact on turtle populations and their habitats, as outlined in the Significant Impact Guidelines (Commonwealth of Australia 2013), with high level of mortality. Recovery of habitats would take a few decades with populations taking several decades.
Catastrophic	Turtle habitat is irretrievably compromised. Mass mortality of turtles and local extinction of species. Recovery over several decades for habitat values and centuries for turtle populations.

7.2 Significant Impact Criteria

The Significant Impact Guidelines (Commonwealth of Australia 2013) provide criteria under which an action can be assessed. An action is likely to have a significant impact on an endangered or vulnerable species if there is a real chance or possibility that it will:

- Lead to a long-term decrease in the size of a population (endangered) or important population (vulnerable);
- Reduce the area of occupancy of the species (endangered) or important population (vulnerable);
- Fragment an existing population (endangered) or important population (vulnerable) into two or more populations;
- Adversely affect habitat critical to the survival of a species;
- Disrupt the breeding cycle of a population (endangered) or important population (vulnerable);
- Modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species is likely to decline;
- Result in invasive species that are harmful to an endangered or vulnerable species becoming established in the endangered or vulnerable species' habitat;
- Introduce disease that may cause the species to decline; or
- Interfere (endangered) or substantially interfere (vulnerable) with the recovery of the species.

The potential for significant impacts is assessed based on the outcomes of the impact assessment.

7.3 Impact Analysis: Marine Turtles

In general, artificial light most disruptive to marine turtles are those rich in short wavelength blue and green light (400 – 550 nm) (Fritsches 2012; Pendoley 2005; Witherington 1992a). The attractiveness to light differs by species (Horch et al. 2008; Pendoley 2005; Wang et al. 2007; Witherington & Bjorndal 1991a, 1991b), however, green, flatback, and loggerhead turtles all show increased sensitivity to wavelengths <600 nm (Fritsches 2012; Pendoley 2005; Levenson et al. 2004). Furthermore, green and flatback turtles show stronger preference for blue light <500 nm (Fritsches 2012; Pendoley 2005). Thus, cooler, whiter lights are more likely to attract turtles in comparison to warmer, amber lights.

Although longer wavelengths of light are less attractive than shorter wavelengths, long wavelength light can still disrupt the ability of hatchlings to locate the sea (Robertson et al. 2016; Pendoley 2005; Pendoley & Kamrowski 2015), and if bright enough, can elicit a similar response to shorter wavelength light (Mrosovsky 1972; Mrosovsky & Shettleworth 1968; Pendoley & Kamrowski 2015; Cabrera-Cruz et al. 2018). Hence, the disruptive effect of light on hatchlings is also strongly correlated with intensity. Red light (~650 – 700 nm) must be almost 600 times more intense than blue light before green turtle hatchlings show an equal preference for the two colours (Mrosovsky 1972).

In the absence of competing light sources, there is potential for artificial light to result in behavioural impacts to marine turtles, should the intensity be great enough, even if spectral output of light sources are outside the peak sensitivity of marine turtles (i.e. >600 nm).

7.3.1 Nesting: Adult Females

Adult female marine turtles return to land, predominantly at night, to nest on sandy beaches, relying on visual cues to select, and orient on, nesting beaches. Disruption to nesting behaviour due to artificial lighting on or near beaches is relatively well documented (Witherington & Martin 2003). For example, beaches with light spill, such as those located adjacent to urban developments, roadways, and piers, often have lower densities of nesting females compared to beaches with less development (Salmon 2003; Hu et al. 2018).

It has been postulated that neophytes (females breeding for the first time) are more vulnerable to nesting disruption by artificial light compared to experienced females that had nested at a given beach prior to the introduction of light sources (pers. comm. C. Limpus, Department of Environment and Science, Queensland Government). Anecdotal outcomes of long-term marine turtle monitoring programs across Australia suggest that (assumed) neophyte turtles favour nesting on dark beaches unaffected by onshore light pollution, whereas experienced nesters continue to use light affected beaches. Over time this could result in changes in nesting distribution in response to artificial light.

In addition to potential impacts to nesting females prior to or during nesting, artificial light also has the potential to impact post-nesting behaviour. On completion of laying, nesting females are thought to use light cues to return to open ocean, orientating towards the brightest light (Witherington & Martin 2003). However, observations of nesting females and emerging hatchlings at the same beach showed that females were disorientated much less frequently than hatchlings (Witherington 1992b), indicating that nesting females are less vulnerable to impacts of artificial light on sea-finding behaviour post nesting.

The viewshed analysis indicates that little nesting habitat directly adjacent to the project in Lighthouse Bay, and none of the western Ningaloo coastline, would have direct visibility of light (**Figures 15 - 17**). Because nesting females do not appear to be as sensitive as hatchlings to light there is a reduced likelihood they will be affected by directly visible light, particularly if the light source is situated a large distance away. It is possible that females that get lost in the dune system immediately adjacent to the resort location and hence crawl inland, could potentially become confused by the light and either fail to return to the ocean or use valuable energy reserves in doing so.

The February 2021 survey found no evidence of misorientation in adult females returning to the ocean following nesting, despite the visibility of sky glow from the antenna array, Harold E Holt base and/or Exmouth from all surveyed nesting beaches.

With the additional control measures applied (outlined in **Section 9**), direct visibility of onshore sources of light at the nesting habitat area is not expected to occur and the proposed colour and intensity of light would minimise any potential disturbance. Therefore, light from onshore sources is not considered bright enough to deter nesting activity at the beach.

Table 11: Summary of the impact assessment for nesting marine turtles.

Impact	Consequence	Likelihood	Ranking
Inherent	Insignificant (1)	Possible (3)	Low (3)
Residual	Insignificant (1)	Unlikely (2)	Low (2)

7.3.2 Emerging Hatchlings

Hatchling turtles emerge from the nest, typically at night (Mrosovsky & Shettleworth 1968), and must rapidly reach the ocean to avoid predation (Salmon 2003). Hatchlings locate the ocean using a combination of topographic and brightness cues, orienting towards the lower, brighter oceanic horizon, and away from elevated darkened silhouettes of dunes and/or vegetation behind the beach (Pendoley & Kamrowski 2015; Lohmann et al. 1997; Limpus & Kamrowski 2013).

Artificial lights interfere with natural light levels and silhouettes, which disrupts hatchling sea-finding behaviour (Witherington & Martin 2003; Pendoley & Kamrowski 2015; Kamrowski et al. 2014). Hatchlings may become disorientated - where hatchlings crawl on circuitous paths; or become misorientated - where they move in the wrong direction, possibly attracted to artificial lights (Witherington & Martin 2003; Lohmann et al. 1997; Salmon 2003). Hatchlings disoriented or misoriented by artificial lighting may take longer, or fail, to reach the sea. This may result in increased mortality through dehydration, predation, or exhaustion (Salmon & Witherington 1995).

Hatchling orientation has been shown to be disrupted by light produced at distances of up to 18 km from the nesting beach (Hodge et al. 2007; Kamrowski et al. 2014), although the degree of impact would be influenced by a number of factors including light intensity, visibility (a function of lamp orientation and shielding), spectral power distribution (wavelength and colour), atmospheric scattering, cloud reflectance, spatial extent of sky glow, duration of exposure, horizon elevation, and lunar phase.

Disruption to orientation of emerging hatchlings was found to occur most often during the new moon phase and least frequently during full moon phases (Salmon & Witherington 1995). Experiments showed that background illumination from the moon (while in phases closer to full moon), restored normal sea-finding behaviour in hatchlings but did not result in attraction in the direction of the moon. It was concluded that background illumination from the moon reduced light intensity gradients of artificial light, reducing, but not eliminating, its effect on hatchling orientation (Salmon & Witherington 1995).

The viewshed analysis indicates that little nesting habitat directly adjacent to the project in Lighthouse Bay, and none of the western Ningaloo coastline, would have direct visibility of light (**Figures 15** – **17**). The orientation of this beach means that light will be visible along the beach (as opposed to behind the dunes at the back of the beaches) and could potentially override the influence of other sea finding cues.

Hatchlings are also strongly influenced by sky glow on the horizon during sea finding and it is important to recognise this is not captured in the viewshed analysis which addressed lights that are directly visible only. Hatchlings integrate light cues on the horizon, across a field of view ~30° high and ~180° wide when sea finding (Lohmann et al. 1997) and consequently any sky glow visible from inland will potentially impact on the ability of hatchlings to find the ocean. The degree to which sky glow impacts on sea finding is a function of the sky glow colour, intensity, areal extent and elevation, with bright white extensive domes of light low on the horizon potentially causing substantial disorientation and misorientation in hatchlings.

Unpublished evidence is emerging that suggests there is a species difference in sensitivity to light by turtle hatchlings during sea finding, with green and hawksbill turtles more sensitive to light cues and beach topography than flatback hatchlings (pers. obs. K. Pendoley and P. Whittock). The predominance of green nesting on the regional beaches at the project site means that these hatchlings might be at a greater risk of misorientation from light, particularly on beaches that are oriented so that the hatchlings lack strong topographic features such as dunes or vegetation providing a tall dark horizon cue needed by hatchlings in sea finding.

The results of the February 2021 benchmark survey found that the green hatchlings were orientating normally and that the sky glow from the antenna array, Harold E Holt base and Exmouth was not causing detectable population level misorientation or reduction in sea finding. While this single survey does not account for any seasonal or interannual variations that might occur in green hatchling orientation on the North West Cape, the sample size was large enough to provide confidence in the results from this survey and the risk assessment has been revised based on those findings.

If uncontrolled, project related night-time lighting could lead to disorientation of hatchling turtles on the beaches north and north east of the project site. This could result in consistent annual mortality and, in the long-term, a potential decrease in the overall size of the population. However, once control measures outlined in **Section 9** are applied, including the shielding and redirection of lighting and the use of lights with suitable wavelengths and intensities, disorientation of hatchling turtles on the beach has a reduced likelihood resulting in a lower risk value. Outcomes of the risk assessment is provided in **Table 12**.

Table 12: Summary of the impact assessment for emerging hatchling marine turtles.

Impact	Consequence	Likelihood	Ranking
Inherent	Minor (2)	Possible (3)	Medium (6)
Residual	Insignificant (1)	Possible (3)	Low ()

7.3.3 Offshore Hatchlings

Once in nearshore waters, artificial lights on land can also interfere with the dispersal of hatchlings. The presence of artificial light can slow their in-water dispersal (Witherington & Bjorndal 1991; Wilson et al. 2018), or increase their dispersion path, potentially depleting yolk reserves, or even attract hatchings back to shore (Truscott et al. 2017). In addition, artificial light can influence predation rates, with increased predation of hatchlings in offshore areas with significant sky glow (Gyuris 1994; Pilcher et al. 2000). Since the nearshore area tends to be predator-rich, hatchling survival may depend on them exiting this area rapidly (Gyuris 1994). Should this be the case, aggregation of predatory fish occurring in artificially lit areas and under artificial structures (see Wilson et al. 2019) may further increase the predation risk to hatchlings.

An internal compass set while crawling down the beach, together with wave cues, are used to reliably guide hatchlings offshore (Lohmann & Lohmann 1992; Stapput & Wiltschko 2005). In the absence of wave cues, however, swimming hatchlings have been shown to orientate towards light cues (Lorne & Salmon 2007; Harewood & Horrocks 2008) and in some cases, wave cues were overridden by light cues (Thums et al. 2013, 2016; Wilson et al. 2018).

The speed and direction of at-sea dispersal is substantially influenced by currents. The offshore trajectory of flatback hatchlings at Thevenard Island, Western Australia was displaced by tidal currents that ran parallel to the beach, an effect that increased as the hatchlings moved further offshore (Wilson et al. 2018, 2019). However, when light was present this effect was diminished, showing that hatchlings actively swam against currents and towards the light source, which slowed their offshore dispersal from 0.5 m/s when no light was present, to 0.35 - 0.44 m/s, depending on the type of light (Wilson et al. 2018). Wilson et al. (2018) demonstrated that when flatback hatchlings were within 150 m of the beach, they were able to swim against currents up to 0.3 m/s. These results suggest that hatchlings can move in any direction when their swimming speed is greater than the speed of the nearshore current, although the speed at which currents can no longer be overcome by hatchlings will be species specific and related to swimming speeds.

The maximum velocity of the tidal current in the nearshore waters of the region (0.5 m/s) is faster than the reported swimming speed of hatchlings (Thums et al. 2016). This means that that once the hatchlings enter the water, they are likely to be influenced by tidal currents and dispersed over a large geographical area. Therefore, if a hatchling turtle was attracted back to shore by the project light, the tidal current would likely be too strong for the hatchling to move towards it and instead would be carried along the coast or offshore. However, during periods when the velocity of the tidal current was slower than the hatchling swim speed, there remains a potential for a hatchling to move towards a light if attracted,, potentially increasing its exposure to predation and causing exhaustion. With control measures for lighting outlined in **Section 9** applied, the risk of impact is likely to be low. Outcomes of the risk assessment is provided in **Table 13**.

Table 13: Summary of the impact assessment for offshore hatchling marine turtles.

Impact	Consequence	Likelihood	Ranking
Inherent	Minor (2)	Possible (3)	Medium (6)
Residual	Minor (2)	Unlikely (2)	Low (4)

7.3.4 Significant Impact Assessment

Considering the information provided above, and the implementation of control measures outlined in **Section 9**, significant impacts to marine turtles are not expected as a result of project lighting as summarised in **Table 14**.

Table 14: Summary of significant impact of the project lighting on marine turtles.

Significant Impact Criteria	Assessment of significance
Lead to a long-term decrease in the size of a population	Of greatest risk is the potential impact of light pollution disrupting hatchling turtle behaviour on the beach. Control measures, including monitoring and adaptive management, will eliminate light spill and shield any light directly visible at the nesting habitat, and minimise additional skyglow, reducing potential impacts to hatchling turtles. Should any changes in hatchling behaviour on the local beaches be detected pre- and post-construction, and throughout operations, adaptive management will identify and rectify potential impacts to prevent long term declines. Accordingly, long-term decreases in the size of the population or genetic stock are not expected.
Reduce the area of occupancy of the species	Light spill on nesting habitat is not anticipated to occur due to the location of the project and the control measures in place to manage and monitor lights and minimise additional skyglow. Furthermore, monitoring and adaptive management will ensure that if changes in turtle nesting behaviour are detected, the cause will be rectified to prevent changes in area occupancy. Accordingly, the project is not expected to reduce the area of occupancy of marine turtle species.
Fragment an existing population into two or more populations	The genetic stocks for each turtle species identified in **Table 2** occur over a large geographical area and comprise numerous nesting beaches. Fragmentation of nesting populations within each genetic stock are not considered likely to occur given the nature of the project lighting.
Adversely affect habitat critical to the survival of a species	Beaches and adjacent waters in the vicinity of the project are identified as habitat critical to the survival of the species for green and loggerhead turtles (**Section 2.1**). Large areas of nesting habitat could be impacted by the direct visibility of light. However, control measures, including monitoring and adaptive management, will eliminate light spill and shield any light directly visible at nesting habitat, and minimise additional skyglow, reducing potential impacts to nesting turtles. Should any changes in hatchling behaviour be detected before and after construction, adaptive management will rectify any identified adverse effects. Therefore, the project is not expected to adversely affect habitat critical to the survival of marine turtles.
Disrupt the breeding cycle of a population	The direct visibility of light at the nesting habitat will be controlled so that no direct light will be detected at nesting beaches and skyglow will be minimised. Should any changes in turtle nesting and hatchling behaviour be detected before and after construction, and throughout operation, adaptive management will identify and rectify potential impacts, preventing disruption to the breeding cycle. Accordingly, disruption to the marine turtle breeding cycles is not expected.

Significant Impact Criteria	Assessment of significance
Modify, destroy, remove, isolate, or decrease the availability or quality of habitat to the extent that the species is likely to decline	There is a pathway for light pollution to decrease the quality of nesting habitat. However, proposed control measures will aim to ensure no direct light is detected at nesting beaches and skyglow will be minimised. Should any changes in turtle nesting and hatchling behaviour be detected before and after construction, and throughout operation, adaptive management will identify and rectify changes to nesting habitat so that the marine turtle populations are not impacted.
Result in invasive species that are harmful to a species becoming established in the endangered or vulnerable species' habitat	Light sources are not expected to result in introduction of invasive species. However, existing populations of invasive species may utilise artificial light to extend foraging conditions. Recently laid turtle nests would be most vulnerable to predation from invasive species such as feral pigs or foxes. However, the proposed control measures will aim to ensure no direct light spill is detected at nesting beaches preventing any significant impact occurring because of invasive species.
Introduce disease that may cause the species to decline	Not applicable to light emissions.
Interfere with the recovery of the species	The status of each marine turtle species' genetic stock is outlined in **Table 2**. With proposed control measures in place, the impact of light pollution on nesting and hatchling emergence behaviour is unlikely to significantly affect the marine turtle populations in the long term. Furthermore, the implementation of monitoring and adaptive management will prevent long term impacts on nesting and hatchling emergence behaviour. Accordingly, the project is not expected to interfere with the recovery of the genetic stocks.

7.4 Impact Analysis: Space Surveillance Telescope

7.4.1 Impact Criteria

There are no published impact criteria for Observatories. Light pollution may impact the successful operation of the SST in two ways; affecting the relative brightness of objects against the night sky, and/or image exposure time. The sky must be darker than the object being observed for the object to be visible to the SST and the exposure time for each image must be short enough that the SST can collect enough images in a night to detect objects moving through the field of view.

The observatory should not experience any loss in detection ability, i.e. they should be able to continue to observe faint objects at the detection limits originally defined for the instrument. The SST was designed to detect objects shining at a brightness of 20.5 apparent magnitudes (Ruprecht et al. 2018). Consequently, if the brightness of the sky at the SST becomes brighter than 20.5 apparent magnitudes then the SST will not be able to detect objects shining at this intensity against the bright sky.

To detect objects moving across the sky, the SST must collect multiple images of the whole sky in the same night. The SST aims to cover the whole sky four times per night, producing thousands of images per night, however, the number of images that can be collected in a night is a function of the number and duration of exposures and this exposure time is strongly influenced by light pollution. The greater the light pollution, the longer the exposure time required to detect dim objects and so the fewer exposures that can be collected in one night.

The sky quality at the SST was measured during the February 2021 ALAN survey. The details of the survey, including methods, data analysis and survey results, are presented in section 6.5 and used in the following impact assessment.

7.4.2 Impact Analysis

The viewshed analysis indicates that light from the project's campground and Sunset Villas will be visible from the SST, however lights from the resort village will not be visible. The February 2021 ALAN survey was carried out after the campground had been decommissioned (i.e. there are no external lights in use at the site) and consequently it was unable to confirm the line of sight analysis. However, the survey did establish the visibility of other light sources in the vicinity of the SST; Exmouth, Harold E Holt base and the antenna array are bright sources of both directly visible light and sky glow (**Figure A.7 Appendix A**) and, the sky to the north of the SST (and in the direction of the project site) is currently dark.

The 15 km distance between the project site and the SST means that the intensity of the light will be substantially reduced when it reaches the SST. If uncontrolled, night-time lighting could impact on SST observing conditions which could result in a reduction in the amount of data collected and, in the long-term, a potential decrease in the ability to monitor space debris.

Consequently, there is a pathway for light pollution to decrease the quality of the observing sky in the direction of the project site from the SST. Proposed control measures outlined in **Section 9**, including the shielding and redirection of lighting and the use of lights with suitable wavelengths and intensities, will ensure no direct light is visible from the SST and that skyglow will be minimised. Should any changes in SST observing be detected before and after construction, and throughout operation, adaptive management will identify and manage lights in the project that impact on the quality of the observing sky, so that the ability of the SST to collect data is not impacted.

8 ARTIFICIAL LIGHT MANAGEMENT PLAN

The objectives of this ALMP are as follows:

- Reduce the output of light from the project to as low as reasonably practicable; and
- Ensure project sources of light are not directly visible from turtle nesting beaches or the SST.

The following sections of the ALMP provides guidance for how best to achieve these objectives. This ALMP applies to lighting associated with the project.

This ALMP does not allow for seasonal light management (i.e. variation in light management around the turtle nesting/hatching season) due to the year round need for maintenance of dark skies for the SST, the potential for year round nesting by hawksbill turtles on nesting beaches and the conservation of dark skies for the enjoyment of guests.

8.1 Best Practice Lighting Design Principles

The following best practice light design principles for external light sources, summarised in **Figure 19**, are modified from **Appendix A** of the guidelines (Commonwealth of Australia 2020) to be specific to the proposed project, and the wildlife and SST values described in **Section 3** and **4**.

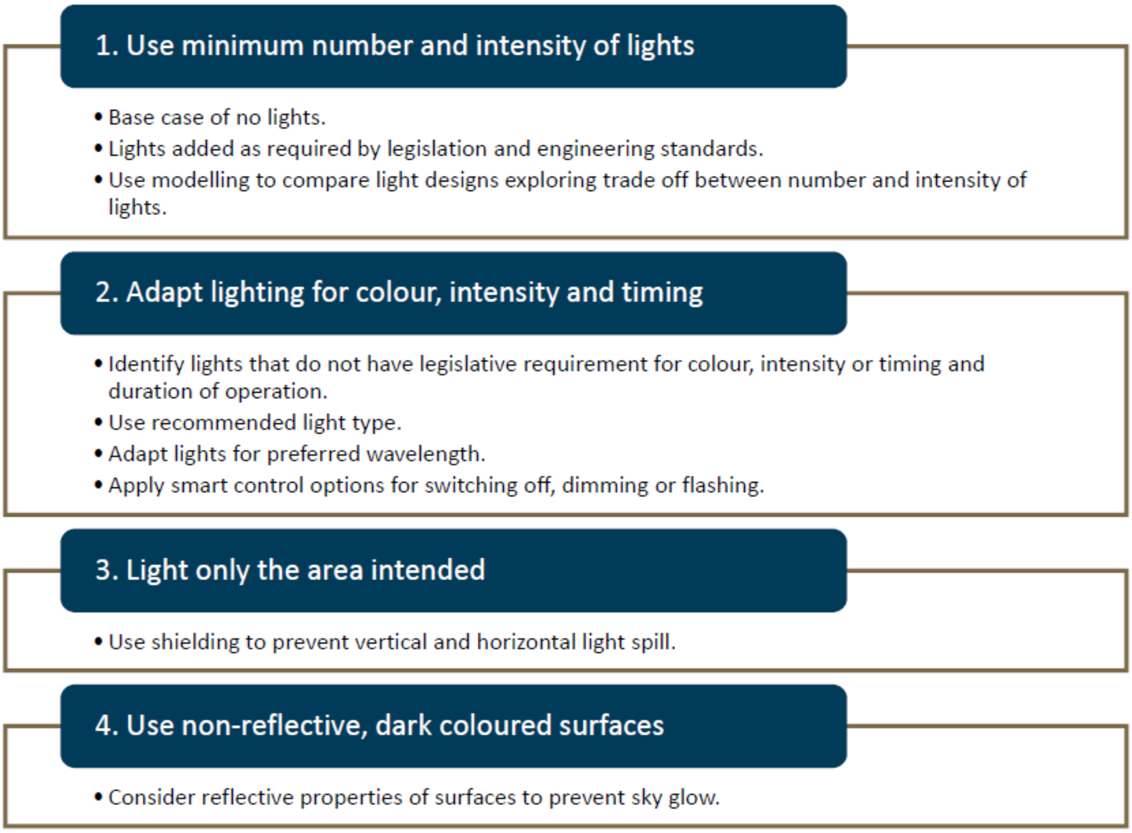

Figure 19: Summary best practice lighting design principles applicable to the proposed project.

8.2 Lighting Design Control Measures

8.2.1 Use Minimum Number and Intensity of Lights

Starting from a base case of no lights, use only the minimum number and intensity of lights needed to provide safe and secure illumination required to meet the lighting objectives, including health and safety requirements. Avoiding light fixtures surplus to needs will decrease overall light emissions. For marine turtles, the intensity of light is as important a cue as colour (Mrosovsky 1972; Mrosovsky & Shettleworth 1968; Pendoley & Kamrowski 2015). Intensity should be reduced to as low as possible, regardless of the type, colour, and planned operation of the light.

There may be a trade-off between the number of lights and intensity of each light, which can only be explored with the use of modelling. Intensity of light should be measured in lumens, not wattage, when comparing intensity between different lighting design options.

Control measure:

- A comparative assessment of lighting designs to identify the minimum number and intensity of lights required to meet lighting objectives.

8.2.2 Adapt Lighting for Colour, Intensity and Timing

Potential for impacts from white light is universal across fauna groups (Commonwealth of Australia 2020). However, the optimum wavelength for reducing potential impacts differs between the species and the behaviours being undertaken. Marine turtles are most sensitive to short wavelength (UV to blue/green) (**Section 3**).

Therefore, where compliant with health and safety requirements, white lights should be avoided and amber/orange lights used instead. Because long wavelength light scatters much less than white light and produces less sky glow, the impacts on both marine turtles and the SST will be reduced. If white lights are required, filters to block green, blue, violet, and ultra-violet wavelengths should be applied.

For lights that are not required to be continuously lit, smart LED technology should be implemented to allow for switching off when not in use, or the use of intermittent flashing lights. The suitability of different commercial lights, with respect to reducing impacts to marine turtles is summarised in **Table 15**.

Independently assessed and certified light types suitable for use in various applications, including those most suitable for use around wildlife, can be found at the ADSA website under the ADSA Approved luminaire program (https://www.australasiandarkskyalliance.org/certified-luminaires). The ADSA Approved luminaires listed on the site, conform with dark sky principles specific to Australasian standards and guidelines including AS/NZS 4282:2019 and the Australian Commonwealth National Light Pollution Guidelines (Commonwealth of Australia 2020).

Table 15: Suitability of commercial lights. Source: Commonwealth of Australia (2020).

Light type	Suitability
Low Pressure Sodium Vapour	Recommended * 'Filtered' means this type of luminaire can be used only if a filter is applied to remove the short wavelength light
High Pressure Sodium Vapour	
Amber/orange LED	
Filtered* LED	
Filtered* metal halide	
Filtered* white LED	
White LED	Not recommended
Metal halide	
White fluorescent	
Halogen	
Mercury vapour	

Control measures:

- Accommodation buildings, outdoor lighting to utilise amber LED emitters (~585 nm 'true amber', 'phosphor-coated (PC Amber').
- Outdoor public areas, high mast floodlighting to be minimised and to utilise reduced blue LED (≤ 2700 K CCT light)
- Walkway/pathway utilise amber LED emitters (~585 nm 'true amber' emitters, 'phosphor-coated amber').
- Streetlights to utilise LEDs with a CCT equal to or lower than 2300 K.
- If specific, intermittent tasks require a brighter white light for better colour rendition (i.e. higher CCT), head torches should be used.
- Lighting design to identify lights that are not required to be continuously lit.
- Lights that are not required to be continuously lit to be motion activated, put on a timer, or wired to allow manual ON/OFF operation.
- All non-essential lighting to be automatically switched off at a predetermined curfew hour, nominally 9 pm each night.
- Flashing/intermittent lights, or reflectors to be installed instead of fixed beam to identify an entrance or delineate a pathway (e.g. to the beach).
- Tennis court lights colour temperature to be as low are practicable for safely playing the game and subject to a 9 pm curfew.

8.2.3 Light only the Area Intended

Light spill is light that falls outside the area that is intended to be lit. Vertical light spill is light that spills above the horizontal plane, which contributes directly to artificial sky glow. Light spill that spills into adjacent areas is known as light trespass, and can potentially impact wildlife, such as marine turtle hatchlings, present in adjacent areas and the operation of the SST. To avoid any form of light spill, light fittings should be designed, located, and directed to avoid lighting anything but the target area.

Control measures:

- All lights to be directed downwards using targeted asymmetrical distribution to illuminate only the specific areas of need, while minimising the reflectance.
- All lights to be mounted at a height as low as possible while meeting lighting objectives e.g. low bollard lighting for pathways and walkways, low wall mounted lights around buildings and on decks, bannister mounted lights on stairs or embedded in risers and focussed downwards.
- Streetlights to only be used where necessary, i.e. in high traffic areas such as road junctions, pole heights should be as low as possible and consideration given to using bollard lighting in place of light poles/masts, pole height should be capped at 3 m.
- The existing vegetation between the project site and adjacent bushland, dunes, and beaches to be maintained and enhanced where feasible.
- No unshielded wall mounted bulkhead lighting to be used on buildings, including balconies (see **Figures 9** and **10**).
- All balcony lighting to be on a curfew and automatically switched off at 9 pm at night.
- Project lights to be directed away from turtle nesting beaches and the SST. For lights required to be directed in the direction of the nesting beaches or the SST, lights should be placed so that buildings provide inherent shielding.
- Shielding of all lights to achieve an upward waste light output ratio (ULR) of 0 %. Shielding can be achieved by recessing the light fitting into roof structures, eaves or building ceilings, and by using the light housing which prevents horizontal light above a 45-degree angle.
- All glass (windows/doors) of buildings to have a glass light transmissivity rating of 0.5 or less.
- All glass (windows/doors) of buildings to have opaque (block-out) blinds/curtains/shutters fitted.
- Position doors and windows facing on the east and west ends of the building to avoid light escaping in the direction of the nesting beaches and the SST.
- The outdoor cinema to confine and contain the projector beam to the surface of the screen and border shields to be installed on the screen edge to prevent the beam escaping and shining in the direction of the beach.
- All pools to be fully enclosed by opaque walls (i.e. no glass walls to contain the water).
- All pool lights to be mounted on the walls only (no upward shining lights mounted on the pool floor).
- No uncontrolled unshielded decorative lighting, no upward facing lights illuminating trees, foliage, or gardens.
- No upward facing lighting to illuminate buildings facades.
- Petrol station (campground site) lighting to be built into and contained by a roof over the refuelling bowsers and forecourt, avoid high mast lighting of standing areas and ensure lights are directed away from the SST.

- All service and laydown areas to be illuminate only where and when it is needed and shielded to prevent light spill. Mast lighting to be mounted at a maximum height of three m.
- Tennis courts (adjacent to turtle nesting beach) consider relocating tennis courts away from nesting beach, lights to be fully shielded.
- Maintain or enhance elevated horizons and topographic features such as vegetation or barriers to screen the resort from nesting beaches or the SST.

8.2.4 Use Non-reflective, Dark Coloured Surfaces

Light reflected from highly polished, shiny, or light-coloured surfaces can contribute to sky glow. Use of dark matte surfaces can reduce reflectance and scattering of light that contributes to sky glow.

Control measures:

- Exterior finishes on all buildings to be matte and have a maximum reflective value of 30 %.
- All other surfaces, including roads, to be matte and have a maximum reflective value of 30 %, unless not technically feasible or presents a health and safety risk.
- Avoid shiny bright white painted surfaces on buildings, on wastewater treatment tanks and facilities and in-service areas.

8.3 Construction Control Measures (Temporary)

- Avoid construction at night during the turtle season.
- Switch off all construction lighting when not in use.
- Prevent mobile light sources shining on nesting beaches or towards the SST and keep the height of these to a minimum.

8.4 Operational Control Measures

- All non-essential lighting to be switched off when not in use.
- Building window blinds to be shut during hours between sunset and sunrise.
- Vehicle headlights to be dipped when operating within the resort boundary.
- Develop a guest guide/handbook on good lighting practices (including campground/caravan guests).

8.5 Marine Turtle Hatchling and Artificial Light Monitoring

Hatchling turtle orientation monitoring should be undertaken prior to construction, during construction and during operations. This enables monitoring of any changes in hatchling behaviour that could be attributed to the change in lighting conditions associated with the project.

Benchmark hatchling orientation data was gathered in February 2021 prior to activities commencing to understand the changes in hatchling behaviour throughout the life of the project.

Artificial light monitoring should be undertaken using a digital camera and fisheye lens technique as recommended by Hänel et al. (2018) and Barentine (2019) and described in the guidelines (Commonwealth of Australia 2020).

Benchmark artificial light measurements were gathered in February 2021 prior to activities commencing to understand changes in ambient light levels throughout the project life. Benchmark light monitoring was also carried out at the SST to understand the current exposure to non-project attributable light and to provide a baseline to measure project attributable light impacts against.

Given the projected operating life of the project (approximately 50 years), there is potential for changes in facility design and operation to occur. It is recommended that, in addition to post-construction light, a light monitoring program should be implemented to periodically monitor project light emissions throughout the operational phase.

8.6 Auditing

At least one annual Audit will be scheduled prior to the commencement of every marine turtle nesting season to ensure:

- Compliance with control measures.
- Identification of, and measures taken to reduce, impacts of problem lights.
- Identification of any new information regarding potential impact pathways between artificial light associated with the project and marine turtles and the SST, and any adaptive management measures that could further reduce potential impacts.

As outlined in the guidelines (Commonwealth of Australia 2020), audits should be undertaken by personnel qualified in environmental auditing and considered in consultation with an appropriately qualified biologist or ecologist.

Additional audits will be scheduled as necessary, i.e. following major weather events or major changes in project facilities or buildings.

8.7 Adaptive Management and Continuous Improvement

8.7.1 Marine Turtles

If the annual light and hatchling orientation program identifies misorientation in hatchlings after they leave the nest, both during sea finding or returning to the beach after they swim offshore, the project lighting will be assessed together with the light audit results to identify the likely problem lighting and additional engineering and/or operational solutions will be implemented where practicable to control or modify the ‘problem light(s)’, such as:

- Changing wavelength of light for the species interacting.
- Additional shielding.
- Changing orientation and direction of light fittings.

- Consideration to whether activities requiring illumination of problem lights can be undertaken during daylight hours only.

Furthermore, an education package for resort guests could be prepared that outlines the regional turtle species and behaviours, appropriate/best practice behaviour around marine turtles and what to do if animals are found in the resort, recognising that birds can drop hatchlings inland and adult females can get lost when returning to the ocean through extensive dune systems. Materials such as the Ningaloo Turtle Watching Code of Conduct should be used to manage guest interactions with turtles.

8.7.2 Space Surveillance Telescope

If a change in sky quality is detected at the SST, the results of the audit and artificial light monitoring data will be assessed to identify any likely problem lighting. Furthermore, if results of the artificial light monitoring program detect changes in artificial light, additional engineering and/or operational solutions should be implemented where practicable.

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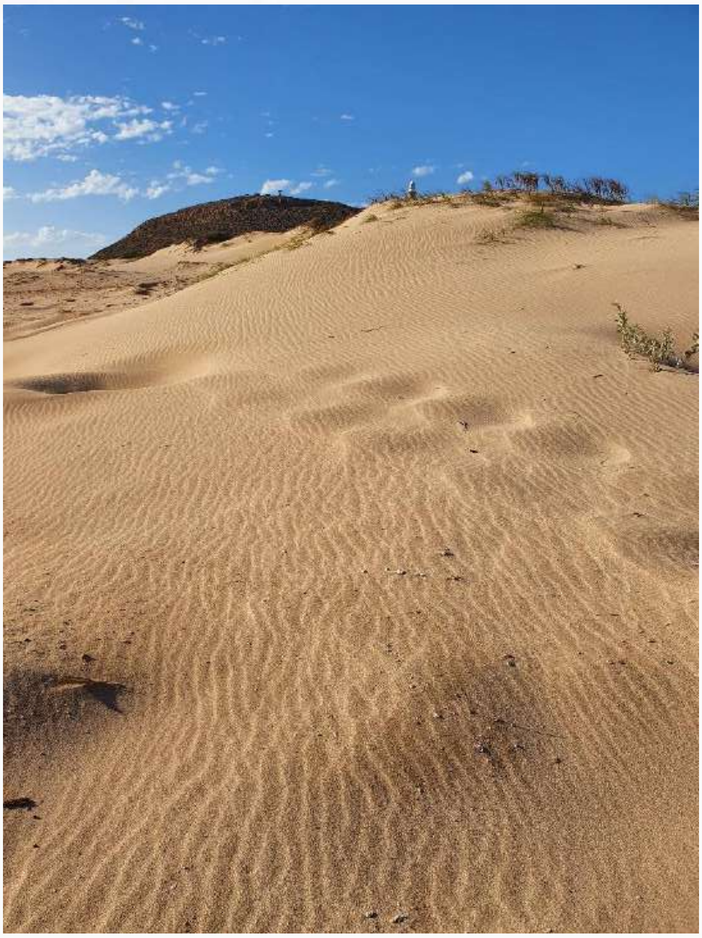
APPENDIX A: MARINE TURTLE AND LIGHT MONITORING REPORT

NORTHWEST RESORTS

LIGHTHOUSE RESORT: MARINE TURTLE AND LIGHT MONITORING PROGRAM 2021



Prepared by

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For

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16 April 2021

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EXECUTIVE SUMMARY

Project proponents, Northwest Resorts Pty Ltd (NWR), are proposing to construct and operate the Ningaloo Lighthouse Resort Development on the footprint of an existing campground and caravan park on north western Cape Range, Western Australia.

The proposed resort is located in the vicinity of known nesting habitat for marine turtles which are protected under both State and Federal legislation. Light from the project is recognised as a source of potential impact on these biological receptors and therefore a preliminary Artificial Light Management Plan (ALMP) was prepared by Pendoley Environmental (PENV) in December 2020. The ALMP will be finalised by incorporating the results of this benchmark marine turtle hatchling and light monitoring survey. The US owned, and Australian Department of Defence (DoD) operated, Space Surveillance Telescope (SST) was also recognised as potentially being impacted by artificial light from the project. Benchmark light monitoring conducted at the SST site will also be incorporated into the final ALMP.

Beaches were surveyed for emerged marine turtle nests between the 10th and 18th February 2021. Fan metrics were collected from 257 nests between the Wobiri and Mildura Wreck East beach sections. Overnight light monitoring data was also collected at 11 monitoring sites, including at the SST.

The survey results show that glow from the regional light sources, including Exmouth, Harold E Holt base, and the antenna array are visible from all monitored sites (including the SST), while offshore oil and gas facilities (due north of the NW Cape) were also visible from monitoring sites on north facing beaches and at the SST. The results suggest the current sky quality across all sites is equivalent to a rural sky on the Bortle scale (approx. 21.69 – 21.89 Vmag/arcsec^2), declining to rural/suburban transition quality (20.49 – 21.69 Vmag/arcsec^2) when cloud cover reflects the local light sources across the landscape.

Nest fan metrics were collected from 257 nests (green turtle = 196; hawksbill/loggerhead turtle = 22; and unknown species = 39) and grouped into four regional beach sections. The largest mean spread angle was recorded for those nest fans situated within the Hunters to Lighthouse Bay Parking section (53.6 ± 17.1°; n = 10) and the smallest mean spread angle on Surf Beach South to Mildura Wreck section (36.2 ± 17.3°; n = 62). The largest mean offset angle was recorded for those nest fans situated within the Ningaloo Coast West section (9.6 ± 8.9°; n = 180) and the smallest mean offset angle on Mildura Wreck to Mildura Wreck East section (3.8 ± 2.6°; n = 7). The overall spread and offset angles were 40.7 ± 17.3° and 8.6 ± 8.2 (n = 257), respectively.

The spread and offset angles indicate the hatchlings across the region are orienting normally and are successful in sea finding. Further statistical analyses investigated the difference between beach sections based on the line-of-sight visibility to the project location (i.e. beaches with no line-of-sight vs beaches with line-of-sight) and found that there was no significant difference in fan spread between the two habitat groupings (p = 0.86) however there was a significant difference in fan offset (p = 0.015).

Integration of hatchling fan data situated within 1 km either side of three light monitoring sites including Wobiri (shielded from the project site by the Cape Range in the Ningaloo Coast West Area), Tamarisk (situated immediately in front of the project site) and Surf Beach (situated north-east and in line-of-sight of the project site) showed that hatchlings oriented seaward and not in the direction of the sky glow that was visible on the horizon at each site.

This report has established the benchmark metrics for hatchling fan and regional light pollution against which the project can be monitored during construction and future operations.

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Appendix A: Complete set of Sky42 images from each monitoring site.

1 INTRODUCTION

The Ningaloo Lighthouse Resort Development (the project) involves the construction and operation of a tourist resort on the footprint of a 30+ year old campground and caravan park on north western Cape Range, Western Australia. The project proponent is Northwest Resorts Pty Ltd (NWR).

The proposed resort village is located in the vicinity of known nesting habitat for marine turtles (**Figure 1**) which are protected under both State and Federal legislation, and consequently any action that has the potential to impact on the populations or their habitat must be assessed and managed to the satisfaction of the regulators (Commonwealth of Australia 2017, 2020). The project is recognised as potentially impacting on these sensitive biological receptors and hence a formal impact assessment and management plan was required. A preliminary Artificial Light Management Plan (ALMP) was prepared in December 2020 (PENV 2020) and will be finalised by incorporating the results of this Marine Turtle and Light Monitoring Program.

In addition to the recognised sensitive biological receptors, socioeconomic receptors such as the US owned and Australian Department of Defence (DoD) operated Space Surveillance Telescope (SST), was also recognised as being potentially impacted by artificial light from the project. The SST detects and tracks orbital debris in addition to near Earth asteroids and is an important contributor to the US Global Space Surveillance network (DoD 2014). Benchmark artificial light monitoring was conducted at the SST site and the results will also be incorporated into the final ALMP.

1.1 Scope of Work and Objectives

The preliminary ALMP objectives recognised that the following work scopes were required:

i. Collection of benchmark marine turtle hatchling orientation data at potentially impacted nesting beaches.

ii. Collection of in-situ benchmark artificial light monitoring data from nesting beaches and the SST.

The purpose of this monitoring report is to present the results of the February 2021 benchmark marine turtle and artificial light monitoring survey that will be subsequently incorporated into a final version of the ALMP.

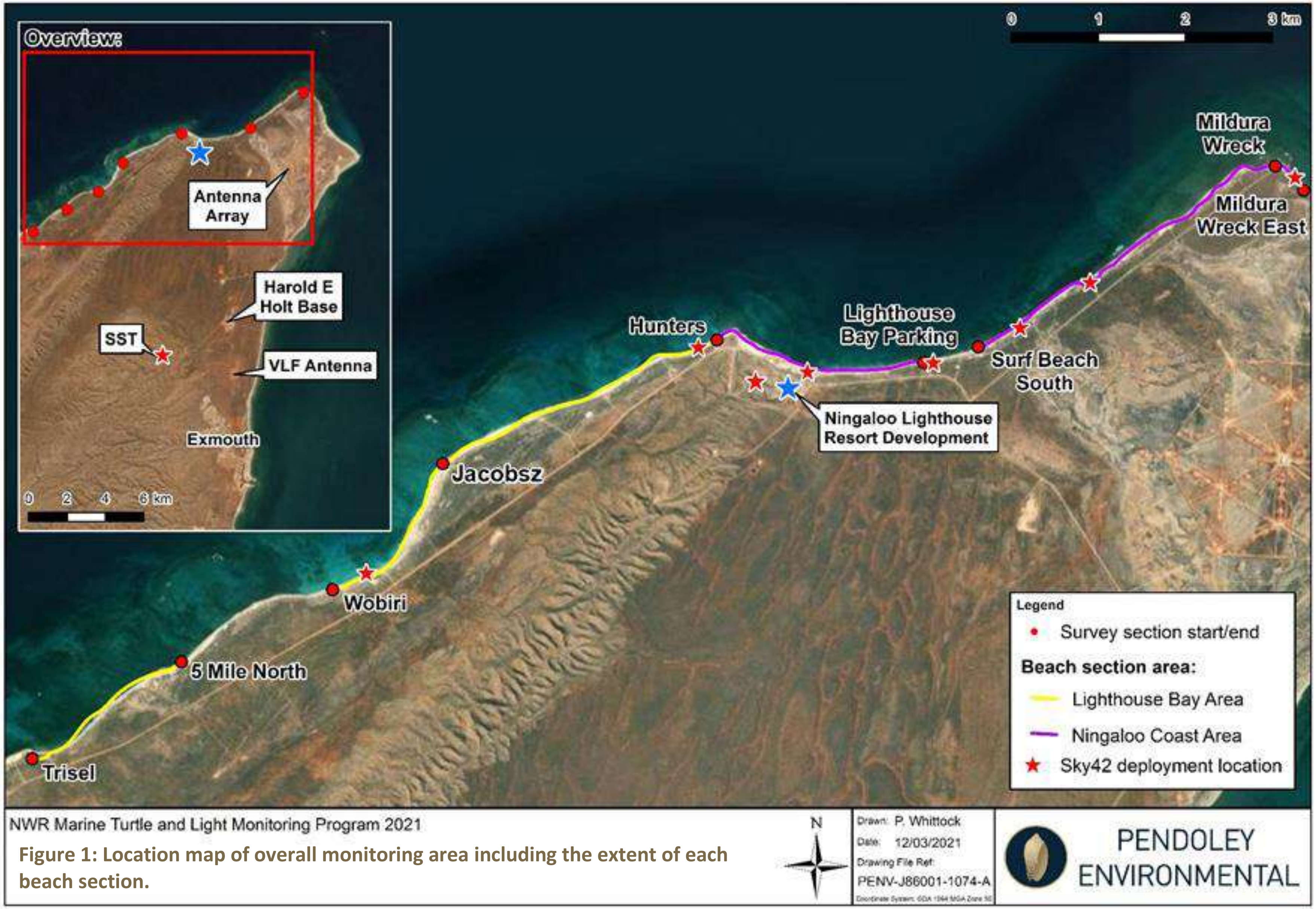


Figure 1: Location map of overall monitoring area including the extent of each beach section.

2 METHODOLOGY

2.1 Survey Location

All monitoring activities were completed within the beach sections shown in **Figure 1**. The selection of beach sections took into consideration the monitoring divisions of the Ningaloo Turtle Program (DBCA 2020).

2.1.1 Lighthouse Bay Area

The Lighthouse Bay Area is situated immediately north and north east of the resort site (**Figure 1**). The beach due north and immediately adjacent to the project location is separated from the project site by a well-developed 10 – 12 m tall dune system. The beaches extending to the north east are backed by well developed dune systems that shield the beaches from light in the south and east.

The beach sections surveyed in this area extended from Hunters to the Lighthouse Bay Parking (1.8 km), Surf Beach South to Mildura Wreck (3.7 km), and from Mildura Wreck to Mildura Wreck East (0.5 km), for a total survey beach length ~6 km. The beaches are located between 200 m (north) and 5.7 km (north east) from the project site. These beaches have potential for line-of-sight view to the project site.

2.1.2 Ningaloo Coast West Area

The Ningaloo Coast West Area is situated along the western coast of the North West Cape. Three separate beach sections were monitored in this area (Trisel to 5 Mile North, Wobiri to Jacobsz, and Jacobsz to Hunters) covering a total length of 5.5 km (**Figure 1**). The beach sections are located between 1 km (west north west) and 9 km (west and south west) from the project site. All three beach sections are shielded from direct line-of-sight view to the project site by the Cape Range.

2.1.3 Space Surveillance Telescope

The SST is located 10 km south southwest of the project location (**Figure 1**) and has direct line-of-sight to the project site.

2.2 Survey Schedule

The field survey was completed over an 8-day period between the 10th and 18th February 2021 and involved marine turtle hatchling orientation and artificial light monitoring work scopes (**Tables 1** and **2**). The field survey was scheduled to coincide with the peak green turtle (*Chelonia mydas*) hatching period for the Exmouth area (February – March) and new moon conditions (important for light monitoring).

All work scopes were completed as planned during the survey period. Survey design was finalised following an on-the-ground inspection of regional beaches and access tracks on days one and two of the field survey. The survey effort was concentrated on beaches closest to the project site and those with most direct line-of-sight to the project site.

2.2.1 Artificial Light Monitoring

Artificial light monitoring was completed over eight survey nights and involved the deployment of Sky42 cameras. The deployment locations were selected based on nesting effort recorded by the Ningaloo Turtle Program (DBCA 2020), distribution of observed hatched nests and the proximity to the project site (**Table 1** and **Figure 1**). The SST was surveyed over three nights from two different camera locations, one immediately adjacent to the facility and one 200 m away, both with line-of-sight visibility to the project location, the Town of Exmouth and the Harold E Holt (HEH) facilities.

Table 1: Sky42 camera deployment location and survey dates.

Artificial light monitoring site	Survey date (February 2021)							
	10th	11th	12th	13th	14th	15th	16th	17th
SST	X		X				X	
Surf Beach		X			X			
Surf Beach North		X						
Tamarisk			X	X				
Mildura Wreck East				X				
Hunters					X	X		
Wobiri						X		
Lighthouse Bay Parking							X	
Vlamingh Head								X
Project Site (Villas)								X

2.2.2 Hatchling Orientation Monitoring

Hatchling orientation monitoring was completed over seven survey days. The survey beaches were selected based on nesting effort recorded by the Ningaloo Turtle Program (DBCA 2020), distribution of observed hatched nests and the proximity to the project site (**Table 2** and **Figure 1**).

The frequency, duration, and location of sampling effort for the hatchling orientation work scope is shown in **Table 2**. Factors impacting survey effort and coverage included track access (2WD only), wind and rain erasing hatchling tracks, driving restrictions (rental contract restricted vehicle use too day light only) and heat stress risk for field team members.

Beaches with most direct line-of-sight to the project and located within 5 km of the project site (Lighthouse Bay Area) were surveyed over five separate days, beaches between Hunters and Jacobsz (Ningaloo Coast North) 0.5 km – 2.7 km due west of the project were surveyed over four separate days, while Wobiri to Jacobsz (Ningaloo Coast North) 2.7 – 5 km south west and the beaches 7 – 9 km south west (Ningaloo Coast South) were surveyed twice (**Table 2**).

Table 2: Hatchling orientation survey beach sections including monitoring effort and dates.

Survey section	Length (km)	Survey date (February 2021)						
		11th	12th	13th	14th	15th	16th	17th
LIGHTHOUSE BAY AREA								
Mildura Wreck to Mildura Wreck East	0.5	X	X	X	X			X
Surf Beach South to Mildura Wreck	3.7	X	X	X	X			X
Hunters to Lighthouse Bay Parking	1.8		X	X	X			X
NINGALOO COAST WEST AREA								
Jacobsz to Hunters	3.5			X	X	X	X	
Wobiri to Jacobsz	2					X	X	
Trisel to 5 Mile North	2.3					X	X	

2.3 Work Scopes

2.3.1 Artificial Light Monitoring

Sky42 cameras were deployed on tripods (set at a height above nearest vegetation) by the field team each afternoon and left unattended until their retrieval by the field team the next morning. The cameras automatically captured images of night-time light emissions on a 360° horizon at 15-minute intervals between sunset and sunrise. The captured imagery was downloaded, cameras charged and cleaned, and redeployed each afternoon. The light monitoring work scope was undertaken in accordance with PENV's Light Monitoring Standard Operating Procedure (SOP) (PIMS-SOP14).

2.3.2 Hatchling Orientation Monitoring

A nest fan was recorded if six or more hatchling tracks were sighted from a hatched clutch (defined by a depression in the sand from which the hatchling tracks were seen to emerge). A sighting compass was used to measure angles of the fan of tracks from the emergence point to where the tracks cross the high tide line on a flat beach surface (reducers variation caused by undulating nesting landscapes i.e. from body pits made by nesting turtles), or at a distance of 5 m, whichever is greater (vectors A and B; Figure 2). Angles measured include the outer tracks that form the outside arms of the fan (A and B angles) and the most direct line to the ocean (X) (**Figure 2**). The approach allows for determination of both the range of dispersion or 'spread' angle of emergent hatchlings and the degree of deflection or 'offset' angle from the most direct route toward the ocean. Any evidence of predation surrounding hatched nests was also recorded by the field team.

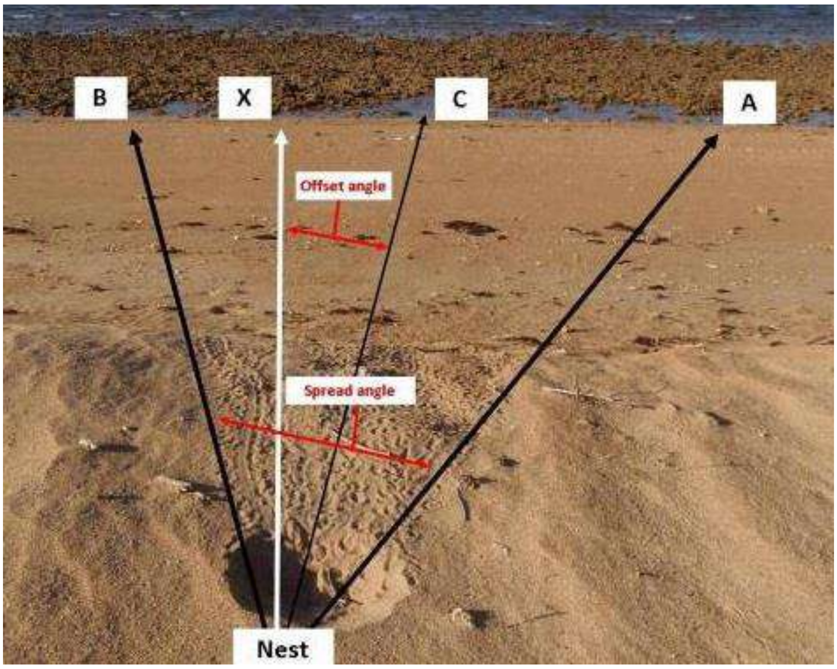


Figure 2: Hatchling orientation indices and emergence spread and offset angles.

A GPS location was recorded at the emergence point of every nest surveyed and a circle drawn in the sand around the depression, and a line drawn through all hatchling tracks, to ensure the same nest fan was not recorded on subsequent monitoring days. The work scope was undertaken in accordance with PENV's Hatchling Orientation SOP (PIMS-SOP04).

2.4 Data Analysis

2.4.1 Artificial Light Monitoring

2.4.1.1 Identification of Light Sources

Existing artificial light sources identified in the preliminary ALMP as potentially visible from the turtle nesting beaches and the SST included; offshore oil and gas industry lighting, onshore lighting associated with the HEH base, antenna array, VLF antenna, and the town of Exmouth.

2.4.1.2 Data Processing

The quality of an image captured by a Sky42 light monitoring camera can be influenced by atmospheric factors such as the presence of the moon, twilight, rain, dust, humidity, or physical factors such as accumulation of sand on the lens. Any images that were affected by these factors were removed from the analysis.

All remaining images were batch processed using specialised software (Sky Quality Camera, Euromix Pty Ltd). The processing involved converting each image into a false-colour map and calculating three sky brightness metrics in units of Vmag/arcsec^2:

- Zenith (directly overhead, 0 – 30° field of view);
- Whole of sky (0 – 90° field of view); and
- Horizon (60 – 90° field of view).

For each monitoring site, the clearest night was selected and all images recorded on that night were processed. The image with the median whole-of-sky brightness image was then used to represent light levels at that location.

Note that the colours used in the false-colour map represents the scale of intensity of light and is not representative of the colour of light as perceived by a human/turtle eye or Sky42 camera. Furthermore, the units of sky brightness (Vmag/arcsec^2) are on an inverted logarithmic scale i.e. higher values represent lower intensity light, while lower values represent higher intensity light. The zenith brightness values can be interpreted using the Bortle scale sky quality guide shown in **Table 3**.

Table 3: Night Sky quality range, Bortle scale, and Vmag/arcsec^2 (Source: Bortle 2001).

Sky quality	Approx. Vmag/arcsec^2	Bortle class
Excellent dark sky site	21.99 – 22.00	1
Typical dark site	21.89 – 21.99	2
Rural sky	21.69 – 21.89	3
Rural/suburban transition	20.49 – 21.69	4
Suburban	19.50 – 20.49	5
Bright suburban	18.94 – 19.50	6
Suburban/urban transition	18.38 – 18.94	7
City	<18.38	8
Inner city sky	<18.38	9

The processed median image was subdivided into 1° segments within the horizon field of view (60 – 90°) (the area most relevant to hatchlings). The mean light intensity value within each segment was calculated and plotted on a line graph. The line graph is used to identify the areas of highest light intensity along the horizon, with comparisons over subsequent seasons allowing for changes in light intensity and its location to be identified (if required). The graph is also integrated with hatchling fan data and allows the orientation of the hatchlings to be compared with the direction of light at the nesting beach (see Section 3.2.2).

2.4.2 Hatchling Orientation Monitoring

Hatchling orientation data was analysed to provide:

- **The range of dispersion (spread angle) of tracks from the emergence point:** Describes the degree of dispersion of all hatchling pathways toward the ocean. A larger value indicates greater dispersion or variation in ocean finding bearings and may indicate disruption to natural hatchling sea finding ability.
- **The degree of deflection (offset angle) of tracks from the most direct route to the ocean:** A smaller value indicates a more direct route (i.e. less deviation from the most direct route) and a larger value demonstrates greater deviation from the most direct route which may indicate disruption to natural hatchling sea finding ability.

Hatchling orientation data was grouped into four separate datasets according to proximity to the project location and analysed separately. The groups included the three beach sections within the Lighthouse Bay Area (**Table 2**), and the Ningaloo West Area (all beach section were combined, **Table 2**).

The hatchling orientation data was further grouped into two separate datasets according to the line-of-site visibility to the project location. This allowed a comparison of fan metrics recorded on nesting habitat with no line-of-sight to the project location with fan metrics recorded on nesting habitat with potential for direct line-of-sight or greater exposure to project related light glow. Nesting habitat with no line-of-sight included all beach sections within the Ningaloo West Area and habitat with potential line-of-sight included Hunters to Lighthouse Bay Parking and Surf Beach South to Mildura Wreck sections. A Wilcox Mann-Whitney test was used to assess if there was any statistical difference between the two datasets.

2.4.3 Integration of Hatchling Orientation and Artificial Light Data

The effect of artificial light on hatchling fan orientation was assessed for three representative locations in the survey area. These locations were Wobiri (Ningaloo Coast West, no line-of-sight to the proposed project), Tamarisk (beach immediately adjacent to and closest to the project site) and Surf Beach (line-of-sight visibility to project location).

Hatchling fan spread and offset metrics from nest fans situated within 1 km either side of three artificial light monitoring sites (Wobiri, Tamarisk, and Surf Beach) was processed and integrated with the light monitoring data from those sites. The purpose of filtering nest fans based on their spatial location was to ensure a suitable comparison between the nest fan and sky brightness recorded by the Sky42 camera at that site.

3 RESULTS

3.1 Artificial Light Monitoring

3.1.1 Night-time Light Emissions

The median level of artificial light during the clearest night sky monitoring conditions for each site are shown in **Table 4**.

Sky brightness values ranged from 21.48 – 21.82 Vmag/arcsec^2 at zenith (directly overhead), 21.26 – 21.52 Vmag/arcsec^2 for the whole of sky, and 21.00 – 21.41 Vmag/arcsec^2 for the region of sky 30° above the horizon.

3.1.1.1 Zenith

The darkest zenith value (21.82 Vmag/arcsec^2) was measured at both the project site and the Vlamingh Head Lighthouse. The brightest zenith value was recorded at the Lighthouse Bay Parking (21.48 Vmag/arcsec^2).

3.1.1.2 Whole of Sky

The darkest whole of sky value (21.52 Vmag/arcsec^2) was measured at Hunters. The brightest whole of sky value was recorded at the Lighthouse Bay Parking (21.25 Vmag/arcsec^2).

The whole of sky values reported at all monitoring sites fell into the range of Bortle Class 3 defined as a rural sky (21.69 – 21.89), indicating some exposure to artificial light at all sites.

3.1.1.3 Horizon

The darkest horizon value (21.41 Vmag/arcsec^2) was measured at Hunters. The brightest horizon value was recorded at the Vlamingh Head Lighthouse (21.00 Vmag/arcsec^2) and the SST (21.03 Vmag/arcsec^2).

Table 4: Sky brightness at each monitored site in February 2021. Orange = brightest values, blue = darkest values.

Light monitoring site	Sky brightness (Vmag/arcsec^2)		
	Zenith (0 – 30°)	Whole of Sky (0 – 90°)	Horizon (60 – 90°)
Wobiri	21.68	21.49	21.33
Hunters	21.76	21.52	21.41
Tamarisk	21.78	21.42	21.20
Lighthouse Bay parking	21.48	21.25	21.18
Surf Beach	21.65	21.4	21.34
Surf North	21.71	21.4	21.31
Mildura East	21.79	21.47	21.32
Project Site (Villas)	21.82	21.35	21.09
Vlamingh Head	21.82	21.26	21.00
SST	21.78	21.28	21.03

3.1.2 Visibility of Individual Light Sources

The visibility of the different regional light sources from the ten monitoring (observer) sites is shown in **Table 5, Figures 3 - 5**, and in **Appendix A** (complete set of annotated images).

3.1.2.1 Antenna Array

The antenna array was visible from every monitoring site i.e. from Mildura East, Surf North, Surf, Lighthouse, Tamarisk, Hunters, Wobiri, Project Site (Villas), Vlamingh Head Lighthouse, and the SST either as line-of-sight or as sky glow.

3.1.2.2 Harold E Holt Base and Exmouth

The light from the HEH base and from Exmouth were directly visible as individually resolved sources from the SST).

At all other beach-based monitoring sites there was no direct line-of-sight visibility of these sources due to shielding by the primary dune system and in all cases the light from the two sources was merged into a single region of sky glow at the horizon (e.g. **Figure 6**). The light from Exmouth, HEH base, and the antenna array was merged into a single region of sky glow when viewed from Mildura East monitoring site, while sky glow from Exmouth/HEH was not detected from the Surf Beach monitoring site.

Light from Exmouth and the HEH base was directly visible from both the project site (Villas), and the Vlamingh Head Lighthouse monitoring sites, however the orientation of the two sources relative to the monitoring sites meant the two sources appeared as a single source of light on the horizon.

3.1.2.3 Offshore Oil and Gas Facilities

Direct light and sky glow attributed to flares from two offshore oil and gas installations were visible intermittently due to either cloud overhead at the rig location reflecting light into the sky, or increased flow rates producing larger and more visible flares (**Figure 3** and **Appendix A**). The two offshore facilities identified from https://www.lightpollutionmap.info/ (2020 VIIRS data) are located 29 km (-21.53924, 114.11620) and 41 km (-21.43325, 114.06754) due north of the Lighthouse Bay coastline and beyond the ~20 km line-of-sight visibility at sea (**Figure 4**).

3.1.2.4 VLF Antenna

The VLF antenna could only be resolved from other light sources when viewed from the SST (**Figure 3** and **Appendix A**).

3.1.2.5 Lighthouse Campground

With the decommissioning of the Lighthouse Campground and the current human presence restricted to two caretakers, there was no detectable light emissions from this monitoring site during the survey.

3.1.3 Impact of Cloud

The influence of cloud on amplifying the visibility of sky glow across the landscape is shown in **Figure 5a** and **5b**. Cloud cover above the source of artificial light can increase the visibility of sky glow across large distances, illuminating inland landscapes and beaches that might otherwise be shielded from direct line-of-sight of a light source. This effect was observed on all monitoring nights influenced by cloud.

Table 5: Bearing and minimum distance to regional light sources from each artificial light monitoring site in February 2021. See Figure 3 for locations.

Light source		Artificial light monitoring site (see Figure 3 for location)									
		Mildura Wreck East	Surf North	Surf Beach	L'house Bay	Tamarisk	Hunters	Wobiri	Project Site (Villas)	Vlamingh Head	SST
Exmouth	Bearing (°)										130-150
	Distance (km)										3.5-8
Harold E Holt base	Bearing (°)										70-80
	Distance (km)										3.7
VLF antenna	Bearing (°)										108
	Distance (km)										4
Exmouth + Harold E Holt base	Bearing (°)	190-200	180-190		170-185	170-180	160-180	140-160	165-180	170-180	
	Distance (km)	15	10-14		8-12	8-12	10-13	11	8-12	9-12	
Antenna array	Bearing (°)	160-200	120-150	100-120	90-120	90-120	90-120	80-90	85-110	90-110	35-45
	Distance (km)	2	1.7	1.7	3	4-6.5	5	9	4	4	10+
Offshore oil and gas	Bearing (°)		355	350-355	352-358		2-355	5-360		1-350	355, 360
	Distance (km)		29-41	29-41	21-49		29-41	41		29-41	42, 29

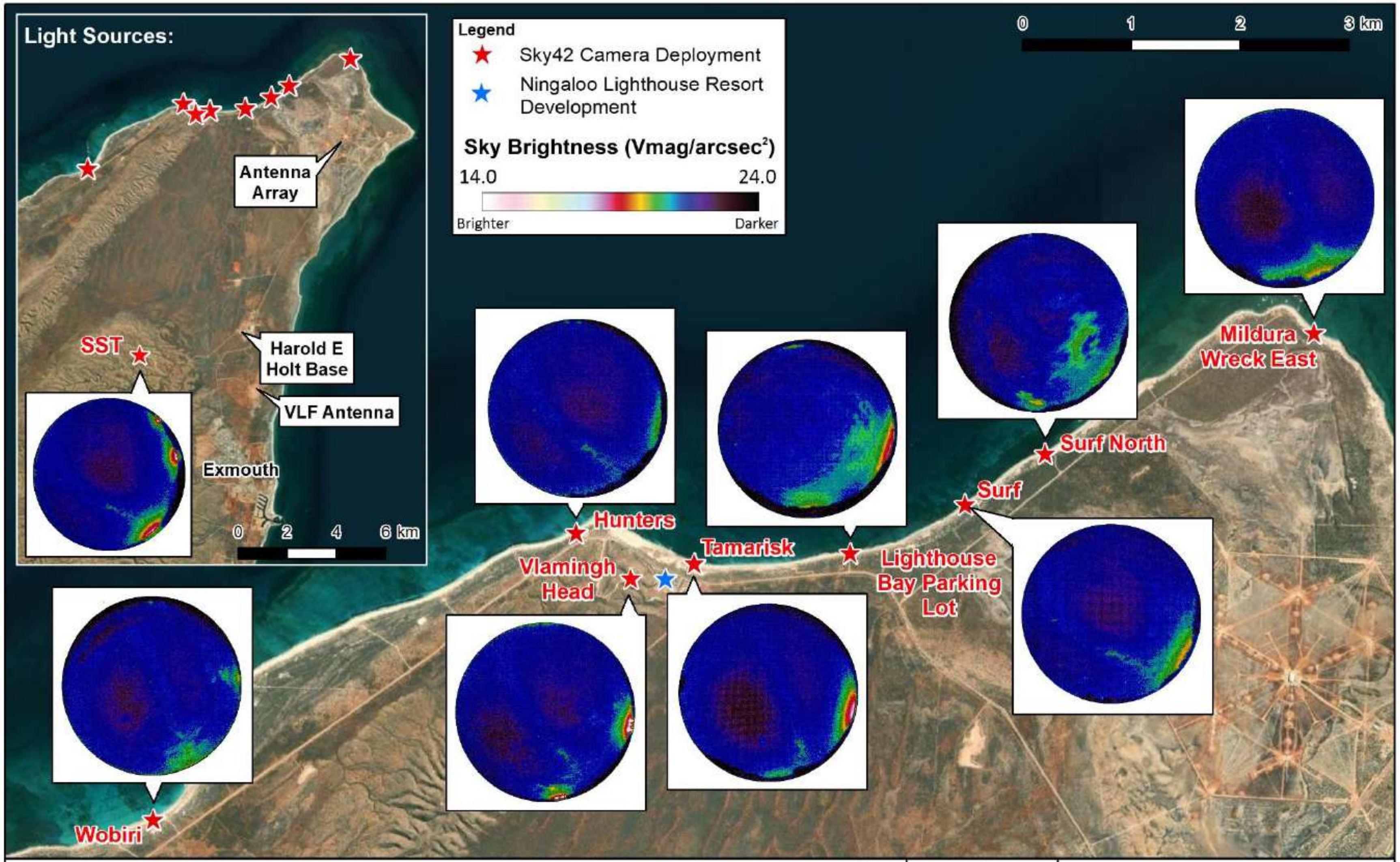
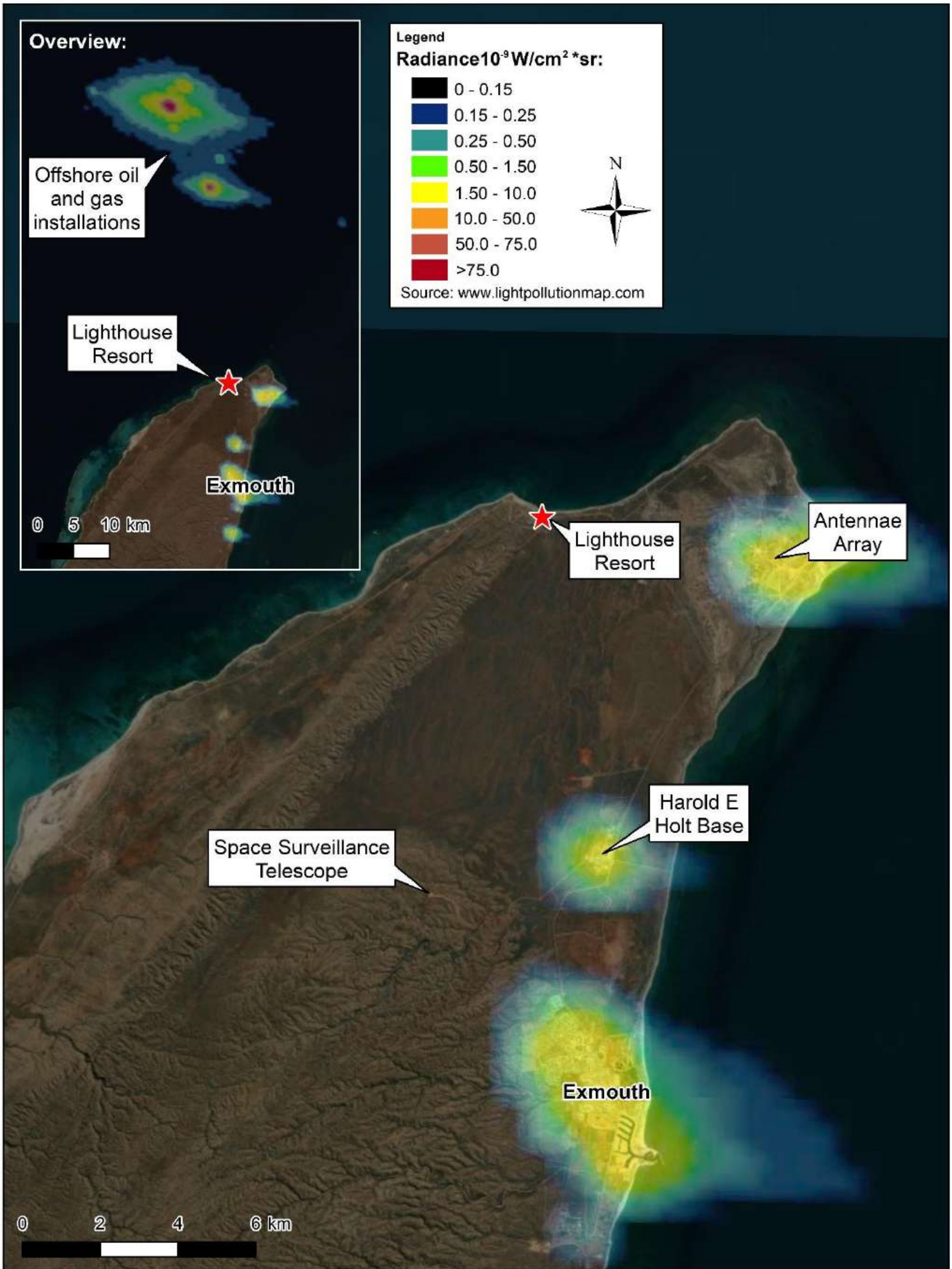


Figure 3: Sky brightness at each artificial light monitoring site. Brightness scale in images ranges from very bright (white/red) to very dark (black). See Appendix A for complete set of images.



NWR Marine Turtle and Light Monitoring Program 2021

Figure 4: Light pollution map imagery of regional light sources on the NW Cape. As recorded from VIIRS satellite in 2020.

Drawn: P. Whittock
Date: 12/03/2020
Drawing File Ref: PENV-J86001-1073-A
Coordinate System: GDA 1994 MGA Zone 50

PENDOLEY ENVIRONMENTAL

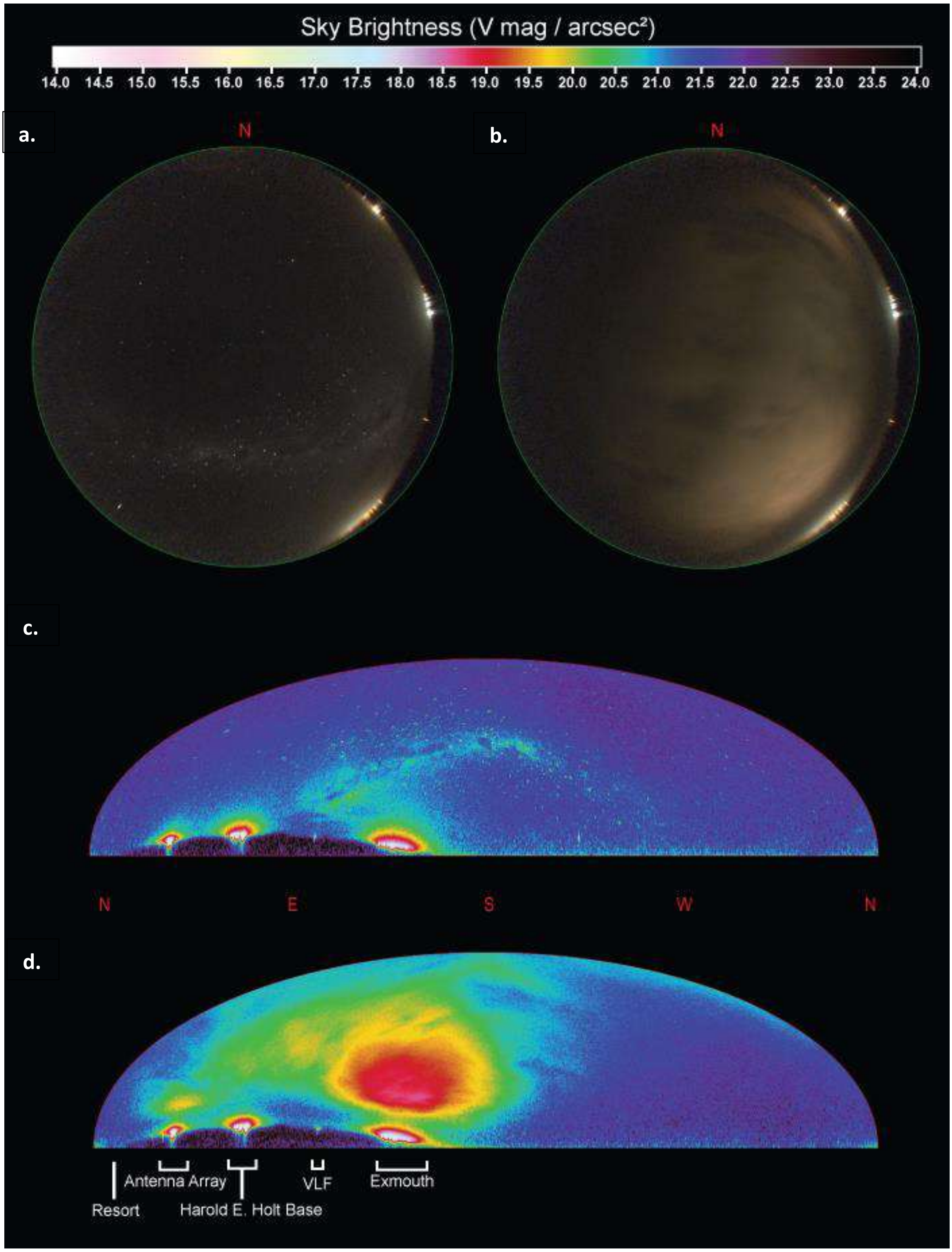


Figure 5: Artificial light monitoring results from the SST under both clear and cloudy conditions on 16th February 2021: a. Raw image (clear); and b. (cloudy); c. Hammer-aitoff projection of the processed false-colour map showing location of visible light sources (clear); and d. (cloudy).

3.2 Hatchling Orientation Monitoring

3.2.1 Benchmark Hatchling Fan Indices

A total of 257 nest fans were recorded during the field survey: 196 green turtles (*Chelonia mydas*), 22 hawksbill (*Eretmochelys imbricata*) or loggerhead (*Caretta caretta*) turtles (inferred from track size and nest position on beach), and 39 unknown species. The mean number of hatchling tracks emerging from each hatched nest was:

- Green turtle: 45.6 ± 40.3 tracks (range = 7 – 100, *n* = 196)
- Hawksbill/loggerhead turtle: 47.3 ± 31.7 tracks (range = 7 – 100, *n* = 22)
- Unknown species: 39.5 ± 12.1 tracks (range = 7 – 50, *n* = 39)

The mean spread angle was largest on the Hunters to Lighthouse Bay Parking section (53.6 ± 17.1°, *n* = 10) and smallest on the Surf Beach South to Mildura Wreck section (36.1 ± 17.3°, *n* = 61) (**Table 6**). The mean offset angle was largest on the Ningaloo Coast West (9.6 ± 8.9°, *n* = 180) and smallest on the Mildura Wreck to Mildura Wreck East section (3.8 ± 2.8°, *n* = 6).

A Wilcox Mann Whitney test found no significant difference in fan spread angles recorded on areas of nesting habitat with direct line-of-sight to the project in comparison to fan spread angles recorded on areas of nesting habitat with no direct line-of-sight to the project (p = 0.86). There was a significant difference in fan offset angles recorded between the areas of nesting habitat with different line-of-sight (i.e. visible vs. non-visible; p = 0.015).

Table 6: Hatchling orientation metrics for nest fan spread and offset angles.

Survey section	Spread angle (°)		Offset angle (°)		*n*
	Mean ± StDev	Range	Mean ± StDev	Range	
Ningaloo Coast West	41.4 ± 16.6	2 – 123	9.6 ± 8.9	0 – 54.5	180
Hunters to Lighthouse Bay Parking	53.6 ± 17.1	35 – 85	6.0 ± 6.5	0.5 – 18	10
Surf Beach South to Mildura Wreck	36.1 ± 17.3	14 – 108	6.7 ± 5.8	0 – 28	61
Mildura Wreck to Mildura Wreck East	46.8 ± 22.8	26 – 81	3.8 ± 2.8	0.5 – 8	6
All	**40.7 ± 17.3**	**2 – 123**	**8.6 ± 8.2**	**0 – 54.5**	**257**

3.2.2 Integration of Hatchling Orientation and Artificial Light

The metrics for nest fans situated within 1 km either side of the Wobiri, Tamarisk, and Surf Beach light monitoring sites are shown in **Table 7**. Camera deployment locations for the monitoring sites are shown in **Figure 3**.

Table 7: Hatchling orientation metrics for nest fans situated 1 km either side of Wobiri, Tamarisk, and Surf Beach light monitoring sites.

Light monitoring site	Spread angle (°)		Offset angle (°)		*n*
	Mean ± StDev	Range	Mean ± StDev	Range	
Wobiri	40.6 ± 17.8	10 – 78	9.5 ± 10.0	0 – 28.5	14
Tamarisk	53.6 ± 18.0	35 – 85	15.4 ± 30.7	0.5 – 100.5	10
Surf Beach	33.7 ± 15.3	1 – 69	7.7 ± 7.0	0 – 39.5	33

The integrated hatchling fan metrics and light data for Wobiri, Tamarisk, and Surf Beach are shown in **Figures 6** – **8**.

The results from Wobiri (**Figure 6**) show the nest fans within 1 km of the monitoring site had a moderate spread angle and were highly oriented seaward in a north westerly direction. They did not orient towards the peak sky glow over the antenna array in the east, nor the south easterly glow from the Exmouth and HEH base, and instead oriented towards the ocean (**Figure 6c**).

The results from Tamarisk (**Figure 7**) show the nest fans within 1 km of the monitoring site had a large spread angle but oriented seaward in an overall northerly direction. They did not orient towards the peak sky glow over the antenna array in the east, nor the southerly glow from the Exmouth and HEH base, and instead oriented towards the ocean (**Figure 7c**).

The results from Surf Beach (**Figure 8**) show the nest fans within 1 km of the monitoring site had the smallest spread angle compared to the other two sites (Wobiri and Tamarisk) and were highly oriented seaward in a westerly direction. They did not orient towards the peak sky glow over the antenna array in the east, and instead oriented towards the ocean (**Figure 8c**).

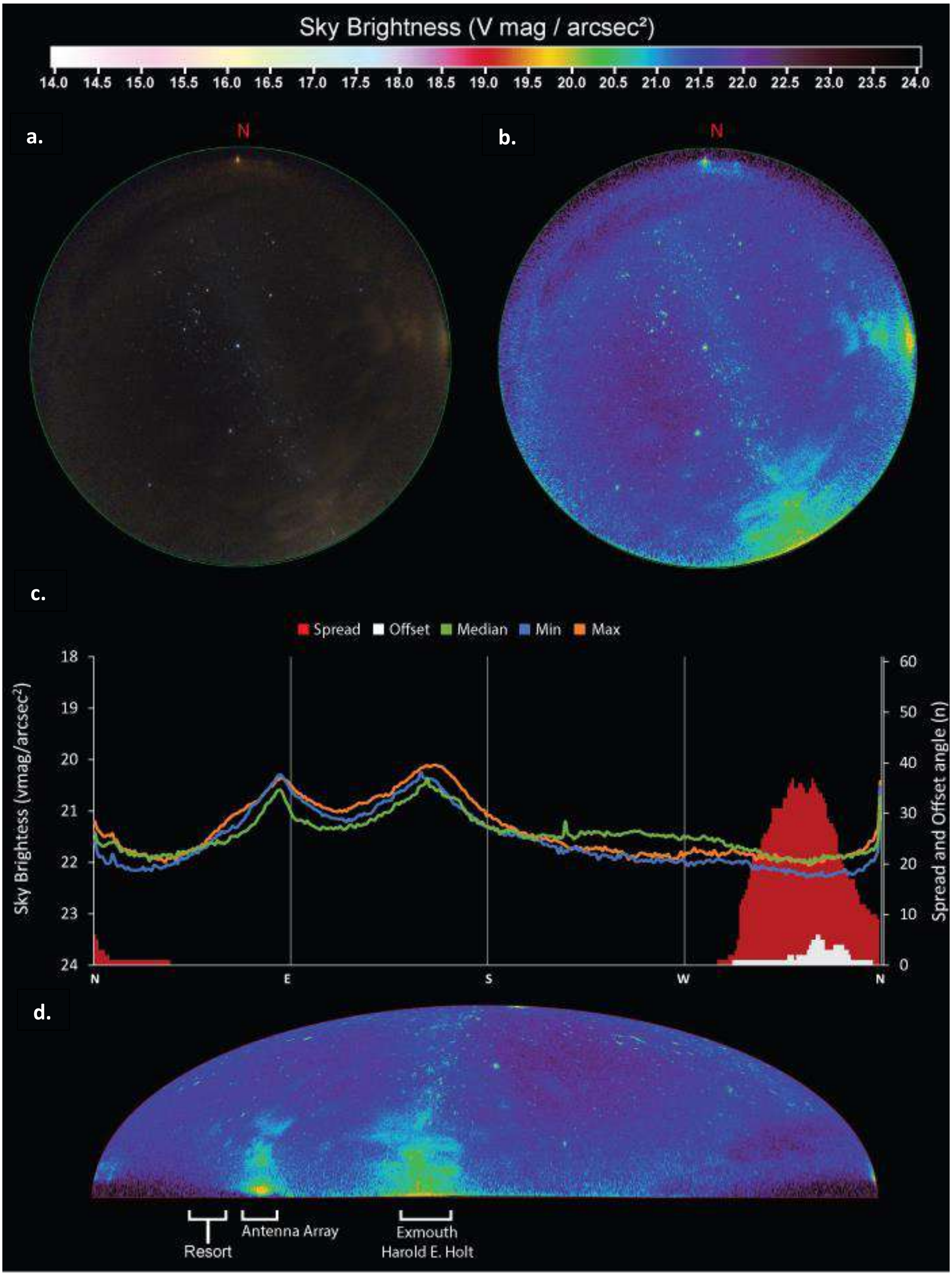


Figure 6: Artificial light and hatchling orientation monitoring results from Wobiri: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources. Sky42 image captured on 15th February 2021.

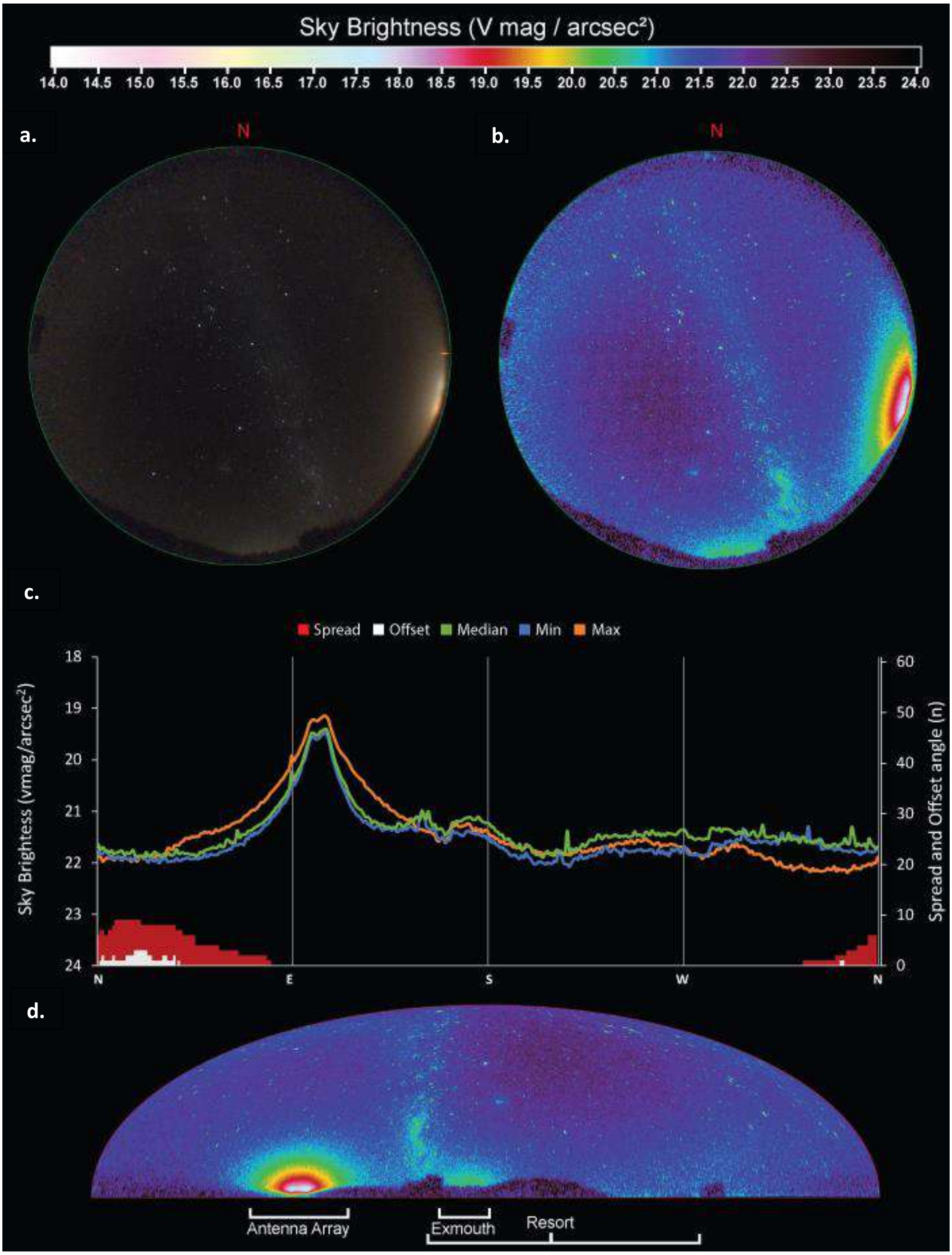


Figure 7: Artificial light and hatchling orientation monitoring results from Tamarisk: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources. Sky42 image captured on 12th February 2021.

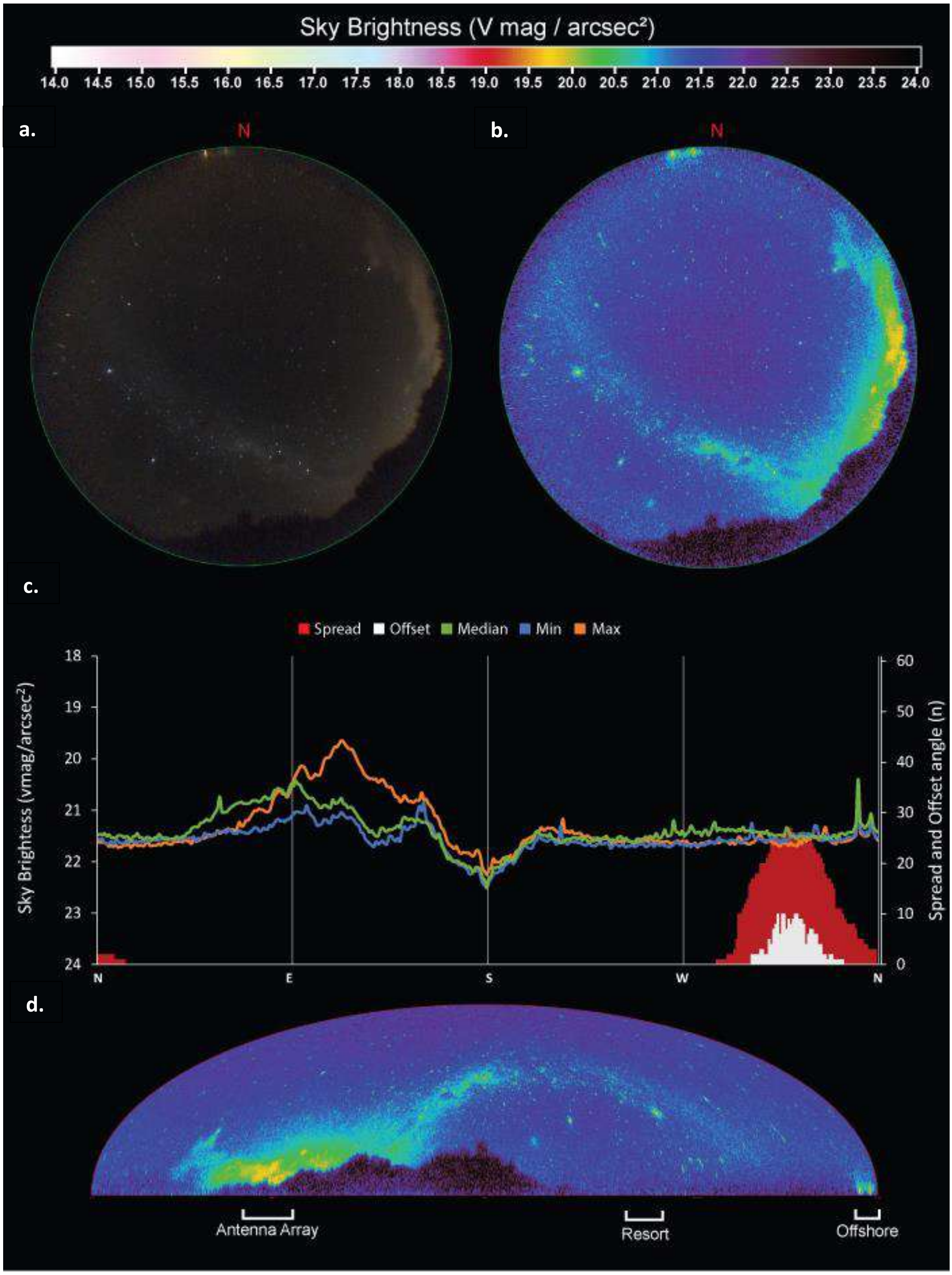


Figure 8: Artificial light and hatchling orientation monitoring results from Surf Beach: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources. Sky42 image captured on 14th February 2021.

3.3 Predation

Evidence of nest/hatchling predation observed during the survey (**Figures 9** and **10**) included:

- Dog/dingo;
- Varanid lizard;
- Silver gull; and
- Ghost crab.

The level of ghost crab activity and predation activity on the Ningaloo Beaches was markedly greater than what has been observed on rookeries in the Pilbara or Kimberley. Predation behavior was inferred from; placement of crab holes over nests, the scale of beach coverage with crab tracks, and patterns of crab tracks mixed with hatchling tracks and drag marks around crab holes. This was observed on all beaches surveyed and is assumed to be the prime source of predation of hatchlings on these beaches.

On day one of the survey, evidence of human digging into seven nests was recorded north of Surf Beach.

Figure 9: Crab predation of nests and hatchlings (left and centre), ghost crab (right).

Figure 10: Dog/dingo tracks, unaccompanied by human footprints.

4 DISCUSSION

4.1 Artificial Light Monitoring

The existing light sources located on or near the North West Cape include the Naval Communications Station Harold E Holt (HEH) base, the HEH antenna array, the VLF antenna, the town of Exmouth, and two offshore Floating Production Storage and Offloading facilities.

The antenna array sits on a 400 hectare site supporting twelve 300 – 380 m tall antenna towers. The HEH base facilities are located on a ~50 hectares site situated 8 km south of the antenna field and both are illuminated at night by security lighting. The town of Exmouth also covers over 400 hectares and is illuminated by street, commercial, and residential lighting. To the north of the northern tip of Cape Range are oil and gas floating production storage and offloading (FPSO) facilities comprising a large floating oil and gas processing facility and flare stack which are permanently illuminated for worker safety. During normal operations a pilot flame maintains the flare which burns the produced gas that is diverted to the flare during commissioning, unplanned events, emergencies and planned maintenance.

The results of the benchmark light monitoring survey found light from the current naval and urban sources was visible from the SST and on all monitored regional turtle nesting beaches between Wobiri on the Ningaloo coast and Mildura Wreck East at the northern most tip of the North West Cape. The visibility of the individual light sources varied depending on shielding by topography (i.e. dunes or the Cape Range), cloud cover, and gas flow rates in the offshore flares. Regionally, the antenna array was the most visible, detected in images from every monitored site. With the exception of one monitoring site (Surf Beach), Exmouth and the HEH base were also visible from all locations thought it is likely the visibility would increase when cloud cover is present. The two FPSO facilities are located over the curve of the horizon and so the visibility of them varied with flaring rates and the presence of cloud overhead at the FPSO site. They were also visible from most beach monitoring sites, including the SST and from the elevated monitoring sites at the project site (Villas) and the Vlamingh Head Lighthouse.

The location of the project site relative to the SST means that any light from the project will introduce sky glow into a region of the SST monitoring horizon that is currently dark.

The sky quality was relatively consistent across the monitoring sites and all of sky brightness was representative of a rural sky, defined as "*light pollution evident on the horizon and clouds illuminated near the horizon while it is dark overhead*" (Bortle 2001). The amplifying effect of clouds on sky glow was evident at the SST on 16th February 2021 where the whole of sky brightness was 21.26 Vmag/arcsec^2 under a clear sky which increased substantially to 20.53 Vmag/arcsec^2 when clouds reflected the light from Exmouth, HEH, and the antenna array across the entire landscape (**Figure 5**).

4.2 Hatchling Orientation

Three species were recorded during the fan monitoring survey, green (76%), hawksbill or loggerhead (8%) and unknown (15%). Species was assigned by experienced biologists based on track size and gait, visible shell fragments, live hatchings emerging and nest placement. No nests were dug to confirm species.

The small range in fan spread and offset results indicate that hatchlings navigated to the ocean successfully from most of the monitored beach sections. Exceptions were for nests emerging inside a dune blowout, where the lack of a strong horizon cue (due to the absence of a dune) resulted in a broader scattering of the hatchling tracks. This, together with the long distances traversed by the hatchlings, often prevented the identification of the emergence point at which nest fan metrics are collected. Consequently, data from dune blowout areas could not be reliably collected.

The metrics of nest fans recorded on beach sections characterized by high density nest craters were also less directed due to the effect of the craters on hatchling navigation i.e. crawling hatchlings constantly fall into holes and have to crawl out again before being able to reorient seaward resulting in a much less directed seaward crawl than observed flat beaches with less cratering. This, together with the effects of a very small sample size, was likely the cause for the largest mean fan spread angle that was recorded on the beach section immediately in front to the project location (Hunters to Lighthouse Bay Parking; **Figure 1**). This area is also characterized by large dune blow out habitat which prevented reliable collection of fan metrics.

The comparison of fan metrics between nesting habitat with no line-of-sight to the project location (Ningaloo Coast West), and nesting habitat with potential for direct line-of-sight and or greater exposure to project related light glow (Hunters to Lighthouse Bay Parking and Surf Beach South to Mildura Wreck) found fan spread was not significantly different between the two areas, however there was a significant difference in fan offset. The difference in fan offset was likely due to the effects of a higher density of nest craters across large sections of Ningaloo Coast West beach influencing the directedness of the hatchling orientation from the ocean.

Regionally, hatchlings were successful in sea finding despite the wide-spread visibility of existing light sources including Exmouth, the HEH base, and antenna array situated onshore, and the oil and gas facilities situated offshore.

4.3 Conclusion

All monitoring activities were successfully completed during the survey and met the objectives of benchmark light and hatchling fan monitoring as outlined by the preliminary Artificial Light Management Plan.

Existing regional light sources, including Exmouth, the Harold E Holt naval base, antenna array, and VLF antenna situated onshore, and two FPSO facilities situated offshore are visible from all nesting beaches and from the SST. No light is visible from the decommissioned Lighthouse Campground on the project site.

Sea finding by turtle hatchlings emerging from regional nesting beaches was consistent across the monitored beaches with most hatchling fans successfully orienting seaward and appeared unaffected by the current levels of visible regional sky glow.

The sky quality at the SST was representative of a rural sky under clear conditions (21.26 Vmag/arcsec^2) however this quality was reduced to a rural/suburban transition when clouds were present (20.53 Vmag/arcsec^2).

5 REFERENCES

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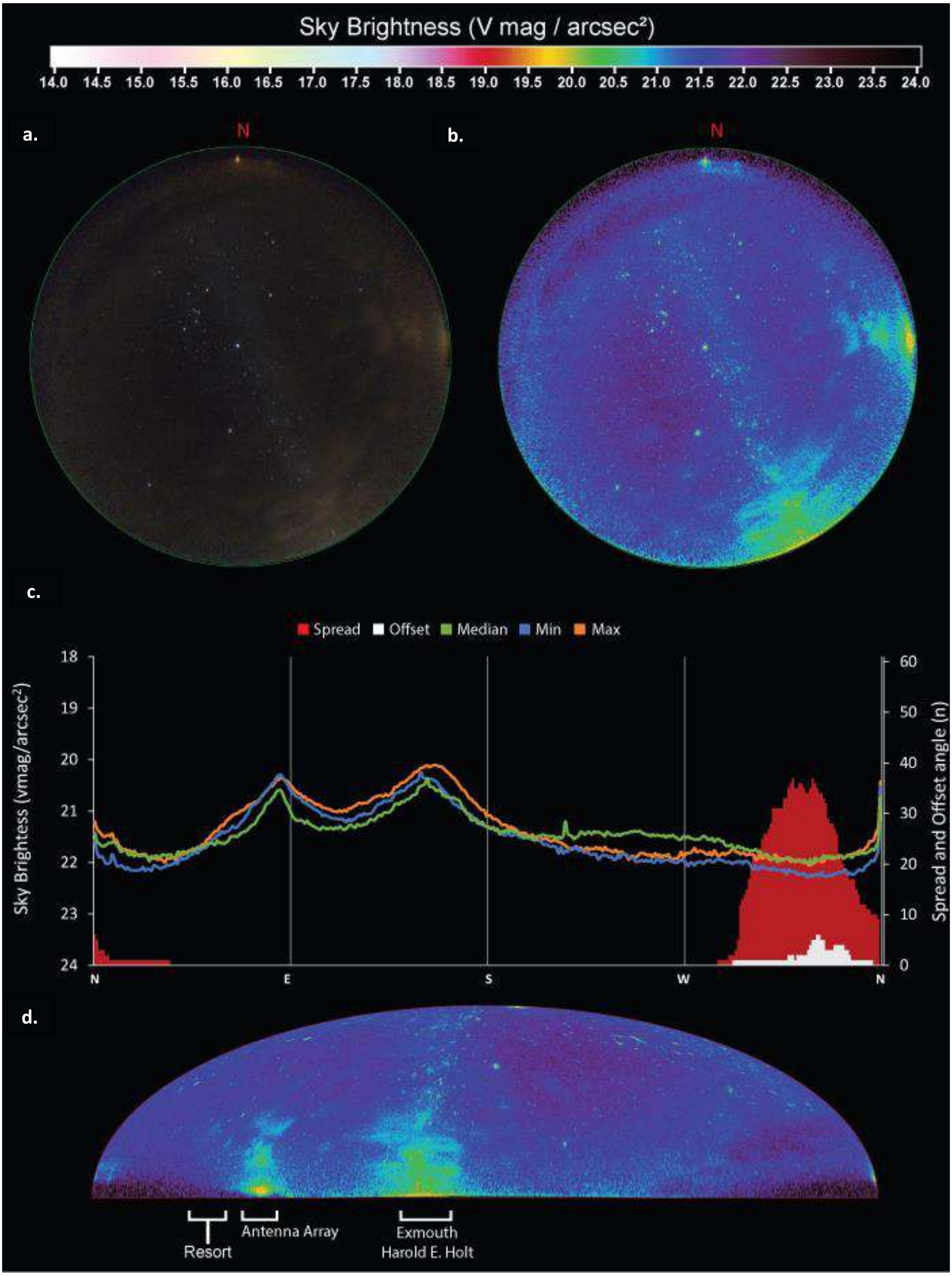
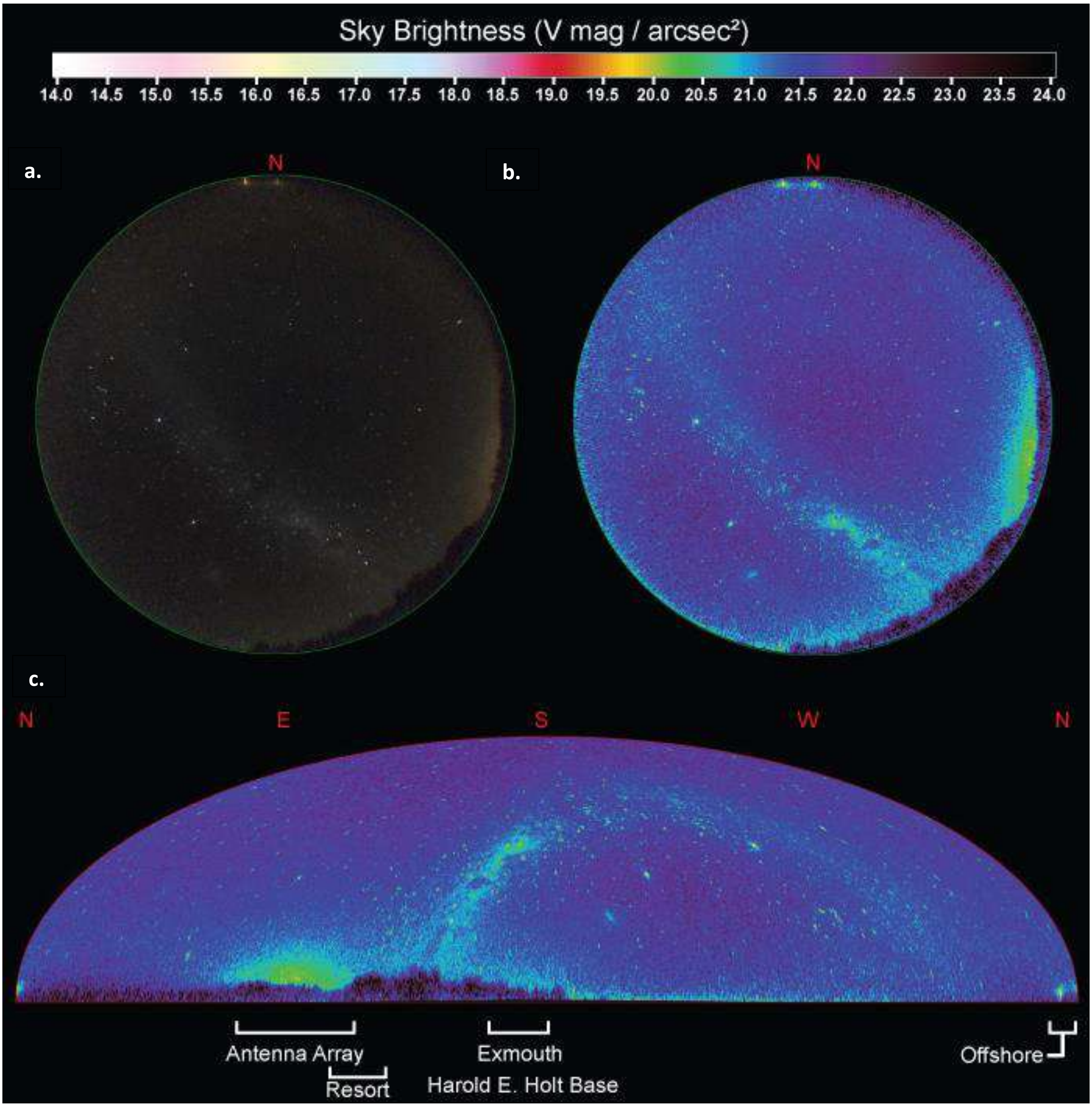
DOD (2014) Australian Government Department of Defence, Space Surveillance Telescope Facilities, Statement to Evidence to the Parliamentary Standing Committee on Public Works.

PENV (2020) Preliminary Artificial Light Management Plan, unpublished report by Pendoley Environmental Pty Ltd to Northwest Resorts Pty Ltd, 23 Dec 2020.

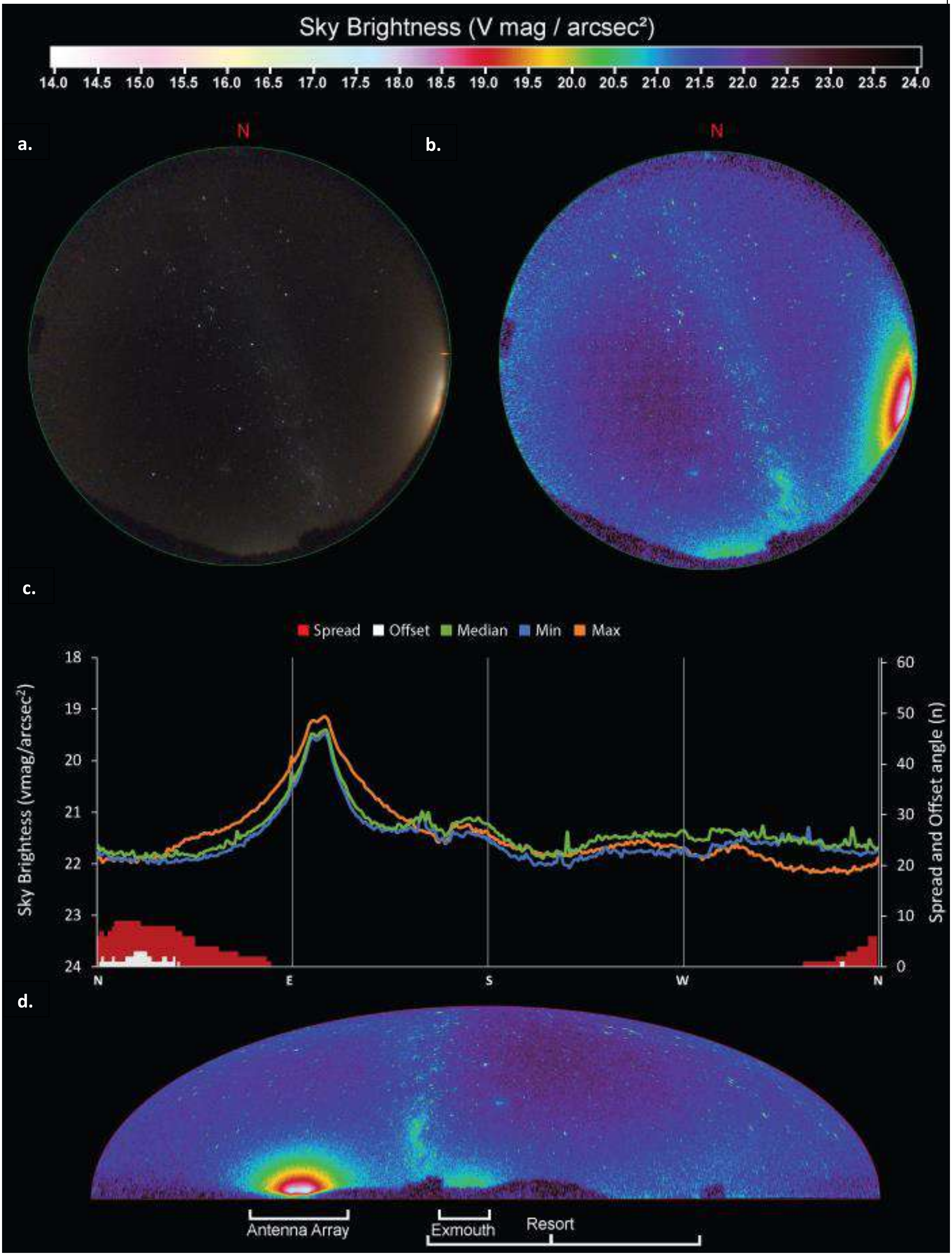
Appendix A: Complete set of Sky42 images from all monitoring sites



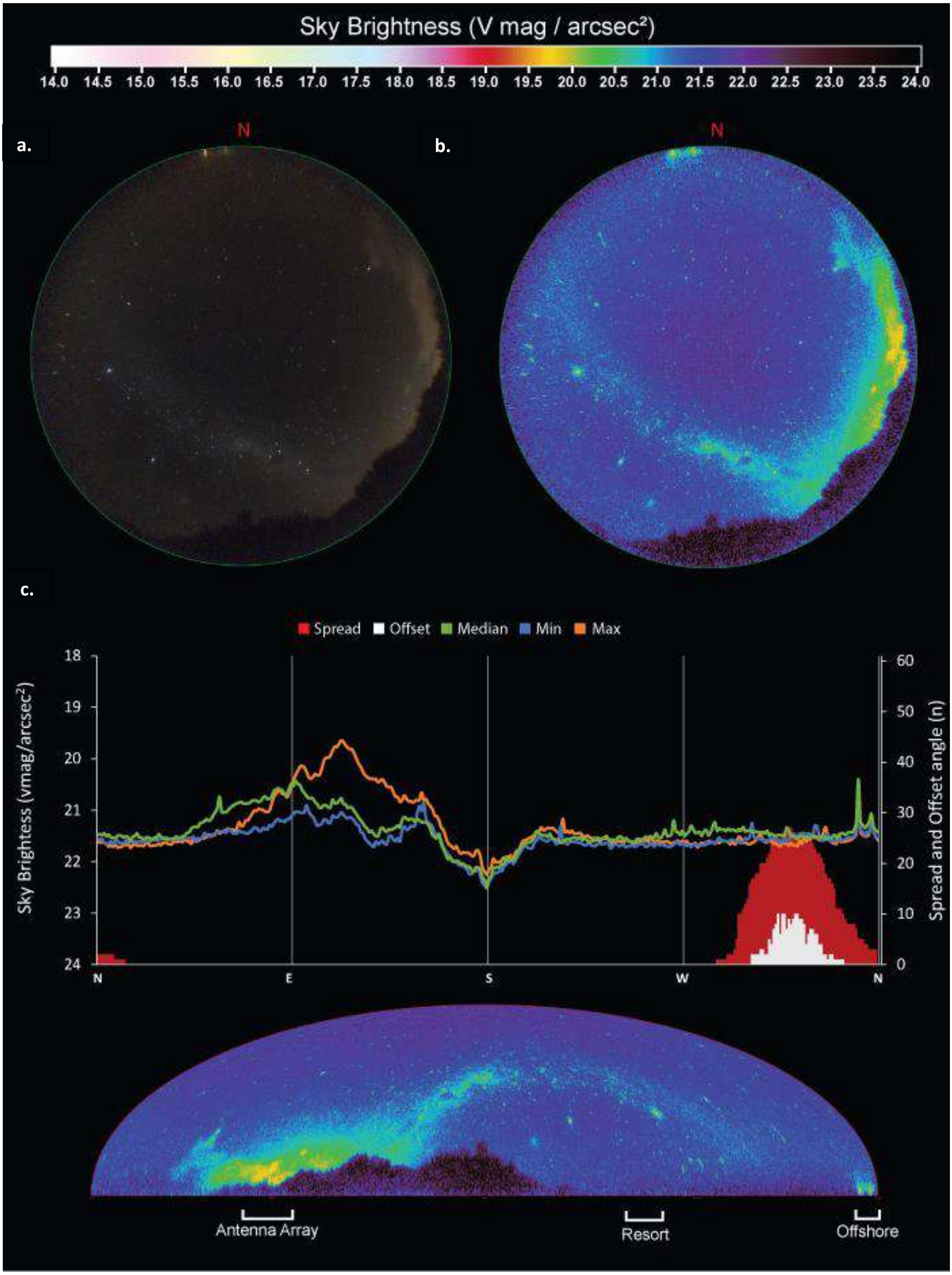
A1: Artificial light monitoring results from Wobiri on 15th February 2021: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



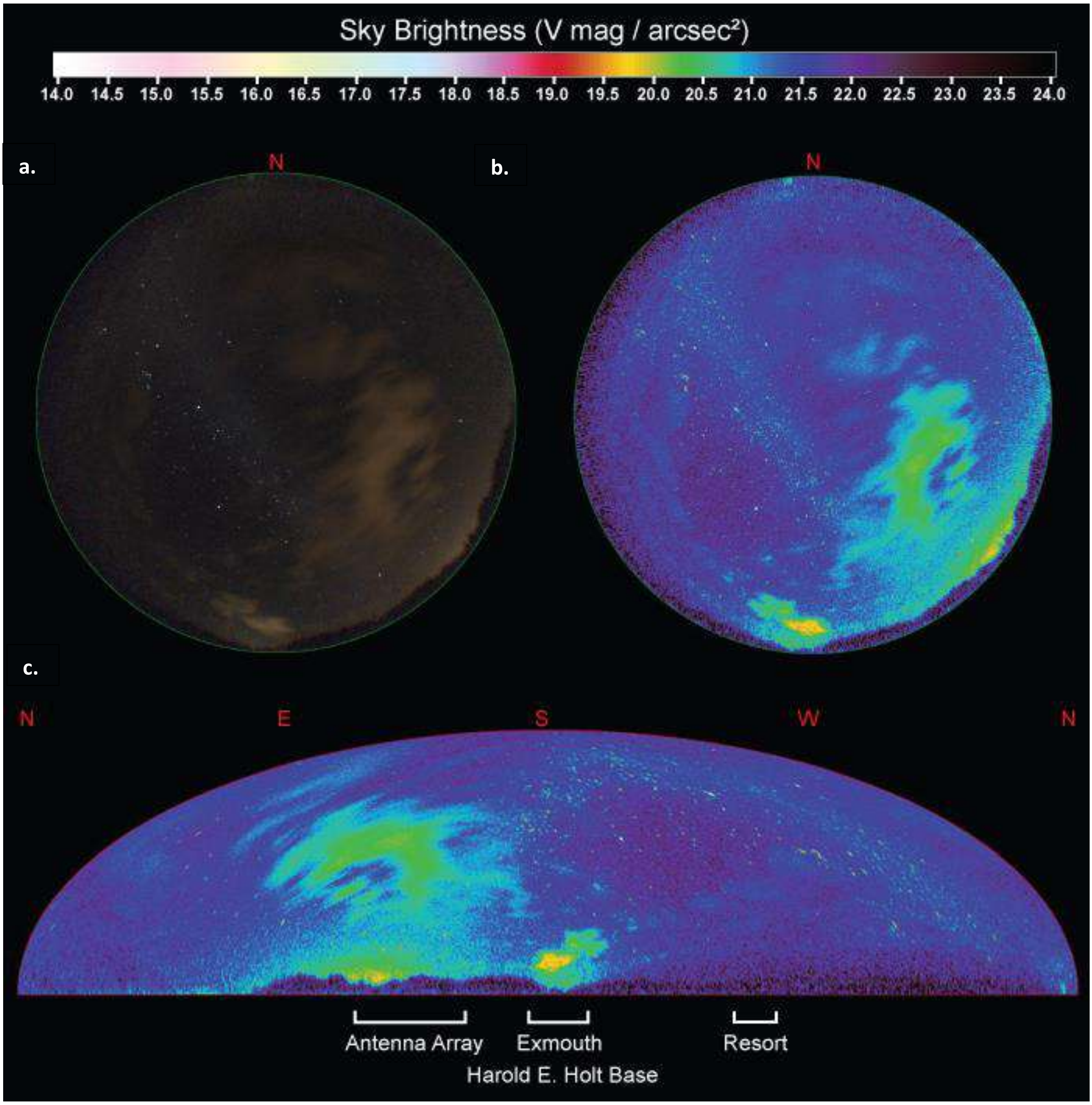
A2: Artificial light monitoring results from Hunters on 14th February 2021: a. Median raw image; b. Median isophote map c. Equirectangular panorama of the circular isophote map showing location of visible light sources.



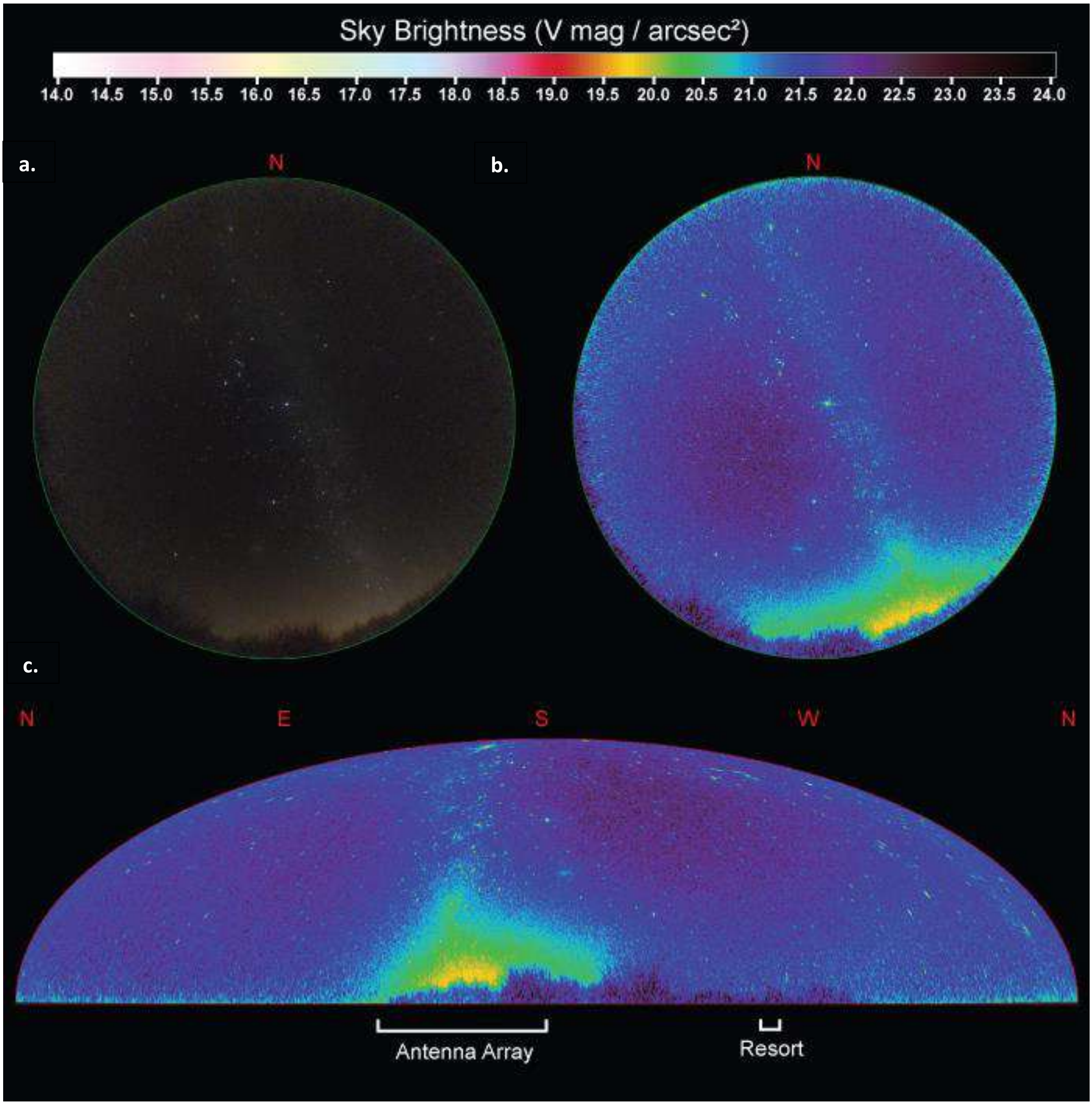
A3: Artificial light monitoring results from Tamarisk on 12th February 2021: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



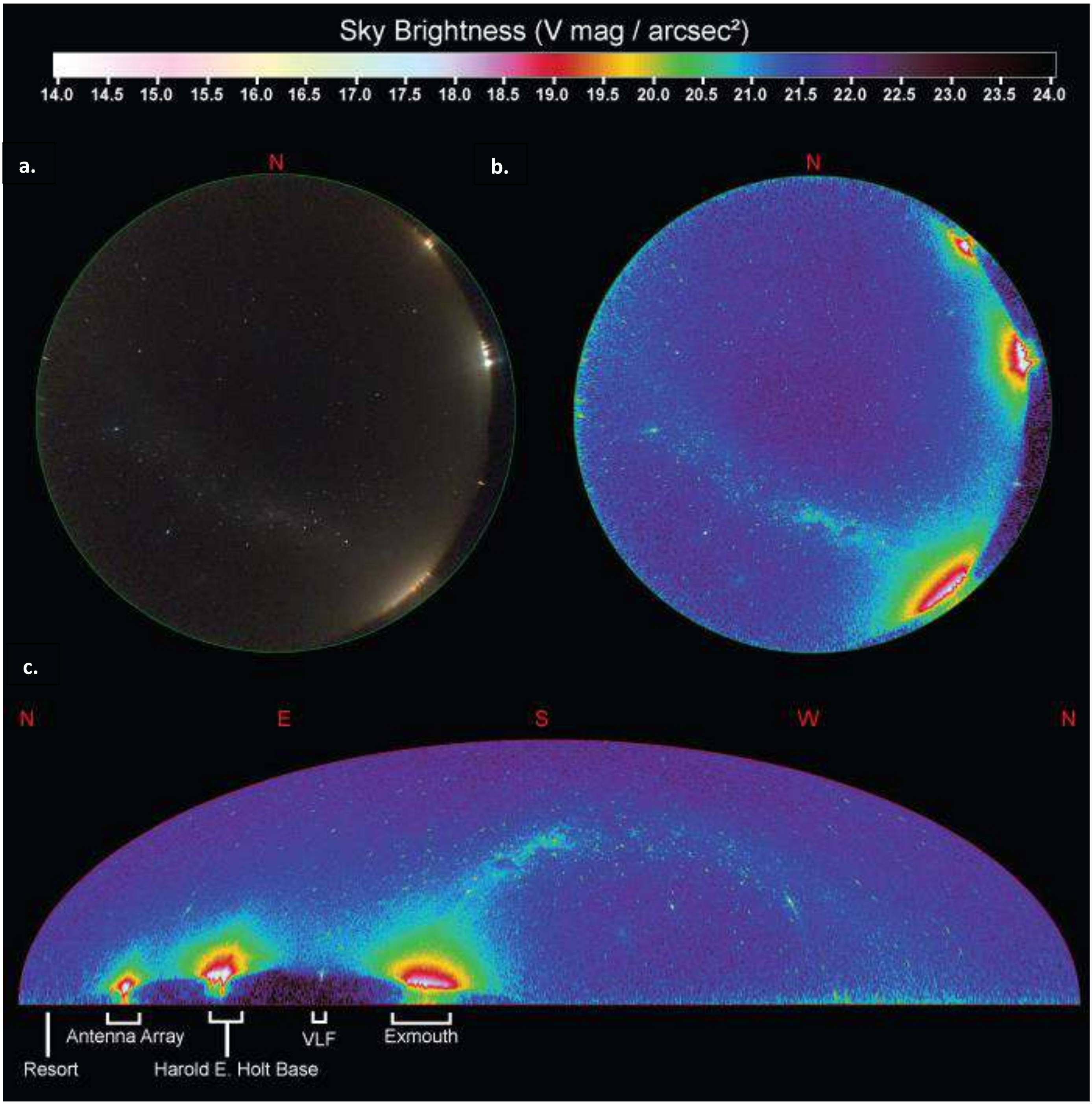
A4: Artificial light monitoring results from Surf on 14th February 2021: a. Median raw image; b. Median false-colour map; c. Light bearing graph showing median (green line), minimum (blue line) and maximum (orange line) sky brightness and associated hatchling bearing frequency for spread (red bars) and offset (white bars); d. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



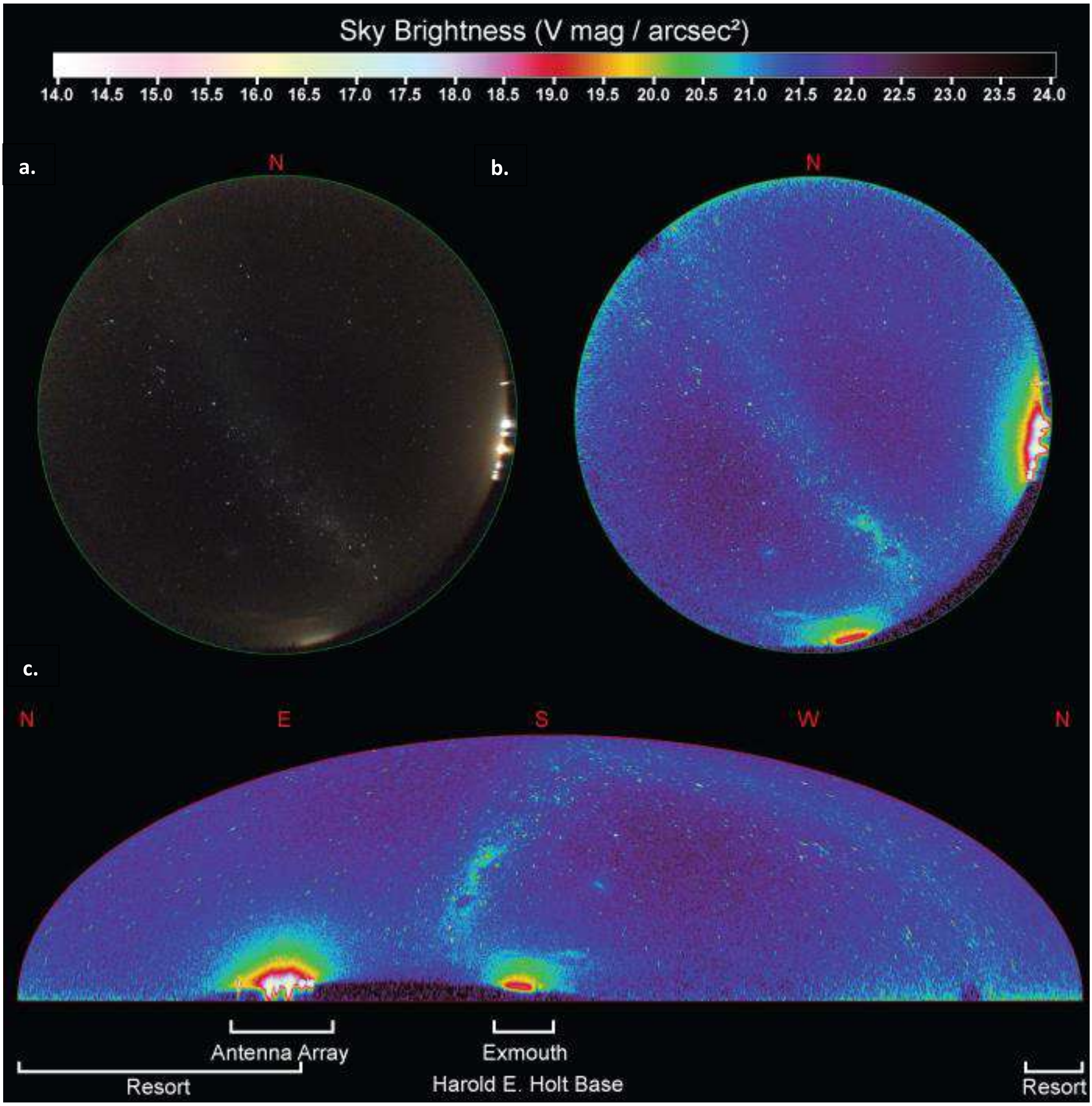
A5: Artificial light monitoring results from Surf North on 11th February 2021: a. Median raw image; b. Median false-colour map; c. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



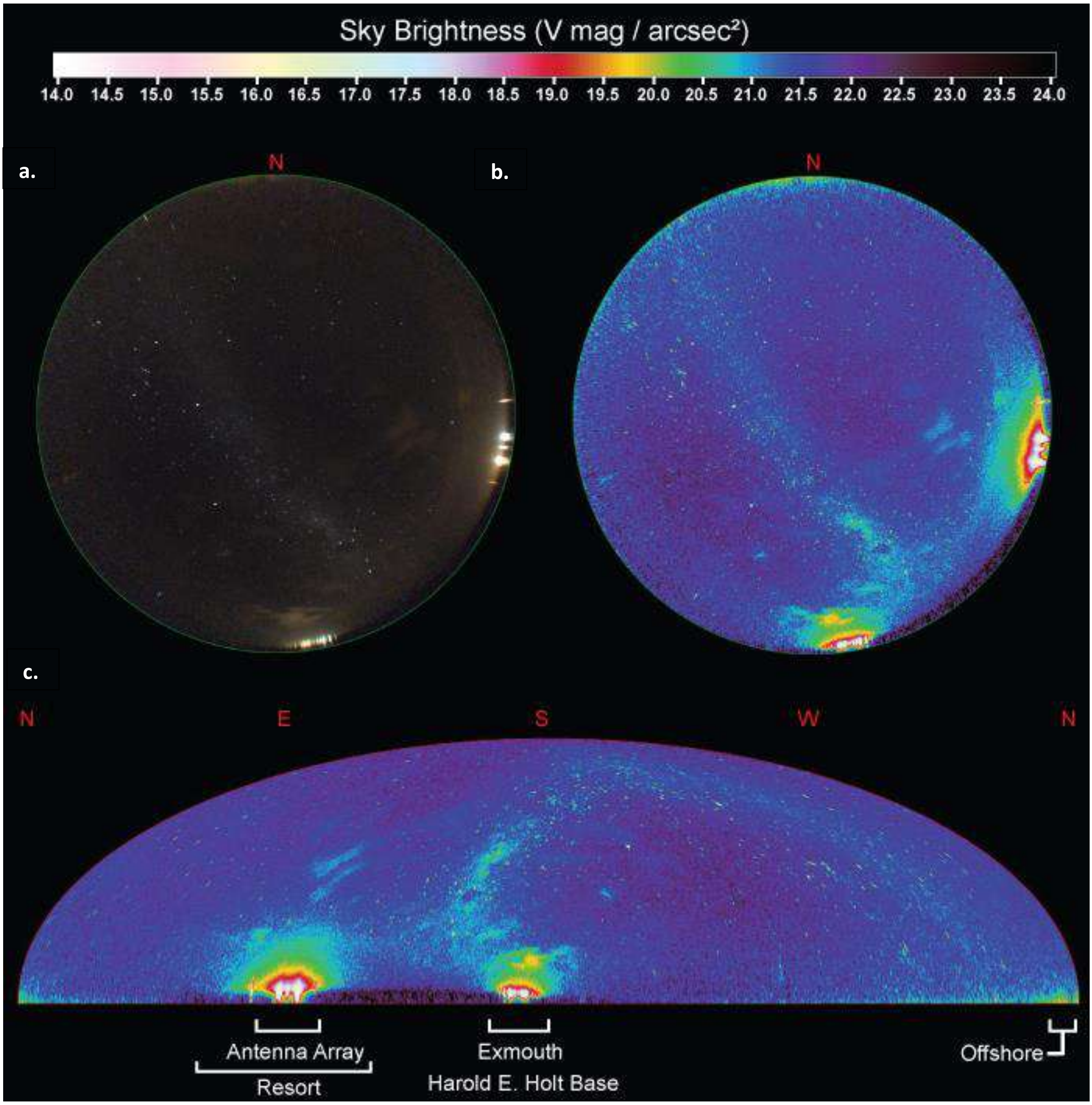
A6: Artificial light monitoring results from Mildura East on 13th February 2021: a. Median raw image; b. Median false-colour map; c. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



A7: Artificial light monitoring results from SST on 16th February 2021: a. Median raw image; b. Median false-colour map; c. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



A8: Artificial light monitoring results from the Project Site (Villas) on 17th February 2021: a. Median raw image; b. Median false-colour map; c. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.



A9: Artificial light monitoring results from Vlamingh Head Lighthouse on 17th February 2021: a. Median raw image; b. Median false-colour map; c. Hammer-aitoff projection of the circular false-colour map showing location of visible light sources.

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