

PROPOSED BROWSE TO NORTH WEST SHELF PROJECT

Turtle Management Plan

Revision 5, July 2025

TABLE OF CONTENTS

EXECUTIVE SUMMARY	9
1. CONTEXT, SCOPE AND RATIONALE	10
1.1 Proposed Browse Project Background.....	10
1.2 Purpose of Plan	10
1.3 Project Overview.....	11
1.3.1 Project Area.....	11
1.3.2 Key Characteristics.....	11
1.3.3 Project Activities	11
1.4 Key Environmental Factors and Matters of National Environmental Significance	15
1.5 Condition Requirements	15
1.6 Rationale and approach.....	15
1.6.1 Environmental outcome or management objective/s.....	15
1.6.2 Survey and study findings.....	15
1.6.3 Uncertainties and assumptions	15
1.6.4 Objective-based EMP	16
1.6.5 Rationale for choice of indicators and/or management actions	16
2. DESCRIPTION OF THE PROTECTED MATTER	17
2.1 Green Turtle	17
2.1.1 Stock Identification and Genetic Exchange	17
2.1.2 Habitat Critical to the Survival of a Species.....	17
2.1.3 Biologically Important Areas.....	19
2.1.4 Life Cycle and Seasonality.....	19
2.1.5 Resilience of Sandy Islet as a Nesting Habitat	20
2.1.6 Internesting Movements and Habitats.....	20
2.1.7 Migratory Movements from Scott Reef.....	23
2.1.8 Knowledge Gaps for the G-ScBr Stock	23
2.1.8.1 Population Size and Inter-seasonal Fluctuations	23
2.1.8.2 Sandy Islet Hatchling Numbers	24
2.1.8.3 Relative Importance of Sandy Islet to the G-ScBr Stock.....	24
2.1.8.4 Migratory Movements.....	24
2.1.8.5 Extent of Illegal Harvest.....	25
2.1.8.6 Key Threats and Priority Actions for the G-ScBr Stock.....	25
2.2 Sensitivity of Marine Turtles to Artificial Light	25
2.2.1 Hatchling Orientation	26
3. ASPECTS RELEVANT TO THIS PLAN.....	28
3.1 Light Emissions.....	28
3.1.1 Source of Aspect	28
3.1.2 Light Modelling.....	29
3.1.2.1 Methodology.....	29

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

3.1.2.2	Description of Model Outputs	29
3.1.2.3	Model Assumptions & Inputs	30
3.1.2.4	Model Scenarios	33
3.1.2.5	Impact Criteria	34
3.1.3	Light Modelling Results	36
3.1.3.1	FPSO	36
3.1.3.2	MODU	37
3.1.3.3	Commissioning flaring (Torosa FPSO)	38
3.1.3.4	Construction & Support vessels	39
3.1.3.5	Cumulative Scenarios	39
3.1.4	Impact Assessment	40
3.2	Seabed Subsidence	46
3.2.1	Source of Aspect	46
3.2.2	Seabed Subsidence Modelling	46
3.2.3	Impact Assessment	47
3.3	Vessel Strike	50
3.3.1	Source of Aspect	50
3.3.2	Impact Assessment	50
4.	MANAGEMENT OBJECTIVES, APPROACH AND PERFORMANCE STANDARDS	51
4.1	Environment Performance Objectives	51
4.2	Management Approach	51
4.3	Performance Standards	52
4.4	Key Management Actions	53
5.	SCIENTIFIC MONITORING & PERFORMANCE VERIFICATION	60
5.1	Green Turtle Monitoring Program	60
5.1.1	Key Objectives	60
5.1.2	Key Components	61
5.2	Anthropogenic Light Monitoring	64
5.3	Seabed Subsidence Monitoring	64
5.3.1	Subsidence Monitoring Program;	65
5.4	Sandy Islet Morphology Monitoring	65
6.	ADAPTIVE MANAGEMENT	66
6.1	Changes in Green Turtle Biologically Important Behaviours	66
6.1.1	Triggers and monitoring	66
6.1.2	Management response	66
6.2	Received Light Measurements	67
6.2.1	Triggers and monitoring	67
6.2.2	Management response	67
6.3	Sandy Islet Habitat Remediation Plan	67
6.3.1	Triggers and monitoring	67

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

6.3.2 Management response 68

7. REPORTING 73

8. PLAN REVIEW..... 73

9. REFERENCES 74

Appendix A Woodside Browse Light Modelling Report (Pendoley Environment 2022) 78

Appendix B Browse Project: Green Turtle and Artificial Light Monitoring Plan Overview . 79

Appendix C Subsidence Monitoring Program..... 80

Appendix D Historic Sediment Texture and Composition at Sandy Islet..... 85

Appendix E Effects of Beach Nourishment on Sea Turtle Nesting and Reproductive Success 92

LIST OF TABLES

Table 1-1 Key Environmental Factors and Matters of National Environmental Significance	15
Table 1-2 Uncertainties in relation to potential impacts on marine turtles as a result of the proposed Browse Project.....	15
Table 2-1 Seasonality for green turtle nesting activities at Sandy Islet	19
Table 3-1 Sources of light emissions.....	28
Table 3-2 Flaring scenarios used for light impact assessment modelling	31
Table 3-3 Summary of historic cloud cover data from the Broome region (2017 - 2021).	32
Table 3-4 Typical cloud coverage in the Broome region (days as % of month) based on five years of historic observations.	32
Table 3-5 Number of days per year (italics) on which combination of flaring and cloud cover used in light modelling scenarios are expected to occur.....	33
Table 3-6 Summary of the modelled scenarios, the vessel inventory and cloud parameters	33
Table 3-7 Proxy artificial light impact criteria for marine turtles, referred to as FME within this plan.	34
Table 3-8 Orientation Field of View (FOV) values for each scenario (FME) and the corresponding Impact Level for the impact potential to marine turtles	36
Table 3-9 Summary of modelling results showing OFOV (FME) and impact level (in brackets) for each operational scenario permutation.	37
Table 3-10 Estimated duration (days per year) at which each given impact level will occur during operation of the Torosa FPSO only.....	37
Table 3-11 Summary of modelled and interpolated results showing OFOV (FME) and impact level (in brackets) for MODU operational scenarios during different cloud conditions.....	37
Table 3-12 Estimated duration (days per year) at which each given impact level will occur during operation of MODU within the Torosa field (prior to Torosa FPSO operations commencing).	38
Table 3-13 Summary of modelling results showing OFOV (FME) and impact level (in brackets) for each operational scenario permutation. Scenarios which increased an impact level are underlined,	39
Table 3-14 Estimated duration (days per year) at which each given impact level will occur during operation of MODU within the Torosa field simultaneously with Torosa FPSO operations. Change to FPSO only (Table 3-10) is shown in brackets.....	40
Table 3-15 Summary key findings for potential impacts to green turtles at Scott Reef across life stages and lighting impact levels.....	40
Table 3-16 Impact Level 1 – Continuous Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.....	41
Table 3-17 Impact Level 1 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.....	42
Table 3-18 Impact Level 2 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.....	43
Table 3-19 Impact Level 3 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.....	44
Table 3-20 Summary of subsidence predictions from 3D subsidence modelling (SLB, 2024)	46
Table 3-21 Predicted subsidence at Sandy Islet reference locations (reference/mid case) throughout project life (SLB, 2024).....	47
Table 4-1 Performance standards.....	52
Table 4-2 Mitigation and management measures applicable to anthropogenic light from proposed Browse Project construction (temporary) activities	55
Table 4-3 Mitigation and management measures applicable to anthropogenic light from long term activities to achieve environment performance outcomes	56
Table 4-4 Mitigation and management measures applicable to vessel strike from proposed Browse Project vessel activities (including MODU and Construction Vessels)	58

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Table 4-5 Mitigation and management measures relevant to reservoir subsidence during Torosa production 59
Table 5-1 The purpose and rationale of each element of the turtle baseline monitoring program. . 61
Table 6-1 Pre-identified Sandy Islet habitat remediation strategies 70
Table 7-1 Summary of reporting..... 73

List of Figures

Figure 1-1 Proposed Browse Development Area and notional field layout	13
Figure 1-2 Proposed Browse Trunkline (BTL) route	14
Figure 2-1 Habitat Critical to the Survival of green turtles at Scott Reef considering revisions to the proposal since referral in 2018	18
Figure 2-2 Areas of particular importance as known internesting areas for green turtles at Sandy Islet, as identified by Guinea (2009)	22
Figure 3-1 Example all-sky modelled image from an observer location showing predicted brightness	30
Figure 3-2 Location of the Sandy Islet observer viewpoint and facilities considered in the modelling (Torosa FPSO and the MODU at TRA and TRD drill centres) (Pendoley Environmental, 2021b)..	35
Figure 3-3 Light modelling results for full moon equivalent (FME) received at Sandy Islet under different flaring rates from Torosa FPSO.....	39
Figure 3-4 Comparison of Sandy Islet size and shape about the high-water mark at four intervals between November 1974 and May 2019 (1974, 2006, 2015 and 2019)	49
Figure 4-1 Location of proposed TRD drill centre relative to Habitat Critical to the Survival of Green Turtles internesting buffer, defined as 20km around Sandy Islet	54
Figure 6-1 Overview of Sandy Islet Habitat Remediation Plan Concept	68
<i>Figure 1-1 - Example CORS that would be representative of that required for the subsidence monitoring program. Equipment would be mounted to a single pole. (Source – Unavco).....</i>	<i>81</i>

LIST OF ABBREVIATIONS & ACRONYMS

Acronym	Meaning
2C	Contingent resources
2TL	Second trunkline
ALMP	Artificial Lighting Management Plan
BC Act	Biodiversity Conservation Act.
BJV	Browse Joint Venture
BTL	Browse Trunkline
DAWE	Department of Agriculture, Water and Environment
EP	Environment Plan
EPA	Environmental Protection Authority
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
EP Act	<i>Western Australia Environmental Protection Act 1986</i>
EQMP	Environmental Quality Management Plan
FOV	Field of View
FPSO	Floating Production Storage and Offloading
FME	Full Moon Equivalent
G-AR	Ashmore Reef green turtle genetic stock
G-ScBr	Green turtle Scott Reef-Browse Island genetic stock
IMMR	Inspection, maintenance, monitoring and repair activities
LOS	Line of sight
MMscfd	Million standard cubic feet per day
MODU	Mobile offshore drilling units
NRC	North Rankin Complex
NWS	North West Shelf
NWSJV	NWS Joint Venture
NWMR	North-west Marine Region
SRTM	Shuttle Radar Topography Mission
SQM	Sky Quality Meter
SURF	Subsea umbilicals, risers and flowlines
TCF	Trillion cubic feet
TMP	Turtle Management Plan
WA	Western Australia

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

EXECUTIVE SUMMARY

Proposal name	Proposed Browse Project
Proponent name	Woodside Energy Ltd
Ministerial Statement No.	TBC
Purpose of the EMP	Provide a Turtle Management Plan that outlines how impacts to marine turtles will be managed to meet the project objectives.
Key environmental factor/s, outcome/s and/or objectives	<p>Relevant key environment factors are:</p> <ul style="list-style-type: none"> • Marine Fauna <p>Relevant matters of environmental significance are:</p> <ul style="list-style-type: none"> • Listed threatened fauna and ecological communities • Listed migratory species <p>The environmental objectives that are relevant to the marine turtles are:</p> <ul style="list-style-type: none"> • Objective 29 - Undertake the Browse Project in a manner that will not disrupt migration, breeding, nesting, internesting and hatchling dispersal of the green turtle population at Scott Reef. • Objective 30 - Undertake the Browse Project in a manner that will not displace the green turtle population from habitat critical to the survival of the species at Scott Reef. • Objective 36 - Undertake the Browse Project in a manner that will not result in impacts to habitat critical to the survival of green turtles that would otherwise result in green turtle critical behaviour (migration, breeding, nesting, internesting and hatchling dispersal) being disrupted.
Condition clauses	TBC
Key components in the EMP (if applicable)	<p>The structure of the Turtle Management Plan is:</p> <ul style="list-style-type: none"> • Project background and overview (Section 1) • Description of the protected matter and receiving environment (Section 2) • Relevant aspects of the proposal that may interact with the protected matter (Section 3) • A detailed overview of the management objectives, approach and performance standards (Section 4) • The scientific monitoring program to inform the adaptive management framework and surveys to verify compliance (Section 5) • An overview of the adaptive management approach (Section 6) • Reporting requirements (Section 7) • Plan review requirements (Section 8).
Proposed construction date	Mid 2020s
EMP required pre-construction?	Yes X No <input type="checkbox"/>

1. CONTEXT, SCOPE AND RATIONALE

1.1 Proposed Browse Project Background

The Browse hydrocarbon resource is located in the Brecknock, Calliance, and Torosa reservoirs, approximately 425 km north of Broome and approximately 290 km off the Kimberley coastline of Western Australia (WA). These three fields will be collectively referred to as the Browse hydrocarbon resources. Hydrocarbon resources contained in these fields are predominately gas, with contingent resources (2C, 100%) of 13.9 trillion cubic feet (tcf) of dry gas, and approximately 390 million barrels of condensate (Woodside resource estimate).

Woodside Energy Ltd (Woodside) is Operator for and on behalf of the Browse Joint Venture (BJV). The participants in the BJV are:

- Woodside Browse Pty Ltd
- BP Developments Australia Pty Ltd (BP)
- Japan Australia LNG (MIMI Browse) Pty Ltd (MIMI)
- PetroChina International Investment (Australia) Pty Ltd (PetroChina).

The BJV proposes to develop the Browse hydrocarbon resources using two 1100 million standard cubic feet per day (MMscfd) (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. The FPSO facilities will be supplied by a subsea production system and will transport gas to existing North West Shelf (NWS) Project infrastructure via a pipeline which will tie in near the existing North Rankin Complex (NRC) in Commonwealth waters (Note: The NRC is owned by the NWS Joint Venture (NWSJV)¹).

Subject to market conditions, all necessary regulatory approvals, joint venture approvals and commercial agreements, execution of the proposed Browse Project would be targeted to commence mid-2020s with activity expected for up to 44 years.

1.2 Purpose of Plan

The purpose of this Plan is to present a management approach that will be used to manage the interactions between the proposed Browse to NWS project (Browse) with marine turtles and their habitat, Sandy Islet and the 20km surrounding interinteresting buffer designated as habitat critical survival to the Scott Reef- Browse (G-ScBr) green turtle population.

This management approach outlined herein outlines environment performance outcomes that were established within the project EIS/ERD and sets management objectives and measurement criteria to achieve these outcomes. Key aspects of the proposal governed by this plan included artificial lighting and seabed subsidence as well as vessel strikes and underwater noise.

The management and mitigation measures defined in this plan have been identified during the underlying impact assessment process and will be implemented to meet the requirements of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), Western Australia *Environmental Protection Act 1986* (EP Act) and other relevant legislation and regulations.

Other aspects of the Browse project that may interact with turtles are planned or unplanned discharges to the marine environment. The management approach for planned marine discharges are defined within the Browse Environmental Quality Management Plan (EQMP). Aspects of the Browse project that can be managed in accordance with standard industry practice or established

¹ The NWSJV comprises six companies: Woodside Energy Ltd. (Operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The NWS Joint Venture owns the infrastructure used as part of the North West Shelf Project.

regulations (e.g. MARPOL requirements for vessel discharges) will be defined as part of activity specific Environment Plans (EPs) that are required to be prepared and approved in accordance with State and Commonwealth legislation prior to activity commencement.

1.3 Project Overview

1.3.1 Project Area

The overall Project Area for the proposed Browse Project comprises:

- the proposed Browse Development Area (in which the Brecknock, Calliance, and Torosa fields, the FPSO facilities and the subsea production systems, including wells, will be located) (**Figure 1-1**)
- the pipeline corridor within which the proposed Browse Trunkline (BTL) and inter-field spur line will be located (**Figure 1-2**).

1.3.2 Key Characteristics

The proposed Browse Project will comprise subsea infrastructure and two FPSO facilities, connected to existing NWS Project infrastructure via the ~900 km BTL.

The key characteristics of the proposed Browse Project are described below:

- hydrocarbon extraction will require up to 50 wells with associated subsea infrastructure, including manifolds and flowlines
- extracted hydrocarbons will be transferred via subsea infrastructure, including wellheads, manifolds and flowlines, up to the FPSO facilities, which are located in Commonwealth waters
- condensate stabilisation and storage will occur on the FPSO facilities prior to offtake to condensate tankers for delivery to market
- gas processing will also occur on the FPSO facilities prior to export via the inter-field spur line and BTL to existing NWS Project infrastructure.

The BTL will tie into the existing second trunkline (2TL) near NRC with transmission of the gas from the tie-in point and onshore processing of the gas to be undertaken using existing NWS Project infrastructure.

1.3.3 Project Activities

Activities associated with the proposed Browse Project include:

- piling for mooring the FPSO facilities, securing the export riser bases and potentially for mooring the MODUs. Suction piling is the most likely option for pile installation, however, depending on the seabed substrate, alternate piling methods such as drilling and cementing or impact piling may be selected
- development drilling and completions for the development of up to 50 production wells
- installation and commissioning of the subsea umbilicals, risers and flowlines (SURF)
- installation and commissioning of the BTL and inter-field spur line
- installation, hook up and commissioning of the FPSO facilities
- operations including hydrocarbon extraction, gas processing and export and condensate offloading
- inspection, maintenance, monitoring and repair activities (IMMR) to ensure the integrity of the infrastructure and identify any problems before they present a risk of loss of containment

- support activities including logistics support, project vessels and helicopters
- decommissioning in accordance with good oilfield practice and relevant legislation and practice at the time.

A detailed description of the activities associated with the proposed Browse Project is provided in Section 3.7 of the draft EIS/ERD.

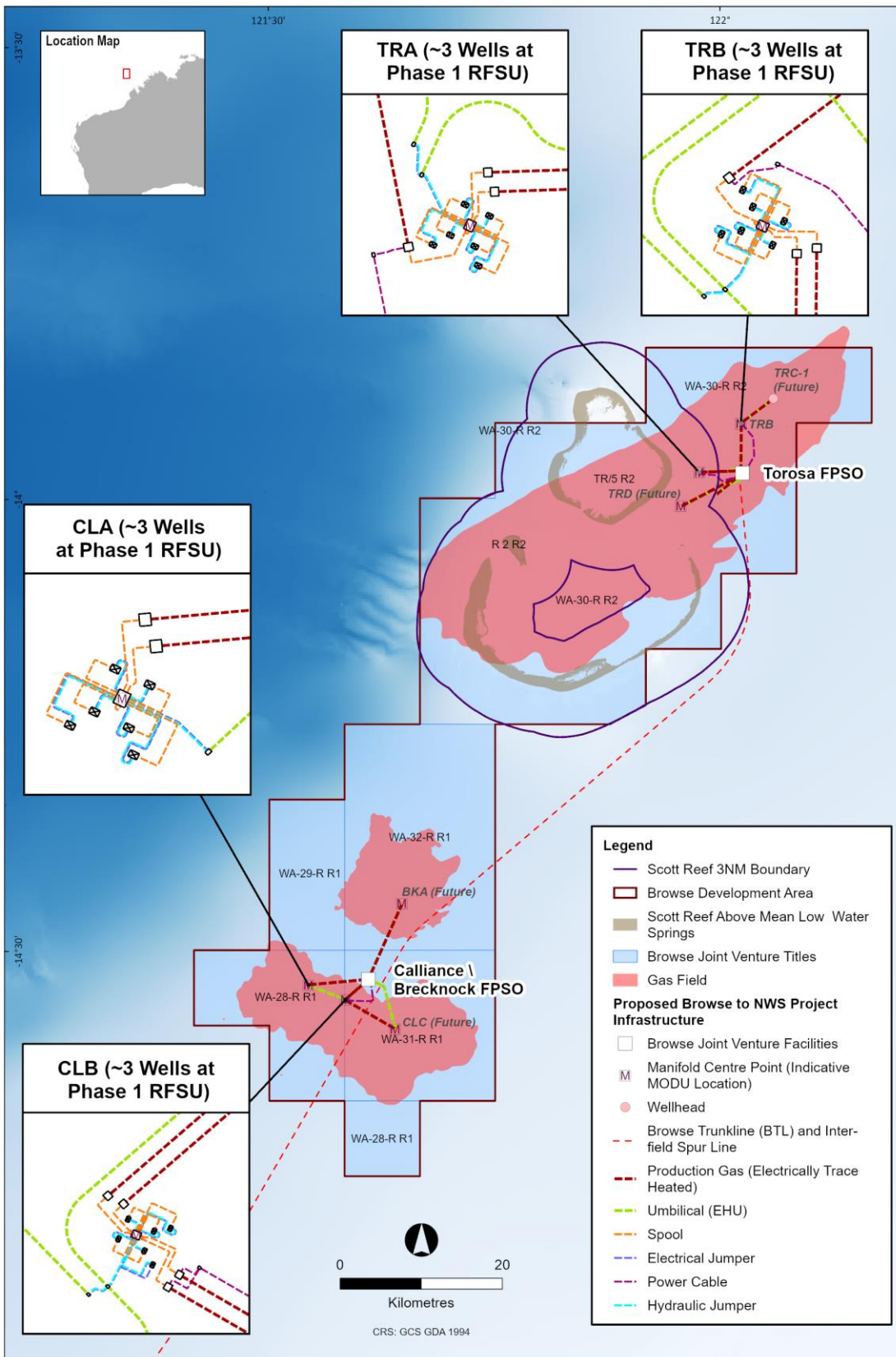


Figure 1-1 Proposed Browse Development Area and notional field layout

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

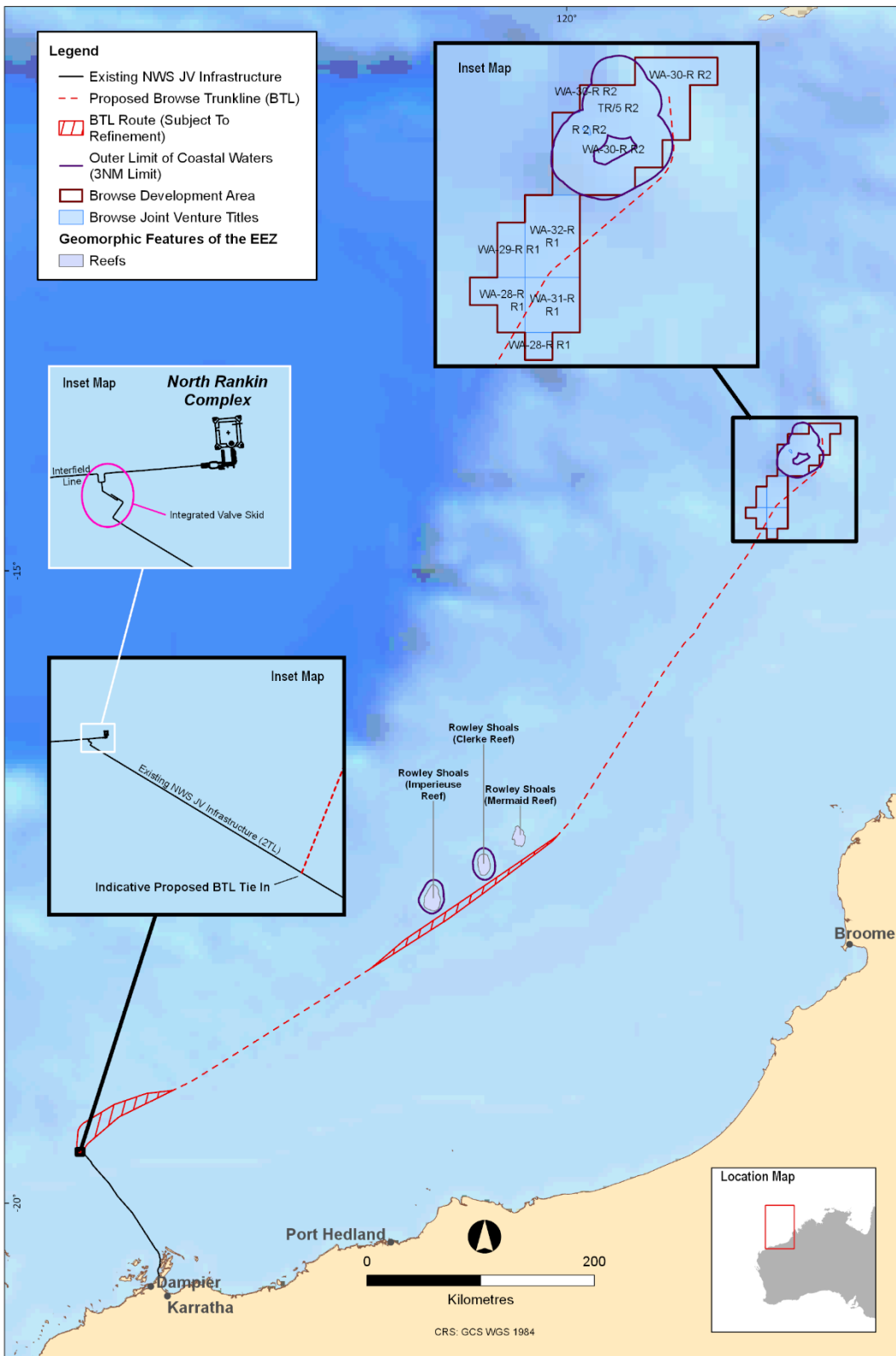


Figure 1-2 Proposed Browse Trunkline (BTL) route

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

1.4 Key Environmental Factors and Matters of National Environmental Significance

Table 1-1 outlines the Key Environmental Factors and Matters of National Environmental Significance and the relevant impacts and risks.

Table 1-1 Key Environmental Factors and Matters of National Environmental Significance

Key Environmental Factors and Matters of National Environmental Significance	EPA Factor	Existing environment	Summary of impacts and risks
Marine fauna (Environmental factor)	<ul style="list-style-type: none"> Protect marine fauna so biological diversity and ecological integrity are maintained. 	Refer to Section 2 for a detailed overview of the existing environment as it relates to green turtles.	<ul style="list-style-type: none"> Light emissions (Section 3.1) Seabed subsidence (Section 3.2) Vessel strike (Section 3.3)
EPBC Act listed threatened species	<ul style="list-style-type: none"> Not applicable 		
EPBC Act listed migratory species	<ul style="list-style-type: none"> Not applicable 		

1.5 Condition Requirements

Condition requirements will be added in a future revision of this plan post State and Commonwealth approval.

1.6 Rationale and approach

1.6.1 Environmental outcome or management objective/s

Environmental management objectives and details of the monitoring and management approach will demonstrate compliance with the management objectives is outlined in **Section 4**.

1.6.2 Survey and study findings

An overview of the available information in relation to green turtles at Scott Reef and within the project area is provided in **Section 2**. An overview of further baseline studies that will be undertaken prior to the commencement of activities that may impact green turtles at Scott Reef is provided in **Section 5**.

1.6.3 Uncertainties and assumptions

Light emissions and seabed subsidence were the two aspects identified by the Department of Agriculture, Water and the Environment (DAWE) (now Department of Climate Change, Energy, the Environment and Water (DCCEEW)) and the WA Environmental Protection Authority (EPA) as presenting a higher level of uncertainty, both with respect to the magnitude of the aspect and the resultant impact on marine turtles (summarised in Table 1-2).

Table 1-2 Uncertainties in relation to potential impacts on marine turtles as a result of the proposed Browse Project

Aspect	Uncertainty
Light emissions	<ul style="list-style-type: none"> • The magnitude and nature of the light emissions (e.g., intensity, brightness) during construction as the specific mobile offshore drilling units (MODU) to be used have not been identified. • The magnitude and nature of the light emissions (e.g. intensity, brightness) during operations due to the early stage design of the FPSO facilities. • Light levels that will be received at Sandy Islet and surrounding waters given: <ul style="list-style-type: none"> – The uncertainty in the magnitude and nature of the light emissions from the MODU and FPSO facilities. – The cumulative effect of light emissions from the MODU and FPSO facilities. – Inherent uncertainties in the light modelling undertaken as part of the impact and risk assessment. • The magnitude and nature of the potential impacts to marine turtles utilising Sandy Islet and surround waters as a result of light emissions, noting that responses are likely to be population, location, life-stage and seasonal dependent.
Seabed subsidence	<ul style="list-style-type: none"> • The magnitude of seabed subsidence at Sandy Islet given the inherent uncertainties in the subsidence modelling undertaken as part of the impact and risk assessment (even considering the bound of maximum uncertainty, subsidence is not considered to present a credible threat of significant impacts to critical habitat, as described in Section 3.2.2). • The effect of seabed subsidence on Sandy Islet given natural processes such as erosion and accretion. • The magnitude and nature of the potential impacts to marine turtles utilising Sandy Islet.

1.6.4 Objective-based EMP

Woodside has objective based approach for the management of potential impacts and risks to marine turtles for the proposed Browse Project. This approach is seen as appropriate as there are clear and achievable objectives that will result an acceptable environmental outcome.

1.6.5 Rationale for choice of indicators and/or management actions

The rational for the choice of management actions and indicators of impacts is provided in **Section 4**.

2. DESCRIPTION OF THE PROTECTED MATTER

Six species of marine turtle occur within Australian waters; the leatherback turtle (*Dermochelys coriacea*), loggerhead turtle (*Caretta caretta*), olive ridley turtle (*Lepidochelys olivacea*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*) and flatback turtle (*Natator depressus*). All six marine turtle species are known to occur within the North-west Marine Region (NWMR) and are protected under the EPBC Act and the Western Australian *Biodiversity Conservation Act 2016* (BC Act).

2.1 Green Turtle

2.1.1 Stock Identification and Genetic Exchange

The green turtle is distributed widely across northern Australia with a total of nine genetic stocks identified to date for this species (Commonwealth of Australia, 2017). There are three genetic stocks within the NWMR; the North West Shelf, Ashmore Reef, and Scott Reef-Browse Island genetic stocks. Dispersal of these genetic stocks occurs over a large area in waters north and east of the northern WA coastline (Department of the Environment and Energy, 2017). The North West Shelf genetic stock comprises multiple nesting rookeries within close proximity, whilst the Ashmore Reef and Scott Reef-Browse Island genetic stocks are comparatively genetically isolated with fewer nesting rookeries. The green turtle Scott Reef-Browse Island genetic stock (herein after referred to as 'G-ScBr') is a discrete unit known to nest at only two locations within the north-east Indian Ocean—Sandy Islet and Browse Island (Commonwealth of Australia, 2017). Only Sandy Islet falls within the Browse Development Area. As identified in the Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia, 2017) there is a lack of data regarding the status of the G-ScBr stock, and the current population trend is unknown. This stock is considered likely to be restricted in its capacity to expand into other nesting areas in the event that availability or quality of nesting habitat is reduced. The G-ScBr stock is vulnerable to a range of threats to all life stages, and its resilience to cope with increasing pressures is likely to be limited by its restricted population gene pool and low number of nesting locations.

Genetic mixing between rookeries is known to occur for green turtle stocks in WA, but the offshore rookeries in the Browse Basin (Ashmore Reef, Scott Reef and Browse Island) appear to form a discrete sub-group weakly isolated from coastal Kimberley rookeries despite their close proximity (Whiting *et al.*, 2018). These offshore rookeries are, in turn, weakly differentiated from each other—SNP (single nucleotide polymorphisms) analyses show low but significant genetic differentiation between the Sandy Islet and Browse Island rookeries (Whiting *et al.*, 2018), whereas mitochondrial DNA data group them together (Jensen, 2010). These rookeries are only ~190 km apart but it appears from the SNP data that there are some limits to gene flow between the two sites (although the sample size for Browse Island was low).

The findings of the Whiting *et al.* (2018) study confirmed previous findings that there is genetic exchange among green turtle rookeries along coastal parts of the Kimberley, but little exchange occurs among offshore atolls, or between offshore and coastal rookeries.

2.1.2 Habitat Critical to the Survival of a Species

In accordance with the *EPBC Act Significant Impact Guidelines 1.1 – Matters of National Environmental Significance* (Commonwealth of Australia, 2013), an action is deemed to have a significant impact if there is a real chance or possibility that it will adversely affect 'habitat critical to the survival of a species' (herein after referred to as 'habitat critical'). Habitat critical refers to areas that are necessary:

- for activities such as foraging, breeding or dispersal
- for the long-term maintenance of the species (including the maintenance of species essential to the survival of the species)

- to maintain genetic diversity and long-term evolutionary development
- for the reintroduction of populations or recovery of the species.

The Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia, 2017) designates habitat critical for the G-ScBr stock as the nesting locations of Sandy Islet and Browse Island, and an interesting buffer of 20 km radius around these rookeries, for the period November to March (refer Table 6 of the Recovery Plan). The habitat critical at Scott Reef (nesting location of Sandy Islet, and 20 km radius interesting buffer) is shown in **Figure 2-1**. The nesting location at Sandy Islet is described further in **Section 2.1.5**.

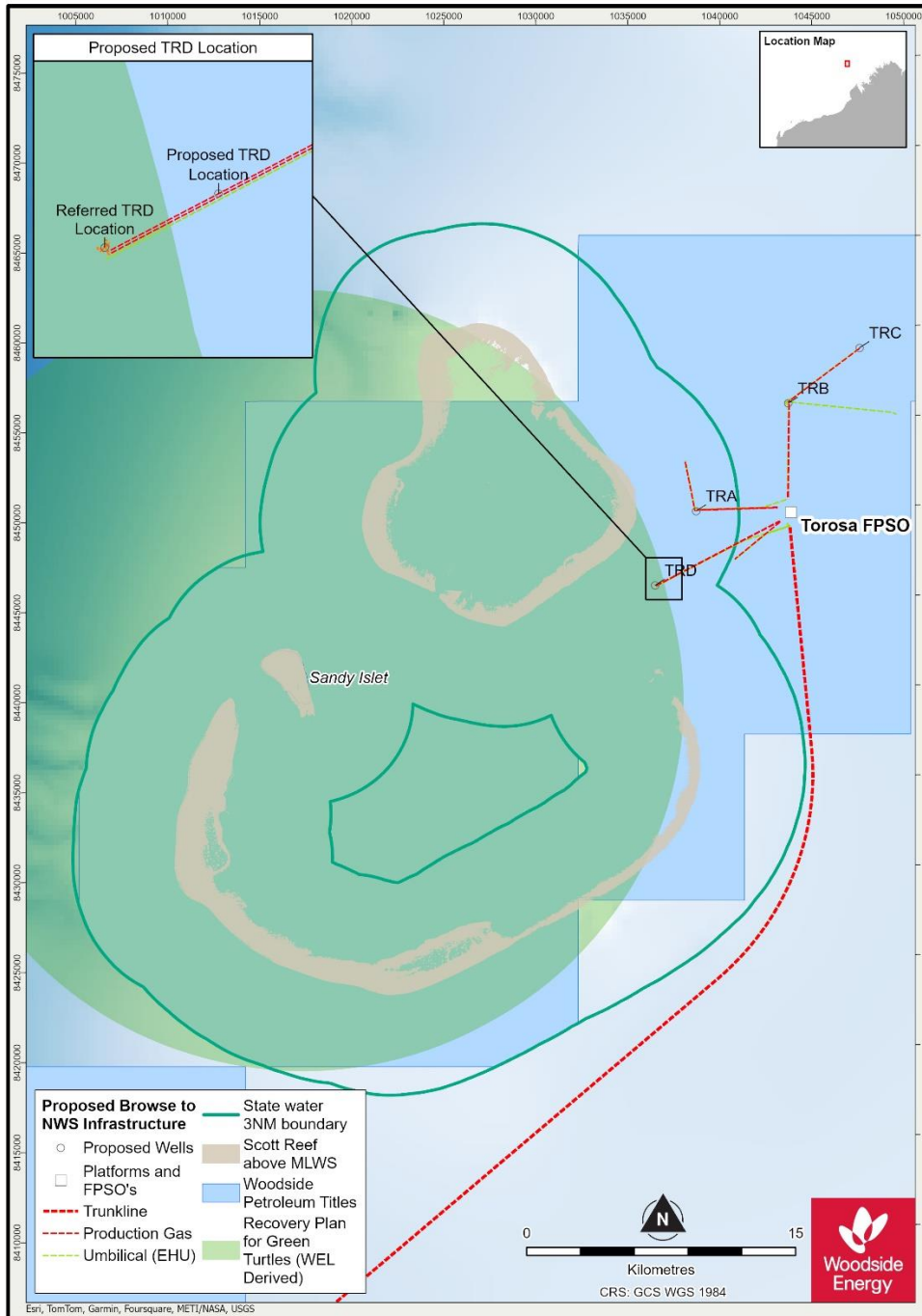


Figure 2-1 Habitat Critical to the Survival of green turtles at Scott Reef considering revisions to the proposal since referral in 2018

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

2.1.3 Biologically Important Areas

While not defined under the EPBC Act, biologically important areas (BIAs) are spatially delineated area where aggregations of individuals of a species are known to display biologically important behaviours such as breeding, foraging, resting or migration (Department of the Environment and Energy, 2019b). BIAs were developed simultaneously with the Marine Bioregional Plans to inform regulatory and management decisions and are not enforced by legislation (Department of the Environment and Energy, 2019b).

Within the Browse Development Area, Sandy Islet (a part of Scott Reef) and the surrounding waters around Scott Reef is a designated internesting BIA for green turtles (specifically the G-ScBr stock). There are a number of other nesting, internesting and foraging BIAs for green turtles within vicinity of the Project Area, including at Ashmore Reef, Cartier Island, Cassini Island and the Lacepede Islands (Commonwealth of Australia, 2017).

2.1.4 Life Cycle and Seasonality

All marine turtle species have complex life cycles involving active dispersal and several stages and periods of migration. For green turtles the life cycle begins with hatchlings moving from the nest above the high water mark to the beach and beyond to oceanic and coastal habitats, before returning 30 to 50 years later to the region of their birth to breed (Guinea, 2013). In the case of green turtles in the G-ScBr and Ashmore Reef green turtle genetic stock (G-AR), this life cycle may involve feeding and moving between reefs in the tropical Indian Ocean and northern Australia. During the breeding season green turtles from the G-ScBr and G-AR stocks congregate in October at their respective reefs where they mate (Whiting & Guinea, 2005; Guinea, 2013).

Seven surveys conducted at Scott Reef in 2006, 2008 and 2009 indicate that the summer months from late November to February are the preferred breeding season for green turtles at Sandy Islet (Guinea, 2009)—refer **Table 2-1**. While peak breeding occurred within this timeframe, 24% of green turtles tagged at Sandy Islet were first encountered during winter/spring surveys indicating that lower level nesting may occur year-round (Guinea, 2009), though to what extent is unknown.

Nesting activity reaches a peak in January and February with a peak in hatchling emergence approximately seven weeks later in March and April (Guinea, 2013)—refer **Table 2-1**. Also on the reef during the breeding season and throughout the year are the non-breeding sub-adult and adult turtles that forage and reside in the area. Genetic studies (Dethmers *et al.*, 2006) revealed that these belong to other green turtle stocks in Western Australia and the Indian Ocean.

Table 2-1 Seasonality for green turtle nesting activities at Sandy Islet

Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Nesting / internesting																
Hatchling emergence																
<i>Shoulder period</i>																
<i>Peak period</i>																

As described by Guinea (2013), within the generalised life cycle there are at least two cycles that involve breeding females in the green turtles in the G-ScBr stock using the reefs, lagoons and beaches (Sandy Islet) at Scott Reef:

- the female nesting cycle – every two to eight years when female green turtles migrate from their foraging grounds to Scott Reef to breed (re-migration interval)

- the internesting cycle – females spend two to three months within the vicinity of the nesting island moving only short distances of some tens of kilometres or less and nesting from three to six times during the nesting season, every eight to 16 days.

2.1.5 Resilience of Sandy Islet as a Nesting Habitat

It is apparent that Sandy Islet represents a spatially restricted nesting habitat—as described in Guinea (2010, 2011) green turtles were found to use the entire habitat of Sandy Islet for nesting, with seasonal variation recorded in the specific areas of the islet used for nesting, as well as in the shape of the sand habitat available for nesting. Disturbance of nests by subsequent nesting attempts of other females was common in the 2006 and 2009 surveys and was considered a main contributor to nest failure (Guinea, 2009). Disturbance was not as prevalent in the 2009/2010 season due to a lower density of nesting females (Guinea, 2010). Preference for nesting below the spring high water mark was observed in 2008/2009 (Guinea, 2009). These clutches are exposed to saltwater inundation which has been shown to increase mortality during incubation and potential result in complete failure of the clutch (Miller *et al.*, 2003).

The resilience of Sandy Islet as a rookery is potentially threatened by increasing sea temperatures and coral bleaching events, an increasing frequency of severe cyclone events, and the anticipated rise in sea level due to climate change.

2.1.6 Internesting Movements and Habitats

As detailed in Section 5.3.2.6.1 of the draft EIS/ERD, based on the movements of 11 satellite tagged females in the 2010 study (Guinea, 2010, 2011), the internesting cycle at Scott Reef in that one season appeared to have a maximum of five nesting events (i.e. the 11 individuals returned between one and four times), with an average internesting interval of 10 days. The females occupy an internesting habitat after each nesting event, primarily to rest and to develop the next clutch of eggs.

For green turtles these internesting habitats appear to be defined by their function rather than by location. At Scott Reef, the Guinea (2010) study showed that the satellite tagged turtles remained within 3 km of Sandy Islet during the internesting period, except for one individual which travelled into the South Scott Reef lagoon, 12 km south of Sandy Islet. The results of the 2010 study were consistent with the previous Pendoley (2005) satellite tagging of nesting green turtles at Sandy Islet, which indicated that individuals were not recorded farther than 14 km from Sandy Islet during the internesting period and most stayed within 5 km of Sandy Islet and in water depths of between 5 and 10 m.

Preferred internesting habitat at Scott Reef has been identified, from both satellite tagging studies and visual census, as the southern region of Sandy Islet, in waters over shallow sand (from 7 to 17 m; refer to Area A in **Figure 2-2**) and two areas of subtidal sandy substrate located to the south-west of Sandy Islet (Areas B and C in **Figure 2-2**). Internesting and other adult turtles preferred habitat comprising sandy substrates amongst coral blocks (Guinea, 2010), in relatively shallow water depths (<20 m). This is consistent with the findings of other studies of the internesting movements and behaviour of green turtles. The maximum depth that tagged green turtles at Ascension Island in the South Atlantic routinely reached during resting dives in the internesting period was between 18 and 20 m, with resting dives deeper than 20 m being extremely rare (Hays *et al.*, 2000).

Based on satellite tracking of eight green turtles at the Lacepede Islands, Waayers *et al.* (2011) found that that during internesting periods females generally remained within 10 km of their nesting beaches (average of ~7 km). The extent of these internesting movements away from nesting beaches are supported by data for green turtles tracked at island and mainland rookeries within the Ningaloo Marine Park and the Muiron Islands Marine Management Area. This study recorded longshore movements in the range 2-9 km (mean of 3.5 km) for island nesting beaches, a range of 4-13 km (mean of 7.0 km) for mainland beaches, and similar offshore movements (island mean = 1.3 km, range 1-3 km; mainland mean = 2.7 km, range 1-7 km) (Tucker *et al.*, 2020).

Male green turtles often aggregate close to nesting sites (1.2 to 8 km away) during October and November each year (Limpus, 1993). Both juvenile and mature male green turtles were observed in the internesting habitat around Sandy Islet during the 2010 survey (Guinea, 2010), indicating habitat use by other life stages.

Pendoley (2005) has also previously undertaken satellite tagging of nesting green turtles at Sandy Islet; four nesting females were tagged during the 2002/2003 and 2003/2004 nesting seasons. In keeping with the Guinea 2010 survey (Guinea 2010, 2011), individuals were not recorded farther than 14 km from Sandy Islet during the internesting period and most stayed within 5 km of Sandy Islet and in water depths of between 5 and 10 m. Furthermore, no tagged turtles swam off Scott Reef into waters deeper than 50 m, or into the channel between North and South Scott Reef (Pendoley 2005).

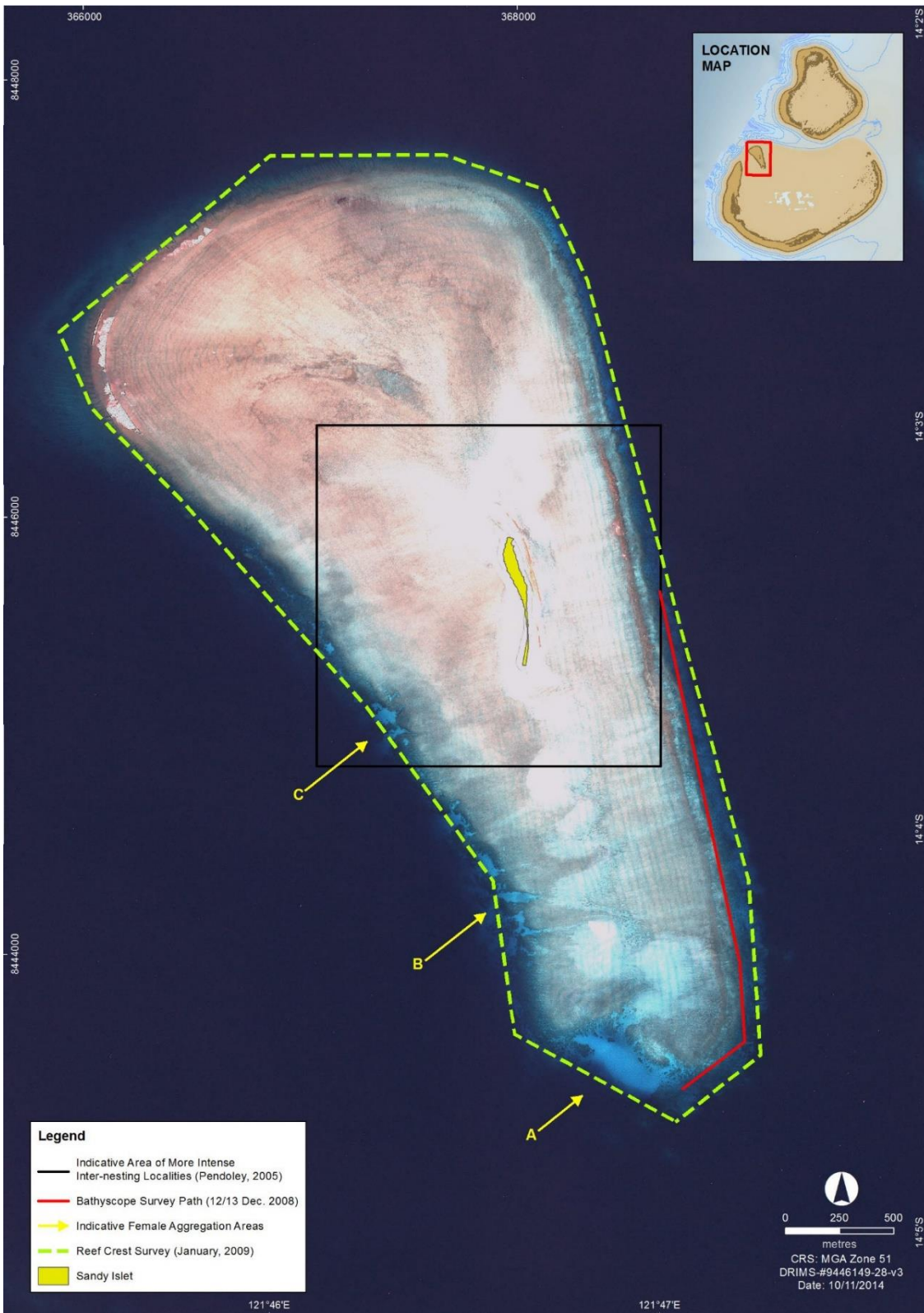


Figure 2-2 Areas of particular importance as known interesting areas for green turtles at Sandy Islet, as identified by Guinea (2009)

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

2.1.7 Migratory Movements from Scott Reef

Satellite tagging studies (Pendoley, 2005; Guinea 2011) have provided an indication of the behaviour and migratory routes of adult green turtles leaving Scott Reef. Most animals appear to swim through South Reef lagoon and disperse toward the Western Australian mainland via two distinct post-nesting migration pathways (shown in Figure 5-38 of the draft EIS/ERD); travelling east and north toward the Bonaparte Archipelago and then north along the coast to foraging areas in Northern Territory waters, or travelling south to Cape Leveque and then south along the coast to the Turtle Islands off the mouth of the De Grey River in the Pilbara region.

Based on an analysis of satellite tracking data for 96 adult, female green turtles from 10 rookeries and two genetic stocks (Northwest Shelf stock and G-ScBr stock) Ferreira *et al.* (2021) broadly identified two migratory corridors, one used by the NWS stock-Pilbara and another used by the NWS stock-Kimberley and the G-ScBr stock with some overlap at the northern and southern extents respectively.

2.1.8 Knowledge Gaps for the G-ScBr Stock

There is a lack of data regarding the status of the G-ScBr stock, and existing data are not contemporary. The Recovery Plan lists the status of this stock as “Unknown”. Currently, there are several key knowledge gaps for this stock, as described below.

2.1.8.1 Population Size and Inter-seasonal Fluctuations

Estimates of green turtle nester abundance was calculated based on recapture history of tagged turtles on eight survey (recapture) nights in the 2008/2009 season (Guinea, 2009). Estimates of abundance varied between survey nights providing a mean (\pm SE) abundance of 779 ± 383 (i.e. a maximum of 1162 individuals) (Guinea, 2009). Mean (\pm SE) female nester abundance for 2009/10 was estimated at 79 ± 25 over eight survey nights using similar methodology (Guinea, 2010). In both seasons, the individual standard error of each estimate exceeded 50% and consequently, abundance estimates should be considered indicative only, especially given the assumptions associated with the methodology are unverified (Guinea, 2009; 2010).

The estimate of a maximum of 1162 females was applied to a modified internesting area (reef environment shallower than 50 m) to calculate a density estimate of 1.79 turtles/km² for Scott Reef, which was used for the ANIMAT modelling presented in the draft EIS/ERD.

Dethmers *et al.* (2006), using an analysis of genetic diversity, provides estimates of the annual number of breeding females as 300, and an effective population size of 2576 individuals. The Recovery Plan appears to take the effective population size estimate from Dethmers *et al.* (2006) as the median for an estimated 1001-5000 females nesting per year for the Scott Reef-Browse Island stock (refer Figure 3 in the Recovery Plan). However, the proportion of this estimated 1001-5000 females utilising Sandy Islet versus Browse Island during any season is not known, as there are no estimates are available for the size of the Browse Island nesting population.

As reported in Guinea (2010) only 16 green turtles were tagged at Browse Island during the 2010 survey (compared to 56 at Scott Reef), and no manta tow surveys were conducted so no population estimates could be calculated. Olsen *et al.* (2017) provide a summary of green turtle sightings around Browse Island during the 2016 and 2017 seasons, with an indication that there was a much higher level of nesting activity occurring in October compared with April. No estimates of overall population size are provided.

As described in Section 5.3.2.6.1 of the draft EIS/ERD, based on the limited data available there appears to be considerable inter-seasonal fluctuation in the nesting population at Sandy Islet. As suggested by Guinea (2010), “Possible reasons for the fluctuation in the Sandy Islet breeding population are likely to be linked to their trophic status and the fluctuations in food supply in the foraging grounds”. In northern and eastern Australia, fluctuations in green turtle nesting numbers

have been linked the Southern Oscillation Index (Limpus & Nicholls, 1994, Limpus & Nicholls, 1988) and sea surface temperatures (Solow *et al.*, 2002).

Additionally, inter-seasonal fluctuations in the numbers of females successfully nesting at Sandy Islet are likely to be linked to the availability of suitable areas of sand for nesting, which will change significantly year to year as a result of cyclonic events and other factors. In addition to monitoring to gain a better understanding of trends in nesting abundance, there is a clear need for long-term monitoring of the extent and quality of nesting habitat available each season at Sandy Islet.

2.1.8.2 Sandy Islet Hatchling Numbers

Information on the number of green turtle hatchlings successfully emerging from their nests on Sandy Islet and reaching the ocean during the peak nesting season is very limited and is complicated by the variation in the estimates of the size of the nesting green turtle population utilising this nesting location (refer above). As described in Section 5.3.2.6.1 of the draft EIS/ERD, hatchling numbers are likely to vary considerably from season to season, given that females can re-nest up to five times in one season, and the variability in the number of nests, hatching success and hatchling emergence success.

Excavation of clutches on Sandy Islet provided mean (± 1 SD) hatch success and hatchling emergence success estimates of $80.2 \pm 10.9\%$ and 70.3 ± 17.4 respectively during the 2008/09 season (Guinea, 2009). In the 2009/2010 season, hatching success varied from 39.6% to 100% and emergence success varied from 28.6% to 96.2% (Guinea, 2010). Since clutches were identified by signs of emergence (e.g. observation of hatchlings emerging or hatchling tracks) these estimates do not account for failed clutches and are likely to overestimate success. Accordingly, extrapolation of success rates to provide estimates of the total number of hatchlings emerging and reaching the ocean within a season, survey period or survey night is limited in accuracy, especially considering the limitations in estimating nester abundance described above.

In absence of systematic marking of clutches, information regarding the fate of clutches is largely anecdotal (Pendoley Environmental, 2020). Predation of hatchlings is thought to be high once they enter the water (Stancyk, 1982) so hatchlings adopt a dispersal phase that involves rapidly swimming away from dangerous coastal water habitats (Wyneken & Salmon, 1992). To date, no information regarding post hatchling predation or dispersal of green turtle hatchlings emerging from Sandy Islet is available. Green turtle hatchlings have been tracked as they disperse through nearshore waters near Ningaloo Reef and were found to move directly away from the shoreline at speeds of 0.5 m/s (Thums *et al.*, 2016). Ocean currents influenced the bearing of hatchling tracks when they reached speeds of approximately 0.3 m/s (Thums *et al.*, 2016).

2.1.8.3 Relative Importance of Sandy Islet to the G-ScBr Stock

Both Sandy Islet and Browse Island have been identified as 'Major' nesting areas for the stock, but given the lack of data on population size and trends in nesting abundance at both locations it is not possible to determine the relative importance of the two rookeries at a stock level. The availability of suitable nesting habitat at Browse Island each season could influence the numbers of females that utilise the alternative nesting location for this stock at Sandy Islet.

As described in the Recovery Plan, the G-ScBr stock is considered likely to be restricted in its capacity to expand into other nesting areas in the event that nesting beaches are lost or sand temperatures increase as a result of climate change.

2.1.8.4 Migratory Movements

Notwithstanding the previous satellite tagging studies (Pendoley, 2005; Guinea 2011), which provide an indication of the behaviour and migratory routes of adult green turtles leaving Scott Reef, there is a need for more information on the movements of hatchlings within the immediate vicinity of Sandy Islet and the broader Scott Reef-Seringapatam Reef area. Additionally, a better understanding is

required of the movements and behaviour of adults migrating between Scott Reef and key foraging grounds for this species in Northern Territory waters and at the Cocos (Keeling) Islands, where individuals from the G-ScBr stock have been identified (Dethmers *et al.*, 2010).

2.1.8.5 Extent of Illegal Harvest

As described in the Recovery Plan, there are anecdotal reports of illegal harvest of green turtle adults and eggs at Sandy Islet and Browse Island but the extent of this take is currently unknown. At present, there is a limited understanding of the current level of visitation by Indonesian fishers to Scott Reef; consequently, it is not possible to estimate the extent of this threat. Historically, the peak period for Indonesian fishing effort at Scott Reef was between July and October, due to more favourable wind conditions (i.e. outside of cyclone season, and the nesting season for green turtles). Monitoring of both levels of visitation by Indonesian fishers to Scott Reef, and their utilisation of Sandy Islet, is required to determine if any illegal harvest is occurring.

2.1.8.6 Key Threats and Priority Actions for the G-ScBr Stock

As identified in the Recovery Plan, there are three threats that are defined as having a High² level of risk for the G-ScBr stock:

- climate change and variability
- chemical and terrestrial discharge – acute and chronic
- habitat modification – infrastructure/coastal development.

Additionally, there are three other threats to this stock that are defined as having a Moderate³ level of risk:

- light pollution
- vessel disturbance
- noise interference – acute and chronic.

Priority actions specifically required to recover this stock are identified in the Recovery Plan as:

- manage anthropogenic activities to ensure marine turtles are not displaced from identified habitat critical to survival
- understand the implications of sea level rise for this stock
- establish a long-term monitoring program at index beaches to assess trends in nesting turtle abundance.

2.2 Sensitivity of Marine Turtles to Artificial Light

Little is known about the impact of artificial light on adult and juvenile turtles when they are offshore. Most studies around light impacts on adult and juvenile turtles at sea have stemmed from interactions of turtles with fishing gear (Pendoley Environmental, 2020). During internesting, turtles rest on the seabed, physically removing them from surface lighting sources, such as vessels, MODUs, FPSOs (Whitlock *et al.* 2014). Since marine turtles do not feed during the breeding season (Limpus *et al.*, 2013), attraction of internesting turtles to light sources as a secondary response to effects of light on prey distribution is not expected. Indeed, to date, there is no evidence to suggest internesting turtles are attracted to light from offshore vessels (Pendoley Environmental, 2020).

² Additional mitigation action and an adaptive management plan required, the precautionary principle should be applied.

³ Obtain additional information and, where multiple threats receive a moderate rating, develop additional mitigation action if required.

Internesting, breeding, foraging and migrating marine turtles do not use light cues to guide these behaviours. Further, there is no evidence, published or anecdotal, to suggest that internesting turtles are impacted by light from offshore vessels or installations. As such, light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages (Pendoley Environmental, 2020).

Turtle hatchlings typically emerge from their nests at night (Mrosovsky & Shettleworth, 1968) and must crawl rapidly to reach the ocean in order to avoid predation (Salmon, 2003). They find 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 point of their emergence on the beach (Pendoley & Kamrowski, 2015; Lohmann *et al.*, 1997; Limpus & Kamrowski, 2013; Salmon *et al.*, 1992). Artificial light at night can interfere with these cues, influencing their sea-finding behaviour (Withington & Martin, 2003; Pendoley & Kamrowski, 2015; Kamrowski *et al.*, 2014). As a result, hatchlings may become disorientated, where they crawl in circuitous paths; or mis-orientated, where they move in the wrong direction, resulting in an increased mortality rate due to exhaustion, dehydration, or increased exposure to predation (Withington & Martin, 2003; Lohmann *et al.*, 1997; Salmon 2003).

It is generally accepted amongst the scientific community that there is insufficient information to derive defensible thresholds/limits of light intensity or its visibility on marine turtles and specifically in relation to hatchling behaviour. This conclusion was determined following a comprehensive literature review on the impacts of artificial light on marine turtle hatchlings by specialists at Pendoley Environmental (Appendix B of Appendix A). Despite the conclusions of the review, valuable insights into the sensitivity of turtle hatchlings to artificial light were provided and are outlined in the section below.

2.2.1 Hatchling Orientation

A range of experimental studies have been undertaken to determine the sensitivity of turtle hatchlings to artificial light emissions. A selection of these studies is discussed below.

- Cruz *et al.* (2018) used an experimental design to measure the orientation of swimming olive ridley hatchlings exposed to lights with different wavelengths (red, 720 nm; yellow, 660 nm, and green, 520 nm) and intensities (0.1 – 3.3 lux, 10.3 – 45.9 lux, 47.5 – 84.2 lux, 91.3 – 140.8 lux, 150.1 – 623 lux), situated 2 m from a hatchling. The results indicated that hatchlings were attracted to green and yellow lights at low light intensities (0.1 – 45.9 lux) as well as red lights at high intensities (>39.3 lux). However, the experiment was undertaken under controlled experimental conditions with no variation in the distance of the light from the hatchling.
- Karnad *et al.* (2009) used controlled arena trial experiments to identify the influence of light wavelength (red, 580 – 800 nm; yellow, 475 – 600 nm; blue, 375 – 575 nm; violet, 300 – 450 nm), intensity (two intensities generated by an LED torch; four LED bulbs and eight LED bulbs of 15,000 mcd), and the influence of vegetation height on the orientation of olive ridley hatchlings. The study found that the wavelength and intensity of light interacted to influence hatchling orientation towards light. Hatchlings were found to orient towards high intensity light more than to low intensity light for all wavelengths except violet.
- Pendoley & Kamrowski (2015) used controlled field-based arena trial experiments involving flatback turtle hatchlings to measure their orientation when different types of light, placed at different orientations and elevations, were visible 150 m away. The type of lights included in the study were high pressure sodium vapour, metal halide, and fluorescent white light. The light's intensity was also varied, with low intensity considered 500 W, medium intensity as 1000 W, and high intensity as 1300 W for the metal halide and high-pressure sodium lights. At medium and high light intensities of all three light types, hatchlings were significantly less oriented towards the ocean when exposed to light at 2° elevation compared to 16° elevation;

however, there was no indication of a limit or threshold at which hatchling sea-finding behaviour was influenced.

In addition to the experimental studies, *in situ* research into the effects of artificial light emissions has been undertaken and the results of relevant studies as summarised by Pendoley Environmental (2021) are presented below.

- Price *et al.* (2018) measured the intensity of visible light (320 – 700 nm) using a Sky Quality Meter (SQM) across various zones of a loggerhead turtle nesting beach in Florida. The study investigated the occurrence of hatchling turtle disorientation events recorded at the same beach and compared the orientation of hatchlings in each zone with the light intensity. The study found that luminance from artificial beachfront lighting may be related to increased incidences of hatchling disorientation but did not determine a luminance/intensity threshold at which more disorientations began to occur.
- Kamrowski *et al.* (2014) used both *in situ* nest fan measurements and results of controlled arena trial experiments to determine the influence of artificial light on the sea-finding of flatback turtle hatchlings at Peak and Curtis islands in Queensland. The study also involved the measurement of ambient light using a stellar photometer fitted with a V filter to ensure light at a wavelength of 480 – 660 nm was measured. The results indicated no disruption to hatchling sea-finding at Peak Island, whereas the sea-finding of hatchlings at Curtis Island was shown to be moderately disrupted. Due to constraints with the approach for measuring light, only comparisons of directional light and light between sights was provided.

Despite the numerous *in situ* and experimental studies that indicated light of a certain intensity and/or wavelength influenced hatchling sea-finding behaviour, no studies were able to account for the numerous inter-related variables that influence the intensity and visibility of artificial light to a hatchling turtle at a landscape scale. Hence, there are no generally accepted levels of artificial light that can be used as thresholds or limits for the purposes of this assessment.

3. ASPECTS RELEVANT TO THIS PLAN

3.1 Light Emissions

3.1.1 Source of Aspect

Lighting from the proposed project activities will be long-term, that is, over the life of the project. Artificial light emissions will be generated from the following sources:

- Navigational and operational lighting – these functional lighting sources are required on vessels, MODU and FPSO facilities at levels that provide a safe working environment for personnel and ensure maritime shipping safety. Standard lighting on marine vessels typically consists of bright white (i.e. metal halide, halogen, fluorescent) lights and is not dissimilar to lighting used for other offshore activities, including fishing and shipping.
- FPSO marine and operational lighting – Browse FPSOs use light sources that to minimise the potential for biological impacts. On average, illumination levels of approximately 200 Lux will be used in outdoor operational areas. Further details on which lighting types are considered appropriate for usage near turtle nesting habits is within Table 6 of the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2023).
- Flaring - during hydrocarbon processing or occasionally during drilling operations, flare stacks are used for burning off flammable gas released, to ensure it is not accidentally ignited in an unsafe location. Light emissions are associated with intermittent flaring from the FPSOs and MODU. These will vary in duration and intensity. There will be no continuous flaring during normal operations, with the exception of pilot gas and compressor seal gas. Flaring most often takes place during start-ups and shutdowns or in emergency events.

Light sources and, therefore, light emissions within the Browse Development Area will vary depending on the phase of the proposed Browse Project. It is likely that the footprint from light emissions will be highest during the construction phase (i.e. drilling and installation) due to the presence of multiple vessels and MODUs. Light sources are likely to be reduced during routine operations as primary light sources will be from the FPSOs. Lighting from MODU operations will be transient at each drill centre (typically in the order of two to three months per well), with flaring associated with well unloading only in the order of 1-2 days per well.

Light emissions will also be generated as part of the proposed BTL and inter-field spur installation activities; however, the impact from these emissions are likely to be temporary and minor. This is because the pipelay vessels will move along the proposed BTL route and inter-field spur line route at a rate of up to approximately 5 km/day (depending on the pipelay vessel and operational conditions such as sea state) meaning light emissions in any one area will be short-term. Once the BTL and inter-field spur lines are operational, there will be no ongoing light emissions except occasional vessel lights during IMR activities.

Table 3-1 summaries the light emissions that will occur in associated with each project activity.

Table 3-1 Sources of light emissions

Activity	Source of light emissions
Piling	<ul style="list-style-type: none"> • Navigational and operational lighting on the piling vessel(s). • Navigational and operational lighting on support vessel(s).
Drilling and completions	<ul style="list-style-type: none"> • Navigational and operational lighting on the MODU(s) • Navigational and operational lighting on support vessel(s). • Intermittent (~48 hours per well) flaring from the MODU during well unloading and unplanned contingency activities. This would be expected to occur at rates of up to approximately 70MM scf/day.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Activity	Source of light emissions
SURF Installation	<ul style="list-style-type: none"> • Navigational and operational lighting on the installation vessel(s). • Navigational and operational lighting and support vessel(s).
BTL and inter-field spur line installation	<ul style="list-style-type: none"> • Navigational and operational lighting on the installation vessel(s). • Navigational and operational lighting on support vessel(s).
FPSO installation / commissioning	<ul style="list-style-type: none"> • Navigational and operational lighting on FPSOs. • Navigational and operational lighting on support vessel(s).
Operations	<ul style="list-style-type: none"> • Navigational and operational lighting on FPSOs. • Navigational and operational lighting on support vessel(s). • Flaring from the FPSOs including during commissioning, operations and upset scenarios.
IMR	<ul style="list-style-type: none"> • Navigational and operational lighting on IMR vessel(s). • Navigational and operational lighting on support vessel(s).
Decommissioning	<ul style="list-style-type: none"> • Navigational and operational lighting on decommissioning vessel(s). • Navigational and operational lighting on support vessel(s).
Support activities and infrastructure	<ul style="list-style-type: none"> • Navigational and operational lighting on support vessel(s).

3.1.2 Light Modelling

To support the outcomes of the assessment of light emissions on marine turtles for the proposed Browse Project, modelling of the artificial light emissions from the proposed offshore facilities was undertaken. The scope, methodology and results of the modelling study (Pendoley Environmental, 2021b) are summarised below and included as Appendix A to this Plan.

3.1.2.1 Methodology

Currently, there are no standard commercial models for landscape scale modelling of artificial light emissions (Commonwealth of Australia, 2020). The base model used for this study was the ILLUMINA model that has been developed at Sherbrooke University, Canada (Aubé *et al.*, 2005). This well-documented, open-source model was selected for its ability to represent light across large areas and distances and equally across the entire visible spectrum, including biologically meaningful light from 350 nm – 700 nm. The model is three-dimensional and accounts for both line-of-sight light visibility in addition to the glow derived from atmospheric scattering of light. The model also addresses the attenuation/loss of light over landscape scale distances and, consequently, the areal extent of light glow across the sky can be modelled (Pendoley Environmental, 2021b).

The model input parameters include project specific details about light type and spectral distribution, including any shielding. The model also includes project location-specific inputs, such as surface reflectance and topographic values that are incorporated from aerial imagery (Pendoley Environmental, 2021b).

3.1.2.2 Description of Model Outputs

The results of the modelling were demonstrated as an ‘all-sky’ panorama image as viewed from the observer viewpoint. The modelled panorama images show the predicted brightness (including direct, reflected and refracted light) across the whole sky, including the horizon, for each of the seven scenarios (see **Figure 3-1** for an example). The predicted brightness is expressed in units of absolute radiance ($W/m^2/sr$), where W = watts, m^2 =metres squared and sr = steradian. This value has then been converted to Full Moon Equivalents (FME – e.g. a relative unit of measure used to

compare light received to that of a full moon) to give the radiance output some biological relevance and to aid interpretation in an environmental impact assessment context.

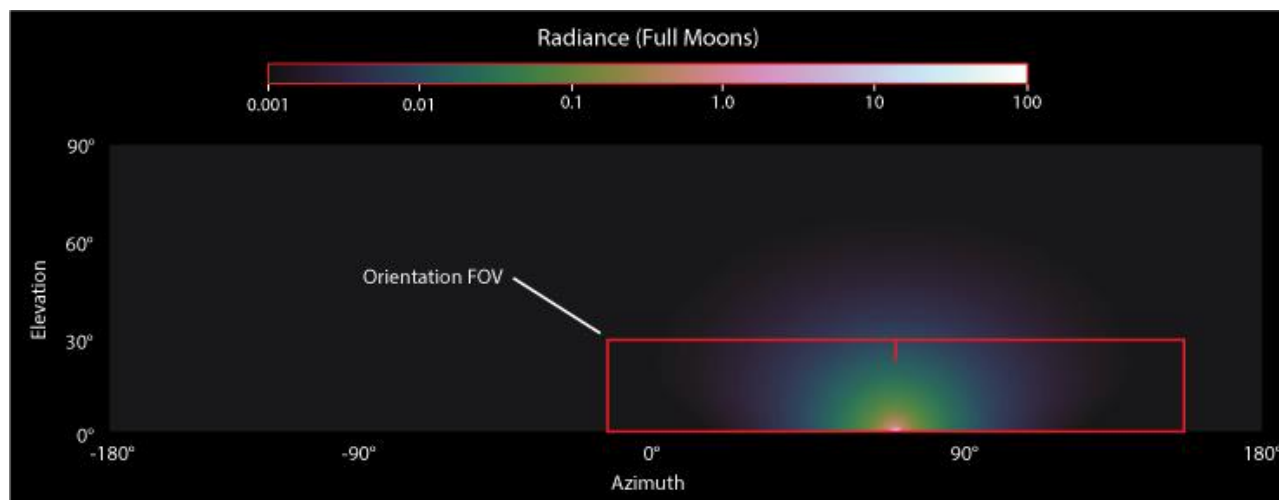


Figure 3-1 Example all-sky modelled image from an observer location showing predicted brightness

The sensitivity of a hatchling turtle to directional light can be described by a specific ‘cone of acceptance’, which indicates how much of the world a hatchling views and measures at any one instant, defined by Witherington (1992) as 180° horizontally and 30° vertically. To understand potential impacts on hatchling behaviour, all pixels in the 180° x 30° window centred over the brightest light source at the observer viewpoint are averaged (**Figure 3-1**), with the results presented as an orientation field of view in FME units.

3.1.2.3 Model Assumptions & Inputs

3.1.2.3.1 Operational Lighting Assumptions (FPSO and MODU)

As there was only high-level lighting detail available at this stage of the project, several assumptions had to be made to generate a lighting inventory for the Torosa FPSO and MODU as follows:

- When generating the lighting inventory, illumination levels were assumed to be 150% higher than required to provide a conservative estimate of light output.
- All operations lighting on the FPSO was assumed to have a colour temperature of 3000 K.
- All operations lighting on the MODU was assumed to have a colour temperature of 6500 K.
- All interior or enclosed lighting was assumed to be 100% shielded and therefore not represented within the model.

All scenarios included standard operational lighting levels. In relation to the Torosa FPSO, this is the normal level of external lighting expected to be required on the facility. The model has been informed through a review of the deck plan of the FPSO and safe working lighting levels required in each area. Operational Lighting has assumed to be installed in accordance with Best Practice guidelines, including appropriate wavelengths using mainly LED lighting, implementing light shielding where necessary.

3.1.2.3.2 Flaring Assumptions

Light from the Torosa FPSO flare tower is the only light source expected to be directly visible (based on height above the horizon at Sandy Islet) for extended periods of time during the Proposal life.

As changes in flare activity are likely to have the greatest impact on light emissions visible from Sandy Islet, a total of five different flares scenarios were modelled, described in **Table 3-2**.

Table 3-2 Flaring scenarios used for light impact assessment modelling

Flaring descriptor	Typical cause	Rate (MM scf/day)	Predicted duration (maximum)	Duration as proportion of year
Background/typical flaring	Normal operational flaring rates	1	335 days per year	92%
Minor upset flaring	Flash gas compressor outage	25	Up to 15 days per year (but average of 8 days per year)	4.1%
Moderate upset flaring	Facility restart	125	240 hours ¹ per year (total 10 days)	2.8%
Major upset flaring	Facility depressurisation post trip	250	96 hours ¹ per year (total 4 days)	1%
Commissioning flaring				
Torosa FPSO Commissioning flaring (one off activity)	Flaring required to commission production equipment	250	Up to 8 weeks during a six month commissioning period	Up to 25% of a single year.

¹ – Events of this nature typically last less than 24 consecutive hours

- **Background flaring:** The Browse FPSOs are designed to eliminate the need for flaring during steady state operations. The background (or baseline) flaring rate is aligned to flaring expected for >92% of the facility life. Flaring only occurs as a result of a pilot flame and compressor seal gas sent to flare. The predicted total flaring rate during these conditions is approximately 0.25 MMscf/day but modelling conservatively assumes a rate of 1 MMscf/day.
- **Minor upset flaring (e.g. flash gas compressor outage):** In some circumstances, equipment required as part of the flaring elimination system may be temporarily offline, with the most obviously example being low pressure gas recovery compressors, which take gas that on typical facilities would be flared, and recovers it back to the production system. If this equipment is offline, there may be relatively small flaring that occurs for the duration of the outage. The flaring rate assumed in the model is conservatively assumed to be 25 MMscf/day. It is assumed to occur for no more than 15 days in any given year but no more than 40 days in any given five year period.
- **Moderate upset flaring (e.g. facility restart flaring):** This rate of flaring can occur for short durations (e.g. less than 48 hours) when the FPSO is re-starting after a trip/shutdown while gas is brought on specification, but is not expected to be sustained for extended durations. The flaring rate assumed in the model is conservatively assumed to be 125 MMscf/day. This flaring rate is assumed to occur for no more than 240 hours per year (total 10 days) per year based on facility reliability forecasts.
- **Major upset flaring (e.g. trips):** Major upset flaring where a significant rate of flaring is required due to a major equipment upset, most typically associated with a facility outage where gas cannot be processed so the facility is depressurised by diverting gas to the flare. The facility would not typically be producing when flaring of this rate is occurring and therefore in normal operations, flaring of this rate would be limited to approximately 96 hours (total four days) per year. This flaring rate is based on the indicative maximum design capacity of the flare system that could be sustained for any significant period of time (i.e. more than 15 minutes) without potentially impacting the integrity of the flare itself.
- **Torosa FPSO commissioning flaring:** During a one-off commissioning activity, flaring at elevated levels may be required as gas must flow through the FPSO to commission equipment but it will not meet gas export specifications. Commissioning flaring is expected

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

to occur for 4 – 6 weeks but is conservatively assumed to occur for up to 90 days during a six month commissioning period to account for unforeseen circumstances. The flaring rate assumed in the model is assumed the indicative maximum design capacity of the flaring system that can be sustained for any significant period of time (i.e. more than 1 hour) without potentially impacting the integrity of the flare itself.

- **Well clean up flaring:** Well unloading during the drilling and completions of the well requires the flaring of gas from the MODU as it cannot be sent to the FPSO for processing as it may contain contaminants from the newly completed well. Gas that cannot be used is flared for safety reasons. The flaring rate assumed in the model is conservatively assumed to be 70 MMscf/day. Clean up flaring is only required for a maximum of 48 hours (total two days) at each well.

3.1.2.3.3 Cloud Cover

To inform the interpretation of modelling results, a review was undertaken of historic cloud coverage, which was obtained from the Broome Observatory (the closest to the project location) for a 5 year period (2017 – 2021) and the results are shown in **Table 3-4**. Cloud cover was examined for both the whole year and for turtle nesting season (November – April). The data showed that the sky was generally fine (very little cloud) for 86.5% of the year or 77.6% of turtle nesting season. The sky was at least partly cloudy (>3/8^{ths} sky covered) for 22% (34 days) of each nesting season historically and cloudy (>6/8^{ths} sky covered) for only 11% of the nesting season. January and February were the months with highest frequency of overcast days.

Cloud cover was split into three categories of cover that align to modelling scenarios and the results are summarised in

Table 3-3 shown in **Table 3-4**.

Table 3-3 Summary of historic cloud cover data from the Broome region (2017 - 2021).

Cloud Descriptor	Cloud Level	# Days per Year	% Days Per Year	#Days per Nesting Season	%Days per Nesting Season
Fine	<25% (<2 oktas)	316	86.5%	118	77.6%
Partly cloudy	25-75%	22	6.1%	17	11.1%
Cloudy / overcast	>75% (>6 oktas)	27	7.3%	17	11.1%

Table 3-4 Typical cloud coverage in the Broome region (days as % of month) based on five years of historic observations.

Typical number of days (% of month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fine	64	68	85	95	93	92	95	95	94	91	89	77
Partly cloudy	14	16	6	3	2	2	1	1	2	5	8	13
Cloudy / overcast	22	16	9	2	5	6	4	3	4	3	3	11

3.1.2.3.4 Relative frequency of occurrence of each lighting scenarios

As is relevant to modelling interpretation, the **Table 3-4** shows the number of days within any given year each of the expected levels of FPSO flaring would be expected to occur in different cloud conditions. The analysis is based on a multiplication of data within

Table 3-3 and **Table 3-2**.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Table 3-5 Number of days per year (italics) on which combination of flaring and cloud cover used in light modelling scenarios are expected to occur.

Calculation of flaring rates occurring during specified cloud conditions.			Cloud coverage (typical % of year)		
			Clear	Partly cloudy	Mostly cloudy
			77.6%	11.1%	11.1%
Flaring rate and expected occurrence (% of year)	Background	92.0%	261	37	37
	Minor	4.1%	12	2	2
	Moderate	2.8%	8	1	1
	Major	1.0%	3	~1	

3.1.2.4 Model Scenarios

Modelling of predicted light from the FPSO, MODU at the TRA drill centre and MODU at the TRD drill centre was undertaken using a single observer viewpoint on Sandy Islet for all scenarios.

Scenarios

The flaring scenarios were separated into three categories:

1. FPSO only: (Individual Scenarios; IS1 – IS6)
2. MODU only (Individual Scenarios; IS5 and IS6)
3. FPSO and MODU together (Cumulative Scenarios; CS1 – CS4)

These scenarios were also run in both clear (**A**) and mostly cloudy (**B**) sky conditions and are outlined in **Table 3-6**.

Table 3-6 Summary of the modelled scenarios, the vessel inventory and cloud parameters

Vessel	Vessel Parameters		Scenario Code ⁴	Cloud Parameters		
	Inventory	Period (days/yr)		Cover (%)	Height (km)	Period (d/yr)
FPSO	Background Flaring	365	IS1A	0	0	118
			IS1B	80	3	17
	Minor Upset Flaring	15	IS2A	0	0	118
			IS2B	80	3	17
	Moderate (Unplanned) Upset Flaring	12	IS3A	0	0	118
			IS3B	80	3	17
	Major Upset Flaring	12	IS4A	0	0	118
			IS4B	80	3	17
MODU	Operation Light at TRD	365	IS5	0	0	118
	Well Clean Up Flaring at TRA	8	IS6	0	0	118
FPSO + MODU	Background Flaring Operation Light at TRD	365	CS1A	0	0	17
			CS1B	80	10	17
	Minor Upset Flaring Well Clean Up Flaring at TRA	15	CS2A	0	0	118
			CS2B	80	10	17
	Moderate Upset Flaring Well Clean Up Flaring at TRA	12	CS3A	0	0	118
			CS3B	80	10	17
	Major Upset Flaring Well Clean Up Flaring at TRA	12	CS4A	0	0	118
			CS4B	80	10	17

Where “A” Scenarios denote clear conditions and “B” Scenarios are in cloudy sky conditions. OFOV units are in Full Moon Equivalents

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

3.1.2.5 Impact Criteria

As outlined in **Section 2.2.1**, there is insufficient information to derive thresholds or limits of light intensity or its visibility on marine turtles, specifically in relation to hatchling behaviour. In the absence of such thresholds, FME units were used and applied to the results of the modelling, with predicted impacts based on these results (**Table 3-7**). This approach is consistent with the process of expert elicitation and builds on available research findings in the absence of detailed empirical data (Burgman 2005; Burgman *et al.*, 2011; Patterson *et al.*, 2007).

Table 3-7 Proxy artificial light impact criteria for marine turtles, referred to as FME within this plan.

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



Figure 3-2 Location of the Sandy Islet observer viewpoint and facilities considered in the modelling (Torosa FPSO and the MODU at TRA and TRD drill centres) (Pendoley Environmental, 2021b)

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Controlled Ref No: BD0006AH0000008

Revision: 5

Page 35 of 92

Uncontrolled when printed. Refer to electronic version for most up to date information.

3.1.3 Light Modelling Results

The modelling of 18 different scenarios was completed, with 10 Individual Scenarios (IS), and eight Cumulative Scenarios (CS), results are shown in **Table 3-8**.

Table 3-8 Orientation Field of View (FOV) values for each scenario (FME) and the corresponding Impact Level for the impact potential to marine turtles

Vessel	Lighting Inventory	Scenario Name ⁵	OFOV (FME)	Impact Level
FPSO	Background Flaring	IS1A	0.004	1
		IS1B	0.010*	2
	Minor Upset Flaring	IS2A	0.009	1
		IS2B	0.028	2
	Moderate (Unplanned) Upset Flaring	IS3A	0.031	2
		IS3B	0.116	3
	Major Upset Flaring	IS4A	0.041	2
		IS4B	0.156	3
MODU	Operational Lighting at TRD	IS5	0.001	1
	Well Clean Up Flaring at TRA	IS6	0.020	2
FPSO + MODU	Background Flaring & MODU (not flaring) at TRD	CS1A	0.006	1
		CS1B	0.012	2
	Minor Upset Flaring & MODU Flaring at TRA	CS2A	0.030	2
		CS2B	0.103	3
	Moderate Upset Flaring & MODU Flaring at TRA	CS3A	0.054	2
		CS3B	0.192	3
	Major Upset Flaring & MODU Flaring at TRA	CS4A	0.065	2
		CS4B	0.236	3

*30% cloud cover has an OFOV of 0.08 as per “additional scenarios” within Appendix A.

3.1.3.1 FPSO

In IS1A - 4A (clear sky conditions, various flaring scenarios) the FPSO is identifiable as a small point source of direct light on the horizon, predominantly due to the height of the flare (base height: 182 m above sea level). The areal extent of sky glow from the FPSO correlates strongly with flaring intensity ranging from minimal levels during background flaring and extending across the sky during minor major upset flaring scenarios.

Orientation FOV (OFOV) Full Moon Equivalent (FME) values correlate strongly with flaring intensity and the resulting changes in sky glow extent, with values decreasing with flaring rates, from 0.041 for major flaring to 0.009 for minor flaring rates and 0.004 from routine or background flaring rates.

The impact of clouds on sky glow is clearly demonstrated in IS1B - 4B by the order of magnitude increase in OFOV FME values, with the smallest increase occurring in IS1B (0.01; 239%) and increasing in IS2B (0.028; 293%), IS3B (0.116; 371%), and IS4B (0.156; 377%) (**Table 3-8**).

A summary of the OFOV and corresponding impact level is show in **Table 3-9**. A summary of the expected number of days at which impact level would occur is shown in **Table 3-10**.

⁵ Where “A” Scenarios denote clear conditions and “B” Scenarios are in cloudy sky conditions. OFOV units are in Full Moon Equivalents

Table 3-9 Summary of modelling results showing OFOV (FME) and impact level (in brackets) for each operational scenario permutation.

Light Impact predictions		Cloud cover scenario		
		Clear	Partly cloudy	Mostly cloudy
Flaring assumption	Background	0.004 (1)	0.008 (1)	0.010 (2)
	Minor	0.009 (1)	0.018 (2)	0.028 (2)
	Moderate	0.031 (2)	0.062 (2)	0.116 (3)
	Major	0.041 (2)	0.08 (2)	0.156 (3)

1 – Interpolated (not modelled) using a ratio of clear:partly cloudy of 1:2 informed by 'background' flaring scenario outcomes.

Table 3-10 Estimated duration (days per year) at which each given impact level will occur during operation of the Torosa FPSO only.

Impact Level	Frequency of occurrence (applicable to years in which no drilling of commissioning occurs)
1	298 days
2	65.5 days
3	1.5 days
4	Not predicted to occur

3.1.3.2 MODU

Modelling demonstrates that in isolation from FPSO operation and in clear conditions, the modelled MODU when operating but not flaring at TRD shows almost no visible sky glow with only very low levels of light reflecting off the ocean below 2° elevation and an OFOV value of 0.001. TRD is the closest MODU to Sandy Islet located approximately 18 km away.

The model results show the impact of flaring from the MODU at the TRA site (IS6), where the extent of the sky glow increases substantially within the OFOV to 0.020, which is approximately 18 times brighter than the MODU without flaring at the TRD site (IS5).

A summary of either modelled or interpolated results for MODU OFOV is shown in **Table 3-11**. Only when the MODU was flaring was it expected to exceed OFOV corresponding to Impact Level 2. In any cloud conditions, the MODU would not exceed impact level 1.

Table 3-11 Summary of modelled and interpolated results showing OFOV (FME) and impact level (in brackets) for MODU operational scenarios during different cloud conditions.

Light Impact predictions		Cloud cover scenario		
		Clear	Partly cloudy	Mostly cloudy
Flaring assumption	MODU Not flaring (Modelled at TRD)	0.001 (1)	0.0021 (1)	0.0041 (1)
	MODU Flaring (Modelled at TRA)	0.02 (2)	0.04 (2)	0.08 (2)

1 – Interpolated (not modelled) using a OFOV (FME) ratio of clear:partly cloudy of 1:2 and clear:mostly cloudy of 1:4 derived conservatively from the modelling data set.

Table 3-12 Estimated duration (days per year) at which each given impact level will occur during operation of MODU within the Torosa field (prior to Torosa FPSO operations commencing).

Impact Level	Frequency of occurrence during MODU operations prior to FPSO operations commencing
1	365 days
2	Not predicted to occur
3	Not predicted to occur
4	Not predicted to occur

3.1.3.3 Commissioning flaring (Torosa FPSO)

A flaring rate representative of the maximum which may occur during commissioning ('major' flaring) was modelled, including in different cloud conditions. In cloudless conditions, commissioning flaring is expected to generate light at impact level 2. In higher cloud cover periods, the effect of this sky glow increases impacts to level 3.

Commissioning of the Torosa FPSO is expected to result in higher than normal rates of flaring for a total of 6 – 12 weeks within a 6 month commissioning window. Woodside has identified that impacts to nesting turtles can be minimise by conducting these commissioning activities outside of peak turtle nesting season, however, noting the magnitude of the residual lighting due to distance from nesting habitat, it can not be guaranteed to limit commissioning to these periods. Delays to proposal commencement that are grossly disproportionate to the magnitude of the potential impacts and significant impacts are not predicted to occur in response to commissioning flaring.

However, to limit the potential for significant impacts in the event of unexpected delays, if commissioning flaring is required to commence during peak turtle nesting or hatching season due then Torosa FPSO commissioning flaring will be strictly managed to limit the total number of nights in which this commissioning flaring will occur at rates which are associated with any risk of biological effects. Specifically, Torosa FPSO Commissioning will be managed such that the maximum number of nights where flaring will exceed 100 MMscf/d (3 hour average) during Peak Green Turtle Nesting and Hatchling Emergence Season (Jan-Apr) to 56 nights (8 weeks). Beyond this allowance, flaring will be further curtailed to be below this magnitude. This limit has been set following a detailed review of commissioning activities including a range of contingencies.

A flaring rate of 100 MMscf/d was selected as the limit at which flaring could be associated with behavioural impacts at Sandy Islet. This was derived by interpolating the results of the different scenarios modelled for the lighting impact assessment, where flaring rates exceeding 100 MMscf/d during 'mostly cloudy' weather conditions would have the potential for behavioural impacts. **(Figure 3-3).**

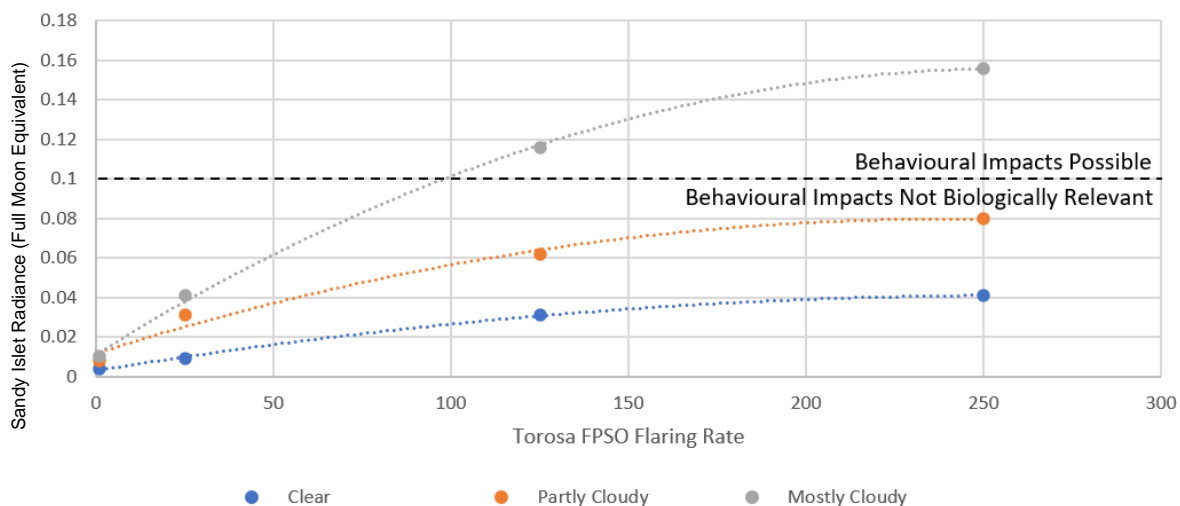


Figure 3-3 Light modelling results for full moon equivalent (FME) received at Sandy Islet under different flaring rates from Torosa FPSO

3.1.3.4 Construction & Support vessels

In addition to the modelling of the FPSO and MODU facilities, a review of the potential impacts on turtles associated with artificial lighting from offshore construction vessels (pipelay and a standard OSV) was undertaken. Light modelling undertaken for the proposed pipelay vessel (*Audacia*) for the Barossa Gas Export Pipeline demonstrated that light emissions from the vessel were reduced to ambient levels at approximately 11 km from the source, and at approximately 3.3 km from the vessel lighting emissions were predicted to be 0.1 FME (equivalent to the light output from the first quarter moon to new moon; **Table 3-7**). Therefore, whilst light will be visible, it is unlikely to result in any behavioural impacts on turtles. However, behavioural impacts may occur within approximately 3.3 km of the pipelay vessel (ConocoPhillips Australia, 2019). Modelling of the construction vessel demonstrated that light emissions were reduced to ambient levels approximately 1.6 km from the vessel. At approximately 0.5 km from the vessel, lighting emissions were predicted to be 0.1 FME and therefore, whilst light will be visible, it is unlikely to result in any behavioural impacts on turtles; however, behavioural impacts may occur within 0.5 km of the construction vessel (ConocoPhillips Australia, 2019).

3.1.3.5 Cumulative Scenarios

A range of cumulative scenarios considering FPSO flaring, MODU activity and cloud coverage stages were assessed. Only in two circumstances did the presence of the MODU increase an increased in impact levels from the non-cumulative equivalent. These were for the for FPSO minor flaring during clear conditions or background flaring during partly cloudy conditions.

A summary of the OFOV (FME) and expected impact level is shown in **Table 3-13** for each of the cumulative scenarios examined. As per **Table 3-14**, the cumulative impact of MODU activities with FPSO operations leads to an additional 49 days per year (assuming the MODU is active every day of the year). This scenario can only occur for a maximum of approximately 5 years, as once the FPSO arrives there is only a need to drill an additional 19 wells, with each well taking a maximum of 3 months each.

Table 3-13 Summary of modelling results showing OFOV (FME) and impact level (in brackets) for each operational scenario permutation. Scenarios which increased an impact level are underlined,

Light Impact predictions	Cloud cover scenario		
	Clear	Partly cloudy	Mostly cloudy
Background	0.005 (1)	<u>0.0101 (2)</u>	0.0141 (2)

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Light Impact predictions		Cloud cover scenario		
		Clear	Partly cloudy	Mostly cloudy
Flaring assumption + MODU lighting (as at TRD)	Minor	0.01 (2)	0.0201 (2)	0.0321 (2)
	Moderate	0.032 (2)	0.0641 (2)	0.1201 (3)
	Major	0.042 (2)	0.0821 (2)	0.1601 (3)

1 – Interpolated (not modelled) as being between modelled cloud cover levels and informed by modelling of background flaring rates during different conditions.

Table 3-14 Estimated duration (days per year) at which each given impact level will occur during operation of MODU within the Torosa field simultaneously with Torosa FPSO operations. Change to FPSO only (Table 3-10) is shown in brackets.

Impact Level	Frequency of occurrence during FPSO operations concurrent with MODU operations (assumes a full 12 months of MODU activity)
1	249 days (-49 days)
2	114 days (+49 days)
3	1.5 days (No change)
4	Not predicted

3.1.4 Impact Assessment

The light modelling study further assessed the likely impacts on the life history stages and behaviours of green turtles associated with each of the modelled scenarios. A summary of this assessment is provided in **Table 3-15** and detailed overview is provided in **Table 3-16** to **Table 3-19**.

Table 3-15 Summary key findings for potential impacts to green turtles at Scott Reef across life stages and lighting impact levels

Impact Level	Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
1	No impact predicted	No impact predicted	No impact predicted	No impact predicted
2	No impact predicted	Light and light glow highly visible, behavioural impact unlikely	Light and light glow highly visible, behavioural impact unlikely	No impact predicted
3	Minor impact possible	Light and light glow highly visible, behavioural impact unlikely	Light and light glow highly visible, behavioural impact unlikely	No impact predicted
4	Not assessed, as not predicted to occur			

Table 3-16 Impact Level 1 – Continuous Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
1. FPSO 2. IS1A; CS1A 3. Continuous throughout 44-year project life 4. ~29 km 1. MODU (TRD) 2. IS5 3. 18 months at given TR site. 4. ~20 km	IS1A – 0.004 CS1A – 0.009 IS5 – 0.001 (Figures 4, 8 and 9 of Appendix A)	No impact predicted <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. 	No impact predicted <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) indicates the facilities will appear as a small area of dim glow within the orientation FOV, which is not likely to have any impact on hatchlings during sea-finding. In the absence of dunes/topographic features, hatchlings may orient towards artificial light source rather than ocean horizon. Behavioural response may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence. 	No impact predicted <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected decreases with distance to shore. Light sources located from ~20 - 29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be very low, and few individuals will be at risk of attraction Surface currents at Scott Reef will carry hatchlings on, and in the direction, of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will either reach or be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	No impact predicted <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that interesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impact to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

Table 3-17 Impact Level 1 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
<ul style="list-style-type: none"> FPSO IS2A Flaring Intermittently ~29 km 	<ul style="list-style-type: none"> IS2A – 0.009 (Figure 5 of Appendix A) 	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. Flaring may occur intermittently during 1 nesting season. 	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) indicates the facility will appear as a small area of dim glow within the orientation FOV, which is not likely to have any impact on hatchlings during sea-finding. In the absence of dunes/topographic features, hatchlings may orient towards artificial light source rather than ocean horizon. Behavioural response may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence. Duration and rate of flaring is difficult to predict but it is likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under different flaring conditions will not be a static long term stressor impacting all emerging hatchlings across an entire nesting season. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected decreases with distance to shore. Light sources located from ~20- 29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be very low, and few individuals will be at risk of attraction Surface currents at Scott Reef will carry hatchlings on, and in the direction, of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will either reach or be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

Table 3-18 Impact Level 2 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
1. FPSO 2. IS3A, IS4A, IS1B, IS2B 3. Flaring and overcast intermittently 4. ~29 km 1. MODU 2. IS6 3. Flaring intermittently 4. ~20 km 1. FPSO + MODU 2. CS1B, CS2A, CS3A, CS4A 3. Flaring intermittently 4. ~20-29 km	IS1B - 0.010 IS2B - 0.029 IS3A – 0.031 IS4A – 0.041 IS6 – 0.020 CS1B – 0.012 CS2A – 0.030 CS3A – 0.054 CS4A – 0.065 (Figures 4 – 12 of Appendix A)	No impact predicted <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. Flaring may occur intermittently during 1 nesting season. 	Light and light glow highly visible, behavioural impact unlikely <ul style="list-style-type: none"> In absence of dunes/topographic features, hatchlings may orient towards artificial light source and sky glow which might be along the islet rather than directly towards the ocean horizon and may result in disorientation behaviour where hatching crawl in circles while trying to orient themselves. Behavioural misorientation and disorientation responses may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Maximum predicted continuous flaring could potentially result in all clutches within a season being exposed to artificial light (weeks). Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence. Cloud cover and thickness is dynamic and will vary with time leading to a range of potential exposure conditions and impacts that are a function of the duration and rate of flaring and difficult to predict but are likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under clouds will not be a static long term stressor impacting all emerging hatchlings across an entire nesting season. 	Light and light glow highly visible, behavioural impact unlikely <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected decreases with distance from shore. Light sources located ~20-29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be low, and few individuals will be at risk of attraction. Surface currents at Scott Reef will carry hatchlings on and in the direction of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	No impact predicted <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that interesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

Table 3-19 Impact Level 3 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting Reduction in nesting attempts Disturbance to nest site selection Disruption to post-nesting sea finding behaviour	Hatchling sea finding Disruption to post-emergence sea finding behaviour	Hatchling dispersal Disruption to in-water dispersal behaviour	Mating / Internesting / Foraging / Migration Disruption to foraging, mating, internesting, migratory behaviours. Displacement from internesting, foraging, mating habitat
1. FPSO 2. IS3B, IS4B 3. Intermittent Flaring and intermittent cloud (< 20 days/yr for each) 4. ~29 km 1. FPSO + MODU 2. CS2B, CS3B, CS4B 3. Intermittent Flaring and intermittent cloud (< 20 days/yr for each) 4. ~20-29 km	IS3B – 0.116 IS4B – 0.156 CS2B – 0.103 CS3B – 0.192 CS4B – 0.236 (Figures 6-7 and 10-12 of Appendix A)	Minor impact possible <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a broad area of sky glow encompassing the entire field of view of the turtles at right angles to the beach (seaward) and at the horizon. Recovery Plan Action Area A8: It is unlikely an Impact Level 3 level of lighting will cause displacement of nesting females from Sandy Islet and any displacement is expected to be minor, limited to individuals potentially exposed to a very short window of high light levels under heavy cloud, and who are likely to move to Browse Island, which is part of the same genetic stock (G-ScBr) as Sandy Islet. Flaring expected to be limited to 8 – 15 days per year and associated with unplanned upset flaring or well clean up flaring, worst case scenario this occurs during the 17 days of cloudy days reported for the area during the nesting season. Impact is intermittent and limited to one nesting season. The intensity of the light is between 0.103 and 0.236 FME, so even under the worst-case scenario of Major Upset Flaring plus Well Clean Up Flaring at TRA (CS4B), the illumination will fall in the lower range of a full moon brightness, closer to a quarter moon than a half moon. The number of days in a moon cycle that this high level of sky brightness could exceed the illumination from a half to new moon is 14 days, further reducing the potential number of days turtles could be exposed to high light levels under full cloud during the nesting season. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts. Experienced nesting females considered less vulnerable to effects 	Light and light glow highly visible, Minor behavioural impact possible <ul style="list-style-type: none"> The modelled radiometric visibility of the worst-case scenario of Major Upset Flaring plus Well Clean Up Flaring at TRA, with cloud cover at 80% and a ceiling height of 10 km (CS4B) shows a bright point source of light on the horizon, and the entire sky illuminated by light. The reflected light and glow extend well beyond the defined orientation FOV box and is almost 4 times brighter than the scenario with no cloud (CS4A). In absence of dunes/topographic features, hatchlings may orient towards artificial light source and sky glow which might be along the islet rather than directly towards the ocean horizon and may result in disorientation behaviour where hatching crawl in circles while trying to orient themselves. Behavioural misorientation and disorientation responses may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Flaring expected to be limited to 8 – 15 days per year, associated with unplanned upset flaring or well clean up flaring, worst case scenario this occurs during the 17 days of cloudy days reported for the area during the nesting season. Impact is intermittent and limited to one nesting season. Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence and differences in individual visual sensitivities. 	Light and light glow highly visible, No behavioural impact predicted <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected by light decreases with distance from shore. Light sources located ~20-29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be low, and few individuals will be at risk of attraction. Surface currents at Scott Reef will carry hatchlings on and in the direction of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	No impact predicted <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting Reduction in nesting attempts Disturbance to nest site selection Disruption to post-nesting sea finding behaviour	Hatchling sea finding Disruption to post-emergence sea finding behaviour	Hatchling dispersal Disruption to in-water dispersal behaviour	Mating / Internesting / Foraging / Migration Disruption to foraging, mating, internesting, migratory behaviours. Displacement from internesting, foraging, mating habitat
		<p>of light on nest site selection, permanent displacement of these individuals is unlikely.</p> <ul style="list-style-type: none"> • Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. • Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. • Sandy Islet and Browse Island green turtles are the same genetic stock (G-ScBr), and so should a neophyte be displaced from Sandy Islet she could potentially move to Browse Island. • Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. • The 5 – 8 year re-nesting interval for green turtles means that only small subset of breeding females could potentially be exposed to this level of brightness in a single season should it overlap with this level of flaring and cloud cover. 	<ul style="list-style-type: none"> • Cloud cover and thickness is dynamic and will vary with time leading to a range of potential exposure conditions and impacts that are a function of the duration and rate of flaring and difficult to predict but are likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under clouds will not be a static long term stressor impacting all emerging hatchlings across an entire nesting season. • Nests will emerge over 8 – 12 weeks at the peak of the nesting season, a small subset of emerging nests could potentially be exposed to this level of brightness in a single season should it overlap with this level of flaring and cloud cover. 		

3.2 Seabed Subsidence

3.2.1 Source of Aspect

Subsea subsidence may manifest as a result of production activities, through the extraction of hydrocarbons from the Torosa reservoir causing a reduction in the reservoir's pressure. Potential impacts of reservoir-related seabed subsidence on the fate and dynamics of Sandy Islet (and as such the turtle nesting habitat) have been assessed in the draft EIS/ERD and Supplement Report to the draft EIS/ERD, against a backdrop of long-term global sea level rise and increasing cyclone intensity.

The phenomenon of subsidence due to oil and gas production is considered rare and is mostly imperceptible. Only a few reported instances are known in the industry worldwide (Nagel, 2001). Instances where higher magnitude production-induced subsidence has been recorded are likely related to specific geologic conditions at these locations. These have included reservoirs located in the offshore North Sea region (44 cm/year at Ekofisk), onshore California (22 cm/year at Wilmington and up to 20 cm/year at South Belridge), offshore Malaysia (M3), offshore Indonesia (Arun) and offshore Oman (4.5 cm/year at Yibal) (Nagel, 2001).

3.2.2 Seabed Subsidence Modelling

Subsidence associated with oil and gas extraction is a physical response of the seabed due to pressure reduction inside the reservoir. In 2014 Woodside modelled the magnitude of potential subsidence and associated horizontal movements for the Browse reservoirs. This modelling estimated subsidence will range from 8.9 cm at the centre of the subsidence bowl to 2.6 cm at the edge of the subsidence bowl over 40 years of hydrocarbon extraction (Woodside, 2014). However, the modelling was not able to estimate the magnitude of subsidence directly under Sandy Islet, and therefore this was extrapolated from estimates of subsidence at locations at the edge of the subsidence bowl.

Revised subsidence modelling was completed in 2024 which was able to derive subsidence predictions at different locations across the Torosa Field, including Sandy Islet. This 3D model was coupled with forecast reservoir pressure over the life of the field, so subsidence at the seabed could be estimated using a simulator throughout the production period.

The maximum subsidence value occurs near the centre of the field, and the value decreases away from the maximum subsidence location. **Table 3-20** summarises the subsidence predictions at the end of the 40 years of production at different locations across the field, and

Table 3-21 summarises the subsidence predictions every five years throughout the production period. This will be used to compare monitored subsidence results with the subsidence predicted through modelling.

Table 3-20 Summary of subsidence predictions from 3D subsidence modelling (SLB, 2024)

Pore pressure case	Subsidence at Sandy Islet (mm)	Subsidence at North Scott Reef Eastern Edge (mm)	Maximum Subsidence at the end of production (centre of the field, in deep ocean water) (mm)
At the end of the low depletion case	1.1	25	51.6
At the end of the reference depletion case	2.3	35.8	51.8
At the end of the high depletion case	3.8	42.7	71.4

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Table 3-21 Predicted subsidence at Sandy Islet reference locations (reference/mid case) throughout project life (SLB, 2024)

Production case	Predicted subsidence (mm) at years of production						
	5	10	15	20	25	30	35
Low	0.2	0.45	0.7	0.9	1.1	1.1	1.1
Reference	0.15	0.7	1.2	1.6	1.9	2.1	2.3
High	0.15	0.75	1.55	2.15	2.7	3.1	3.8

The geomechanics properties used for modelling were well calibrated to multiple core samples, so there is low uncertainty in this information. Sensitivity analysis also concluded that surface subsidence predictions are not significantly sensitivities to changes in overburden geomechanical properties. Therefore, there is high confidence in these results. As the production predictions (i.e. forecast reservoir pressure) were used as an input to the model, the subsidence modelling will be repeated every 5 years to incorporate the latest actual pore pressure data (this is captured as a commitment in **Table 4-5**).

3.2.3 Impact Assessment

The long-term fate of Sandy Islet at Scott Reef under rising sea levels, increased cyclone intensity and minor subsidence remains to a degree uncertain; however, historical evidence ranging from decades to millennia, coupled with modelling and case studies elsewhere, indicate that it is unlikely to become completely submerged in the future.

Empirical physical evidence has been collected to demonstrate that sand has accumulated at the approximate current location of Sandy Islet for millennia. In 1974, two 30 m long cores were drilled into Sandy Islet from above the high water mark (King, 1975). These cores revealed the presence of a sand type that was equivalent to the sand on the current islet down to a depth of approximately 25 m in both cores. Collins *et al.* (2011) dated cores of this depth in the Scott Reef region date between 7000 to 8500 years before present. During the last 8500 years, sea level rise, reef subsidence and ongoing reef growth has been dynamic, with sea levels rising rapidly at times (up to 10 mm/yr), South Scott Reef naturally subsiding at rates of approximately of 0.45 mm/yr and the reef growing at 1-4 mm/yr towards the sea surface (Collins *et al.*, 2011). The 1974 coring results suggest that accumulation of sand has continued throughout these changing reef conditions.

Sea level has been rising in response to a changing climate for over a century in the Scott Reef region. Between 1993 and 2009, it is estimated that sea levels have risen 4.5 ± 1.3 mm/yr in north-west Australia, or 2.7 ± 0.6 mm/yr after the signal directly correlated with ENSO is removed (White *et al.*, 2014). Through this change there has been little evidence of large-scale, long-term net erosion of Sandy Islet. A comparison of Sandy Islet size and morphology at four intervals between 1975 and 2019 has shown the islet has changed morphology and position but has maintained a similar spatial area of between 1.8 ha and 2.4 ha above the high-water mark over the last 45 years (see **Figure 3-4**).

As predicted by modelling and case studies undertaken elsewhere, Sandy Islet has migrated away from the direction of the prevailing wave fronts and has change morphology becoming narrower and longer. Sandy Islet is also resilient to extreme episodic events. In March 2004, Cyclone Fay, a Category 5 cyclone that passed directly over Scott Reef, caused extreme wave and storm surges that eroded the island, reducing its size by approximately one-third (Gilmour *et al.*, 2013). Following this event, Sandy Islet recovered to its former size above the high water mark. These long-term

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

assessments of Sandy Islet response to long-term sea-level rise and extreme events suggest that Sandy Islet is dynamic and resilient in the long term.

Sediment analyses at Sandy Islet was completed in 2014 which was used to draw the following conclusions:

- Observations of the exposed beachrock outcrops along the eastern shoreline of Sandy Islet, and the changes in the southern 'tail' end of Sandy Islet from 2006 to 2014 indicate that the ambient hydrodynamic conditions on Scott Reef Central are sufficiently energetic to concentrate a large volume of sediment from the Scott Reef Central platform to the area where Sandy Islet occurs.
- The grainsize distributions across Sandy Islet sediment samples were 'well' to 'very well' sorted, suggesting a high degree of hydrodynamic sorting as waves concentrate sediments across the platform.
- The sediments at Sandy Islet are mostly coarse and very coarse sands, and mostly derived from corals. The polished and rounded appearance of a large number of coral and mollusc derived sediments suggest that they have endured a long period of abrasion as they are transported across the reef platform, and alongshore as the reef island adjusts its shape to seasonal and other shifts in winds and waves. The molluscs are likely to be produced from molluscs living in habitats close to Sandy Islet. Finer sediments are likely to be transported off the reef platform by currents and wave action.
- Foraminifera ('forams') are also likely to be important contributors to the Sandy Islet sediment budget. The relatively pristine condition of the more fragile *Amphistegina* foram tests (hard outer shells) suggest that they are more recently delivered to the island from the algal rim habitats along the edge of Scott Reef Central in which they grow, with the implication that the link between the biological production of these tests and sediment supply to the island is tight. In some geomorphic zones these sediments comprise more than 20% of the sediment content. Any reduction in the biological productivity of these organisms would be quickly expressed in the Sandy Islet's sediment budget and geomorphology (Smithers 2015).

A summary of the sampling program methods and results is included in 0.

The current information available on Sandy Islet suggests that (1) the location of Sandy Islet has changed over time, but the island has remained a feature of Scott Reef, (2) sediments on Sandy Islet are likely sourced from within the reef platform, (3) sediments concentrate across the reef platform to form Sandy Islet, and (4) Sandy Islet is dynamic and resilient in the long-term.

Net erosion of Sandy Islet (or net loss of sediment within the Scott Reef Central flat) in the future, while not likely in the long-term, cannot be completely ruled out. However, the worst-case estimated rate of project-attributed subsidence at Sandy Islet (total 3.8 mm over 40 years) is negligible when compared with natural change in sea level rise observed in the area (4.5 ± 1.3 mm/yr, or 2.7 ± 0.6 mm/yr removing ENSO (White et al., 2014)).

Turtle nesting is unlikely to be influenced by any island morphology changes related to sea level rise, which are likely to operate over timeframes of ~~months to~~ years (except during extreme cyclone events). Given the green turtle nesting to hatchling period is approximately 60 days, "normal" island morphology change is highly unlikely to impact on turtle nest success via erosion. However, during future intense cyclones, like Cyclone Fay in 2004, major island erosion and morphology changes, coupled with overtopping by waves and storm surge is likely to substantially increase mortality rates of eggs incubating on the island. Furthermore, evidence suggests that nesting space is likely to reduce following these events but accretion of sediments in subsequent months is anticipated to return the island to its former size.

Sandy Islet is unlikely to disappear below the highwater mark over the 40 years of hydrocarbon production, and evidence to date suggests it is unlikely to become completely submerged in coming decades but will continue to change morphology. Future island morphology changes will be at

timescales that will not directly affect turtle nests and hatchlings. However, future cyclonic impacts to turtle nesting at Sandy Islet may become more damaging as cyclone intensity increases. The impact of reservoir subsidence, given its minor contribution to future sea height (on the reef flats surrounding Sandy Islet) is not expected to meaningfully influence the long-term fate of Sandy Islet and the turtles that use it as nesting habitat.

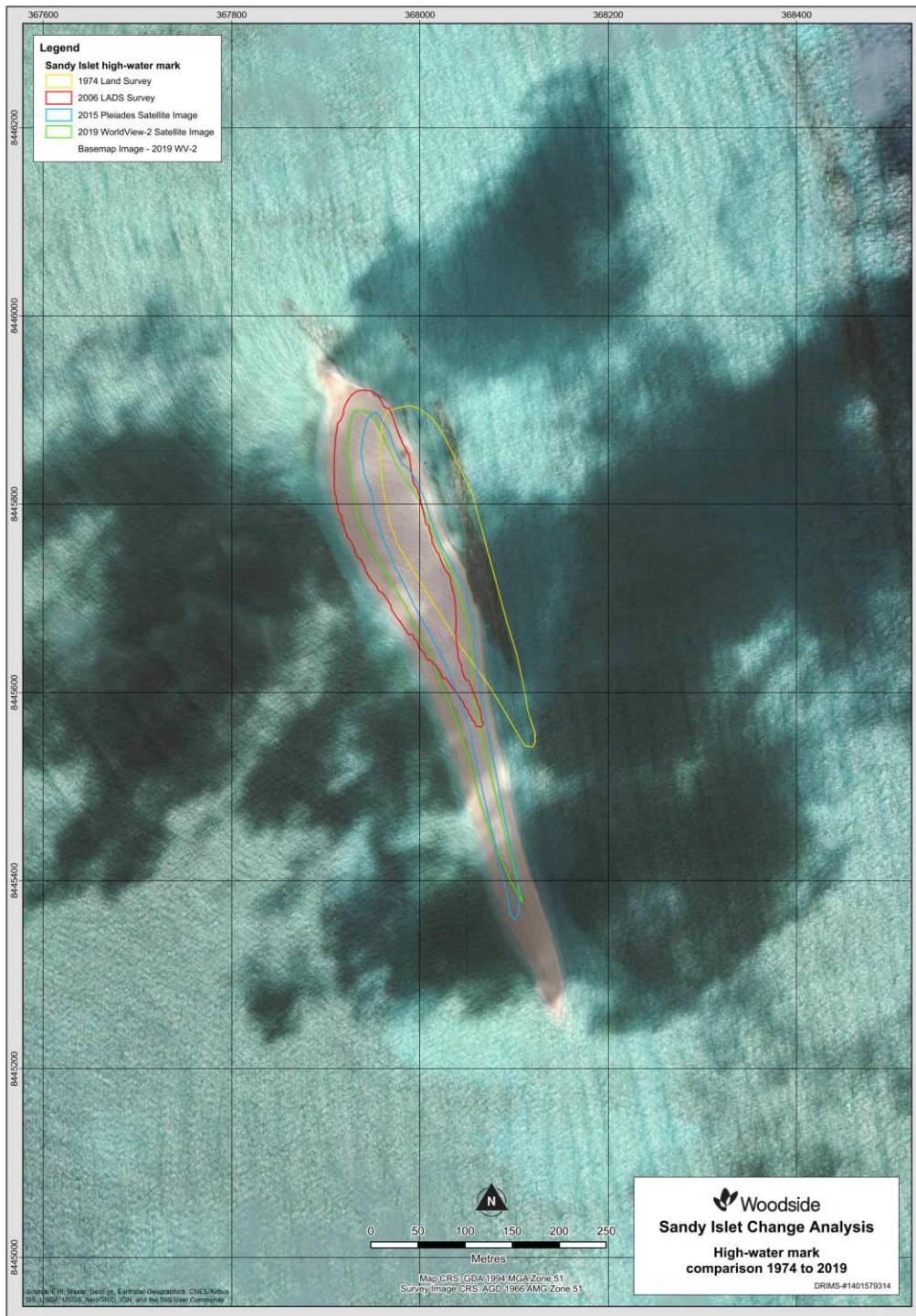


Figure 3-4 Comparison of Sandy Islet size and shape about the high-water mark at four intervals between November 1974 and May 2019 (1974, 2006, 2015 and 2019)

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

3.3 Vessel Strike

3.3.1 Source of Aspect

Vessel movements during all phases of the proposed Browse to NWS Project have the potential to cause injury or mortality to marine fauna as a result of accidental collisions. During drilling and construction and, project vessels will include barges, tugs, survey vessels, supply vessels, installation and pipelay vessels. During operations project vessels will include supply vessels, tugs, IMR vessels, FCTVs (as discussed below) and condensate tankers.

The type and number of vessels in the Project Area (and transiting to and from the Project Area) at any one time, and the duration of presence, will differ depending on the project phase. Vessel presence is expected to be greatest for short term project phases (e.g. drilling and completions, subsea installation including BTL, and commissioning), with the longer-term operational phase requiring fewer vessels.

3.3.2 Impact Assessment

Vessel movements can affect marine fauna in a number of ways, including the disruption of behaviour (e.g. feeding, nursing, mating, migrating) displacement from habitats due to vessel noise emissions and collisions leading to injury or mortality.

Vessel speed has been demonstrated as a key factor in collisions with marine fauna (Laist et al., 2001). Large (>80 m), fast moving vessels pose the highest risk. Collisions are difficult to avoid as the vessels are potentially not able to slow down or evade marine fauna upon sighting (Laist et al., 2001). All project vessels will not travel at speeds greater than 6 knots within the State Proposal Area, which will reduce the risk of accidental collisions (Laist et al., 2001).

4. MANAGEMENT OBJECTIVES, APPROACH AND PERFORMANCE STANDARDS

4.1 Environment Performance Objectives

Receptor specific environmental objectives were identified for the proposed Browse Project in the draft EIS/ERD. In preparing responses to the regulatory and public submission on draft EIS/ERD and the State ERD, Woodside reviewed and where appropriate revised these environmental objectives.

The environmental objectives of the Browse Project that are relevant to the marine turtles are:

- Objective 29 - Undertake the Browse Project in a manner that will not disrupt migration, breeding, nesting, internesting and hatchling dispersal of the green turtle population at Scott Reef.
- Objective 30 - Undertake the Browse Project in a manner that will not displace the green turtle population from habitat critical to the survival of the species at Scott Reef.
- Objective 36 - Undertake the Browse Project in a manner that will not result in impacts to habitat critical to the survival of green turtles that would otherwise result in green turtle critical behaviour (migration, breeding, nesting, internesting and hatchling dispersal) being disrupted.

4.2 Management Approach

Management of the potential impacts to marine turtles from light emissions, seabed subsidence and vessel strike is required so that the above management objectives are achieved. The management approach incorporates:

- light emissions minimisation during design
- light emissions minimisation during execution
- impact avoidance during execution via:
 - application of seasonal based restrictions to activities where the achievement of the management objectives would be compromised should the activity occur at times when green turtles are nesting at Sandy Islet
 - application of marine fauna observers and shut down zones.
 - Reduced vessel speeds (<6 knots) within State Proposal Area
- implementation of a science verification monitoring program including:
 - biological monitoring to inform adaptive management
 - light emissions monitoring to verify predicted light emission levels, assess light emissions for comparison with performance standards (**Section 4.3**) and inform management response and adaptive management.
 - subsidence monitoring to verify predicted subsidence levels, assess subsidence for comparison with performance standards (**Section 4.3**) and inform management response and adaptive management.

Specific mitigation and management measures that will be applied are detailed in Section 4. The adaptive management approach is detailed in **Section 6**.

4.3 Performance Standards

Performance standards required in order to achieve the stated management objectives are outlined in **Table 4-1**. The management actions and measurement criteria in place to achieve these will be achieved are described in the following section. Exceedance of a performance standard will trigger a management response as per Section 6.

Table 4-1 Performance standards

Environment Performance Objectives	Environment Performance Standards
<ul style="list-style-type: none"> • Undertake the Browse Project in a manner that will not disrupt migration, breeding, nesting, internesting and hatchling dispersal of the green turtle population at Scott Reef. • Undertake the Browse Project in a manner that will not displace the green turtle population from habitat critical to the survival of the species at Scott Reef. • Undertake the Browse Project in a manner that will not result in impacts to habitat critical to the survival of green turtles that would otherwise result in green turtle critical behaviour (migration, breeding, nesting, internesting and hatchling dispersal) being disrupted. 	<ol style="list-style-type: none"> 1. Received levels of artificial light at Sandy Islet will not exceed 0.1 FME (as defined in (Table 3-7)), excluding during commissioning and emergency flaring events. 2. Commissioning flaring leading to received levels of artificial lights exceeding 0.1 FME will not occur for more than 56 nights. 3. Remediation plans will be enacted to ensure Sandy Islet nesting remains above historically recorded minimum extents (1.8 ha above HAT).

4.4 Key Management Actions

As part of the impact and risk assessment process undertaken for the proposed Browse Project, management and mitigation measures have been identified to reduce the level of impact and risk to an acceptable level and meet the environmental objectives and performance standards for each aspect. The following framework tools were applied, as appropriate, to assist with identifying appropriate management and mitigation measures:

- Good industry practice – identifies further engineering control standards and guidelines which may be applied by Woodside in addition to those required to meet the legislation, codes and standards.
- Professional judgement – uses relevant personnel with the knowledge and experience to identify alternative controls.

In accordance with Woodside's HSE risk management procedures, risk reduction measures should be prioritised and categorised in accordance with the hierarchy of controls, where risk reduction measures at the top of the hierarchy take precedence over risk reduction measures further down. The proposed management and mitigation measures have been developed using the following adaptive framework:

- eliminate the risk by removing the hazard
- substitute a hazard with a lesser one
- prevent a credible impact from occurring through the implementation of additional engineering control measures
- reduce the magnitude of a credible impact through the implementation of additional engineering control measures
- mitigate the credible impact on the environment through the reduction in extent, scale, duration of impact
- apply environmental offsets where justified
- carry out emergency response and contingency planning to facilitate recovery from the credible impact of an event.

The proposed mitigation and management measures pertaining to anthropogenic light are presented in **Table 4-2** (construction and operational vessels) and **Table 4-3** (FPSO operations). Mitigation and management measures relevant to vessel strike (construction and operations) are presented in **Table 4-4**. For subsidence, these are shown in **Table 4-5**. These tables also incorporate the relevant Scientific Monitoring commitments (**Section 5**) and the implementation of the adaptive management approach which is presented in **Section 6**.

Note, no MODU used for drilling operations may approach closer than 20km to Sandy Islet. Vessels required for short-term mooring and/or transponder installation and retrieval, or involved in conducted scientific research or servicing monitoring equipment may approach closer. Vessels conducting research activities are far smaller than those involved in construction, with impacts expected to be equivalent to that which would occur from fishing or tourism boats that frequent the area.

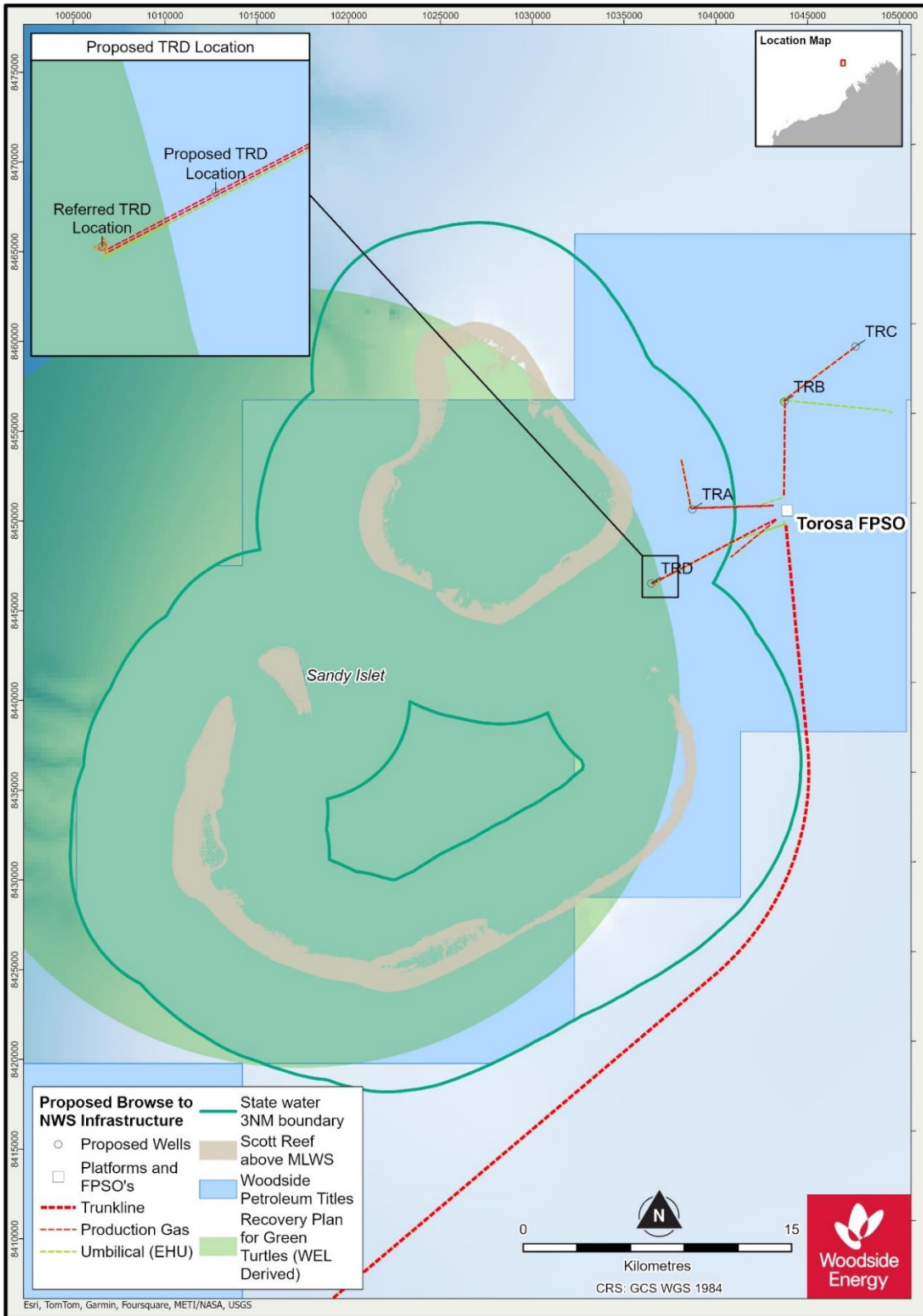


Figure 4-1 Location of proposed TRD drill centre and notional field layout relative to Habitat Critical to the Survival of Green Turtles interesting buffer, defined as 20km around Sandy Islet

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Table 4-2 Mitigation and management measures applicable to anthropogenic light from proposed Browse Project construction (temporary) activities

Relevant project activity	Management Actions / Controls	Environment Performance Standards	Monitoring & Measurement criteria
<p>Navigational and operational lighting from project vessels & MODUs.</p>	<p>All vessels operating within State waters in proximity to Scott Reef will be required to develop an artificial light management plan (ALMP). ALMP's will be developed in accordance with the guidelines in Appendix F of the National Light Pollution Guidelines for Wildlife and must include consideration of light spill, selective use of long wavelength light sources, installation of light shades and blinds and the minimisation of lighting levels for external operational areas.</p>	<p>Artificial light from proposal activities received by turtles at Sandy Islet as a result of vessel activities will not exceed 0.1 FME (as defined in (Table 3-7)) as a result of operational lighting on project vessels and MODUs.</p>	<p>Received light levels as measured at Sandy Islet do not exceed specified limits.</p>
<p>Planned flaring from MODU operations</p>	<p>There will no planned flaring from MODU at night time with State Waters.</p>	<p>Artificial light from proposal activities received by turtles at Sandy Islet as a result of flaring during drilling operations will not exceed 0.1 FME (as defined in (Table 3-7)).</p>	<p>Received light levels as measured at Sandy Islet does not exceed specified limits.</p>

Table 4-3 Mitigation and management measures applicable to anthropogenic light from long term activities to achieve environment performance outcomes

Relevant project activity	Management actions / controls	Environment Performance Standards	Monitoring & Measurement criteria
Operational lighting from Browse FPSOs	<p>The design of the FPSO facilities will incorporate the Principles of Best Practice Lighting Design, outlined in Appendix A of the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2023).</p> <p>The FPSO lighting design will minimise lighting impacts through measures where applicable, including but not limited to:</p> <ul style="list-style-type: none"> • Use of adaptive light controls (e.g. motion sensors) • Lighting only the area intended • Using a lighting intensity appropriate for the task • Using lights with reduced or filtered out blue, violet and ultraviolet wavelengths • Incorporation of light shielding or shrouding to minimise light spill/glow. 	<p>Artificial light in FPSO design adheres to best practice design principles.</p> <p>Artificial light from FPSO activities received by turtles at Sandy Islet does not exceed 0.1 FME (as defined in (Table 3-7)) during routine operations.</p>	<p>No permanent lights installed as part of base Torosa FPSO design will be non-compliant with best practice lighting design principles.</p> <p>Verification of design confirms FPSO designed to requirements. Periodic audits conducted at a minimum every 5 years to confirm no change or design modifications have been implemented beyond design intent.</p>
Commissioning Flaring from Torosa FPSO	<p>Torosa FPSO Commissioning will limit the number of nights where flaring exceeds 100 MMscf/ during Peak Green Turtle Nesting and Hatchling Emergence Season (Jan-Apr) to 56 nights.</p> <p>Flaring rates to measured across a rolling three hour average.</p> <p>If Torosa FPSO commissioning flaring above 100mmscfd occurs for more than 56 nights in peak green turtle nesting and hatchling season, then planned activities that result in flaring will be deferred or modified to rates less than 100mmscfd until after the end of Peak Green Turtle Nesting and Hatchling Season.</p>	<p>Turtles not exposed to light >0.1FME for more than 20 nights during peak nesting and hatchling emergence season. Note – flaring rates subject to management action only result in exceedances of this threshold where there is sufficient cloud cover to generate sky glow.</p>	<p>During a one off commissioning period, flaring above 100 MMscf/day will not occur for more than 56 nights (cumulative).</p>
Continuous flaring from Torosa FPSO	<p>The FPSO facilities will be designed such that continuous flaring will be limited to pilot gas and compressor seal gas and design continuous flaring rates will not exceed 1 MMscf/day.</p>	<p>Browse FPSO's designed such that continuous flaring is limited to pilot gas and compressor seal gas and that continuous flaring rates from routine operations are below 1 MMscf/day.</p>	<p>Received light levels as measured at Sandy Islet do not exceed 0.1FME during routine FPSO operations.</p>
Planned intermittent flaring during Torosa FPSO operations	<p>Torosa FPSO will plan major shutdowns to avoid planned flaring during night-time during the Sandy Islet green turtle nesting and hatchling emergence periods (peak and shoulder; November-April).</p> <p>Torosa FPSO will also plan routine maintenance (i.e., annual inspections) to avoid planned flaring during night-time in the Sandy Islet green turtle nesting and hatchling emergence periods. Reactive / Corrective maintenance will occur as required.</p>	<p>Shut-down/maintenance schedules and planning documentation demonstrate that planning activities around sensitive periods for green turtles is considered.</p> <p>Planned flaring does not occur at night-time during Torosa FPSO major shutdowns or routine maintenance events during Sandy Islet green turtle peak nesting and hatchling emergence period (peak and shoulder; November-April) (excluding flaring for safety reasons).</p>	<p>Received light levels as measured at Sandy Islet does not exceed 0.1FME as a result of planned flaring from FPSO operations.</p>
Unplanned flaring during Torosa steady state operations	<p>Torosa FPSO flaring events due to equipment failure will be rectified at the earliest practicable opportunity</p> <p>Minor upset flaring (at rates of between 1 MM and 125 MMscf/day) from the Torosa FPSO will be targeted to occur on no more than 10 nights per year during the Sandy Islet green turtle nesting and hatchling emergence periods, beyond the first year of FPSO operations.</p> <p>Major upset flaring (>125 and <250 MMscf/day) from the Torosa FPSO will be targeted to occur on no more than 4 nights per year during the Sandy Islet green turtle nesting and hatchling emergence periods, beyond the first year of FPSO operations.</p> <p>Major upset flaring (>250 MMscf/day) will not occur for more than 60 minutes on any given night in the Sandy Islet green turtle nesting and hatchling emergence periods and will be targeted to</p>	<p>Project review of FPSO operational records and monthly / annual flaring reports.</p>	<p>FPSO operational records and flaring reports that flaring during Sandy Islet green turtle nesting and hatchling emergence periods was no more than:</p> <ul style="list-style-type: none"> • 10 nights total for minor upset flaring between (1 MMscf/day and 125 MMscf/day) • 4 nights total for major upset flaring (>125 and <250 MMscf/day) • 60 minutes on any given night for major upset flaring (>250 MMscf/day).

	not occur for more than one night during each annual Sandy Islet green turtle nesting and hatchling emergence period.		
--	---	--	--

Table 4-4 Mitigation and management measures applicable to vessel strike from proposed Browse Project vessel activities (including MODU and Construction Vessels)

Relevant project activity	Management actions / controls	Environment Performance Standards	Monitoring & Measurement criteria
Project vessels and fast crew transfer vessels	No MODU operations within the green turtle internesting buffer (20 km radius around Sandy Islet as defined in the Recovery Plan for Marine Turtles in Australia).	No MODU operations within critical habitat.	No injury to any marine turtle from vessel activities.
	Project vessels will not travel at speeds greater than 6 knots within the State Proposal Area.	Risk of fauna collisions minimise through application of best practice vessel management controls.	No injury to any marine turtle from vessel activities.
	Interactions between vessels and marine fauna will not be inconsistent the EPBC Regulations 2000 – Part 8 Division 8.1, and in the Australian National Guidelines for Whale and Dolphin Watching and the Whale Shark Code of Conduct, whereby unless in a permitted emergency situation, vessels will not travel at speeds greater than the speed restrictions prescribed for marine fauna encounters.	Records demonstrate that vessels did not travel greater than 6 knots within 300m of a turtle.	No injury to any marine turtle from vessel activities.
		No vessel collision with marine fauna occurs	No injury to any marine turtle from vessel activities.
	Fast crew transfer vessels (FCTV) will operate under a FCTV Management strategy (to be detailed in subsequent EPs as required) which will describe the appropriate additional control measures to manage vessel strike risk for the FCTV. Subject to the potential for technological innovation and additional engineering controls, FCTVs will not travel at speeds greater than 30 knots in sensitive areas at sensitive times, and will have vessel crew trained in marine fauna observation.	Fast crew transfer vessels operate under a FCTV Management Strategy that describes the control measures to manage vessel strike risk.	No injury to any marine turtle from vessel activities.
		No vessel collision with marine fauna occurs	No injury to any marine turtle from vessel activities.

Table 4-5 Mitigation and management measures relevant to reservoir subsidence during Torosa production

Relevant project activity	Management actions or controls	Environment Performance Standards	Monitoring & Measurement criteria
Subsidence attributed to hydrocarbon extraction	Subsidence Modelling Updates Regular (five yearly) updates to modelling of predicted subsidence rates will be conducted, based on actual reservoir performance and subsidence measurements.	Observed seabed subsidence attributable to the proposed Browse Project will not occur at a rate such that it may cause a significant (>25% over 5 years) loss of nesting habitat at Sandy Islet.	Sand Islet Morphology assessment (including sediment budget assessment) to be incorporated into Sandy Islet Habitat Remediation Plan to inform. Ongoing monitoring of any observed subsidence against rates associated with potentially significant habitat loss. Exceedance will trigger implementation of the Sandy Islet Habitat Remediation Plan (Section 6.3) .
	Seabed Subsidence Monitoring Program (Section 5.3) An integrated monitoring approach using Radar Satellite Interferometry (InSAR) and Global Navigation Satellite System (GNSS) will be used to monitor subsidence rates.	Subsidence monitoring results are obtained ongoing during production.	Subsidence monitoring in place prior to operations, including at impact and control sites. Monitoring program designed with sufficient accuracy to detect hydrocarbon extraction related subsidence at Sandy Islet if subsidence rate exceeds >1mm.year.
	Sandy Islet Morphology Monitoring Program (Section 5.4) High resolution satellite imagery will be reviewed to monitor the aerial extent of available nesting habitat relative to historical estimates of available nesting habitat.	Records demonstrate that high resolution satellite imagery is reviewed every 6 months during operations. The area of available nesting habitat on Sandy Islet is within historic variability with no trend in area reduction.	Sandy Islet habitat monitoring program in place prior to operations. Monitoring is sufficient to detect significant change in island morphology.

5. SCIENTIFIC MONITORING & PERFORMANCE VERIFICATION

Four separate scientific monitoring programs are to be conducted as part of implementation of the TMP, focussing on both the aspects of the Browse project (e.g. lighting, seabed subsidence) and the impacts (e.g. changes to green turtle behaviour or change to morphology of sandy islet). For each monitoring program, there is a corresponding set of adaptive management actions (**Section 6**) that could be triggered depending on outcomes of the monitoring program.

The scientific monitoring programs for green turtles within the project area will involve:

- a green turtle monitoring program at Sandy Islet and surrounds (**Section 5.1**) to update baseline information on green turtle demographics at Scott Reef
- an anthropogenic light monitoring program (**Section 5.2**) to verify predicted light emissions from construction and operational activities
- a seabed subsidence monitoring (**Section 5.3**) to verify predicted subsidence levels which may be used to better understand causes of and changes to Sandy Islet morphology
- a Sandy Islet size and morphology monitoring program (**Section 5.4**) to monitor the size and morphology of Sandy Islet for comparison with historic minimum available nesting habitats.

5.1 Green Turtle Monitoring Program

A green turtle monitoring program will be implemented as a core component of the proposed Browse Project. The purpose of this program will be to verify and update baseline data through on-going data acquisition at relevant times throughout the proposed Browse Project on the distribution, abundance, seasonality and behaviour of green turtles at Scott Reef and within habitat critical to survival for the G-ScBr stock.

The green turtle monitoring program outlined herein has been designed on the advice of a suitably experienced, independent marine turtle expert. The detailed design of the program will cover key demographic parameters, specific monitoring techniques, frequency and timing of monitoring, data analysis techniques, corrective action triggers, and reporting requirements. Key components of the baseline monitoring program are outlined in **Appendix B**. The monitoring will be implemented such as to collect a minimum of four (with a target of five) years of data prior to commencement of gas processing at the Torosa FPSO and a minimum three years of data prior to the introduction of any light associated with construction of the proposal.

Operational Monitoring

The monitoring program will be continued to be implemented during operational phase. However, the design of the operational monitoring program will need to be informed by outcomes of the baseline monitoring program. The operational phase of the monitoring program will also be designed on the advice of a suitably experienced, independent marine turtle expert. It is likely to include many of the key components of the baseline monitoring program, but potentially at different frequencies or using different sample sizes.

At a minimum, 14 days of monitoring will occur in each of the first five years of operations. This is consistent with guidance in the National Light Pollution Guidelines for Wildlife.

5.1.1 Key Objectives

The key objectives of the baseline phase of the green turtle monitoring program are as follows:

- To investigate nesting turtle behaviour and habitat usage within Scott Reef and to establish a baseline demographic data set for nesting turtles.
- To understand the key breeding parameters (e.g. nest abundance, incubation success, emergence success, hatchling sea finding behaviour and post hatching dispersal) for green turtles at Scott Reef.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

- To understand the relative importance of Sandy Islet as a nesting site for the G-ScBr green turtle stock.

The monitoring information will provide baseline data that can be used to verify the potential impacts and risks that the proposed Browse Project may have on green turtles, to determine compliance against the proposed performance standards and to inform adaptive management if necessary. Data will be reviewed in the context of regional, national and international trends.

5.1.2 Key Components

The green turtle monitoring program will be comprised of the following key activities;

- Satellite tracking of adult nesting individuals to determine internesting, foraging and migration behaviour.
- Track and nest counts and Capture-Mark-Recapture (CMR) tagging of adult nesting individuals to facilitate abundance estimates, long-term life history traits, and to estimate the proportion of neophytes present each season.
- Hatchling and nest counts and observations to determine nesting abundance and density, nesting success and hatchling sea-finding behaviour.
- Hatchling in-water dispersal behaviour in area immediately surrounding Sandy Islet.

The monitoring program will be made up of the following 6 key components, each with dedicated specific techniques dedicated to quantifying a particular element of biological information. The key components including a notation of monitoring techniques are summarised in Table 5-1. Further specific detail of each key component is described in Appendix B.

- KC1 - Adult in-water behaviour
 - Satellite telemetry
- KC2 - Adult Nesting & Sea-Finding Behaviour
 - Remote sensing
 - Adult turtle track census (including nest counts)
 - Capture-Mark-Recapture (CMR, flipper/PIT tagging)
 - Adult turtle track orientation
- KC3 - Hatchling (i.e., Incubation) Success
 - Incubation and emergence success (marking, excavation, and elevation)
- KC4 - Hatchling Sea-Finding Behaviour
 - Arena trials
- KC5 - Hatchling In-Water Dispersal
- KC6 - Artificial Light Monitoring
 - In-situ measurement of received light

KC2 and KC3 are also relevant for any monitoring post Sandy Islet habitat adaptive management activities if they are required.

Table 5-1 The purpose and rationale of each element of the turtle baseline monitoring program.

Key component	Rationale
Quantify the movement and distribution patterns of G-ScBr turtles (KC1).	Satellite telemetry is required to quantify the extent of connectivity of adult female green turtles between Sandy Islet and Browse Island within nesting seasons, and to resolve the spatio-temporal extent of inter-nesting, migratory, and foraging behaviours of turtles of the G-ScBr stock. Without this information, it would not be possible to assess the relative importance of Sandy Islet as a nesting site for G-ScBr turtles (GTMP Objective C). Additionally, it would not be possible to quantify potential shifts in the nesting activity of green turtles from Sandy Islet

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

	to Browse Island as a result of Project-associated activities because the extent of nester connectivity between these two sites is currently unknown.
Confirm the peak nesting and hatching season for G-ScBr turtles (KC2).	Remote sensing technology provides a means to monitor the nesting activity of G-ScBr turtles at Sandy Islet and Browse Island year-round without needing to mobilise field teams to both of these remote locations for on-ground surveys. By confirming the peak nesting season for G-ScBr turtles during the first year of the GTMP, subsequent field surveys targeting nesting adult female green turtles and hatchlings can be more accurately scheduled. This will improve the capture of baseline data for the GTMP and ALMP.
Quantify adult female nesting behaviour for G-ScBr turtles (KC2).	Track census data will facilitate estimates of nester abundance at Sandy Islet and Browse Island. These data will then be used to establish a baseline trend level for nesting activity and success at Sandy Islet relative to Browse Island against which future monitoring outcomes can be compared to assess potential impacts of the Project on nesting adult green turtle behaviour and distribution at Sandy Islet. Without this track census data being collected at both monitoring sites, it would not be possible to quantify the natural, climate-driven (e.g., El Niño Southern Oscillation) variations and fluctuations occurring in the wider G-ScBr adult nesting female population that occur over periods of two to eight years. This would subsequently impede efforts to detect potential Project-attributable impacts to nesting turtles at Sandy Islet.
Quantify the fidelity of individual adult female green turtles of the G-ScBr stock to nesting beaches (KC2).	Flipper and Passive Integrated Transponder (PIT) tagging will provide evidence of the extent, or lack of, connectivity for nesting female green turtles between Sandy Islet and Browse Island within and between nesting seasons <i>via</i> a capture-mark-recapture program. Quantifying the current level of connectivity between these two sites throughout the baseline monitoring period will demonstrate whether Browse Island is currently used as an alternative nesting site within-seasons by Sandy Islet nesters, and also allow for potential shifts in G-ScBr nesting activity from Sandy Islet to Browse Island as a result of Project-associated activities to be detected and assessed. Flipper and PIT tagging are therefore necessary to determine baseline levels of female G-ScBr nester fidelity to monitoring sites and to capture current natural population-scale variation in connectivity between Sandy Islet and Browse Island prior to the construction and operational phases of the Project.
To quantify the sea-finding behaviour of adult green turtles nesting at Sandy Islet under ambient light conditions (KC2).	Artificial light is known to impact the sea-finding behaviour of hatchling marine turtles and other marine fauna (Commonwealth of Australia 2020). While the impact of artificial light on the sea-finding behaviour of adult marine turtles remains poorly understood, characteristics of adult female G-ScBr turtle tracks can be quantified during the baseline monitoring period of the GTMP in order to assess

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

	<p>potential impacts of Project-associated artificial lighting on this cohort of the stock during construction and operational phases of the Project. Without capturing this data during the baseline monitoring period, the potential impact of artificial lighting on nesting adult female green turtles at Sandy Islet will not be able to be detected or assessed.</p>
<p>To quantify nest success for G-ScBr turtles (KC3)</p>	<p>An understanding of baseline egg hatching and hatchling emergence success (collectively, incubation success) at Sandy Islet relative to Browse Island is necessary to detect and assess the impact to the G-ScBr stock of reduced nesting habitat availability and/or the shift of Sandy Islet nesters to Browse Island as a result of Project-associated activities or changes to Sandy Islet nesting habitat.</p>
<p>Quantify the sea-finding behaviour of hatchling G-ScBr turtles under ambient lighting conditions (KC4).</p>	<p>Arena trials allow for the baseline sea-finding behaviours of hatchling marine turtles to be quantified under controlled experimental conditions and with respect to the surrounding lighting environment. Given the recognised potential for Project-associated artificial lighting to cause mis- and dis-orientation in G-ScBr hatchlings at Sandy Islet, arena trials must be conducted throughout the baseline monitoring period under ambient lighting conditions in order to provide a reference dataset for future arena trial monitoring outputs to be compared to following the introduction of artificial light into the landscape during the construction and operational phases.</p>
<p>Predict the localised dispersal pathway of virtual hatchling turtles and the environmental conditions that increase their likelihood of interaction with Project-related infrastructure (KC5).</p>	<p>Recording the dispersal and movement patterns of hatchling marine turtles once they enter the sea remains challenging as their small size prohibits the use of satellite transmitters. It remains important, however, to quantify their in-water dispersal in order to assess the likelihood of hatchlings interacting with Project-related infrastructure. In the place of satellite transmitters, an oceanographic modelling system and particle tracking platform by will be used to simulate the dispersal of green turtle hatchlings from Sandy Islet. The model will also have adequate spatial and temporal resolution to predict dispersal pathways under different environmental conditions (e.g., spring/neap tide, high water/low water, El Niño/La Niña conditions, cyclones). Without this modelling process, it would not be possible to accurately estimate the likelihood and frequency of G-ScBr hatchling interactions with Project-associated infrastructure, and how environmental conditions may influence the observed dispersal patterns. Furthermore, the outputs of the dispersal models will inform the design of subsequent field studies involving acoustic receiver arrays.</p>
<p>Quantify the natural dispersal patterns of hatchling G-ScBr turtles under different environmental conditions and validate or refine the distribution of</p>	<p>Uniquely coded acoustic transmitters are small enough in size and weight to be deployed on hatchling marine turtles for in-water tracking (see Thums et al. 2016). Using the outputs of the virtual</p>

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

<p>virtual hatchlings predicted from dispersal models (KC5).</p>	<p>hatchling dispersal modelling, acoustic receivers will be deployed and acoustic transmitters used to passively track the behavioural parameters of G-ScBr hatchlings as they leave Sandy Islet. These movement data are required to ground-truth modelled dispersal patterns for virtual hatchlings and further quantify the in-water dispersal behaviour of G-ScBr hatchlings in order to fully resolve the likelihood of hatchlings from Sandy Islet interacting with Project-associated infrastructure.</p>
<p>Establish a baseline of ambient light conditions that is biologically relevant for marine turtles (KC6).</p>	<p>Light monitoring across the full 360° horizon is required to establish a reliable ambient lighting baseline for future monitoring comparisons and to verify light modelling predictions. These baseline data will also inform the interpretation of adult and hatchling turtle orientation and sea-finding behaviour data in a biologically relevant manner.</p>

5.2 Anthropogenic Light Monitoring

The primary objective of the light monitoring program will be to verify the modelling predictions for drilling (MODU) and FPSO operations as outlined in **Section 3.1.2**. Specifically, the light monitoring program at Sandy Islet will comprise the following two key elements

- Establishing a baseline of ambient light conditions (prior to any project activities) across the lunar cycle during nesting season (refer to KC6 of the Green Turtle Monitoring Program, Section 5.1).
- Determining light intensity (i.e. direct light and sky glow) at Sandy Islet during nesting season during MODU and FPSO operations to verify modelling predictions and determine compliance with performance standards.

The monitoring program will be implemented at Sandy Islet and will employ specialised light monitoring equipment to detect direct light and sky glow visible from the monitoring location across the full 360° horizon. Specific details on the monitoring program (i.e. monitoring locations, techniques, frequency, timing, performance standard threshold criteria, data analysis techniques and reporting requirements) will be described in a specific monitoring program to be developed post FID on the advice of a suitably experienced, independent marine turtle expert.

Light monitoring will also be used to validate modelling predictions, which will be re-run once MODU/FPSO activities commence and MODU details are known.

5.3 Seabed Subsidence Monitoring

An integrated subsidence monitoring approach will be applied where two monitoring techniques will be combined to monitor seabed subsidence at locations across the field:

- 1. Radar Satellite Interferometry (InSAR):** Radar satellite interferometry (InSAR) is a surveying technique that is able to measure the motion of terrain structures over wide areas to a (vertical) resolution of 1 mm. The InSAR technique gives a spatially dense set of geodetic observations of ground surface movement in the viewing geometry of the satellite platform, but with a temporal sampling frequency which is limited to the orbital revisit of the satellite. InSAR can use natural targets (e.g. the rocky and stable surfaces at North/South Scott Reefs when exposed at low tide) however these are limited across the Monitoring Area. Artificial corner reflectors will be installed to supplement the suitable natural targets.
- 2. Global Navigation Satellite System (GNSS):** GNSS measures can provide a temporally dense set of geodetic coordinate observations in three dimensions at a small number of

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

discrete measurement points on the ground. These measurements are recorded at Continuously Operating Reference Stations (CORS) that have an array of passive retroreflectors around it.

These two methods can be integrated to derive more accurate, validated surface displacement estimates with both high temporal and spatial resolution (Fuhrmann *et al* 2018). This is expected to be able to measure local subsidence rates of 1 mm/year LE90w. The actual level of precision will be determined following detailed program design.

5.3.1 Subsidence Monitoring Program;

At a minimum the subsidence monitoring program will include the following;

- To be in place for at least 2 years prior to development of TRD to establish reference information;
- Combination of GNSS monitoring and InSAR monitoring:
 - Involved location of 2 GNSS sites, co-located with corner reflectors notionally up to 8 to be installed at or near Sandy Islet, and at the North Scott Reef edge (a reference point used for subsidence modelling closer to the centre of the field). Control sites will be established outside the hydrocarbon extraction zone, at Northern and Southern Scott Reef;
- Minimum of monthly tasked acquisition of Scott Reef SAR data, by a sensor with a minimum of 5 m pixel size.
- Quarterly reporting on subsidence trends, including trends over the area of subsidence of the 'bowl' predicted as a result of hydrocarbon extraction.
- The latest subsidence trends detected through InSAR monitoring will be incorporated into the 5 yearly updates to the subsidence modelling described in **Table 4-5**.

Further details of this monitoring program are outlined in **Appendix C**. A detailed inSAR execution plan will be developed post FID upon award of program design and execution to specialised monitoring contractors.

This plan will only provide further details such as;

- Where reflectors and GNSS will be located;
- How this equipment will be installed;
- Detailed description of SAR data interrogation and reporting.

5.4 Sandy Islet Morphology Monitoring

Since records are available (1974) the size of Sandy Islet has naturally varied between 1.8 ha and 2.3 ha, a variation of approximately 20%.

Some information is available on the sediment characteristics and indicative sediment budget of Sandy Islet (AIMS 2015). However, a further detailed study of the sediment budget and geomorphological processes of Sandy Islet will be conducted prior to operations commencing so that the design of strategies in the Sandy Islet Habitat Remediation Plan (as per **Section 6.3**) can be validated and refined.

High resolution satellite imagery will be reviewed at least two times per year to monitor the areal extent of available nesting habitat (e.g. land above HAT). These will be compared to historic estimates of available nesting habitat in determining whether corrective actions are required.

6. ADAPTIVE MANAGEMENT

To support adaptive management, three distinct monitoring programs have been proposed in relation green turtles (**Section 5**). These monitoring programs will support adaptive management responses based on:

- Changes in green turtle biologically important behaviours.
- Received light levels at Sandy Islet.
- Changes to availability of Sandy Islet turtle nesting habitat.

6.1 Changes in Green Turtle Biologically Important Behaviours

6.1.1 Triggers and monitoring

The following corrective action triggers are based those in the Gorgon Gas Development and Jansz Feed Gas Pipeline Long-term Marine Turtle Management Plan (Chevron 2018).

Corrective action triggers will be established based on statistical deviations from the baseline conditions for each demographic parameter. During design of the monitoring program, a power analysis will be conducted to determine the statistical power of various deviation bands to detect changes or impacts to demographic parameters related to population viability for the Scott Reef green turtle population.

Dependent on the outcome of the power analysis, each trigger will be represented as a trend towards, or change beyond, a ± 1 , ± 2 , or ± 3 statistical deviation (standard deviation [SD], standard error [SE] or median absolute deviation from median [MAD]) from baseline conditions:

- Alert: A trend towards the ± 1 statistical deviation limit for two consecutive years, or, a change beyond ± 1 statistical deviation from baseline conditions.
- Review: A change beyond ± 2 statistical deviation from baseline conditions.
- Action: A change beyond ± 3 statistical deviation from baseline conditions.

Demographic data will be compared against the corrective action triggers annually as part of the Green Turtle Monitoring Program described in **Section 5.1**.

6.1.2 Management response

The aim of the initial response to activation of any trigger will be to determine whether the cause is attributable to the proposed Browse Project i.e. it cannot be confidently attributed to natural variations in green turtle population trends at genetic stock, regional and national levels. If deemed to be Project-attributable or related to any long term changes in Sandy Islet nesting habitat, the associated response actions will be initiated according to the level of trigger activated. The following action will be initiated in response to each trigger:

- Alert: Conduct an internal investigation of existing data and other relevant information into cause for activation of the management trigger.
 - If the cause is related to a reduction in nesting habitat, then the Sandy Islet Habitat Adaptive Management Response outlined in Section 6.3.2 will be implemented.
- Review: As for Alert, but additionally, conduct risk assessment to identify any potential risk of significant adverse impacts and conduct further data analysis, monitoring or studies if necessary to confirm actual or potential risk of significant adverse impacts.
- Action: As for review, but additionally, conduct a review of existing management measures and, where necessary, propose and implement additional management measures. Actions to offset any significant impacts may be required.

The tiered approach outlined above does not preclude early management action if a trigger is determined to be attributable to a stressor from the proposed Browse Project and/or represents a significant threat to the viability of the Scott Reef green turtle population.

6.2 Received Light Measurements

6.2.1 Triggers and monitoring

The Artificial Light monitoring program outlined in Section 5.2 will be used to monitor received light levels during operations.

The trigger to enact the management response is based on Performance Standard 1 in Table 4-1:

- Received levels of artificial light at Sandy Islet from Browse Project activities (excluding commissioning and emergency flaring events) exceed 0.1 FME.

6.2.2 Management response

Management responses will depend on the cause of the incident and source of the lighting but possible mitigative actions to be considered are as follows;

If the light is associated with a MODU:

- Retrofitting MODU lighting to incorporating best practice lighting design such as applying colour filters to existing lights or light shields to any lights causing excessive light spill.

If the light is associated with Torosa FPSO flaring:

- Improving facility reliability to reduce the occurrence of any unplanned flaring events.

If the light is associated with Torosa FPSO operational lighting:

- Implementing further changes to operational lighting design, such as increasing shrouding on operational lights to reduce sky glow.

6.3 Sandy Islet Habitat Remediation Plan

6.3.1 Triggers and monitoring

The Sandy Islet habitat adaptive management response will be implemented in response to significant changes in green turtle demographic parameters (where cause is attributed to habitat change or loss), higher than expected subsidence at Sandy Islet, or a significant change to Sandy Islet size or morphology beyond historic natural variability.

A holistic review of the green turtle monitoring data, subsidence monitoring (**Section 5.3**) and sandy islet morphology monitoring data will occur annually to assess whether there are any changes to the habitat that could impact green turtle nesting success.

The specific triggers to commence the management response are based on vertical distance of subsidence monitored through subsidence monitoring remains on a trajectory predicted to cause significant loss of habitat for a period of 5 years. An estimate of what magnitude of subsidence may result in a significant change in beach habitat is currently subject to further assessment, and will be established based on the local oceanographic conditions and sediment budget.

Initial triggers and management parameters expected to form part of the plan are included in Appendix E.

6.3.2 Management response

In the event any of these triggers are exceeded, pre-identified response strategies in the Sandy Islet Habitat Remediation Plan will be reviewed to determine if they are appropriate to implement, given the changes detected through physical and biological monitoring programs. This is presented in **Figure 6-1**. Intervention in natural processes through beach nourishment is not without risk, as with any artificial intervention in a natural system. Therefore, the need for beach nourishment should be limited to those circumstances where there is a clearly defined need, in order to not unnecessarily impact on available nesting habitat.

The first step will involve a further review or investigation of the data with support from the relevant experts to understand the potential causes and any interactions between green turtle indicators and habitat data. For example, if revised subsidence modelling or subsidence monitoring results indicate higher subsidence rates than predicted by the modelling, further investigation will be initiated into understanding if there are likely to be any Sandy Islet habitat or biological effects. Recent weather events will also be reviewed, for example, if habitat loss can be directly attributed to a recent cyclone and there is confidence that the Islet is likely to recover naturally, intervention may not be appropriate.

A set of pre-identified habitat remediation strategies will then be assessed using a ‘Net Environmental Benefit Analysis’ (NEBA) format to assess whether any of the pre-identified habitat remediation strategies should be enacted based on the risk (i.e. will the intervention cause other impacts), and benefit (i.e. will the intervention improve or halt the impacts observed through monitoring).

Browse Project – Sandy Islet Habitat Remediation Plan

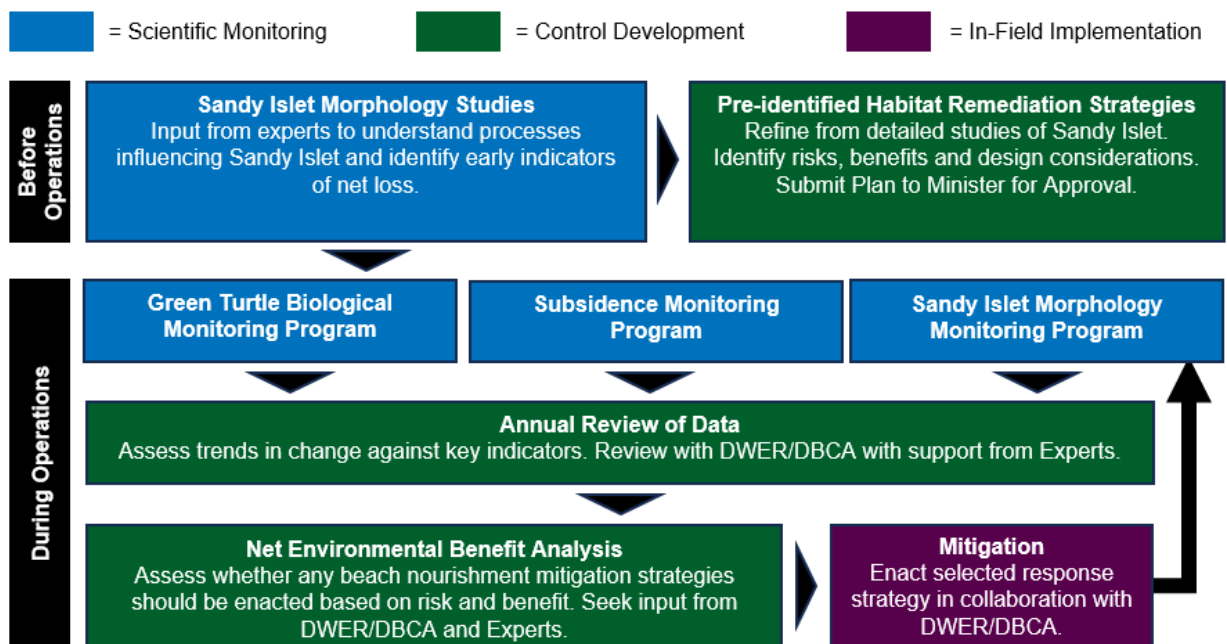

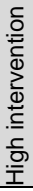


Figure 6-1 Overview of Sandy Islet Habitat Remediation Plan Concept

A set of pre-identified remediation strategies is presented in **Table 6-1**. These include beach reprofiling (moving sand within Sandy Islet), beach nourishment (adding sand to Sandy Islet) and shore face nourishment (adding sand to the reef platform allowing natural accretion onto Sandy Islet). The list and detail of the pre-identified habitat remediation strategies will continue to be refined based on new information, and following a detailed study on the sediment budget of Sandy Islet. Any intervention will be carefully planned, with measures in place to reduce impacts to as low as reasonably practicable. Monitoring will also occur following any beach nourishment activities, as

outlined in **Section 5.1.2**. This will be outlined in a Sandy Islet Habitat Remediation Plan that will be submitted to the Minister for approval prior to operations commencing.

Table 6-1 Pre-identified Sandy Islet habitat remediation strategies

	Strategy	Feasibility	Benefits	Risks/Impacts	Mitigations
low intervention 	Protection				
	Beach scraping/reprofiling of Sandy Islet Mechanical movement of small to medium quantities of sand from the intertidal zone around Sandy Islet to the upper beach of Sandy Islet ¹ .	Reprofiling was successfully completed at Raine Island to improve the area of turtle nesting habitat (Smithers and Dawson 2023), without need for repeating activities in the same area ² . Raine Island is slightly larger than Sandy Islet so there may not be sufficient sand available on Sandy islet. More appropriate if slope/shape changes, rather than size.	Sand does not need to be imported into the local system ¹ . Simple, low cost method for restoring a beach following storms ¹ .	Sufficient sand reserves are needed for the scraping to successfully increase nesting area ¹ . Use of dozers or excavators on Sandy Islet ¹ .	Timing to avoid covering nests and direct and indirect impacts to nesting turtles or eggs.
	Shore face nourishment: from Donor site to Scott Reef Central Relocate sand from donor location outside of Scott Reef Central and deposit onto the Scott Reef Central flat	Could be undertaken without the need for a vessel to enter the shallow waters of Scott Reef Central & the flats around Sandy Islet. Sediment characteristics studies of Sandy Islet indicated that all sediment on Sandy Islet is produced from marine life within the Scott Reef Central platform, suggesting that additional sand added to the platform would accumulate at Sandy Islet.	Does not require placement of sand directly onto Sandy Islet and allows sand to accumulate on Sandy Islet naturally. Scale is large enough to offset impacts of extreme erosion events and sea level rise ¹ . Variety of dredger types and placement techniques available to minimise impacts ¹ .	Fauna entrainment during dredging ⁵ . Risk of translocating species from a donor location to Scott Reef Central Construction vessel presence within proximity of Sandy Islet and other Scott Reef locations (e.g. donor site) ¹ Physical impacts to borrow area ¹ .	Sediment transport studies required to ensure small scale changes to bathymetry don't result in other impacts ¹ . Timing to avoid sensitive interesting periods for turtles who inhabit the platform area around Sandy Islet.
High intervention 	Beach nourishment: within Scott Reef Central to Sandy Islet Relocate sand from a donor location on the Scott Reef Central flat or East Hook and deposit onto Sandy Islet	Requires additional vessel intervention and logistics, but modest volumes of sand are within scale means minimal heavy equipment required.	Scale is large enough to offset impacts of extreme erosion events and sea level rise ¹ . Variety of dredger types and placement techniques available to minimise impacts ¹ .	Fauna entrainment during dredging ⁵ . Construction vessel presence within proximity of Sandy Islet and other Scott Reef locations (e.g. donor site) ¹	Sediment transport studies required to ensure small scale changes to bathymetry don't result in other impacts ¹ . Matching the existing beach profile to ensure there are no

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

			<p>Likely to increase nesting habitat availability and total number of nests³</p>	<p>Physical impacts to borrow area¹. Decreased nesting and hatching success as a result of beach compaction, altered nest-chamber geometry, nest concealment, nutrient availability³ Potentially shallower nests⁴</p>	<p>significant effects on beach selection by female turtles³ Matching the existing beach profile to ensure there are no significant effects on beach selection by female turtles. Design considers important physical characteristics for marine turtles including sand characteristics, beach compaction, moisture content, mineral content, porosity/gas diffusion³ Timing to avoid covering nests and direct and indirect impacts to nesting turtles. Ensure sediment grain size and composition is comparable⁵. Apply sediment criteria from US Army Corps of Engineers⁵</p>
	<p>Beach nourishment: from Donor site to Sandy Islet Dredge sand from a donor location outside Scott Reef Central and deposit onto Sandy Islet</p>	<p>Requires additional vessel intervention and logistics, but modest volumes of sand are within scale means minimal heavy equipment required.</p>	<p>Scale is large enough to offset impacts of extreme erosion events and sea level rise¹. Variety of dredger types and placement techniques available to minimise impacts¹. Likely to increase nesting habitat availability and total number of nests³</p>	<p>Fauna entrainment during dredging⁵. Construction vessel presence within proximity of Sandy Islet and other Scott Reef locations (e.g. donor site)¹ Physical impacts to borrow area¹. Decreased nesting and hatching success as a result of beach compaction, altered nest-chamber geometry, nest concealment, nutrient availability³ Potentially shallower nests⁴</p>	<p>Matching the existing beach profile to ensure there are no significant effects on beach selection by female turtles. Design considers important physical characteristics for marine turtles including sand characteristics, beach compaction, moisture content, mineral content, porosity/gas diffusion³ Timing to avoid covering nests and direct and indirect impacts to nesting turtles. Ensure sediment grain size and composition is comparable⁵. Apply sediment criteria from US Army Corps of Engineers⁵</p>

Information sources:

1. [Sand Nourishment Guidelines Science and Synthesis for NSW](#)
2. Smithers and Dawson 2023
3. Crain et al. 1995
4. Fletemeyer 1983
5. Pendoley Technical Note

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

BD0006AH0000008

Rev
5

Page 72 of 92

Uncontrolled when printed. Refer to electronic version for most up to date information.

7. REPORTING

The results of the monitoring programs will be routinely reported internally. External reporting will be undertaken in line with the subsequent approval decision and following any incident or non-compliance of performance standards as determined by the monitoring.

Reviews of the monitoring data and resultant recommendations will be undertaken by suitably qualified marine turtle experts.

A summary of the reporting requirements is provided below in **Table 7-1**.

Table 7-1 Summary of reporting

Report	Recipient	Details	Frequency
Lighting in design report	DWER and DCCEEW	Results demonstrating application of best practice lighting design to FPSO	Once, prior to FPSO construction.
Baseline Turtle Monitoring Report Baseline Light Monitoring Report	Published online DWER and DCCEEW	Results of monitoring programs with reporting and discussion on the separate monitoring scopes (i.e., Light, green turtles and seabed subsidence).	Annually Five yearly summary report.
Annual Subsidence Monitoring Report	Published online DWER and DCCEEW	Results of subsidence monitoring	Annually
Sandy Islet Morphology Monitoring Report	Published online DWER and DCCEEW	Results of Sandy Islet morphology monitoring outcomes.	Five yearly or earlier if management triggers exceeded.
Annual vessel & MODU activity reports	DWER and DCCEEW	Summarises of all vessel activity, including records of locations in which activity occurred and implementation of management actions as required.	Annually following commencement of construction
Incident Reports	DWER and DCCEEW	Incident reporting.	As necessary
Annual Turtle Management Plan Compliance Reports	DWER and DCCEEW	Annual compliance review against commitments within this plan	Annually

8. PLAN REVIEW

The plan will be reviewed on an annual basis to ensure the proposed measures and objectives continue to be met. In addition, a review process will be initiated following a non-compliance of the performance standards, in accordance with the adaptive management framework outlined in **Section 6**.

9. REFERENCES

Brock, KA., Reece, JS., Ehrhart, LM. 2007. The effects of artificial beach nourishment on marine turtles: Differences between Loggerhead and Green Turtles. *Restoration Ecology*, 9: 304-310.

Burgman, m. (2005). *Risks and decisions for conservation and environmental management*. Cambridge university press.

Burgman, m., carr, a., godden, l., gregory, r., mcbride, m., flander, l., & maguire, l. (2011). Redefining expertise and improving ecological judgment. *Conservation letters*, 4(2), 81-87.

Commonwealth of Australia, 2017a. *Recovery plan for marine turtles in Australia 2017-2027*. Department of the Environment and Energy, Canberra.

ConocoPhillips, 2019. *Barossa Area Development Offshore Project Proposal*. ConocoPhillips Australia.

Collins, L., Testa, V., Zhao, J., 2009. *Quaternary growth history and evolution of the Scott Reef carbonate platform and coral reef: core study* (Produced for Woodside Energy Ltd). Curtin University of Technology.

Commonwealth of Australia (2023). *National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds*.

Crain, Drew & Bolten, AB & Bjornda, KA. (1995). Effects of Beach Nourishment on Sea-turtles – Review and Research Initiatives. *Restoration Ecology*. 3. 95-104.

Cruz, I.m., Shillinger, G.I., Robinson, n.j., tomillo, p.s. & paladino, f.v. (2018) effect of light intensity and wavelength on the in-water orientation of olive ridley turtle hatchlings. *Journal of experimental marine biology and ecology*, 505, 52 – 56.

CGSS, 2012. *Review of Reports on possible Subsidence at Scott Reef: Torosa Field*.

Department of the Environment and Energy, 2019b. *Biologically important areas of regionally significant marine species [WWW Document]*. Department of the Environment and Energy. URL <http://www.environment.gov.au/> (accessed 3.19.19).

Dethmers KE, Broderick D, Moritz C, Fitzsimmons NN, Limpus CJ, Lavery S, Whiting S, Guinea M, Prince RI, Kennett R. (2006). The genetic structure of Australasian green turtles (*Chelonia mydas*): exploring the geographical scale of genetic exchange. *Molecular Ecology* 15: 3931-3946.

Thums M, Whiting SD., Reisser J, Pendoley KL., Pattiaratchi CB., Proietti M, Hetzel Y, Fisher R and Meekan MG (2016). Artificial light on water attracts turtle hatchlings during their near shore transit. *R. Soc. open sci.* 3:160142

Ferreira, L. C., Thums, M., Fossette, S., Wilson, P., Shimada, T., Tucker, A. D., Pendoley, K., Waayers, D., Guinea, M. L., Loewenthal, G., King, J., Speirs, M., Rob, D., & Whiting, S. D. (2021). Multiple satellite tracking datasets inform green turtle conservation at a regional scale. *Diversity and Distributions*, 27(2), 249-266.

Ferretti, Alessandro, Savio, Giuliano, Barzaghi, R., Borghi, Alessandra, Musazzi, Sergio, Novali, Fabrizio, Prati, Claudio Rocca, Fabio (2007) *Submillimeter Accuracy of InSAR Time Series: Experimental Validation - Geoscience and Remote Sensing*, IEEE Transactions on Geoscience and Remote Sensing.

Fletemeyer, J.R. 1983, *Sea turtle Monitoring Report*, Nova University Oceanographic Centre Dania, Florida.

Guinea, M.L., 2009. *Long Term Marine Turtle Monitoring at Scott Reef*. Report prepared for Woodside Pty Ltd.

Gilmour, James, Smith, L., Pincock, S., Cook, K., 2013. *Discovering Scott Reef: 20 years of exploration and research*. Australian Institute of Marine Science, Townsville

- Guinea, M., 2010. Long term monitoring of the marine turtles of Scott Reef: February 2010 field survey report. Charles Darwin University, Darwin.
- Guinea, M.L., 2011. Long Term Monitoring of the Marine Turtles of Scott Reef Satellite Tracking of Green Turtles from Scott Reef #1.
- Guinea ML (2013) Surveys of the Sea Snakes and Sea Turtles on Reefs of the Sahul Shelf. Monitoring Program for the Montara Well Release Timor Sea, Monitoring Study S6 Sea Snakes / Turtles. Draft Final Report 2012-2013. 91 pp.
- Hays, G.C., Adams, C.R., Broderick, A.C., Godley, B.J., Lucas, D.J., Metcalfe, J.D. and Prior, A.A (1999). The diving behaviours of green turtles at Ascension Island. *Animal Behaviours* 59: 577-586.
- Hughes, B., 2012. A Review of Analytical Compaction and Subsidence Modelling - First Order Analytical Estimates of Scott Reef Subsidence as a result of Reservoir Compaction in the Torosa Field, Browse Basin. Report prepared for Woodside Pty Ltd.
- Jensen MP (2010) Assessing the composition of green turtle (*Chelonia mydas*) foraging grounds in Australasia using mixed stock analyses. PhD Dissertation, University of Canberra.
- Kamrowski, r.l., limpus, c., pendoley, k. & hamann, m. (2014) influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings. *Wildlife research* 41 (5), 421-434.
- Karnad, d., isvaran, k., chandrasekhar, s.k. & shanker, k. (2009) lighting the way: towards reducing misorientation of olive ridley hatchlings due to artificial lighting at rushikulya, india. *Biological conservation*, 142, 2083 – 2088.
- Mrosovsky, n. & shettleworth, s.j. (1968) wavelength preferences and brightness cues in the water finding behaviour of sea turtles. *Behaviour*, 32, 211-257.
- Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., Podesta, M., 2001. Collisions between ships and whales. *Marine Mammal Science* 17, 35-75.
- Limpus CJ (1993) The green turtle, *Chelonia mydas*, in Queensland: breeding males in the southern Great Barrier Reef. *Wildlife Research* 20, 513-523.
- Limpus, c.j. & kamrowski, r.l. (2013) ocean-finding in marine turtles: the importance of low horizon elevation as an orientation cue, *behaviour*, 150, 863-893.
- Limpus CJ and Nicholls N (1994) Progress report on the study of the interaction of the El Nino Southern oscillation on annual *Chelonia mydas* numbers at the southern Great Barrier Reef rookeries. Proceedings of the Australian Marine Turtle Conservation Workshop, Gold Coast, Queensland, Nov.1990. Queensland. Dept. Environment & Heritage: 73-78.
- Limpus, C.J., Parmenter, C.J. & Chaloupka, M. (2013) Monitoring of coastal sea turtles: Gap analysis 5. Flatback turtles, *Natator depressus*, in the Port Curtis and Port Alma region. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program.
- Limpus CJ and Nicholls N (1988) The southern oscillation regulates the annual numbers of green turtles (*Chelonia mydas*) breeding around Northern Australia. *Australian Journal of Wildlife Research* 15: 157-161.
- Lohmann, k.j., witherington b.e., lohmann c.m.f. & salmon m. (1997) orientation, navigation, and natal beach homing in sea turtles, in the biology of sea turtles. Volume i, p.l. Lutz and j.a. Musick, editors., crc press: washington d.c. P. 107-135.
- Lohmann, K.J., Lohmann, C.M.F., 1998. Migratory Guidance Mechanisms in Marine Turtles. *Journal of Avian Biology* 29, 585. <https://doi.org/10.2307/3677179>
- Lohmann, K.J., Lohmann, C.M.F., 1992. Orientation to Oceanic Waves by Green Turtle Hatchlings. *Journal of Experimental Biology* 171, 1–13.

- Miller J. D., Limpus C. J., Godfrey M. H. (2003). Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead turtles. In *Loggerhead sea turtles* (eds Bolten A. B., Witherington B. E.), pp. 125–143 Washington, DC: Smithsonian Press.
- Nagel, N.B., 2001. Compaction and subsidence issues within the petroleum industry: From Wilmington to Ekofisk and beyond. *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy* 26, 3–14.
- Olsen YS, Bessey C, McLaughlin J, and Keesing J (2017). 2017 Annual Report: Patterns in primary producers, herbivory and reef metabolism around Browse Island. Shell/INPEX ARP7-2 Milestone 2017 Report #2. 69 pp.
- Patterson, j., meek, m. E., strawson, j. E., & liteplo, r. G. (2007). Engaging expert peers in the development of risk assessments. *Risk analysis: an international journal*, 27(6), 1609-1621.
- Pendoley, KL 2005, *Sea Turtles and the Environmental Management of Industrial Activities in North West Western Australia*, PhD Thesis, Murdoch University, Australia, pp. 310.
- Pendoley Environmental 2020. Proposed Browse Project Desktop Lighting Assessment. Unpublished Report, prepared by Pendoley Environmental for Jacobs, May 2020. 38 pp.
- Pendoley environment (2021a) literature review: thresholds of artificial light and marine turtle hatchling. A report prepared on behalf of Jacobs
- Pendoley environment (2021b) Woodside Browse Light Modelling. A report prepared on behalf of Jacobs
- Pendoley, k.l. & kamrowski, r.l. (2015) influence of horizon elevation on the sea-finding behaviour of hatchling flatback turtles exposed to artificial light-glow. *Marine ecology progress series*, 529, 279-288.
- Price, j.t., drye, b., donague, r.j. & paldino, f.v. (2018) exploring the role of artificial lighting in loggerhead turtle (*Caretta caretta*) nest-site selection and hatchling disorientation. *Herpetological conservation and biology*, 13(2), 415 – 422.
- Rumbold, DG., Davis, PW., Perretta, C. 2001. Estimating the effect of beach nourishment on *Caretta caretta* (Loggerhead Sea Turtle) nesting. *Restoration Ecology*: 9(3), 304-310.
- Stancyk, S. E. (1982). Non-human predators of sea turtles and their control. In 'Biology and Conservation of Sea Turtles'. (Ed. K. A. Bjorndal.) pp. 139–152. (Smithsonian Institution Press: Washington, DC.)
- Salmon, m., wyneken, j., fritz, e. & lucas, m. (1992) seafinding by hatchling sea turtles: role of brightness, silhouette and beach slope as orientation cues. *Behaviour*, 122, 56 – 77
- Salmon, m. (2003) artificial night lighting and sea turtles. *Biologist*, 2003 (50), 163-168.
- Smithers, S.S (2015) Sediment Texture and Composition at Sandy Islet, Scott Reef. Prepared for: Australian Institute of Marine Science (Western Australia).
- SLB, (2024), 3D Geomechanical Modelling to Estimate Production Induced Subsidence at Torosa Field, Browse Basin. Prepared for Woodside Energy.
- Solow, A.R., Bjorndal, K.A. and Bolten, A.B. (2002), Annual variation in nesting numbers of marine turtles: the effect of sea surface temperature on re-migration intervals. *Ecology Letters*, 5: 742-746.
- Tucker, T., Fossette, S., Whiting, S., Rob, D., & Barnes, P. (2020). Internesting and migrations by marine turtles of the Muiron Islands and Ningaloo Final Report. Prepared for Woodside Energy Limited. Department of Biodiversity, Conservation and Attractions, Perth.
- Thums M, Whiting SD., Reisser J, Pendoley KL., Pattiaratchi CB., Proietti M, Hetzel Y, Fisher R and Meekan MG (2016). Artificial light on water attracts turtle hatchlings during their near shore transit. *R. Soc. open sci.* 3:160142

- Witherington, b. & martin, r.e. (2003) understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches. Florida fish and wildlife conservation commission fmri technical report tr-2: jensen beach, florida. P. 84.
- Waayers D, Smith LM and Malseed BE (2011) Inter-nesting distribution of green turtles (*Chelonia mydas*) and flatback turtles (*Natator depressus*) at the Lacepede Islands, Western Australia. Journal of the Royal Society of Western Australia 94: 359-364.
- Witherington, B.E., Bjorndal, K.A., 1991. Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles *Caretta caretta*. Biological Conservation 55, 139–149.
- White, N.J., Haigh, I.D., Church, J.A., Koen, T., Watson, C.S., Pritchard, T.R., Watson, P.J., Burgette, R.J., McInnes, K.L., You, Z.J., Zhang, Z., 2014. Australian sea levels—Trends, regional variability and influencing factors. Earth-Science Reviews 136, pp.155-174.
- Whiting S, Tucker T, Pendoley K, Mitchell N, Bentley B, Berry O, FitzSimmons N (2018). Final Report of Project 1.2.2 prepared for the Kimberley Marine Research Program, Western Australian Marine Science Institution, Perth, Western Australia, 146 pp.
- Whiting SD and Guinea M (2005) The Sea Turtles of Ashmore Reef. Report prepared for the Commonwealth Department of Environment and Heritage. Biomarine International. pp 172.
- Whitlock P.A, Pendoley K.L. & Hamann, M. (2014) Internesting distribution of flatback turtles (*Natator depressus*) and industrial development in Western Australia. Endangered Species Research, 26: 25-38.
- Woodside, 2012. First Order Analytical Estimates of Scott Reef Subsidence as a result of Reservoir Compaction in the Torosa Field, Browse Basin, Browse Reservoir Development Team.
- Wyneken, J. and Salmon, M. (1992). Frenzy and post frenzy swimming activity in loggerhead, green and leatherback hatchlings sea turtles. Copeia 2, 478-484.

APPENDIX A WOODSIDE BROWSE LIGHT MODELLING REPORT (PENDOLEY ENVIRONMENT 2022)

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Controlled Ref No: BD0006AH0000008

Revision: 5

Page 78 of 92

Uncontrolled when printed. Refer to electronic version for most up to date information.

JACOBS

WOODSIDE BROWSE LIGHT MODELLING



Prepared by

Pendoley Environmental Pty Ltd

For

Jacobs

9th June 2022



**PENDOLEY
ENVIRONMENTAL**

MARINE CONSERVATION
ENVIRONMENTAL SERVICES

DOCUMENT CONTROL INFORMATION

TITLE: WOODSIDE BROWSE LIGHT MODELLING

Disclaimer and Limitation

This report has been prepared on behalf of and for the use of Jacobs. Pendoley Environmental Pty Ltd. takes no responsibility for the completeness or form of any subsequent copies of this Document. Copying of this Document without the permission of Jacobs is not permitted.

Document History

Revision	Description	Date received	Date issued	Personnel
Draft	Report Draft		27/08/2021	A. Mitchell / E. Charlton
Rev IA	Internal Review	27/08/2021	27/08/2021	K. Pendoley
Rev A	Client Review	27/08/2021	07/09/2021	D. Stone, A. McDonald, J. Colman
Rev B	Comments Addressed	07/09/2021	16/09/2021	A. Mitchell
Rev 0	Final report issued	18/11/2021	18/11/2021	A. Mitchell
Rev 1	Additional scenario	14/02/2022	04/02/2022	A. Mitchell / E. Charlton / K. Pendoley
Rev 2	Additional scenarios	27/04/2022	09/06/2022	A. Mitchell / E. Charlton / K. Pendoley
Rev 3	Address client comments	13/07/2022	18/07/2022	A. Mitchell / E. Charlton / K. Pendoley

Printed:	18 July 2022
Last saved:	18 July 2022 09:32 AM
File name:	P:\06 Projects\J67 Jacobs\05 Programs\J67005 Browse Light Modelling\03 Technical Reports
Author:	Adam Mitchell
Project manager:	Adam Mitchell
Name of organisation:	Pendoley Environmental Pty Ltd
Name of project:	Browse Light Modelling
Client	Jacobs
Client representative:	Arne De Vos
Report number:	J67005
Cover photo:	Pendoley Environmental

EXECUTIVE SUMMARY

Woodside Energy Limited (Woodside), is proposing to develop the Browse hydrocarbon resource located in the Brecknock, Calliance, and Torosa reservoirs. The Torosa reservoir is located near Sandy Islet within the Scott Reef complex and is identified as sensitive turtle nesting habitat for green turtles, while the surrounding waters may also be used by leatherback (*Dermochelys coriacea*), flatback (*Natator depressus*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*) and loggerhead (*Caretta caretta*) turtles.

Pendoley Environmental (PENV) undertook artificial light modelling of the proposed Torosa Floating Production Storage and Offloading (FPSO) and Mobile Offshore Drilling Unit (MODU) facilities, that will be located within 30 km of Sandy Islet, to predict if there will be any impacts to hatchling marine turtles as a result of light emissions from the facilities. A total of 24 scenarios were modelled, covering five flaring types and five cloud/sky conditions. Eighteen of these 24 scenarios were then analysed as best and worst cases of Individual and Cumulative lighting scenarios.

Results from the Individual Scenarios (IS) modelled showed Orientation FOV (OFOV) Full Moon Equivalent (FME) light intensity values correlated strongly with flaring rates and the associated changes in sky glow extent, with the brightest values generated in IS4A (0.041 FME; Impact Level 2), and decreasing in IS3A (0.031 FME; Impact Level 2), IS2A (0.009 FME; Impact Level 1) and IS1A (0.004 FME; Impact Level 1). When these scenarios are influenced by cloud, these values increase substantially with IS1B increasing by 238% (0.010 FME; Impact Level 2), and IS4B increasing by 377% (0.156 FME; Impact Level 3).

In IS5 and IS6 the MODU is visible from Sandy Islet as a point source of direct light on the horizon, with the visibility of the TRD site (IS5) marginally greater than the TRA site (IS6) due to its shorter distance from Sandy Islet. As there is no flaring at the TRD site, there is very little sky glow (0.001 FME; Impact Level 1). Flaring from the MODU at the TRA site increases the extent of sky glow substantially to 0.020 FME (Impact Level 2), which is approximately 18 times brighter than the non-flaring MODU at the TRD site.

In the Cumulative Scenarios (CS) the combination of flaring from both the FPSO and MODU at TRA caused an increase in light received by the sensitive receptor at Sandy Islet. The brightest OFOV values were generated in CS4A (0.065 FME; Impact Level 2), and decreasing in CS3A (0.054 FME; Impact Level 2), CS2A (0.030 FME; Impact Level 2) and CS1A (0.006 FME; Impact Level 1). Similar to the Individual Scenarios, cloud coverage increased OFOV values by 202% in CS1B (0.012 FME; Impact Level 2) and moved CS2B (0.103 FME; 344%), CS3B (0.192 FME; 356%) and CS4B (0.246 FME; 364%) to Impact Level 3.

The predicted impacts of the modelled Scenarios with continuous impacts on marine turtles were assessed as 'no expected impact'. However, modelled Scenarios that may intermittently affect a given turtle nesting season ranged from "no expected impact" to "unlikely impact", and "possible impact".

In accordance with the approach outlined in the National Light Pollution Guidelines, PENV recommend the following biological and light monitoring programs be implemented to confirm these predictions and to provide a basis for adaptive management as required:

- Ground-truth the modelled results by measuring light from the facilities (or equivalent).
- Monitor the biological response of hatchlings at Sandy Islet during commissioning, flaring and operations.
- Monitor the water around vessels and facilities during commissioning and operations to confirm if hatchlings are aggregating around the FPSO, MODUs or associated vessels.

Table 1: Impact Level 1 – Continuous Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
<p>1) FPSO 2) IS1A; CS1A 3) Continuous throughout 44-year project life 4) ~29 km</p> <p>1) MODU (TRD) 2) IS5 3) 18 months at given TR site. 4) ~20 km</p>	<p>IS1A – 0.004 FME Figure 4a CS1A – 0.009 FME Figure 9a IS5 – 0.001 FME Figure 8a</p>	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. 	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) indicates the facilities will appear as a small area of dim glow within the orientation FOV, which is not likely to have any impact on hatchlings during sea-finding. In the absence of dunes/topographic features, hatchlings may orient towards artificial light source rather than ocean horizon. Behavioural response may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected decreases with distance to shore. Light sources located from ~20 - 29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be very low, and few individuals will be at risk of attraction Surface currents at Scott Reef will carry hatchlings on, and in the direction, of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will either reach or be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

Table 2: Impact Level 1 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
1) FPSO 2) IS2A 3) Flaring Intermittently 4) ~29 km	IS2A – 0.009 FME Figure 5a	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. Flaring may occur intermittently during one nesting season. 	<p>No impact predicted</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) indicates the facility will appear as a small area of dim glow within the orientation FOV, which is not likely to have any impact on hatchlings during sea-finding. In the absence of dunes/topographic features, hatchlings may orient towards artificial light source rather than ocean horizon. Behavioural response may result in hatchlings taking a longer route to the ocean. Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence. Duration and rate of flaring is difficult to predict but it is likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under different flaring conditions will not be a static long term stressor impacting all emerging hatchlings across an entire nesting season. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected decreases with distance to shore. Light sources located from ~20-29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be very low, and few individuals will be at risk of attraction Surface currents at Scott Reef will carry hatchlings on, and in the direction, of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will either reach or be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

Table 3: Impact Level 2 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
<p>1) FPSO 2) IS3A, IS4A, IS1B, IS2B 3) Flaring and overcast intermittently 4) ~29 km</p> <p>1) MODU 2) IS6 3) Flaring intermittently 4) ~20 km</p> <p>1) FPSO + MODU 2) CS1B, CS2A, CS3A, CS4A 3) Flaring intermittently 4) ~20-29 km</p>	<p>IS1B - 0.010 FME Figure 4b</p> <p>IS2B - 0.029 FME Figure 5b</p> <p>IS3A – 0.031 FME Figure 6a</p> <p>IS4A – 0.041 FME Figure 7a</p> <p>IS6 – 0.020 FME Figure 8b</p> <p>CS1B – 0.012 FME Figure 9b</p> <p>CS2A – 0.030 FME Figure 10a</p> <p>CS3A – 0.054 FME Figure 11a</p> <p>CS4A – 0.065 FME Figure 12a</p>	<p>No impact predicted</p> <ul style="list-style-type: none"> • The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a small area of dim glow low on the horizon, which will have no impact on nesting females. • Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. • Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. • Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. • Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. • Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts, depending upon the intensity. • Flaring may occur intermittently during one nesting season. 	<p>Light and light glow highly visible, behavioural impact unlikely</p> <ul style="list-style-type: none"> • In absence of dunes/topographic features, hatchlings may orient towards artificial light source and sky glow which might be along the islet rather than directly towards the ocean horizon and may result in disorientation behaviour where hatching crawl in circles while trying to orient themselves. • Behavioural misorientation and disorientation responses may result in hatchlings taking a longer route to the ocean. • Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. • Maximum predicted continuous flaring could potentially result in all clutches within a season being exposed to artificial light (weeks). • Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of 	<p>Light and light glow highly visible, behavioural impact unlikely</p> <ul style="list-style-type: none"> • Potential for hatchling dispersal behaviour to be affected decreases with distance from shore. • Light sources located ~20-29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be low, and few individuals will be at risk of attraction. • Surface currents at Scott Reef will carry hatchlings on and in the direction of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. • Therefore, it is unlikely that large numbers of hatchlings will be attracted to the facility. • Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	<p>No impact predicted</p> <ul style="list-style-type: none"> • Marine turtles do not use light cues to guide breeding behaviours. • No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. • Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. • Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

			<p>light sources, and lunar phase at emergence.</p> <ul style="list-style-type: none">• Cloud cover and thickness is dynamic and will vary with time leading to a range of potential exposure conditions and impacts that are a function of the duration and rate of flaring and difficult to predict but are likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under clouds will not be a static, long-term stressor impacting all emerging hatchlings across an entire nesting season.		
--	--	--	--	--	--

Table 4: Impact Level 3 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.

1. Vessel / facility 2. Scenario code 3. Duration of impact 4. Distance from Sandy Islet	Scenario code Orientation FOV (FME) Figure #	Life history stage / behaviour and impact pathway			
		Nesting	Hatchling sea finding	Hatchling dispersal	Mating / Internesting / Foraging / Migration
<p>1) FPSO 2) IS3B, IS4B 3) Intermittent Flaring and intermittent cloud (< 20 days/yr for each) 4) ~29 km</p> <p>1) FPSO + MODU 2) CS2B, CS3B, CS4B 3) Intermittent Flaring and intermittent cloud (< 20 days/yr for each) 4) ~20-29 km</p>	<p>IS3B – 0.116 FME Figure 6b</p> <p>IS4B – 0.156 FME Figure 7b</p> <p>CS2B – 0.103 FME Figure 10b</p> <p>CS3B – 0.192 FME Figure 11b</p> <p>CS4B – 0.236 FME Figure 12b</p>	<p>Minor impact possible</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the light source(s) flare indicates the facility will appear as a broad area of sky glow encompassing the entire field of view of the turtles at right angles to the beach (seaward) and at the horizon. Recovery Plan Action Area A8: It is unlikely an Impact Level 3 level of lighting will cause significant displacement of nesting females from Sandy Islet. Any displacement is expected to be minor, limited to individuals potentially exposed to a very short window of high light levels under heavy cloud. Any females displaced from Sandy Islet are likely to move to nesting beaches on Browse Island, which is the only other known nesting location for the G-ScBr genetic stock. Flaring expected to be limited to 8 – 15 days per year and associated with unplanned upset flaring or well clean up flaring, worst case scenario this occurs during the 17 days of cloudy days reported for the area during the nesting season. Impact is intermittent and limited to one nesting season. 	<p>Light and light glow highly visible, Minor behavioural impact possible</p> <ul style="list-style-type: none"> The modelled radiometric visibility of the worst-case scenario of Major Upset Flaring plus Well Clean Up Flaring at TRA, with cloud cover at 80% and a ceiling height of 10 km (CS4B) shows a bright point source of light on the horizon, and the entire sky illuminated by light. The reflected light and glow extend well beyond the defined orientation FOV box and is almost 4 times brighter than the scenario with no cloud (CS4A). In absence of dunes/topographic features, hatchlings may orient towards artificial light source and sky glow which might be along the islet rather than directly towards the ocean horizon and may result in disorientation behaviour where hatchling crawl in circles while trying to orient themselves. Behavioural misorientation and disorientation responses may result in hatchlings taking a longer route to the ocean. 	<p>Light and light glow highly visible, No behavioural impact predicted</p> <ul style="list-style-type: none"> Potential for hatchling dispersal behaviour to be affected by light decreases with distance from shore. Light sources located ~20-29 km from Sandy Islet. At this range the density of dispersing hatchlings is expected to be low, and few individuals will be at risk of attraction. Surface currents at Scott Reef will carry hatchlings on and in the direction of the tidal flow over extended time frames, reducing the number of hatchlings reaching or aggregating around the facility. Therefore, it is unlikely that large numbers of hatchlings will be attracted to the facility. Following sunrise, any effect of light sources on hatchlings will be eliminated allowing dispersal behaviour to resume. 	<p>No impact predicted</p> <ul style="list-style-type: none"> Marine turtles do not use light cues to guide breeding behaviours. No evidence, published or anecdotal, suggests that internesting turtles are impacted by light from offshore vessels or installations. Large aggregations of adult foraging turtles are not expected to occur in the vicinity of project vessels and facilities. Potential impacts to the low number of foraging turtles is likely limited to short term behavioural changes in response to prey attraction linked to increased visibility of prey. Light emissions are unlikely to result in displacement of, or behavioural changes to, individuals in these life stages.

		<ul style="list-style-type: none"> • The intensity of the light is between 0.103 and 0.236 FME, so even under the worst-case scenario of Major Upset Flaring plus Well Clean Up Flaring at TRA (CS4B), the illumination will fall in the lower range of a full moon brightness, closer to a quarter moon than a half moon. The number of days in a moon cycle that this high level of sky brightness could exceed the illumination from a half to new moon is 14 days, further reducing the potential number of days turtles could be exposed to high light levels under full cloud during the nesting season. • Spectral output of flares outside peak sensitivity for green turtles, reducing potential for behavioural impacts. • Experienced nesting females considered less vulnerable to effects of light on nest site selection, permanent displacement of these individuals is unlikely. • Neophytes may be more vulnerable to nesting disruption, but no published data is available to substantiate this. • Unknown what level of disruption is tolerable before long-term displacement of neophytes may occur. • Sandy Islet and Browse Island green turtles are from the same genetic stock (G-ScBr) and so should a neophyte be displaced she could potentially move to Browse Island nesting beaches. • Risk of negative impacts to post-nesting sea-finding behaviour considered low, particularly as females are never more than ~30 m from the ocean. • The 5 – 8 year re-nesting interval for green turtles means that only small subset of breeding females could potentially be exposed to this level of brightness in a single season should it overlap with this level of flaring and cloud cover. 	<ul style="list-style-type: none"> • Consequences are expected to be limited to a negligible increase in energy expenditure given the maximum width of the cay is ~60 m and is not expected to result in reduced survival at the population level. • Flaring expected to be limited to 8 – 15 days per year, associated with unplanned upset flaring or well clean up flaring, worst case scenario this occurs during the 17 days of cloudy days reported for the area during the nesting season. Impact is intermittent and limited to one nesting season. • Not all hatchlings exposed to artificial light are expected to be negatively impacted, due to spectral output and orientation of light sources, and lunar phase at emergence and differences in individual visual sensitivities. • Cloud cover and thickness is dynamic and will vary with time leading to a range of potential exposure conditions and impacts that are a function of the duration and rate of flaring and difficult to predict but are likely to be limited to a small proportion of hatchlings emerging at any time, i.e. the increased brightness and extent of sky glow under clouds will not be a static long term stressor impacting all emerging hatchlings across an entire nesting season. • Nests will emerge over 8 – 12 weeks at the peak of the nesting season, a small subset of emerging nests could potentially be exposed to this level of brightness in a single season should it overlap with this level of flaring and cloud cover. 		
--	--	--	---	--	--

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

1 INTRODUCTION..... 1

 1.1 Background 1

 1.2 Scope of Work..... 1

2 METHODOLOGY 2

 2.1 Artificial Light Modelling 2

 2.1.1 Modelling Scenarios 2

 2.1.2 Model Inputs 3

 2.1.3 Model Outputs 6

 2.1.4 Model Assumptions..... 7

 2.1.5 Model Limitations 7

 2.1.6 Literature Review and Impact Criteria..... 7

4 RESULTS AND DISCUSSION 10

 4.1 Individual Scenarios 10

 4.2 Cumulative Lighting Inventories..... 15

 4.3 Potential Impacts 18

 4.3.1 Impact Level 1 (<0.01 FME) 18

 4.3.2 Impact Level 2 (0.01 – 0.1 FME) 18

 4.3.3 Impact Level 3 (0.1 – 1 FME) 19

 4.4 Summary 20

5 REFERENCES..... 21

LIST OF TABLES

Table 1: Impact Level 1 – Continuous Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef. v

Table 2: Impact Level 1 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.vi

Table 3: Impact Level 2 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.vii

Table 4: Impact Level 3 – Intermittent Conditions. Key findings of the artificial light impact assessment for green turtles at Scott Reef.ix

Table 5: Summary of the flares used in the scenarios. The flare rate (in mmscfD), power of flare (in mega-lumens), and expected flare period in number of days per year. 2

Table 6: Summary of the modelled scenarios, the vessel inventory and cloud parameters. 3

Table 7: Location of Sandy Islet observer, FPSO and MODU sites considered in the modelling. 4

Table 8: Potential artificial light impact criteria (marine turtles). 9

Table 9: Orientation FOV values for each scenario, and the corresponding impact levels. 10

LIST OF FIGURES

Figure 1: Location of the Sandy Islet observer viewpoint and facilities considered in the modelling (Torosa FPSO and the MODU at TRA and TRD sites). 5

Figure 2: Example all-sky modelled image from an observer location showing predicted brightness.. 6

Figure 3: Cone of acceptance centred over the brightest light source.. 6

Figure 4: Model outputs for the FPSO – Individual Scenario 1..... 12

Figure 5: Model outputs for the FPSO – Individual Scenario 2..... 12

Figure 6: Model outputs for the FPSO – Individual Scenario 3..... 13

Figure 7: Model outputs for the FPSO – Individual Scenario 4..... 13

Figure 8: Model outputs for the MODU – Individual Scenario 5 and 6 14

Figure 9: Model outputs for the FPSO and MODU – Cumulative Scenario 1..... 16

Figure 10: Model outputs for the FPSO and MODU – Cumulative Scenario 2..... 16

Figure 11: Model outputs for the FPSO and MODU – Cumulative Scenario 3..... 17

Figure 12: Model outputs for the FPSO and MODU – Cumulative Scenario 4..... 17

1 INTRODUCTION

1.1 Background

Woodside Energy Limited (Woodside), as operator for and on behalf of the Browse Joint Venture, is proposing to develop the Browse hydrocarbon resource located in the Brecknock, Calliance, and Torosa reservoirs. The Torosa reservoir is located near Sandy Islet within the Scott Reef complex, identified as sensitive turtle nesting habitat for green turtles in the discrete Scott Reef - Browse Island (G-ScBr) genetic stock, while the surrounding waters may also be used by leatherback (*Dermochelys coriacea*), flatback (*Natator depressus*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*) and loggerhead (*Caretta caretta*) turtles.

A desktop lighting assessment of the Browse project (Pendoley 2020) found that the behavioural response of marine turtles to artificial light is well documented in the scientific literature. The vulnerability of individuals to behavioural impacts is influenced by a number of factors including the properties of the artificial light (including intensity and wavelength), duration of exposure, visibility (e.g., shielding from topography) and the life stage or behaviour being undertaken. Green turtle hatchlings are most sensitive to short wavelength blue light and show preference for wavelengths <600 nm.

Therefore, Woodside requested Pendoley Environmental (PENV) undertake artificial light modelling of their proposed Floating Production Storage and Offloading (FPSO) and Mobile Offshore Drilling Unit (MODU) facilities that will be located within 30 km of Sandy Islet (**Figure 1**) to determine if there will be any impacts to hatchling marine turtles as a result of light emissions from the facilities.

1.2 Scope of Work

Jacobs engaged PENV on behalf of Woodside to conduct artificial light modelling of the Torosa FPSO, and a MODU at the TRD and TRA sites, as viewed from Sandy Islet, under different conditions. Specifically, PENV modelled a total of 24 scenarios, covering five flaring types and five cloud/sky conditions. These scenarios are further divided into Individual Scenarios (IS; containing either the FPSO or MODU in isolation), or Cumulative Scenarios (CS; containing the FPSO and MODU together). Of the 24 scenarios completed, 18 are presented in this report representing best- and worst-case scenarios, with additional scenarios included as **Appendix D**.

PENV also undertook a review of current literature to identify any existing light intensity thresholds for impacts on hatchling marine turtles. (**Appendix C**)

2 METHODOLOGY

2.1 Artificial Light Modelling

Currently, there are no standard commercial models for landscape scale modelling of artificial light emissions (Commonwealth of Australia 2020). Recognising this gap and the growing need to respond to both local and national regulatory concerns over artificial light impacts on wildlife, PENV has invested in considerable research and development effort to develop a landscape-scale artificial light model. This has been recently applied for our Australian oil and gas clients, and for a large-scale development in Saudi Arabia (The Red Sea Development Project).

The base model used for this work was the ILLUMINA model (version 2) that has been developed by Physics Professor Dr Martin Aubé of Sherbrooke University, Canada (Aube et al. 2005). This well-documented, open-source model was selected for its ability to represent light across large areas and distances and equally across the entire visible spectrum, including biologically meaningful light from 350 nm – 700 nm.

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

2.1.1 Modelling Scenarios

Modelling of predicted light emissions visible from the FPSO, MODU at TRD and MODU at TRA was undertaken using a single observer viewpoint on Sandy Islet for all scenarios. All scenarios included standard operational lighting levels based on information provided by Woodside (see **Appendix A**). As changes in flare activity are likely to have the greatest impact on light emissions visible from Sandy Islet, a total of five different flares were modelled (**Table 5**).

Table 5: Summary of the flares used in the scenarios. The flare rate (in mmscfD), power of flare (in mega-lumens), and expected flare period in number of days per year.

Vessel	Flaring Type	Rate (mmscfD)	Power (Mlm)	Period (~d/yr)
FPSO	Background Flaring	1	5.44	335
FPSO	Minor Upset Flaring	25	17.12	15
FPSO	Unplanned Upset Flaring	125	77.48	10
FPSO	Major Upset Flaring	250	104.63	4
MODU	Well Clean Up Flaring	70	35.43	8

The flaring scenarios were separated into three categories:

1. FPSO only: (Individual Scenarios; IS1 – IS6)
2. MODU only (Individual Scenarios; IS5 and IS6)
3. FPSO and MODU together (Cumulative Scenarios; CS1 – CS4)

These scenarios were also run in both clear (A) and cloudy (B) sky conditions and are outlined in **Table 6**.

Table 6: Summary of the modelled scenarios, the vessel inventory and cloud parameters. Where “A” scenarios denote clear conditions and “B” scenarios are in cloudy sky conditions. Operations lighting has been assumed to be on for all scenarios.

Vessel	Vessel Parameters		Scenario Code	Cloud Parameters		
	Inventory	Period (days/yr)		Cover (%)	Height (km)	Period (d/yr)
FPSO	Background Flaring	335	IS1A IS1B	0 80	0 3	118 17
	Minor Upset Flaring	15	IS2A IS2B	0 80	0 3	118 17
	Unplanned Upset Flaring	10	IS3A IS3B	0 80	0 3	118 17
	Major Upset Flaring	4	IS4A IS4B	0 80	0 3	118 17
MODU	Operation Light at TRD	335	IS5	0	0	118
	Well Clean Up Flaring at TRA	8	IS6	0	0	118
FPSO + MODU	Background Flaring	365	CS1A	0	0	17
	Operation Light at TRD		CS1B	80	10	17
	Minor Upset Flaring	15	CS2A	0	0	118
	Well Clean Up Flaring at TRA	8	CS2B	80	10	17
	Unplanned Upset Flaring	10	CS3A	0	0	118
	Well Clean Up Flaring at TRA	8	CS3B	80	10	17
	Major Upset Flaring	4	CS4A	0	0	118
	Well Clean Up Flaring at TRA	8	CS4B	80	10	17

2.1.2 Model Inputs

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

1. Topography and reflectance: NASA Shuttle Radar Topography Mission (SRTM) digital elevation data (1 arc-second resolution).
2. GPS coordinates for the observer viewpoint on Sandy Islet and the FPSO, MODU (TRA) and MODU (TRD) locations (**Table 7** and **Figure 1**).
3. Weather conditions: All scenarios have been run in clear sky conditions as well as a variety of cloudy sky conditions as listed below:
 - Cloud type: thick cirrus;
 - Cloud height: 3 km and 10 km;

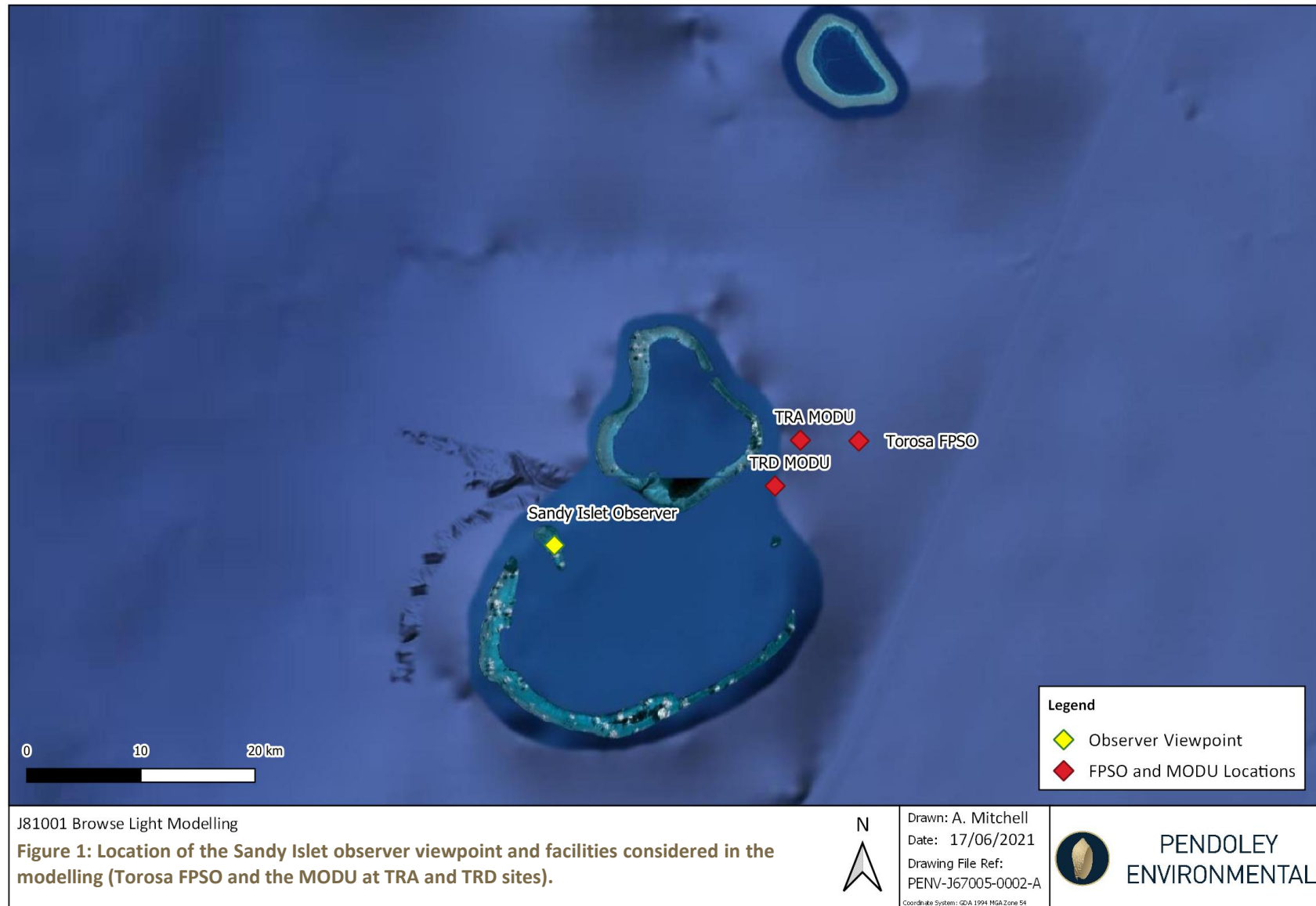
- Cloud coverage: 0%, 30% (not presented) and 80%.

These parameters were selected based off historical average weather data from the closest weather station (Broome) and agreed to by Woodside. This data has been averaged over the assumed turtle nesting season of October to February.

4. A detailed lighting inventory (light types, positions, heights, intensity) for each modelled scenario based on information provided by Woodside. Refer to **Appendix A** for a more detailed methodology describing the generation of the lighting inventory.

Table 7: Location of Sandy Islet observer, FPSO and MODU sites considered in the modelling.

Locations	Scenario	Latitude	Longitude	Distance to Sandy Islet (km)
Sandy Islet Observer	All	-14.055552	121.777309	0
Torosa FPSO	1 – 5	-13.970850	122.024592	29
MODU at TRD site	6	-13.970140	121.977139	20
MODU at TRA site	7	-14.007399	121.956549	23



J81001 Browse Light Modelling

Figure 1: Location of the Sandy Islet observer viewpoint and facilities considered in the modelling (Torosa FPSO and the MODU at TRA and TRD sites).



Drawn: A. Mitchell
Date: 17/06/2021
Drawing File Ref:
PENV-J67005-0002-A
Coordinate System: GDA 1994 MGA Zone 54



**PENDOLEY
ENVIRONMENTAL**

2.1.3 Model Outputs

All-sky modelled image: An all-sky modelled panorama ‘as viewed’ from the observer viewpoint was produced and shows the predicted brightness (including direct, reflected and refracted light) across the whole sky, including the horizon, for each of the seven scenarios (see **Figure 2** for an example).

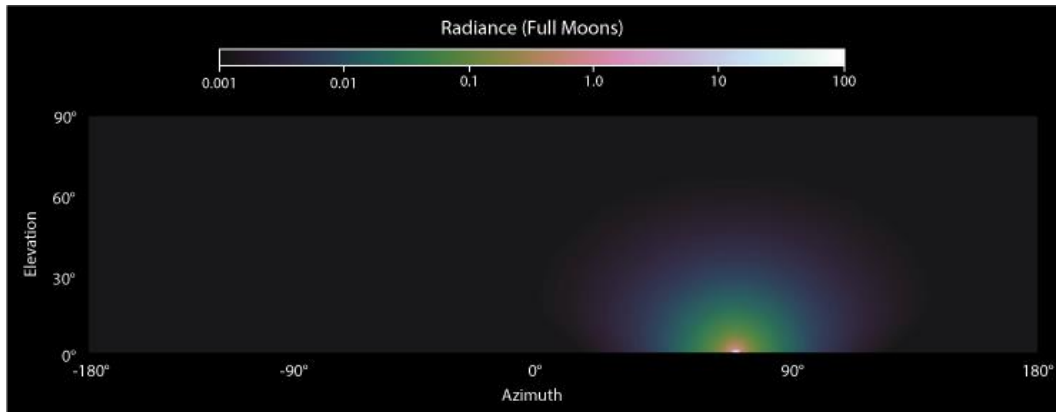


Figure 2: Example all-sky modelled image from an observer location showing predicted brightness.

The model outputs in units of absolute radiance; $W/m^2/sr$, where W = watts, m^2 =metres squared and sr = steradian. In the absence of any published or generally accepted units of measurement, or scale, for measuring the impact of artificial light at night (ALAN) on marine turtles, moonlight has been selected as a proxy. The model output has been converted to Full Moon Equivalents (FME) to give the radiance output some biological relevance and to aid interpretation in an environmental impact assessment context. The rationale behind this approach is outlined in **Section 2.1.4**.

The sensitivity of a hatchling turtle to directional light can be described by a specific ‘cone of acceptance’ which indicates how much of the world a hatchling views and measures at any one instant, defined by Witherington (1992) as 180° horizontally and 30° vertically. To understand potential impacts on hatchling behaviour, all pixels in the $180^\circ \times 30^\circ$ window centred over the brightest light source at the observer viewpoint are averaged (**Figure 2**), with the results presented as Orientation Field of View (OFOV) in FME units.

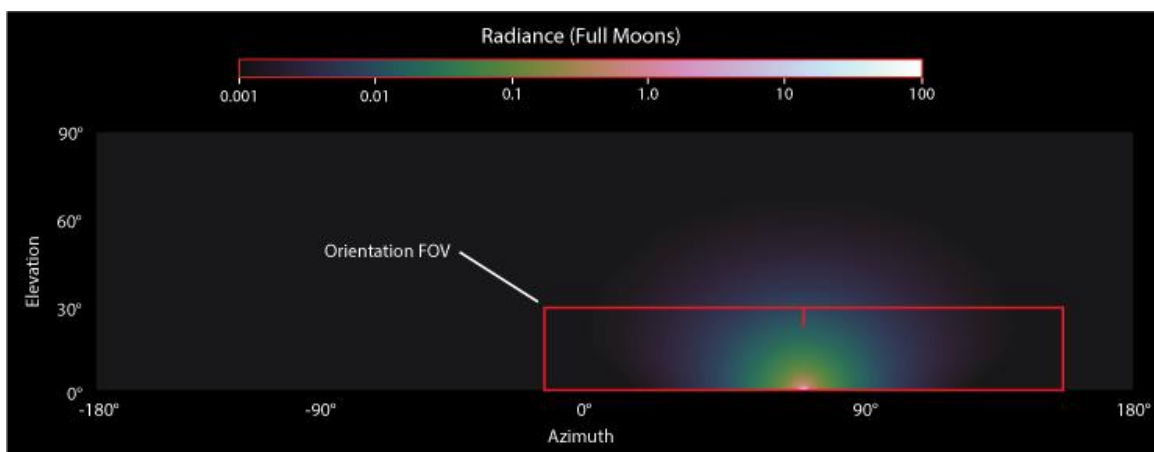


Figure 3: Cone of acceptance centred over the brightest light source. Pixels within this area are averaged and presented as Orientation Field Of View in FME.

2.1.4 Model Assumptions

As there was only high-level lighting detail available at this stage of the project, several assumptions had to be made to generate a lighting inventory for the FPSO and MODU. These are summarised below and outlined in more detail within **Appendix A**.

- When generating the lighting inventory, illumination levels were considered to be 150 % higher than required to meet lighting requirements specified in Woodside’s engineering standards, to provide a conservative estimate of light output.
- All operations lighting on the FPSO is assumed to have a colour temperature of 3000 K. This assumes best practice lighting design measures are incorporated into the FPSO design.
- All operations lighting on the MODU is assumed to have a colour temperature of 6500 K.
- All interior or enclosed lighting is considered to be 100 % shielded and therefore not represented within the model.

2.1.5 Model Limitations

- As this model is still developmental, results have not yet been definitively ground-truthed for large-scale projects (Linares et al. 2018; Linares Arroyo et al. 2020). While the approach outlined within this report is considered sound at the time of writing, future model results may not be comparable due to updates in the science and methodology that underpin the current software.
- The precision of the model outputs is directly related to the level of input detail. At this stage of the project, only high-level detail was available and thus many assumptions were needed to generate a lighting inventory, potentially reducing the precision of the model outputs.
- The model considers light equally across the spectrum (radiometrically) at 100 % sensitivity to all wavelengths. Therefore, it is not representative of the vision of marine turtles which have a high sensitivity to short wavelengths and less sensitivity to longer wavelengths. While it is possible to weight model outputs to a spectral sensitivity curve for marine turtles, after discussion between PENV and Woodside it was agreed that outputs would be represented in the radiometric format as this provides a conservative “worst case” output where light is assumed to be received at a maximum level across all wavelengths.

2.1.6 Literature Review and Impact Criteria

Recognising the absence of any limits or thresholds as well as the many limitations associated with estimating a likelihood of impact from light to hatchling turtles, Woodside engaged PENV to undertake a literature review to determine if thresholds or limits have been defined in the literature that relate to the intensity, visibility, or direction of light from a nesting beach at which an impact to a hatchling turtle could occur. The objective of the literature review was to identify any threshold or limit that could be used to improve the interpretation of modelled outputs of light from the resource development and better inform the EIA outcomes.

The literature review found there were no conclusive thresholds/limits of light intensity, or its visibility, defined within reviewed literature that specified that when exceeded, would influence hatchling sea-finding behaviour (see full review in **Appendix B**). In the absence of these thresholds, PENV has used the FME units and tied these results to impact criteria based on our collective professional experience observing hatchling behaviour (**Table 8**). This approach is consistent with the process of expert elicitation, which builds on the available research findings in the absence of detailed empirical data (Burgman 2005; Burgman et al. 2011; Patterson et al. 2007). The reasoning used includes:

1. The range of moon brightness across a whole lunar cycle is a realistic scale representative of the ambient light levels that turtle eyes are adapted to, at the lower end of the scale the radiant output is equivalent to no light in the sky while the upper limit is greater than the radiance from a single full moon and was selected to try to account for the reasonable increase in radiance levels that would occur if bright light was reflected from clouds.
2. While the behavioural response of marine turtles to light is relatively well understood (see Witherington and Martin (2003) for review), there is currently no agreed upon intensity limits for determining what the impact of a given light might be. A large range of factors influence the visibility and impact of light on hatchlings including light intensity, visibility (a function of lamp orientation and shielding), spectral power distribution (wavelength and colour), atmospheric scattering, cloud reflectance, spatial extent of sky glow, duration of exposure, horizon elevation, lunar phase, hatchling swimming speeds, species, tide and current speeds and flow direction etc. Using the scale of light radiance derived from the calculated decrease in light intensity with distance (proportion radiance of a full moon) and together with our extensive subject matter experience observing marine turtles and their response to both onshore and offshore construction light in field settings, we have proposed conservative, potential impact criteria for marine turtles based on radiance thresholds relative to moon radiance, as shown in **Table 8**.
3. The scale for the units “the proportion of radiance of one full moon” is derived from the logarithmic nature of light decay with distance (a function of the inverse square law), e.g. the scale of <0.01, 0.01 – 0.1, 0.1 – 1, 1 – 10 represents a range of radiant brightness from a minimum of <0.01 full moon (so essentially a new moon) to a maximum radiant brightness of the equivalent to 10 full moons.

Table 8: Potential artificial light impact criteria (marine turtles).

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

4 RESULTS AND DISCUSSION

The modelling of 18 different scenarios was successfully completed, with 10 Individual Scenarios (IS), and 8 Cumulative Scenarios (CS), results are shown in **Table 9**. Results from these scenarios are outlined in further detail in **Sections 4.1 and 4.2**.

Table 9: Orientation FOV values for each scenario, and the corresponding impact levels. Where “A” Scenarios denote clear conditions and “B” Scenarios are in cloudy sky conditions. OFOV units are in Full Moon Equivalents (FME; refer to Section 2.1.3).

Vessel	Lighting Inventory	Scenario Name	OFOV (FME)	Impact Level
FPSO	Background Flaring	IS1A	0.004	1
		IS1B	0.010	2
	Minor Upset Flaring	IS2A	0.009	1
		IS2B	0.028	2
	Unplanned Upset Flaring	IS3A	0.031	2
		IS3B	0.116	3
	Major Upset Flaring	IS4A	0.041	2
		IS4B	0.156	3
MODU	Operation Light at TRD	IS5	0.001	1
	Well Clean Up Flaring at TRA	IS6	0.020	2
FPSO + MODU	Background Flaring Operation Light at TRD	CS1A	0.006	1
		CS1B	0.012	2
	Minor Upset Flaring Well Clean Up Flaring at TRA	CS2A	0.030	2
		CS2B	0.103	3
	Unplanned Upset Flaring Well Clean Up Flaring at TRA	CS3A	0.054	2
		CS3B	0.192	3
Major Upset Flaring Well Clean Up Flaring at TRA	CS4A	0.065	2	
	CS4B	0.236	3	

4.1 Individual Scenarios

In IS1A - 4A (clear sky conditions) the FPSO is identifiable as a small point source of direct light on the horizon, predominantly due to the height of the flare (base height: 182 m above sea level). The areal extent of sky glow from the FPSO correlates strongly with flaring intensity ranging from minimal levels during background flaring (IS1A; **Figure 4a**) and extending across the sky during minor (IS2A; **Figure 5a**), unplanned (IS3A; **Figure 6a**), and major upset flaring (IS4A; **Figure 7a**). Orientation FOV (OFOV) Full Moon Equivalent (FME) values also correlate strongly with flaring intensity and the resulting changes in sky glow extent, with the brightest values generated in IS4A (0.041), and decreasing in IS3A (0.031), IS2A (0.009) and IS1A (0.004; see **Table 9**).

The impact of clouds on sky glow is clearly demonstrated in IS1B - 4B by the order of magnitude increase in OFOV FME values, with the smallest increase occurring in IS1B (0.01; 239%) and increasing in IS2B (0.028; 293%), IS3B (0.116; 371%), and IS4B (0.156; 377%; see **Table 9**). The impact of the low cloud ceiling on sky glow from the different FPSO flaring conditions is shown in **Figures 4b – 7b**.

In Scenarios IS5 and IS6 the MODU is also an identifiable point source of direct light on the horizon and the visibility of direct lighting at the TRD site (IS5; **Figure 8a**) is marginally higher than the TRA site (IS6;

Figure 8b) because of its shorter distance from Sandy Islet. As there is no flaring at the TRD site, there is almost no visible sky glow with only very low levels of light reflecting off the ocean below 2° elevation and an OFOV value of 0.001. The model results show the impact of flaring from the MODU at the TRA site (IS6), where the extent of the sky glow increases substantially within the OFOV to 0.020, which is approximately 18 times brighter than the MODU at the TRD site (IS5; **Table 9**).

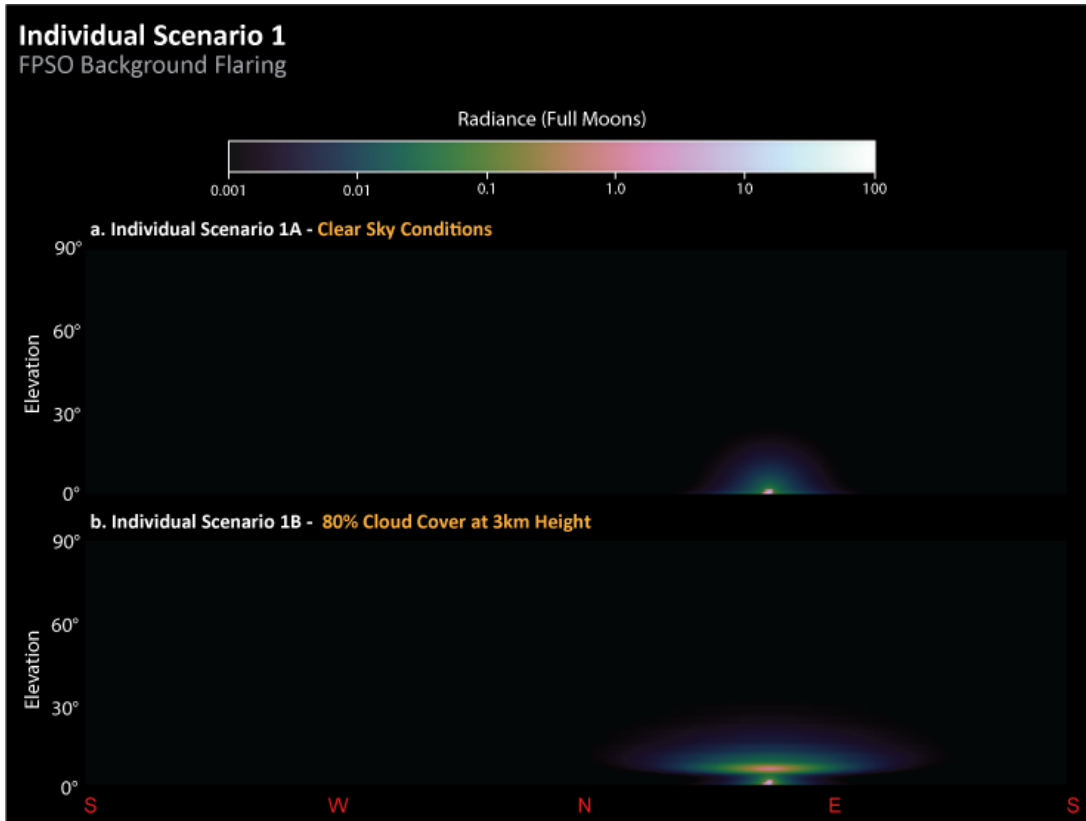


Figure 4: Model outputs for the FPSO – Individual Scenario 1: a. Clear sky conditions (IS1A); b.80% Cloud Cover at a height of 3km (IS1B).

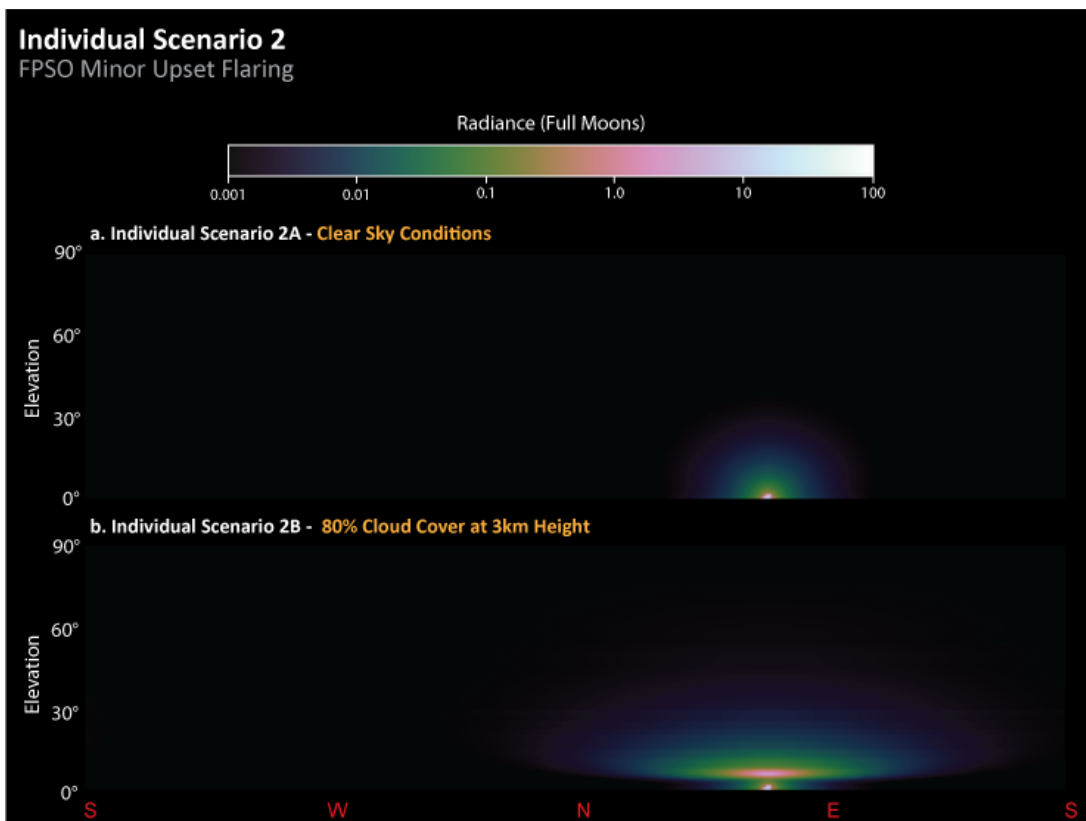


Figure 5: Model outputs for the FPSO – Individual Scenario 2: a. Clear sky conditions (IS2A); b.80% Cloud Cover at a height of 3km (IS2B).

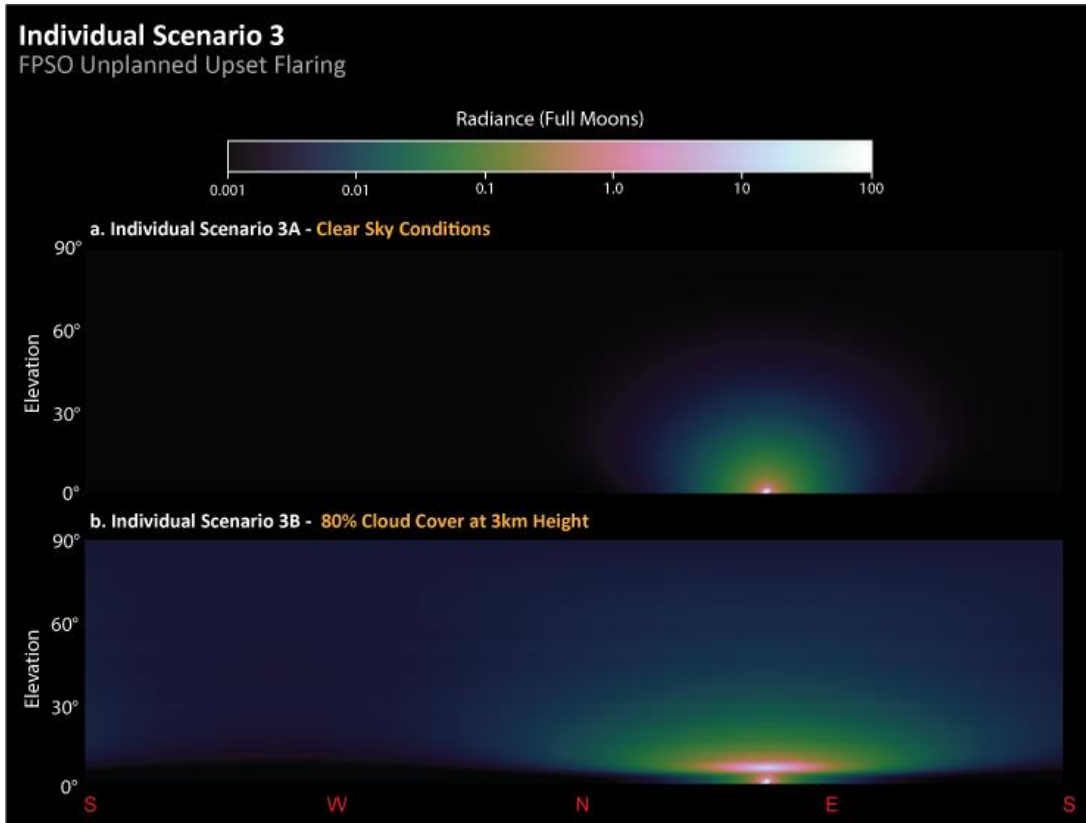


Figure 6: Model outputs for the FPSO – Individual Scenario 3: a. Clear sky conditions (IS3A); b.80% Cloud Cover at a height of 3km (IS3B).

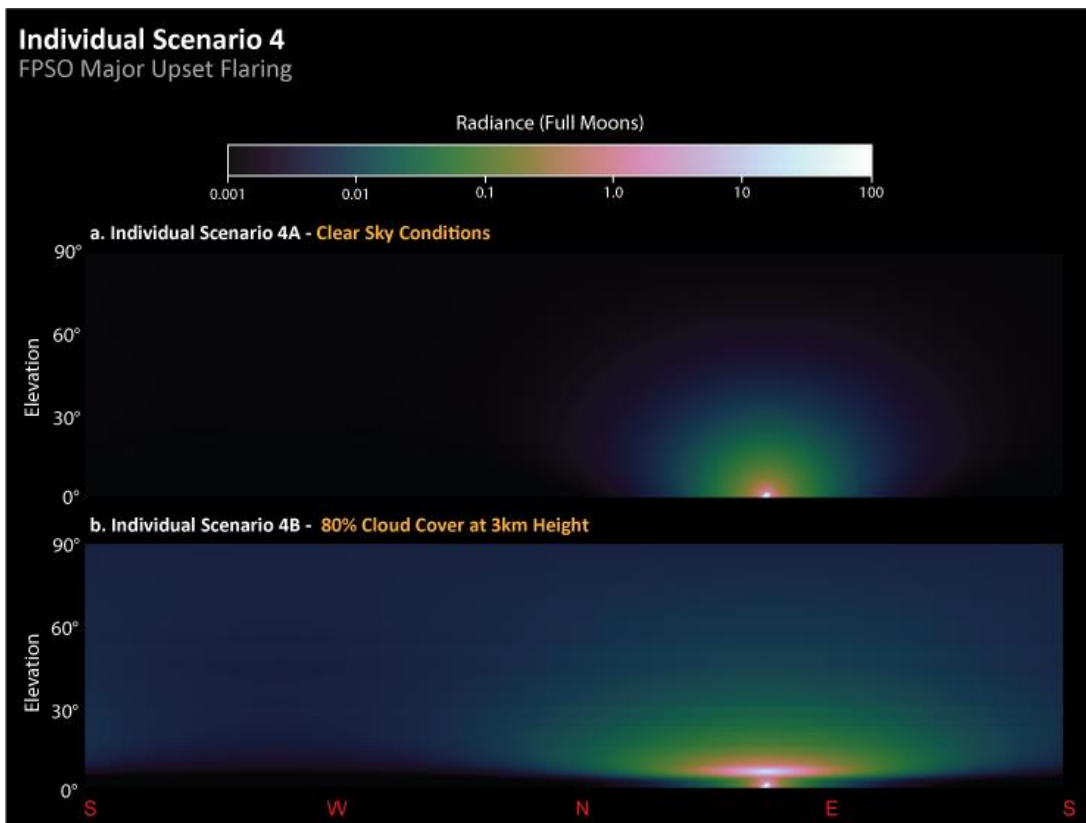


Figure 7: Model outputs for the FPSO – Individual Scenario 4: a. Clear sky conditions (IS4A); b.80% Cloud Cover at a height of 3km (IS4B).

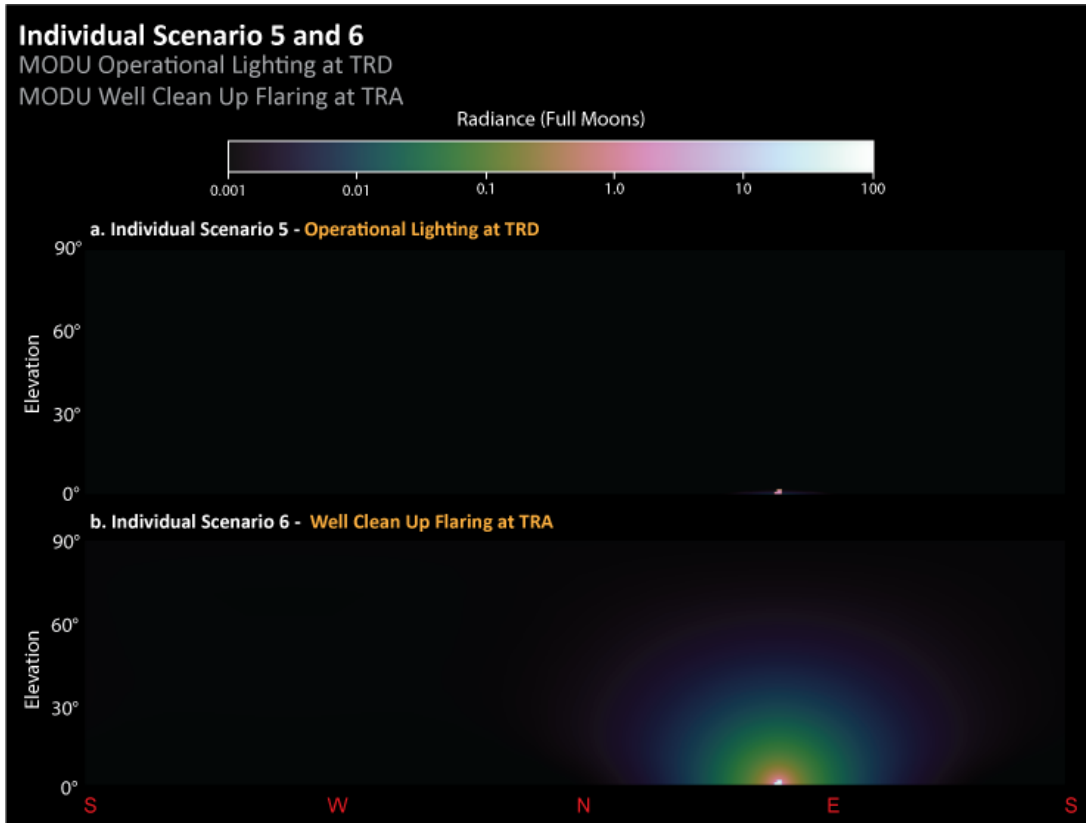


Figure 8: Model outputs for the MODU – Individual Scenario 5 and 6: a. MODU Operational Lighting at TRD (IS5); b. MODU Well Clean Up Flaring at TRA (IS6).

4.2 Cumulative Scenarios

Clear sky conditions were modelled for the cumulative inventories of the four FPSO flaring scenarios and the MODU Well Clean Up Flaring scenario in CS1A-4A. Both the FPSO and the MODU are identifiable as small point sources of direct light on the horizon. The areal extent of sky glow from the cumulative inventories correlates strongly with flaring intensity from the FPSO, ranging from minimal levels during background flaring (CS1A; **Figure 9a**) and extending across the sky during minor (CS2A; **Figure 10a**), unplanned (CS3A; **Figure 11a**), and major upset flaring (IS4A; **Figure 12a**). OFOV FME values also correlate strongly with flaring intensity and the resulting changes in sky glow extent, with the brightest values generated in CS4A (0.065), and decreasing in CS3A (0.054), CS2A (0.030) and CS1A (0.006; see **Table 9**).

The impact of cloud on sky glow is clearly demonstrated in CS1B - 4B by the order of magnitude increase in OFOV FME values (**Table 9**), with the smallest increase occurring in CS1B (0.012; 202%; **Figure 9b**) and increasing in CS2B (0.103; 345%; **Figure 10b**), CS3B (0.192; 356%; **Figure 11b**), and CS4B (0.236; 364%; **Figure 11b**).

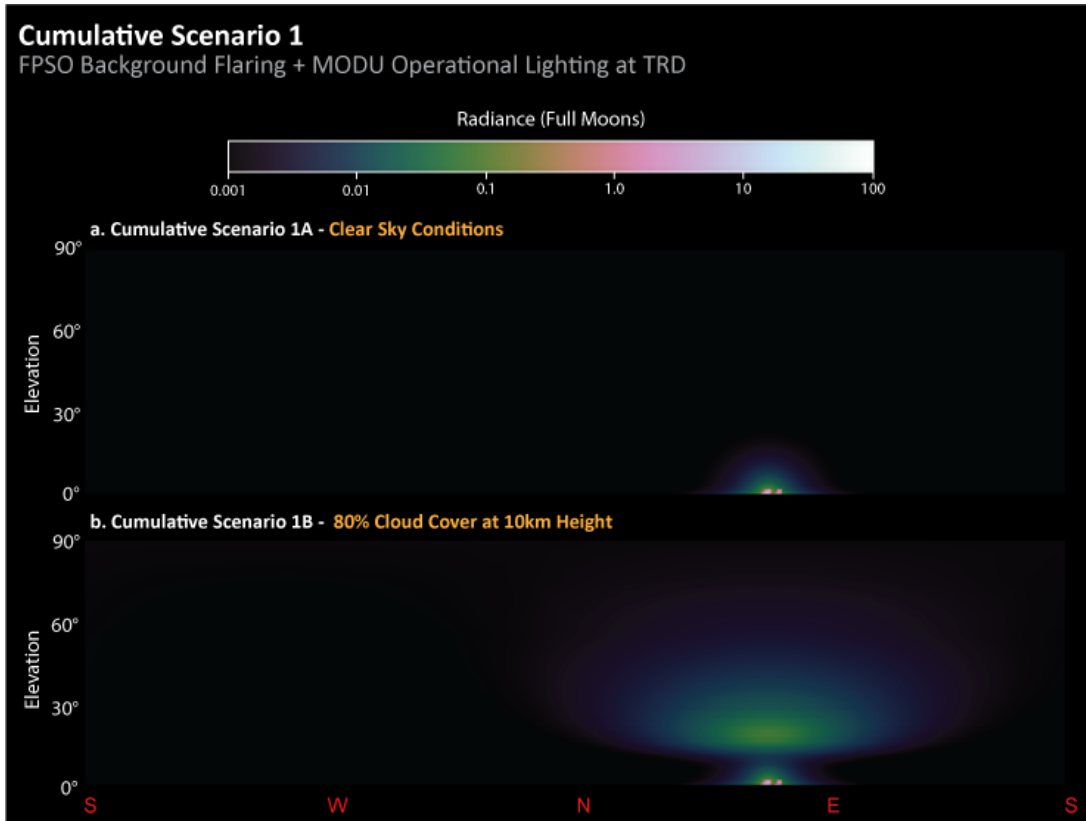


Figure 9: Model outputs for the FPSO and MODU – Cumulative Scenario 1: a. Clear sky conditions (CS1A); b.80% Cloud Cover at a height of 10km (CS1B).

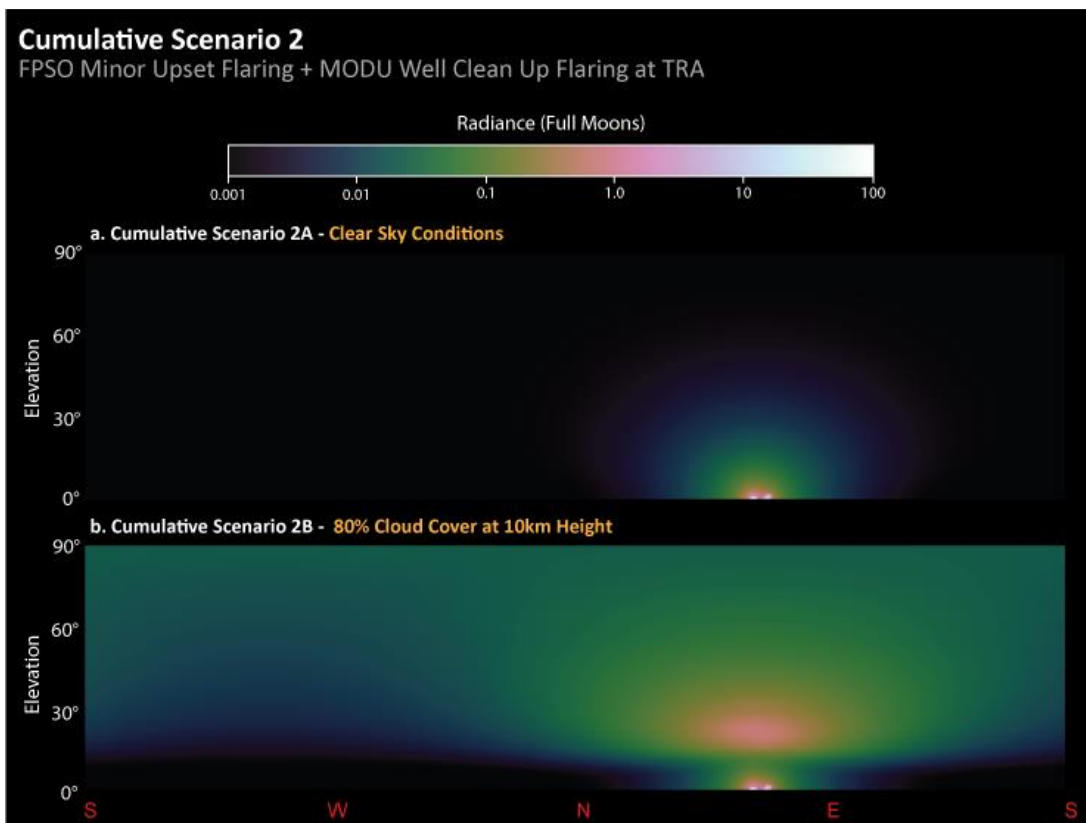


Figure 10: Model outputs for the FPSO and MODU – Cumulative Scenario 2: a. Clear sky conditions (CS2A); b.80% Cloud Cover at a height of 10km (CS2B).

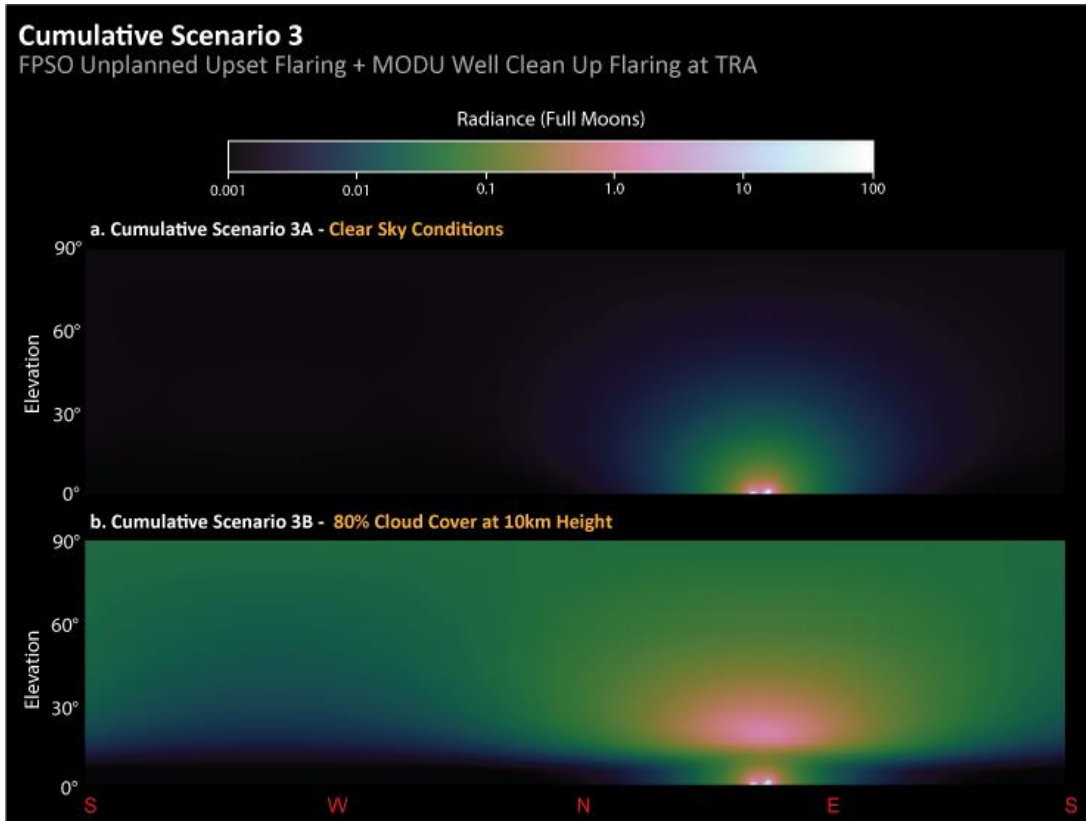


Figure 11: Model outputs for the FPSO and MODU – Cumulative Scenario 3: a. Clear sky conditions (CS3A); b.80% Cloud Cover at a height of 10km (CS3B)

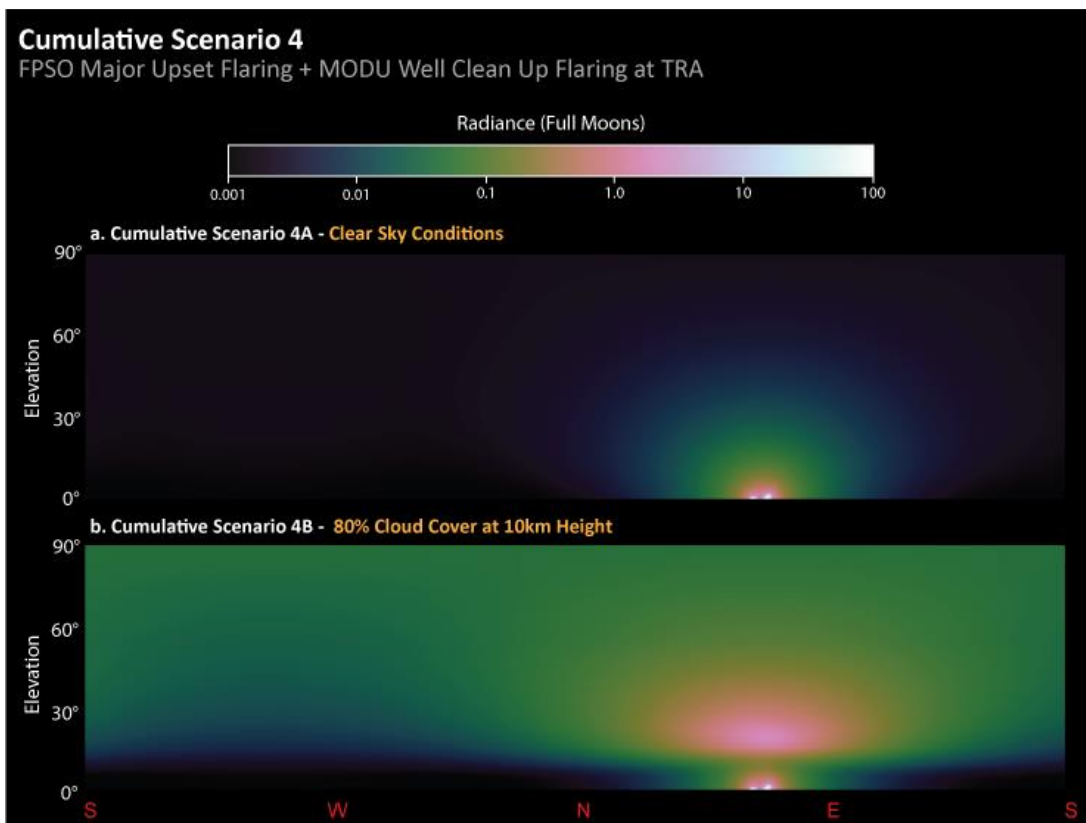


Figure 12: Model outputs for the FPSO and MODU – Cumulative Scenario 4: a. Clear sky conditions (CS4A); b.80% Cloud Cover at a height of 10km (CS4B).

4.3 Potential Impacts

For the purposes of the assessment the modelled Scenarios have been categorised based on:

- the expected duration of impact (intermittent or continuous) and;
- the modelled impact level (FME - **Table 8**).

Intermittent is a short-term potential impact which is defined as less than or equal to one nesting season, while continuous potential impacts are defined as the routine light impacts that will occur for the lifetime of the project, i.e. over multiple concurrent turtle seasons. The assessment considers the intermittent nature both of flaring and of cloud cover (height, percent and period; **Table 6**). Four impact tables have been generated based on the duration and level of impact (refer to Executive Summary).

The three categories of impact level generated by the 18 modelled scenarios considered in the assessment are summarised below.

4.3.1 Impact Level 1 (<0.01 FME)

Impact level 1 is described as “Light or light glow is considered ambient, and no impact expected, equivalent to a new moon”. Scenarios falling into this category are predicted to have no impact on hatchling behaviours.

Scenarios which returned an Impact Level 1 result from the modelling included:

- **IS1A:** FPSO background flaring (no cloud, continuous),
- **IS2A:** FPSO minor upset flaring (no cloud, intermittent),
- **IS5:** MODU operation lighting at TRD (no cloud, continuous),
- **CS1:** FPSO background flaring and MODU operation lighting at TRD (no cloud, continuous).

4.3.2 Impact Level 2 (0.01 – 0.1 FME)

Impact level 2 (0.01 – 0.1 FME) is described as “Light or light glow visible but behavioural impact unlikely (i.e., not biologically relevant). Equivalent to the light output from the first quarter moon to new moon.”. Consequently, while the source may be visible, no impacts are expected on hatchling sea finding behaviour from these light emissions.

Scenarios which returned an Impact Level 2 result from the modelling included:

- **IS1B:** FPSO background flaring (cloud, intermittent)
- **IS2B:** FPSO minor upset flaring (cloud, intermittent)
- **IS3A:** FPSO unplanned upset flaring (no cloud, intermittent)
- **IS4A:** FPSO major upset flaring (no cloud, intermittent)
- **IS6:** MODU well clean up flaring (no cloud, intermittent)
- **CS1B:** FPSO background flaring and MODU operations lighting at TRD (cloud, intermittent)

- **CS2A:** FPSO minor upset flaring and MODU well clean up flaring at TRA (no cloud, intermittent)
- **CS3A:** FPSO unplanned upset flaring and MODU well clean up flaring at TRA (no cloud, intermittent)
- **CS4A:** FPSO major upset flaring and MODU well clean up flaring at TRA (no cloud, intermittent)

Scenarios are considered intermittent due to either sporadic flaring (IS3A, IS4A, IS6, CS2A, CS3A, CS4A), cloud conditions (IS1B, CS1B), or a combination of both (IS2B).

4.3.3 Impact Level 3 (0.1 – 1 FME)

Impact level 3 (0.1 – 1 FME) is described as “Light or light glow visible and behavioural impact possible, depending on ambient moon phase at the time of exposure, which will influence the visibility of the artificial light sources, equivalent to the light output. Artificial lights will be more visible to marine turtles under a first quarter moon than under a full moon”. Light sources falling into this category will be brighter than the moon for approximately half of its monthly cycle, and less detectable in the other half, meaning that the likely impact on receptors will change across the lunar cycle.

Scenarios which returned an Impact Level 3 result from the modelling included:

- **IS3B:** FPSO unplanned upset flaring (cloud, intermittent)
- **IS4B:** FPSO major upset flaring (cloud, intermittent)
- **CS2B:** FPSO minor upset flaring and MODU well clean up flaring at TRA (cloud, intermittent)
- **CS3B:** FPSO unplanned upset flaring and MODU well clean up flaring at TRA (cloud, intermittent)
- **CS4B:** FPSO major upset flaring and MODU well clean up flaring at TRA (cloud, intermittent)

In all of these Scenarios the modelled bright and widespread sky glow is caused by the presence of heavy cloud cover which strongly reflects and scatters light across the entire sky. While the potential to impact on hatchling behaviour is greatest at this impact level, the likelihood of this impact level being reached is mediated by the relatively low number of days (~17 days) during the nesting season that clouds are typically present at the project site (**Table 6**). Furthermore, the flaring is expected to be limited to 8 – 15 days per year, associated with unplanned upset flaring or well clean up flaring. Under worst-case conditions, to create enough light emissions to reach an impact level 3 threshold, the unplanned flaring would have to coincide with the 17 cloudy days reported for the area during the nesting season. The potential impact on nesting adults and hatchlings is therefore considered intermittent, limited to one nesting season and assessed as minor should it occur.

The Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia 2017) Action Area A8 (Minimise light pollution) has the following action:

- Artificial light within or adjacent to habitat critical to the survival of marine turtles will be managed such that marine turtles are not displaced from these habitats.

It is unlikely an Impact Level 3 level of lighting will cause significant displacement of nesting females from Sandy Islet, and should it occur, any displacement is expected to be minor and limited to

susceptible individuals potentially exposed to a very short window of high light levels under heavy cloud. Any females displaced from Sandy Islet are likely to move to nesting beaches on Browse Island (~190 km to the east), which is the only other known nesting location for the G-ScBr genetic stock. Experienced nesting females are not considered vulnerable to the effects of light on nest site selection and therefore permanent displacement of these individuals is unlikely.

4.4 Summary

A summary of the artificial light impact assessment for green turtles at Sandy Islet for all Scenarios incorporating the model results is shown in **Appendix C, Tables C1 – C4**

The predicted impacts of the modelled Scenarios with continuous impacts on marine turtles were assessed as ‘no expected impact’. However, modelled Scenarios that may intermittently affect a given turtle nesting season ranged from “no expected impact” to “unlikely impact”, and “possible impact”.

The predicted impact under the worst-case scenario of unplanned flaring and heavy cloud cover are assessed as “minor impacts possible”, however the risk of this impact is considered low given the limited number of days this flaring is expected to occur, the limited number of days of predicted heavy cloud cover, the small proportion of the nesting population that could be exposed in any one season and the limited number of emerging hatchlings that could be exposed during this level of light exposure.

In accordance with the approach outlined in the National Light Pollution Guidelines we recommend the following biological and light monitoring programs be implemented to confirm these predictions and to provide a basis for adaptive management as required:

- Ground-truth the modelled results by measuring the facilities (or equivalent).
- Monitor the biological response of hatchlings at Sandy Islet during commissioning, flaring and operations.
- Monitor the water around vessels and facilities during commissioning and operations to confirm if hatchlings are aggregating around the FPSO, MODUs or associated vessels.

5 REFERENCES

BURGMAN, M. (2005). Risks and decisions for conservation and environmental management. Cambridge University Press.

BURGMAN, M., CARR, A., GODDEN, L., GREGORY, R., MCBRIDE, M., FLANDER, L., & MAGUIRE, L. (2011). Redefining expertise and improving ecological judgment. *Conservation Letters*, 4(2), 81-87.

COMMONWEALTH OF AUSTRALIA (2017) Recovery Plan for Marine Turtles in Australia (2017-2027).

PATTERSON, J., MEEK, M. E., STRAWSON, J. E., & LITEPLO, R. G. (2007). Engaging expert peers in the development of risk assessments. *Risk Analysis: An International Journal*, 27(6), 1609-1621.

Horch, Kenneth & Gocke, Judith & Salmon, Michael & Forward, Richard. (2008). Visual spectral sensitivity of hatchling loggerhead (*Caretta caretta* L.) and leatherback (*Dermochelys coriacea* L.) sea turtles, as determined by single-flash electroretinography. *Marine and Freshwater Behaviour and Physiology*. 41. 107-119. 10.1080/10236240802106556.

Appendix A: Generation of Lighting Inventories

1 GENERATION OF LIGHTING INVENTORIES

The lighting inventories used in each scenario for the FPSO and MODU were generated using information provided by Woodside. In the absence of detailed lighting design plans at this phase of the project, assumptions were made about the light types likely to be used for standard operations, illuminance levels of major areas within the FPSO and MODU, and the output of the flare. These assumptions can calculations are outlined in more detail in the following sections.

1.1 Operations Lighting

1.1.1 FPSO

Two light types were selected for input into operations lighting calculations (**Table A1**):

1. A “normal” 6900-lumen LED light (based off a fluorescent equivalent) with no light emitted above the horizontal plane) and a colour temperature of 3000 K.
2. A 25000-lumen floodlight with no light emitted above the horizontal plane and a colour temperature of 3000 K.

Table A1: Light types used for standard operations lighting in the FPSO.

Fixtures	Type	Colour Temperature	Shielding (%)	Power (Lumens)
Normal	LED	3000 K	50	6900
Floodlight	LED	3000 K	50	25,000

Required illumination levels of main areas in the FPSO were provided by Woodside and are outlined in **Table A2**.

Table A2: Illumination levels for different areas in the FPSO (note: levels are 150% of the minimum required).

Area type	Areas included	Illumination level (lux)
Operating areas	<ul style="list-style-type: none">• Main Deck (MD)• Process modules• Turret module (levels 1 – 3)	225
Access ways	<ul style="list-style-type: none">• Accommodation module• Turret module (levels 4 – 9)	37.5

To calculate the number of lights required to illuminate an area to the specified level, the following formula is used:

$$\Phi = E \times A$$

Where Φ is total power required measured in lumens, E is illumination measured in lux, and A is the area on which the light lands measured in metres squared. The assumptions made regarding lit operations areas on the FPSO and the resulting total lumen outputs are summarised in **Sections 1.1.1.1 – 1.1.1.5**.

1.1.1.1 Main Deck

- Dimensions of 66 x 300 metres with a total area of 19,800 m².
- Lights mounted at 2 m high.
- Required illumination levels of 75 lux.
- A ratio of approximately 90% normal to 10% floodlights was assumed
- The required lumens to light this area was calculated to be 1,485,000 lumens (122 normal lights and 26 floodlights).

1.1.1.2 Accommodation Module

- Dimensions of 25 x 50 m. The total area of each level is 1250 m², however the interior of the module is considered to be shielded and unlit. This leaves only the 2 m-wide access ways around the exterior which equate to an area of 284 m².
- Six levels at 4 m intervals, from MD + 10.5 m to MD + 30.5 m.
- Lights are mounted at 2 m high
- Required illumination levels of 37.5 lux.
- All normal lighting with no floodlights
- A total of 22 lights required for a total of 151,800 lumens per level.
- 910,800 lumens for the whole module.

1.1.1.3 Turret Module

The turret module consists of several different levels of different sizes:

- Level 1, 30 x 30 m (900 m²). Height: MD + 0 m
- Levels 2-9, 10 m x 10 m each (100 m²). Heights:
 - Level 2: MD + 3 m
 - Level 3: MD + 7 m
 - Level 4: MD + 13.5 m
 - Level 5: MD + 16.5 m
 - Level 6: MD + 20.5 m
 - Level 7: MD + 24.5 m
 - Level 8: MD + 28.5 m
 - Level 9: MD + 32.5 m
- Lights are mounted at 2m
- Levels 1-3 are illuminated to 225 lux.
- Levels 4-9 are illuminated to 37.5 lux.
- The required lumens for level 1 is 202,500.
- The required lumens for levels 2 and 3 is 22,500 for each level.
- The required lumens for levels 4 – 9 is 3750 for each level.
- Total lumens required across all levels: 293,200 lumens, consisting of 28 normal lights and two floodlights.

1.1.1.4 Process Modules

- Dimensions of 25 x 30 m (750 m²) for each level.
- There are 14 process modules. Each module has three levels each, separated by 8 m in height (MD +6.5, +14.5, +22.5) for a total of 42 levels.
- Illumination requirement of 225 lux.
- Each level requires 168,750 lumens, which is satisfied using 18 normal lights and two floodlights per level. The combined total of the process modules is 7,361,400 lumens, consisting of 756 normal lights and 84 floodlights.

1.1.1.5 Summary

A summary of all lights considered as part of the standard operations lighting for the FPSO is shown in **Table A3**

Table A3: Lighting inventory containing a summary of lights used in the modelling of the FPSO.

Location	Quantity	Levels	Number of lights per level	Fixture type
Process Modules	14	1-3	18	Normal
Process Modules	14	1-3	2	Floodlight
Accommodation Module	1	1-6	22	Normal
Turret Module	1	1	14	Normal
Turret Module	1	1	4	Floodlight
Turret Module	1	2-3	4	Normal
Turret Module	1	4-9	6	Normal
Main Deck	1	1	122	Normal
Main Deck	1	1	26	Floodlight

1.1.2 MODU

The two light types selected for input into MODU operations lighting were similar to the FPSO, however were not considered to be “turtle-aware” (Table A4), and therefore had a colour temperature of 6500 K (Cool White):

Table A4: Light types used for standard operations lighting in the MODU.

Fixtures	Type	Colour Temperature	Shielding (%)	Power (Lumens)
Normal	LED	6500 K	50	6900
Floodlight	LED	6500 K	50	25,000

Required illumination levels of main areas in the FPSO were provided by Woodside and are outlined in Table A5.

Table A5: Illumination levels for different areas in the MODU (note: levels are 150% of the minimum required).

Area type	Areas included	Illumination level (lux)
Operating areas	<ul style="list-style-type: none"> • Drill Floor • Drill Derrick Base 	225
Non-operating areas	<ul style="list-style-type: none"> • Main Deck 	75
Access ways	<ul style="list-style-type: none"> • Derrick • Accommodation • Draw Works Roof 	37.5

The assumptions made regarding lit operations areas on the MODU and the resulting total lumen outputs are summarised in Sections 1.1.2.1 – 1.1.2.7.

1.1.2.1 Main Deck

- Dimensions 75 x 75 m (5,625 m²).
- Level height of 16 m (above sea level).
- Lights mounted at 2 m.
- Required illumination of 75 lux.
- Requires 421,875 lumens, consisting of 33 normal lights and eight floodlights.

1.1.2.2 Accommodation

- Dimensions of 40 x 40 m. The total area of each level is 1600 m², however the interior of the module is considered to be shielded and unlit. This leaves only the 2 m-wide access ways around the exterior which equate to an area of 354 m².
- Two Levels at MD + 3 m and MD + 7 m.
- Required illumination of 37.5 lux.
- A total of 30 normal lights per level for a total of 60 normal lights and 414,000 lumens.

1.1.2.3 Drill Floor

- Dimensions 40 x 40 m (1,600 m²).
- Level height of MD + 10 m.
- Lights mounted at 2 m high.
- Required illumination of 225 lux.
- Requires a total of 363,900 lumens consisting of 31 normal lights and six floodlights.

1.1.2.4 Drill Derrick Base

- Dimensions 17 x 40 m (680 m²).
- Level height of MD + 14 m.
- Lights mounted at 2 m high.
- Required illumination of 225 lux.
- Requires a total of 153,500 lumens consisting of 15 normal lights and two floodlights.

1.1.2.5 Draw Works Roof

- Dimensions 17 x 45 m (765 m²).
- Level height of MD + 20 m.
- Lights mounted at 2 m high.
- Required illumination of 37.5 lux.
- Requires a total of 34,500 lumens consisting of five normal lights.

1.1.2.6 Derrick

- Dimensions 17 x 17 m (289 m²).
- 15 levels spaced 5 m apart from MD + 20 m to MD + 90 m.
- Lights mounted at 2 m high on each level.
- Required illumination of 37.5 lux.
- Requires a total of 207,000 lumens consisting of 30 normal lights.
- There are 24 floodlights mounted at MD + 30 m with a total of 600,000 lumens, bringing the final total on the derrick to 807,000 lumens.

1.1.2.7 Summary

A summary of all lights considered as part of the standard operations lighting for the FPSO is shown in **Table A6**.

Table A6: Lighting inventory containing a summary of lights used in the modelling of the MODU.

Location	Quantity	Levels	Number of lights per level	Fixture type
Main Deck	1	1	33	Normal
Main Deck	1	1	8	Floodlight
Drill Floor	1	1	31	Normal
Drill Floor	1	1	6	Floodlight
Drill Derrick Base	1	1	15	Normal
Drill Derrick Base	1	1	2	Floodlight
Draw Works Roof	1	11	5	Normal
Derrick	1	1-15	2	Normal
Derrick	1	5	24	Floodlight
Accommodation Module	1	1-2	30	Normal

1.1.3 Flaring calculations

To generate the power of each flare we used the Stefan Boltzmann Law:

$$P = A\epsilon\sigma T^4,$$

Where P is the power in watts, A is the surface area in metres squared, ϵ is the emissivity (assumed to be 1), σ is the Stefan Boltzmann constant and T is the blackbody temperature of the flame (assumed to be 1800K).

The power in watts for each flare was calculated based on the surface area of the flame (modelled by Woodside for each Scenario – see **Table A7**) and multiplying by the amount of light emitted into the visible spectrum (0.327%). This value is low due to the large proportion of energy that is emitted as heat in the infrared part of the spectrum.

The calculated power was then converted into Lumens using assuming a luminous efficacy of 170 lumens per watt. Each flare is listed in **Table A7**. The base height of the FPSO flare was 180 m and the MODU was 15 m.

Table A7: Flare intensities used as inputs into the modelling for the FPSO and MODU.

Vessel	Scenario	Scenario Description	Colour Temperature	Surface Area (m ²)	Power (Kilowatts)	Power (Millions of Lumens)	Potential Flare Period (d/yr)
FPSO	IS1, CS1, AS1-2	Background	1800 K	16.42	32	5.44	365
FPSO	IS2, CS2	Minor Upset	1800 K	51.71	101	17.12	15
FPSO	IS3, CS3, AS3-6	Unplanned Upset	1800 K	234	456	77.5	12
FPSO	IS4, CS4	Major Upset	1800 K	316	615	105	12
MODU	IS6, CS1-4, AS6	Well Clean Up	1800 K	175	208	35.4	8

Appendix B: Literature Review

JACOBS

**LITERATURE REVIEW: THRESHOLDS OF ARTIFICIAL LIGHT &
MARINE TURTLE HATCHLINGS**



Prepared by

Pendoley Environmental Pty Ltd

For

Jacobs

17 August 2021



**PENDOLEY
ENVIRONMENTAL**



DOCUMENT CONTROL INFORMATION

TITLE: LITERATURE REVIEW: THRESHOLDS OF ARTIFICIAL LIGHT & MARINE TURTLE HATCHLINGS

Disclaimer and Limitation

This report has been prepared on behalf of and for the use of Jacobs. Pendoley Environmental Pty Ltd. takes no responsibility for the completeness or form of any subsequent copies of this Document. Copying of this Document without the permission of Jacobs is not permitted.

Document History

Revision	Description	Date received	Date issued	Personnel
Draft	Report Draft		11/08/2021	P. Whittock
Rev IA	Internal Review	12/08/2021	16/08/2021	K Pendoley
Rev A	Client review	27/08/2021	07/09/2021	D. Stone, A. McDonald, J. Colman
Rev 0	Final report issued	07/09/2021	16/09/2021	P. Whittock / A. Mitchell

Printed:	18 July 2022
Last saved:	18 July 2022 09:35 AM
File name:	P:\06 Projects\J67 Jacobs\05 Programs\J67005 Browse Light Modelling\03 Technical Reports\Appendix B - Literature Review Rev 0.docx
Author:	Paul Whittock
Project manager:	Adam Mitchell
Name of organisation:	Pendoley Environmental Pty Ltd
Name of project:	Browse Light Modelling
Client	Jacobs
Client representative:	Arne De Vos
Report number:	J67004 Literature Review
Cover photo:	Flatback turtle hatchling (credit: Catherine Bell)

TABLE OF CONTENTS

1	INTRODUCTION.....	1
1.1	Background	1
1.2	Scope of Work.....	3
1.3	Approach.....	4
2	LITERATURE REVIEW	5
2.1	Review Papers.....	5
2.2	Hatchling Orientation and Artificial Light	5
2.2.1	Experimental Design	5
2.2.2	In-situ	6
3	SUMMARY.....	8
4	REFERENCES.....	9

1 INTRODUCTION

1.1 Background

Hatchling sea turtles typically emerge from their nest on the beach at night (Mrosovsky & Shettleworth 1968) and must crawl rapidly to reach the ocean in order to avoid predation (Salmon 2003). They find 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 point of their emergence on the beach (Pendoley & Kamrowski 2015; Lohmann et al. 1997; Limpus & Kamrowski 2013; Salmon et al. 1992). Artificial light at night (ALAN) can interfere with these cues, influencing their sea-finding behaviour (Withington & Martin 2003; Pendoley & Kamrowski 2015; Kamrowski et al. 2014). As a result, hatchlings may become disorientated - where they crawl in circuitous paths; or misorientated - where they move in the wrong direction, resulting in an increased mortality rate due to exhaustion, dehydration, or increased exposure to predation (Withington & Martin 2003; Lohmann et al. 1997; Salmon 2003).

On a broader scale, if the threat of ALAN transpires as a long-term impact to emerging hatchlings at a nesting beach, it has the potential to impact an entire marine turtle population. Within Australia, the current threat of ALAN is highlighted by the Commonwealth Government's *Recovery Plan for Marine Turtles 2017 – 2027* (Recovery Plan), which lists ALAN as a moderate or high threat for the recovery of 14 of 22 marine turtle genetic stocks in Australia (Commonwealth of Australia 2017).

In direct response to the recognised threat of ALAN under the Recovery Plan, the Commonwealth Government drafted the *National Light Pollution Guidelines for Wildlife* (the guidelines), which defined a 20 km zone around any development with externally visible lighting where the potential impact of light on listed species (e.g. marine turtles) and their important habitat should be risk assessed in an Environmental Impact Assessment (EIA). As part of the EIA, the guidelines also recommend that project specific control measures to minimise the impact of ALAN identified in the risk assessment be outlined within an Artificial Light Management Plan (Commonwealth of Australia 2020).

Predicting the likelihood of an impact from artificial light on hatchling turtles within the EIA is particularly challenging. This is because there are numerous biological and physical factors that affect the perception of a light source by a hatchling turtle and whether it subsequently impacts the cues they use in sea-finding. This is further complicated by the potential for these factors to act independently or in combination. The factors for consideration include:

- The sensitivity of a hatchling turtle to directional light can be described by a specific 'cone of acceptance' which indicates how much of the world a hatchling views and measures at any one instant, defined by Witherington (1992) as 180° horizontally and 30° vertically. This defined cone of acceptance will only include a limited part of the entire horizontal (360°) and vertical (90°) field-of-view that is available to a hatchling. The light that is visible within this cone of acceptance at any instant in time can critically influence its determination of brightest direction when sea-finding. This means that a hatchling turtle may not perceive a light source outside of this cone of acceptance when sea-finding, furthermore the visibility of the light in this cone of acceptance may vary as it crawls on the beach.

- Local atmospheric conditions can cause light to scatter and increase its visibility as sky glow, with the amount of scattering dependent on the wavelength of the light and the presence of atmospheric dust, salt, and other aerosols at the time of the hatchling's emergence (Kyba et al. 2011). The short wavelength blue light that is most visible to marine turtles scatters more strongly than long wavelength orange and red light producing a highly visible sky glow close to and above the light source. However, because short wavelength light is attenuated more quickly by the atmosphere, the intensity of blue light also decreases rapidly with distance from the light source while the proportion of long wavelength light increases (Kocifaj et al. 2021).
- Presence of cloud can reflect light back to earth and substantially illuminate the surrounding landscape and its visibility to a hatchling turtle, with the amount of light reflected dependent on cloud height, thickness, and the location of the cloud relative to the light source and habitat (Kyba et al. 2011).
- Localised topography or vegetation on a beach may shield light influencing its visibility to a hatchling turtle at the point of emergence or at varying locations on the beach as it crawls.
- The topography behind the point of emergence generates a darkened silhouette that provides a visual cue for a hatchling to orient away from when sea-finding (Limpus 1971; Salmon et al. 1992, Salmon & Witherington 1995). Varying topography and vegetation screening at a beach will therefore influence the strength of this cue to a hatchling when sea-finding and potentially override any influencing cue from visible light.
- The physical properties of light follow the inverse square law which means that the visibility of the light at an area of habitat, as a function of its intensity and spatial extent, decreases with distance from the source. The rate of decrease in light intensity is inversely proportional to the square of the distance between the light source and the receiver, so as the light waves travel away from a light source they spread out, become less concentrated in space and consequently appear less bright to the observer. Therefore, the intensity of visible light in a habitat will vary at different distances away from the light source.
- Artificial light that is rich in short wavelength blue and green is considered most disruptive to marine turtles (Fritsches 2012; Pendoley 2005); however, marine turtles are not equally sensitive to light of all wavelengths meaning its attractiveness differs by species (Pendoley 2005; Horch et al. 2008; Witherington & Bjorndal 1991). Furthermore, while considered less attractive to hatchlings, light with longer wavelengths can still disrupt their behaviour when sea-finding.
- The presence of moonlight can 'smooth out' variations in background light intensity, thus potentially moderating or reducing the disruptive influence of visible artificial light on sea-finding by hatchling turtles (Salmon & Witherington 1992). Therefore, the presence/absence of a moon, its phase, illumination, and direction it rises/sets as viewed from habitat, can influence the visibility of artificial light sources to a hatchling turtle (as described in Salmon & Witherington 1992; Kamrowski et al. 2014; Berry et al. 2013; Tuxbury & Salmon 2005).
- The orientation of the light source in relation to the point of hatchling emergence will influence how likely it could disrupt sea-finding. For example, if the light source is situated directly offshore it can influence the hatchlings sea-finding behaviour by attracting it seaward.

In contrast, a light source adjacent to, or behind a beach, may lead to a different outcome for the hatchling in terms of its success in reaching the ocean.

A further complicating factor influencing the ability of scientists to confidently predict the impact of light on a sensitive receptor is the lack of an agreed upon standard method for modelling, measuring and monitoring light (Hänel et al. 2018; Kalinkat et al. 2021; CMS 2021). Instruments are either restricted in the wavelengths they measure, the detection limits they can achieve or are research grade instruments that require specialised knowledge to operate and maintain. Similarly, the literature acknowledges that there are no conclusive intensity thresholds below which artificial light is not harmful to species and habitats (Schroer et al. 2021) and even the low intensity light characteristic of skyglow can affect organisms (Grubisic et al. 2019; Kupprat et al. 2020).

Recognising these factors and the complexities in establishing a likelihood of impact from a source (or multiple sources) of light to hatchling turtles across varying spatial scales, the guidelines considered the 20 km distance a precautionary limit and based this distance on the limited published studies that described/measured the actual impact of artificial light on hatchling and adult turtles *in situ*. These studies included realised impacts to hatchling turtles from a Liquefied Natural Gas (LNG) facility (Kamrowski et al. 2014) and anecdotal observations of disorientation of nesting adults from an aluminium refinery (Hodge et al. 2007) situated 15 km and 18 km from their habitat, respectively.

Other than the distance threshold, the guidelines feature general advice on light limits (i.e. avoid bright white lights and consider Amber or PC Amber LEDs in sensitive habitats) with no other specific limits or thresholds that relate to the physical properties of light and its visibility or direction from important habitat. Recognising the huge variability in light characteristics, visibility and impact on sensitive receptors in different environmental settings, the guidelines recommend a case-by-case approach to assessment of risk to account for the unique physical and biological factors characteristic of a project that could potentially affect impacts. Further, the guidelines recommend an outcomes-based approach to assessing the success of light mitigation and management actions; monitoring (biological and light) and auditing should be used in an adaptive management approach to wildlife protection.

To improve the understanding of the appearance and output of light from a source (e.g. development, activity) and aid the likelihood of impact estimate within an EIA, luminaire details including the wattage, wavelength, and location, can be modelled and combined with local topography data to determine its cumulative directionality, visibility, and intensity at areas of important habitat. While the output of the model is quantified in terms of its intensity, in the absence of any other specific thresholds or limits above or below which an impact could occur, the interpretation of the model in terms of estimating the likelihood of its impact on hatchling behaviour is still limited to a qualitative assessment of the model outcomes by a subject matter expert. The absence of any threshold or limit leads to the EIA following a precautionary principle and prevents any quantitative target being set in terms of how much light needs to be reduced by (e.g. through control measures) to lower the estimated likelihood of an impact occurring.

1.2 Scope of Work

As the Operator for and on behalf of the Browse Joint Venture, Woodside Energy Limited (Woodside) are proposing to develop the Browse hydrocarbon resource located in the Brecknock, Calliance, and

Torosa reservoirs. The Torosa reservoir is located near Sandy Islet within the Scott Reef complex, identified as sensitive turtle nesting habitat for green turtles in the discrete Scott Reef - Browse Island (G-ScBr) genetic stock for which ALAN is recognised as a moderate threat to its recovery (Commonwealth of Australia 2017).

Recognising the absence of any limits or thresholds as well as the many limitations associated with estimating a likelihood of impact from light to hatchling turtles described in **Section 1.1**, Woodside engaged Pendoley Environmental (PENV) to undertake a literature review to determine if thresholds or limits have been defined in the literature that relates to the intensity, visibility, or direction of light from a nesting beach at which an impact to a hatchling turtle could occur. The objective of this literature review was to identify any threshold or limit could be used to improve the interpretation of modelled outputs of light from the resource development and better inform the EIA outcomes.

1.3 Approach

The following combination of keywords were searched within Google Scholar for relevant literature:

- Artificial light
- Turtle
- Hatchling orientation

A total of 182 entries were produced. Each entry was reviewed and discarded unless there was any indication of a defined limit or threshold at which an impact from artificial light to a hatchling turtle was realised. Furthermore, suitable entries were separated into those that indicated a limit or threshold using measurements recorded within a controlled experimental design or measurements recorded *in situ* under natural conditions. Any relevant review paper that featured discussion on thresholds or limits of artificial light was also included.

2 LITERATURE REVIEW

2.1 Review Papers

Gaston et al. (2013) reviewed the ecological impacts of night-time light pollution and featured examples of the levels of lighting (lux) at which night-time lighting has been observed to have biological effects. The setting for all examples was laboratory based and did not feature any example for a marine turtle species. Furthermore, the review paper highlighted the absence of thresholds of light intensity and duration at different wavelengths above which artificial lighting has significant ecological impacts and outlined this absence as a key issue and priority for future research.

Bennie et al. (2016) and Kalinkat et al. (2021) reviewed the ecological effects of artificial light on plants and insects. Both studies emphasised the absence of a defined ecologically meaningful measure of artificial light in the natural environment and in its absence, the importance of developing an understanding of the thresholds at which light-sensitive processes in plants and insects occur.

These gaps were echoed in a 2021 review by the Convention on the Conservation of Migratory Species of Wild Animals, who released a report *The Impact of Light on Different Taxa of Migratory Species* which built on the guidelines (Schroer et al. 2021; CMS 2021). As awareness of the issue of light pollution grows so do the calls for biologist, engineers and physicists to collaborate on establishing standardised assessment methods that can be easily used by non-specialists (Kalinkat et al. 2021; CMS 2021; Schroer et al. 2021)

2.2 Hatchling Orientation and Artificial Light

2.2.1 Experimental Design

Cruz et al. (2018) used an experimental design to measure the orientation of swimming olive ridley (*Lepidochelys coriacea*) hatchlings exposed to lights situated 2 m from the hatchling with different wavelengths (red, 720 nm; yellow, 660 nm, and green, 520 nm) and intensities (0.1 – 3.3 lux, 10.3 – 45.9 lux, 47.5 – 84.2 lux, 91.3 – 140.8 lux, 150.1 – 623 lux). Results indicated that hatchlings were attracted to green and yellow lights at low light intensities (0.1 – 45.9 lux) as well as red lights at high intensities (>39.3 lux). This experiment was undertaken under controlled conditions with no variation in the distance of the light from the hatchling. Conclusions from the study indicated that applying the same experiment at a landscape scale would be beneficial as it may allow a specific light threshold to be defined that could improve protection to hatchling turtles.

Karnad et al. (2009) used controlled arena trial experiments to identify the influence of light wavelength (red, 580 – 800 nm; yellow, 475 – 600 nm; blue, 375 – 575 nm; violet, 300 – 450 nm), intensity (two intensities generated by an LED torch; four LED bulbs and eight LED bulbs of 15,000 mcd), and the influence of vegetation height on the orientation of olive ridley hatchlings. The study found that the wavelength and intensity of light interacted to influence hatchling orientation towards light. Hatchlings were found to orient towards high intensity light more than to low intensity light for all wavelengths except violet. One limitation with the experiment was that its setup involved a constant light source. This meant that the light intensity could not be adjusted to account for the varying sensitivity of hatchling turtles to light of different wavelengths meaning they would perceive

some wavelengths as brighter than others. This limited the reporting of an actual intensity value at which an influence on a hatchling turtle occurred.

Tuxbury & Salmon (2005) designed a laboratory experiment involving an arena trial to simultaneously present artificial light (that was known to attract turtles) and natural cues (a dark silhouette of the dune behind the beach) that promoted seaward orientation. The artificial light used in the study was a book light placed 1.2 m from the hatchling at the edge of the arena and had a photon flux of $4.6 - 4.9 \times 10^{11}$ photons/cm²/s. The study confirmed the inter-related factors that influence hatchling sea-finding including horizon elevation, background illumination, the direction of the light. There was no indication of a limit or threshold at which hatchling sea-finding behaviour was influenced.

Pendoley & Kamrowski (2015) used controlled field-based arena trial experiments involving flatback turtle hatchlings to measure their orientation when different types of light, placed at different orientations and elevations, were visible 150 m away. The type of lights included in the study were high pressure sodium vapour, metal halide, and fluorescent white light. The light's intensity was also varied, with low intensity considered 500 W, medium intensity as 1000 W, and high intensity as 1300 W for the metal halide and high-pressure sodium lights. At medium and high light intensities of all three light types, hatchlings were significantly less oriented towards the ocean when exposed to light at 2° elevation compared to 16° elevation. There was no indication of a limit or threshold at which hatchling sea-finding behaviour was influenced.

Robertson et al. (2016) tested two different type of LED light to determine if they influenced the sea-finding behaviour of loggerhead turtle hatchlings. The results of controlled arena trial experiments indicated that amber light (peak wavelength of 620 nm) influenced hatchling sea-finding whereas the red light (peak wavelength of 640 nm) was less disruptive. The study was limited in that it did not record the actual intensity of the light and therefore no limit or threshold at which hatchling sea-finding behaviour was influenced was provided.

2.2.2 *In situ*

Price et al. (2018) measured the intensity of visible light (320 – 700 nm) using a Sky Quality Meter (SQM) across various zones of a loggerhead turtle (*Caretta caretta*) nesting beach in Florida. The study investigated the occurrence of hatchling turtle disorientation events recorded at the same beach and compared the orientation of hatchlings in each zone with the light intensity. The study found that luminance from artificial beachfront lighting may be related to increased incidences of hatchling disorientation but did not determine a luminance/intensity threshold at which more disorientations began to occur. It is important to note that the value of the results of this study are limited as the authors misused the SQM by collecting light pollution data on the horizon, in addition to at zenith (i.e. overhead). The SQM can only return accurate data when aimed at zenith and cannot be aimed at landward light sources or out to sea at horizon level (Hänel et al. 2018, Longcore et al. 2020).

Kamrowski et al. (2014) used both *in situ* nest fan measurements and results of controlled arena trial experiments to determine the influence of artificial light on the sea-finding of flatback turtle (*Natator depressus*) hatchlings at Peak and Curtis islands in Queensland. The study also involved the measurement of ambient light using a stellar photometer fitted with a V filter to ensure light at a wavelength of 480 – 660 nm was measured. Results indicated no disruption to hatchling sea-finding at Peak Island, whereas the sea-finding of hatchlings at Curtis Island was shown to be moderately

disrupted. Due to constraints with the approach for measuring light, only comparisons of directional light and light between sights was provided. There were no actual quantified light values provided in the study, with only qualitative descriptions of '*the field team observed light levels at Curtis Island that appeared visibly brighter than those observed at Peak Island*' included.

3 SUMMARY

There were no conclusive thresholds/limits of light intensity, or its visibility, defined within reviewed literature that specified that above which would influence hatchling sea-finding behaviour.

There were numerous *in situ* and experimental studies that indicated light of a certain intensity or wavelength influenced hatchling sea-finding behaviour under different lighting scenarios which often involved the placement of lights at different orientations and height from the hatchling. However, no studies were able to account for the numerous inter-related variables that influence the intensity and visibility of artificial light to a hatchling turtle at a landscape scale and were therefore unable to define a threshold or limit.

4 REFERENCES

- BENNIE, J., DAVIES, T.W. & GASTON, K.J. (2016) Ecological effects of artificial light at night on wild plants. *Journal of Ecology*, 104(3), 611 – 620.
- BERRY, M., BOOTH, D.T. & LIMPUS, C.J. (2013) Artificial lighting and disrupted sea-finding behaviour in hatchling loggerhead turtles (*Caretta caretta*) on the Woongarra coast, south-east Queensland, Australia. *Australian Journal of Zoology*, 61, 137 – 145.
- COMMONWEALTH OF AUSTRALIA (2017) Recovery Plan for Marine Turtles in Australia 2017 - 2017.
- COMMONWEALTH OF AUSTRALIA (2020) National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds. January 2020.
- CMS 2021 Convention on the conservation of Migratory Species of Wild Animals, Impact of Light Pollution on Different Taxa of Migratory Species, Report to the 5th Meeting of the Sessional Committee of the CMS Scientific Council (ScC-SC5) 28 June – 9 July, 2021 CMS https://www.cms.int/sites/default/files/document/cms_scc-sc5_inf.7_impact-of-light-pollution-on-migratory-species_e.pdf
- CRUZ, L.M., SHILLINGER, G.L., ROBINSON, N.J., TOMILLO, P.S. & PALADINO, F.V. (2018) Effect of light intensity and wavelength on the in-water orientation of olive ridley turtle hatchlings. *Journal of Experimental Marine Biology and Ecology*, 505, 52 – 56.
- FRITSCHES, K.A. (2012) Australian Loggerhead sea turtle hatchlings do not avoid yellow. *Marine and Freshwater Behaviour and Physiology*, 45(2), 79-89.
- GASTON, K.J., BENNIE, J., DAVIES, T.W. & HOPKINS, J. (2013) The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews*, 88(4), 912 – 927.
- GRUBISIC, M.; HAIM, A.; BHUSAL, P.; DOMINONI, D.M.; GABRIEL, K.M.A.; JECHOW, A.; KUPPRAT, F.; LERNER, A.; MARCHANT, P.; RILEY, W.; et al. Light pollution, circadian photoreception, and melatonin in vertebrates. *Sustainability* 2019, 11, 6400
- HÄNEL, A., POSCH, T., RIBAS, S.J., AUBÉ, M., DURISCOE, D., JECHOW, A., KOLLATH, Z., LOLKEMA, D.E., MOORE, C., SCHMIDT, N. AND SPOELSTRA, H., 2018. Measuring night sky brightness: methods and challenges. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 205, pp.278-290.
- HODGE, W., LIMPUS, C.J. & SMISSEN, P. (2007) *Queensland turtle conservation project: Hummock Hill Island nesting turtle study December 2006*. In: Conservation technical and data report. Environmental Protection Agency, Brisbane, p 1–10.
- HORCH, K.W., GOCKE, J.P., SALMON M. & FORWARD R.B. (2008) Visual spectral sensitivity of hatchling loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles, as determined by single-flash electroretinography. *Marine and Freshwater Behaviour and Physiology*, 41(2), 107-119.
- KALINKAT, G., GRUBISIC, M., JECHOW, A., VAN GRUNSVEN, R. H., SCHROER, S., & HÖLKER, F. (2021). Assessing long-term effects of artificial light at night on insects: what is missing and how to get there. *Insect Conservation and Diversity*, 14(2), 260-270.

- KAMROWSKI, R.L., LIMPUS, C., PENDOLEY, K. & HAMANN, M. (2014) Influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings. *Wildlife Research* 41 (5), 421-434.
- KARNAD, D., ISVARAN, K., CHANDRASEKHAR, S.K. & SHANKER, K. (2009) Lighting the way: Towards reducing misorientation of olive ridley hatchlings due to artificial lighting at Rushikulya, India. *Biological Conservation*, 142, 2083 – 2088.
- KYBA, C.C.M., RUHTZ, T., FISCHER, J. & HOLKER, F. (2011) Cloud coverage acts as an amplifier for ecological light pollution in urban ecosystems. *PLoS One*, 6(3), e17307.
- KUPPRAT, F.; HÖLKER, F.; KLOAS, W. Can skyglow reduce nocturnal melatonin concentrations in Eurasian perch? *Environ. Pollut.* 2020, 114324.
- LIMPUS, C.J. (1971) Sea turtle ocean finding behaviour. *Search*, 2, 385 – 387.
- LIMPUS, C.J. & KAMROWSKI, R.L. (2013) Ocean-finding in marine turtles: The importance of low horizon elevation as an orientation cue, *Behaviour*, 150, 863-893.
- LOHMANN, K.J., WITHERINGTON B.E., LOHMANN C.M.F. & SALMON M. (1997) Orientation, navigation, and natal beach homing in sea turtles, in *The Biology of Sea Turtles. Volume I*, P.L. Lutz and J.A. Musick, Editors., CRC Press: Washington D.C. p. 107-135.
- MROSOVSKY, N. & SHETTLEWORTH, S.J. (1968) Wavelength preferences and brightness cues in the water finding behaviour of sea turtles. *Behaviour*, 32, 211-257.
- PENDOLEY, K.L., (2005) *Sea Turtles and Industrial Activity on the North West Shelf, Western Australia*. Ph.D thesis, Murdoch University, Perth.
- PENDOLEY, K.L. & KAMROWSKI, R.L. (2015) Influence of horizon elevation on the sea-finding behaviour of hatchling flatback turtles exposed to artificial light-glow. *Marine Ecology Progress Series*, 529, 279-288.
- PRICE, J.T., DRYE, B., DONAGUE, R.J. & PALDINO, F.V. (2018) Exploring the role of artificial lighting in loggerhead turtle (*Caretta caretta*) nest-site selection and hatchling disorientation. *Herpetological Conservation and Biology*, 13(2), 415 – 422.
- ROBERTSON, K., BOOTH, D.T. & LIMPUS, C.J. (2016) An assessment of 'turtle-friendly' lights on the sea-finding behaviour of loggerhead turtle hatchlings (*Caretta caretta*). *Wildlife Research*, 43(1), 27-37.
- SALMON, M. (2003) Artificial night lighting and sea turtles. *Biologist*, 2003 (50), 163-168.
- SALMON, M. & WITHERINGTON, B. (1995) Artificial lighting and seafinding by loggerhead hatchlings: Evidence for lunar modulation. *Copeia*, 1995, 931-938.
- SALMON, M., WYNEKEN, J., FRITZ, E. & LUCAS, M. (1992) Seafinding by hatchling sea turtles: role of brightness, silhouette and beach slope as orientation cues. *Behaviour*, 122, 56 – 77
- SCHROER, S., HUGGINS, B. J., AZAM, C., & HÖLKER, F. (2020). Working with inadequate tools: legislative shortcomings in protection against ecological effects of artificial light at night. *Sustainability*, 12(6), 2551.
- TUXBURY, S.M. & SALMON, M. (2005) Competitive interactions between artificial lighting and natural cues during seafinding by hatchling marine turtles. *Biological Conservation*, 121, 311-316.

- WITHERINGTON, B.E. (1992) Sea-finding behaviour and the use of photic orientation cues by hatchling sea turtles. PhD thesis, University of Florida, Gainesville.
- WITHERINGTON, B.E. & BJORN DAL, K.A. (1991) Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles *Caretta caretta*. *Biological Conservation*, 55(2), 139-149.
- WITHERINGTON, B. & MARTIN, R.E. (2003) Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches. Florida Fish and Wildlife Conservation Commission FMRI Technical Report TR-2: Jensen Beach, Florida. p. 84.

APPENDIX B BROWSE PROJECT: GREEN TURTLE AND ARTIFICIAL LIGHT MONITORING PLAN OVERVIEW

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Controlled Ref No: BD0006AH0000008

Revision: 5

Page 79 of 92

Uncontrolled when printed. Refer to electronic version for most up to date information.

WOODSIDE ENERGY GROUP LIMITED

**BROWSE PROJECT: GREEN TURTLE AND ARTIFICIAL LIGHT
MONITORING PLAN (OVERVIEW)**



Prepared by

Pendoley Environmental Pty Ltd

For

Woodside Energy Group Limited

3 February 2023



**PENDOLEY
ENVIRONMENTAL**

DOCUMENT CONTROL INFORMATION

TITLE: BROWSE PROJECT: GREEN TURTLE AND ARTIFICIAL LIGHT MONITORING PLAN (OVERVIEW)

Disclaimer and Limitation

This report has been prepared on behalf of and for the use of Woodside Energy Group Limited. Pendoley Environmental Pty Ltd. takes no responsibility for the completeness or form of any subsequent copies of this Document. Copying of this Document without the permission of Woodside Energy Group Limited is not permitted.

Document History

Revision	Description	Date received	Date issued	Personnel
Draft	Report Draft		01/02/2023	Dr L. Peel / Dr P. Whittock / Dr P. Wilson / A. Mitchell
Rev IA	Internal Review	01/02/2023	03/02/2023	Dr K. Pendoley
	Technical Review			
Rev A	Client review	03/02/2023		
Rev 0	Final report issued			

Printed:	3 February 2023
Last saved:	3 February 2023 10:59 AM
File name:	P:\06 Projects\J16 Woodside (WOD)\J16007 Browse Turtle and Light Monitoring Plan\04 Technical Reports\01 Monitoring Plan\01 Overview\BrowsePlan_Overview_RevA.docx
Author:	Dr L. Peel / Dr. P. Whittock / Dr. K. Pendoley / Dr. P. Wilson / A. Mitchell
Project manager:	Dr L. Peel
Name of organisation:	Pendoley Environmental Pty Ltd
Name of project:	Browse Project: Green Turtle and Artificial Light Monitoring Plan (Overview)
Client	Woodside Energy Group Limited
Client representative:	Aaron McDonald
Report number:	J16007
Cover photo:	A green turtle hatchling entering the water © iStock

TABLE OF CONTENTS

GLOSSARY.....	4
1 INTRODUCTION.....	5
1.1 Parameter Definitions.....	5
1.2 Disclaimer.....	5
2 PLAN OVERVIEW.....	6
2.1 GTMP.....	6
2.2 ALMP.....	7
3 FIELD SURVEY SCHEDULE.....	8
4 PLAN ELEMENTS.....	9
4.1 Satellite Telemetry.....	9
4.2 Remote Sensing.....	10
4.3 Adult Turtle Track Census.....	11
4.4 Capture-Mark-Recapture.....	12
4.5 Adult Turtle Track Orientation.....	13
4.6 Incubation Success.....	14
4.7 Arena Trials.....	15
4.8 Virtual Hatchling Dispersal Modelling.....	16
4.9 Passive Acoustic Telemetry.....	17
4.10 Light Monitoring.....	18
5 ADAPTIVE MANAGEMENT TRIGGERS.....	19
5.1 Selection of Key Reportable Parameters.....	19
5.2 Trigger Values and Corrective Action Conditions.....	19
6 REFERENCES.....	21

LIST OF TABLES

Table 1: Elements included within the Browse Green Turtle and Artificial Light Monitoring Plan.....	6
Table 2: Overview of plan elements and survey frequency for the Green Turtle (GTMP) and Artificial Light (ALMP) Monitoring Programs within the Browse Green Turtle and Artificial Light Monitoring Plan.....	8
Table 3: Overview of the satellite telemetry element of the GTMP.....	9
Table 4: Overview of the stand-alone remote sensing study element of the GTMP.....	10
Table 5: Overview of the adult turtle track census element of the GTMP.....	11
Table 6: Overview of the capture-mark-recapture element of the GTMP.....	12
Table 7: Overview of the adult turtle track orientation element of the GTMP.....	13
Table 8: Overview of the incubation success element of the GTMP.....	14
Table 9: Overview of the arena trial element of the GTMP.....	15
Table 10: Overview of the stand-alone virtual hatchling dispersal modelling study of the GTMP.....	16
Table 11: Overview of the passive acoustic telemetry element of the GTMP.....	17
Table 12: Overview of the light monitoring element of the ALMP.....	18

APPENDICES

Appendix A: Infographic summarising the structure of the Plan.

GLOSSARY

Acronym	Definition
ALMP	Artificial Light Monitoring Program
Clutch size	Total number of eggs laid within a turtle nest.
DBCA	Department of Biodiversity, Conservation, and Attractions
DSLR Camera	Digital Single-Lens Reflex Camera
Egg hatching success	The proportion of hatched eggs within a clutch.
Hatchling emergence success	The proportion of hatchlings that successfully emerged from a nest after hatching.
FPSO	Floating Production Storage and Offloading
G-ScBr	Green turtles from the Scott Reef-Browse stock
GTMP	Green Turtle Monitoring Program
Incubation success	The overall success of a clutch (i.e. egg hatching and hatchling emergence success).
Inter-nesting period	The period between two successful nesting attempts.
KC	Key Component
Key reportable parameter	A metric that has been selected as a compulsory component of future monitoring plans encompassing the construction and operations phase of the Project based on outcomes of the baseline monitoring period of this Plan.
MODU	Mobile Offshore Drilling Unit
Nesting Success	The proportion of successful nesting attempts by nesting adult female turtles.
NLPG	National Light Pollution Guidelines for Wildlife including marine turtles, seabirds, and migratory shorebirds
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
PENV	Pendoley Environmental
RTK	Real-time Kinematic
Reportable parameter	A metric that will not be able to detect potential Project-related impacts but will inform interpretation and diagnosis of trigger parameter data and broaden our understanding of G-ScBr ecology and biology.
Remigration interval	The time between nesting seasons for adult female marine turtles, including post-nesting migration to foraging grounds and post-foraging migration back to the nesting site.
RPA	Remotely Piloted Aircraft
Trigger parameter	A metric that can be used to detect and assess potential Project-associated impacts on biologically important behaviours of G-ScBr turtles.

1 INTRODUCTION

This document provides an overview of the Green Turtle and Artificial Light Monitoring Plan (hereafter, the Plan) for the Browse Project, which is currently being developed for Woodside Energy Group Limited (Woodside) by Pendoley Environmental (PENV). The focus of the Plan is baseline monitoring of green turtles from the Scott Reef-Browse stock (G-ScBr), which are known to nest on Sandy Islet and forage within the broader Browse Development Area.

Specifically, this document provides an overview of the following:

1. Outline of the Green Turtle (GTMP) and Artificial Light (ALMP) Monitoring Programs and their associated elements that comprise the Plan as a whole (**Section 2**; page 6);
2. Field survey schedule for the Plan (**Table 2**; page 8);
3. Plan elements associated with the Key Components (KC) of each Program (see **Section 2**), including their purpose, the rationale behind their inclusion, and their associated trigger and reportable parameters as defined below (pages 9 - 18);
4. Summary of the process for determining Adaptive Management Triggers at the completion of the baseline monitoring period.

An infographic summarising the overarching structure of the Plan is also provided in **Appendix A**.

1.1 Parameter Definitions

Trigger and reportable parameters are defined within this document and for each Plan element, where relevant, as follows:

- Trigger parameter: A metric that can be used to detect potential Project-related impacts on biologically important behaviours of G-ScBr turtles* and is likely to be selected as a key reportable parameter in future monitoring plans encompassing later stages of the Project.
- Reportable parameter: A metric that will not be able to detect potential Project-related impacts but will inform interpretation and diagnosis of trigger parameter data and broaden our understanding of G-ScBr ecology and biology.

Furthermore, key reportable parameters are defined within this document as follows:

- Key reportable parameter: A metric selected to be a compulsory component of future monitoring plans that encompass the construction and operations phase of the Project based on the outcomes of the baseline monitoring period of this Plan (e.g. amount and complexity of baseline data available for future Impact detection and assessment).

1.2 Disclaimer

This overview provides a summary of the major components of the Plan. Some smaller details may differ in the final version of the main Plan document.

2 PLAN OVERVIEW

An overview of the GTMP and ALMP and their associated elements, which together comprise the full Plan, is presented in Table 1.

Table 1: Elements included within the Browse Green Turtle and Artificial Light Monitoring Plan. KC = Key Component. * = elements of the GTMP that will incorporate ALMP data. § = stand-alone study.

Monitoring Program	Key Component	Element	Page
Green Turtle Monitoring Program (GTMP)	KC1: Adult In-Water Behaviour	Satellite telemetry	9
		Remote sensing [§]	10
	KC2: Adult Nesting & Sea-Finding Behaviour	Adult turtle track census (including nest counts)	11
		Capture-Mark-Recapture	12
		Adult turtle track orientation*	13
	KC3: Hatchling (i.e. Incubation) Success	Incubation success (marking, excavation, and elevation)	14
	KC4: Hatchling Sea-Finding Behaviour	Arena trials*	15
	KC5: Hatchling In-Water Dispersal	Virtual hatchling dispersal modelling [§]	16
Passive acoustic telemetry*		17	
Artificial Light Monitoring Program (ALMP)	KC6: Baseline Artificial Light Monitoring	Light monitoring	18

The Objectives and associated Key Components (KC) within each Program are provided below.

2.1 GTMP

Three objectives have been defined within the GTMP:

GTMP-A: To investigate nesting turtle behaviour and habitat usage within Scott Reef and to establish a baseline dataset for nesting turtles.

GTMP-B: To understand the key breeding parameters (e.g. nest abundance, incubation success, hatchling sea-finding behaviour, and post-hatching dispersal) for green turtles at Scott Reef.

GTMP-C: To understand the relative importance of Sandy Islet as a nesting site for the G-ScBr green turtle stock.

To address these objectives, five KC's relative to G-ScBr turtle biology have been defined:

1. Adult in-water behaviour (KC1);
2. Adult nesting and sea-finding behaviour (KC2);
3. Hatchling (i.e. incubation) success (KC3);
4. Hatchling sea-finding behaviour (KC4); and,
5. Hatchling in-water dispersal (KC5).

Field methodologies (i.e. elements) and survey frequencies required to capture the necessary baseline data for each element of the GTMP relative to these five key components and the overarching GTMP Objectives are presented on pages 8 – 17 and summarised in **Table 2**.

2.2 ALMP

Two objectives have been defined within the ALMP:

ALMP-D: Establishing a baseline of ambient light conditions (prior to any Project activities) during nesting season.

ALMP-E: Determining light intensity at Sandy Islet during nesting season during MODU and FPSO operations to verify modelling predictions and determine compliance with performance standards.

To address these objectives, one KC has been defined within the ALMP:

1. Baseline light monitoring across the full 360° horizon at Sandy Islet (KC6).

The field methodology (i.e. element) and survey frequency required to capture the required baseline data for the ALMP relative to this KC and the overarching program Objectives is outlined on page 18 and summarised in **Table 2**.

3 FIELD SURVEY SCHEDULE

Table 2: Overview of plan elements and survey frequency for the Green Turtle (GTMP) and Artificial Light (ALMP) Monitoring Programs within the Browse Green Turtle and Artificial Light Monitoring Plan. *asterisks indicate elements of the GTMP that will incorporate ALMP data. § = stand-alone study. FS# = field survey number per season. Duration of FS1 and FS2 are 21 and 14 days, respectively.

Monitoring Element	Objective	Sites	Season 1	Season 2	Season 3	Season 4	Season 5
<i>Field Survey Schedule</i>							
Estimated Number of Field Surveys	All	Sandy Islet	1	2	2	2	2
		Browse Island	1	2	2	2	2
<i>Green Turtle Monitoring Program (GTMP)</i>							
KC1: Adult In-Water Behaviour							
Satellite telemetry	GTMP-A, C	Sandy & Browse	Deployments (FS1)	Deployments (FS1)	Deployments (FS1)	Monitor deployed tags	Monitor deployed tags
KC2: Adult Nesting & Sea-Finding Behaviour							
Remote sensing [§]	GTMP-A, C	Sandy & Browse	Fortnightly (min. monthly)	As required	As required	As required	As required
Track census (including nest counts)	GTMP-A, B, C	Sandy & Browse	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)
Capture-Mark-Recapture	GTMP-A, B, C	Sandy & Browse	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)
Adult turtle track orientation*	GTMP-A, B	Sandy Only	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)	Yes (FS1)
KC3: Hatchling (i.e. Incubation) Success							
Incubation success (marking, excavation, and elevation)	GTMP-B, C	Sandy & Browse	No	Yes (FS1 & FS2)	Yes (FS1 & FS2)	Yes (FS1 & FS2)	Yes (FS1 & FS2)
KC4: Hatchling Sea-Finding Behaviour							
Arena trials*	GTMP-B, C	Sandy Only	No	Yes (FS2)	Yes (FS2)	Yes (FS2)	Yes (FS2)
KC5: Hatchling In-Water Dispersal							
Virtual hatchling dispersal modelling [§]	GTMP-B	Sandy Only	Yes	As required	As required	As required	As required
Passive acoustic telemetry*	GTMP-B	Sandy Only	No	As required (FS2)	As required (FS2)	As required (FS2)	As required (FS2)
<i>Artificial Light Monitoring Program (ALMP)</i>							
KC6: Baseline Artificial Light Monitoring							
Light monitoring	ALMP-D	Sandy Only	Yes (FS1 & FS2)	Yes (FS1 & FS2)	Yes (FS1 & FS2)	Yes (FS1 & FS2)	Yes (FS1 & FS2)
<i>Adaptive Management Triggers</i>							
Power analyses for GTMP	GTMP-A, B, C	Sandy & Browse	No	Yes	As required	As required	As required
Analysis of artificial light data	ALMP-D, E	Sandy Only	Yes	Yes	Yes	Yes	Yes
Selection of trigger values and corrective actions	All	Sandy & Browse	No	No	No	No	Yes

4 PLAN ELEMENTS

4.1 Satellite Telemetry

The purpose, rationale, survey details, and parameters associated with the satellite telemetry element of the GTMP are provided in **Table 3**.

Table 3: Overview of the satellite telemetry element of the GTMP.

Satellite Telemetry	
Purpose	Quantify the movement and distribution patterns of G-ScBr turtles (KC1).
Rationale	Satellite telemetry is required to quantify the extent of connectivity of adult female green turtles between Sandy Islet and Browse Island within nesting seasons, and to resolve the spatio-temporal extent of inter-nesting, migratory, and foraging behaviours of turtles of the G-ScBr stock. Without this information, it would not be possible to assess the relative importance of Sandy Islet as a nesting site for G-ScBr turtles (GTMP Objective C). Additionally, it would not be possible to quantify potential shifts in the nesting activity of green turtles from Sandy Islet to Browse Island as a result of Project-associated activities because the extent of nester connectivity between these two sites is currently unknown.
Methods	<p><i>Transmitter Deployment</i></p> <ul style="list-style-type: none"> Fastloc-GPS and time-depth recorder equipped satellite transmitters will be deployed on adult female green turtles and their movement patterns monitored remotely <i>via</i> the Argos satellite system. <p><i>Data Processing</i></p> <ul style="list-style-type: none"> Low quality positions will be filtered from received datasets and erroneous positions removed prior to state-space models being used to assign behavioural phases (inter-nesting, migration, foraging) to turtle tracking data. Overlap assessments for G-ScBr biologically important behaviours will consider the core areas of use relative to both the amount of time spent by individuals in an area and the number of individuals using that area (see Ferreira et al. 2021).
Monitoring Sites	Sandy Islet and Browse Island.
Timing	Peak nesting season.
Frequency	Deployments in Seasons 1, 2, and 3.
Sample Size	Minimum $n = 15$ transmitters deployed per site per monitoring season.
Trigger Parameters	<p><i>Inter-nesting:</i></p> <ul style="list-style-type: none"> Within-season fidelity to monitoring sites
Reportable Parameters	<p><i>Inter-nesting:</i></p> <ul style="list-style-type: none"> Number of confirmed emergences Inter-nesting period Spatio-temporal descriptors (e.g. inter-nesting areas) Overlap of core areas of use with Project footprint <p><i>Post-nesting migration:</i></p> <ul style="list-style-type: none"> Spatio-temporal descriptors (e.g. start and end points, durations, displacement, and distance travelled) Comparisons between monitoring sites <p><i>Foraging:</i></p> <ul style="list-style-type: none"> Spatio-temporal descriptors (e.g. fidelity to foraging grounds, area of foraging ground/s, consistency/variability of foraging ground use amongst tracked individuals) Comparisons between monitoring sites Overlap of core areas of use with Project footprint

4.2 Remote Sensing

The purpose, rationale, survey details, and parameters associated with the stand-alone remote sensing study of the GTMP are provided in **Table 4**.

Table 4: Overview of the stand-alone remote sensing study element of the GTMP.

Remote Sensing	
Purpose	Confirm the peak nesting and hatching season for G-ScBr turtles (KC2).
Rationale	Remote sensing technology provides a means to monitor the nesting activity of G-ScBr turtles at Sandy Islet and Browse Island year-round without needing to mobilise field teams to both of these remote locations for on-ground surveys. By confirming the peak nesting season for G-ScBr turtles during the first year of the GTMP, subsequent field surveys targeting nesting adult female green turtles and hatchlings can be more accurately scheduled. This will improve the capture of baseline data for the GTMP and ALMP.
Methods	GIS software will be used to quantify the nesting activity levels of G-ScBr turtles within high resolution (15 – 30 cm) satellite images.
Monitoring Sites	Sandy Islet and Browse Island.
Timing	<ul style="list-style-type: none"> Year-round during Season 1. Continuation of the remote sensing scope within the GTMP in later seasons will be reviewed in the first annual report.
Frequency	Fortnightly images (minimum = monthly).
Sample Size	N/A
Trigger Parameters	N/A: a stand-alone study to determine peak nesting period.
Reportable Parameters	<ul style="list-style-type: none"> Peak nesting period Total number of nesting attempts within each fortnightly period Regional environmental conditions (e.g. major storms, cyclones)

4.3 Adult Turtle Track Census

The purpose, rationale, survey details, and parameters associated with the adult turtle track census element of the GTMP are provided in **Table 5**.

Table 5: Overview of the adult turtle track census element of the GTMP.

Adult Turtle Track Census	
Purpose	Quantify adult female nesting behaviour for G-ScBr turtles (KC2).
Rationale	Track census data will facilitate estimates of nester abundance at Sandy Islet and Browse Island. These data will then be used to establish a baseline trend level for nesting activity and success at Sandy Islet relative to Browse Island against which future monitoring outcomes can be compared to assess potential impacts of the Project on nesting adult green turtle behaviour and distribution at Sandy Islet. Without this track census data being collected at both monitoring sites, it would not be possible to quantify the natural, climate-driven (e.g. El Niño Southern Oscillation) variations and fluctuations occurring in the wider G-ScBr adult nesting female population that occur over periods of two to eight years. This would subsequently impede efforts to detect potential Project-attributable impacts to nesting turtles at Sandy Islet.
Methods	Nesting beaches will be monitored nightly and all encountered adult turtle tracks processed based on the observed track characteristics (e.g. marine turtle species, last associated nesting activity per track, and GPS location).
Monitoring Sites	Sandy Islet and Browse Island.
Timing	Peak nesting season.
Sample Size	All encountered adult turtle tracks.
Frequency	Surveys will span 1 – 1.5 inter-nesting cycles for green turtles (i.e. 21 days) during the peak of the nesting season in each baseline monitoring year of the GTMP. This duration is consistent with the recommendations made within the National Light Pollution Guidelines (NLPG) for assessing the importance of a marine turtle population and existing behaviour (Commonwealth of Australia 2020)
Trigger Parameters	<ul style="list-style-type: none"> • Nesting success (i.e. the proportion of false crawls, nesting attempts, and successful nests) • Distribution of and pattern nesting activity • Nester abundance relative to Browse Island
Reportable Parameters	<ul style="list-style-type: none"> • Total number of emergences • Species composition • Influence of environmental factors in reported nester patterns

4.4 Capture-Mark-Recapture

The purpose, rationale, survey details, and parameters associated with the capture-mark-recapture element of the GTMP are provided in **Table 6**.

Table 6: Overview of the capture-mark-recapture element of the GTMP.

Capture-Mark-Recapture	
Purpose	Quantify the fidelity of individual adult female green turtles of the G-ScBr stock to nesting beaches (KC2).
Rationale	Flipper and Passive Integrated Transponder (PIT) tagging will provide evidence of the extent, or lack of, connectivity for nesting female green turtles between Sandy Islet and Browse Island within and between nesting seasons <i>via</i> a capture-mark-recapture program. Quantifying the current level of connectivity between these two sites throughout the baseline monitoring period will demonstrate whether Browse Island is currently used as an alternative nesting site within-seasons by Sandy Islet nesters, and also allow for potential shifts in G-ScBr nesting activity from Sandy Islet to Browse Island as a result of Project-associated activities to be detected and assessed. Flipper and PIT tagging are therefore necessary to determine baseline levels of female G-ScBr nester fidelity to monitoring sites and to capture current natural population-scale variation in connectivity between Sandy Islet and Browse Island prior to the construction and operational phases of the Project.
Methods	<ul style="list-style-type: none"> Nesting adult female green turtles will be flipper and PIT tagged and assigned a unique ID following approved DBCA protocols. Tag numbers and associated ID's of encountered tagged individuals will be recorded within a capture-mark-recapture program to identify remigrant individuals.
Monitoring Sites	Sandy Islet and Browse Island.
Timing	Peak nesting season.
Sample Size	All encountered nesting female turtles.
Frequency	Tagging efforts will span 1 – 1.5 inter-nesting cycles for green turtles (i.e. 21 days) during the peak of the nesting season in each baseline monitoring year of the GTMP. This duration is consistent with the recommendations made within the NLPG for assessing the importance of a marine turtle population and existing behaviour (Commonwealth of Australia 2020)
Trigger Parameters	<ul style="list-style-type: none"> Within-season nesting fidelity to Sandy Islet and/or Browse Island
Reportable Parameters	<ul style="list-style-type: none"> Proportion of remigrants* Inter-nesting period Re-migration interval**

*Likely to be low during entirety of baseline monitoring period given the two-to-eight-year remigration period of green turtles and lack of existing tagging program for the G-ScBr stock. Saturation tagging unlikely to be achieved for one to two decades.

**Unlikely to capture until at least the third season of GTMP monitoring at both sites.

4.5 Adult Turtle Track Orientation

The purpose, rationale, survey details, and parameters associated with the adult turtle track orientation element of the GTMP are provided in **Table 7**.

Table 7: Overview of the adult turtle track orientation element of the GTMP.

Adult Turtle Track Orientation	
Purpose	To quantify the sea-finding behaviour of adult green turtles nesting at Sandy Islet under ambient light conditions (KC2).
Rationale	Artificial light is known to impact the sea-finding behaviour of hatchling marine turtles and other marine fauna (Commonwealth of Australia 2020). While the impact of artificial light on the sea-finding behaviour of adult marine turtles remains poorly understood, characteristics of adult female G-ScBr turtle tracks can be quantified during the baseline monitoring period of the GTMP in order to assess potential impacts of Project-associated artificial lighting on this cohort of the stock during construction and operational phases of the Project. Without capturing this data during the baseline monitoring period, the potential impact of artificial lighting on nesting adult female green turtles at Sandy Islet will not be able to be detected or assessed.
Methods	<ul style="list-style-type: none"> • Aerial surveys will be conducted using Remotely Piloted Aircraft (RPA) • RPAs will capture aerial imagery of nesting beaches from which adult turtle track characteristics (e.g. bearings) can subsequently be measured using appropriate GIS software. • Manual measurements of adult track characteristics will also be conducted during nightly on-ground surveys using a compass and a measuring wheel.
Monitoring Sites	Sandy Islet.
Timing	Peak nesting period.
Frequency	Each morning and night of field surveys spanning 1 – 1.5 inter-nesting cycles (i.e. 21 days) during the peak of the nesting season in each baseline monitoring year of the GTMP. This duration is consistent with the recommendations made within the NLPG for assessing the importance of a marine turtle population and existing behaviour (Commonwealth of Australia 2020).
Sample Size	Minimum 30 adult track measurements per monitoring season.
Trigger Parameters	<ul style="list-style-type: none"> • Adult track bearing angles • Adult track tortuosity
Reportable Parameters	No additional reportable parameters.

4.6 Incubation Success

The purpose, rationale, survey details, and parameters associated with the incubation success element of the GTMP are provided in **Table 8**.

Table 8: Overview of the incubation success element of the GTMP.

Incubation Success (Marking, Excavation, and Elevation)	
Purpose	To quantify nest success for G-ScBr turtles (KC3).
Rationale	An understanding of baseline egg hatching and hatchling emergence success (collectively, incubation success) at Sandy Islet relative to Browse Island is necessary to detect and assess the potential impact to the G-ScBr stock of reduced nesting habitat availability and/or the shift of Sandy Islet nesters to Browse Island that may occur as a result of Project-associated activities.
Methods	<p><i>Nest Marking</i></p> <ul style="list-style-type: none"> Green turtle nests will be marked at oviposition. A temperature logger will be lowered into each nest prior to the start of egg laying, and the total number of eggs laid (i.e. clutch size) subsequently recorded. The position and elevation of marked nests will be recorded using a Real Time Kinematics Global Positioning System (RTK GPS; < 10 cm accuracy). Control temperature loggers (minimum $n = 3$) will be deployed on nesting beaches at a similar depth to those in marked nests. <p><i>Nest Excavation</i></p> <ul style="list-style-type: none"> Nests will be excavated approximately 50 days after they are marked and located using the RTK GPS data. The contents of each excavated clutch will be categorised into hatched and unhatched eggs, and live and dead hatchlings. Where unhatched eggs are present, they will be categorised relative to their developmental stage. The RTK will be used to record the position and elevation of the spring high tide line at nesting beaches. Control loggers will be recovered from nesting beaches last. <p><i>Data Processing</i></p> <ul style="list-style-type: none"> Clutch fate will be determined for each marked nest using the temperature data profile, comparison between egg count at oviposition and those recovered at excavation, and the results of the excavation. Categories include: hatched, lost due to predation/turtle, disturbance from predator/turtle, inundated, and mixed with another clutch.
Monitoring Sites	Sandy Islet and Browse Island.
Timing	Nest marking: peak nesting season. Nest excavation: >50 days after nest marking.
Frequency	Every season of the GTMP baseline monitoring period, commencing in the second year of monitoring.
Sample Size	A minimum of 30 marked nests per monitoring site per season.
Trigger Parameters	<ul style="list-style-type: none"> Egg hatching success Hatchling emergence success Clutch fate Clutch elevation
Reportable Parameters	<ul style="list-style-type: none"> Clutch size Incubation period Incubation temperature during both the overall period and thermosensitive period (i.e. mid-trimester of incubation) Clutch distance to high tide line

4.7 Arena Trials

The purpose, rationale, survey details, and parameters associated with the arena trial element of the GTMP are provided in **Table 9**.

Table 9: Overview of the arena trial element of the GTMP.

Arena Trials	
Purpose	Quantify the sea-finding behaviour of hatchling G-ScBr turtles under ambient lighting conditions (KC4).
Rationale	Arena trials allow for the baseline sea-finding behaviours of hatchling marine turtles to be quantified under controlled experimental conditions and with respect to the surrounding lighting environment. Given the recognised potential for Project-associated artificial lighting to cause mis- and dis-orientation in G-ScBr hatchlings at Sandy Islet, arena trials must be conducted throughout the baseline monitoring period under ambient lighting conditions to provide a reference dataset for future arena trial monitoring outputs to be compared to following the introduction of artificial light into the landscape during the construction and operational phases of the Project.
Methods	<p>Groups of hatchling turtles are released at the centre of a cleared, levelled arena (minimum diameter = 5 – 10 m) on nesting beaches and the bearing (i.e. orientation angle) of each hatchling track from the release point to the point where it exits the area is measured.</p> <p>Light monitoring imagery (see Section 4.10) and environmental data will be captured on nights when arena trials are completed to allow for orientation data to be considered relative to ambient lighting and environmental conditions.</p>
Monitoring Sites	Sandy Islet.
Timing	Peak hatching season during a new moon phase under clear sky conditions (NLPG; Commonwealth of Australia 2020).
Frequency	Every season of the GTMP baseline monitoring over a period of 14 days, commencing in the second year of monitoring. This duration is consistent with the recommendations made within the NLPG for assessing the importance of a marine turtle population and existing behaviour (Commonwealth of Australia 2020).
Sample Size	Minimum of 30 arena trials involving 20 G-ScBr hatchlings in each trial each season.
Trigger Parameters	<ul style="list-style-type: none"> • Angle of the mean vector (estimated) • Length of the mean vector
Reportable Parameters	<ul style="list-style-type: none"> • Consistency of hatchling direction (i.e. uniformity) • Bearing to artificial light sources of interest, if present • Environmental conditions

4.8 Virtual Hatchling Dispersal Modelling

The purpose, rationale, survey details, and parameters associated with the stand-alone virtual hatchling dispersal modelling study within the GTMP are provided in **Table 10**.

Table 10: Overview of the stand-alone virtual hatchling dispersal modelling study of the GTMP.

Virtual Hatchling Dispersal Modelling	
Purpose	Predict the localised dispersal pathway of virtual hatchling turtles and the environmental conditions that increase their likelihood of interaction with Project-related infrastructure (KC5).
Rationale	Recording the dispersal and movement patterns of hatchling marine turtles once they enter the sea remains challenging as their small size prohibits the use of satellite transmitters. It remains important, however, to quantify their in-water dispersal in order to assess the likelihood of hatchlings interacting with Project-related infrastructure. In the place of satellite transmitters, an oceanographic modelling system and particle tracking platform will be used to simulate the dispersal of green turtle hatchlings from Sandy Islet. The model will also have adequate spatial and temporal resolution to predict dispersal pathways under different environmental conditions (e.g. spring/neap tide, high water/low water, El Niño/La Niña conditions, cyclones). Without this modelling process, it would not be possible to accurately estimate the likelihood and frequency of G-ScBr hatchling interactions with Project-associated infrastructure, or to assess how environmental conditions may influence the observed dispersal patterns. Furthermore, the outputs of the dispersal models will inform the design of subsequent field studies involving acoustic receiver arrays (see Section 4.9).
Methods	<ul style="list-style-type: none"> Release and track “virtual hatchlings” in an oceanographic particle model forced by surface currents under different temporal scales and environmental conditions. Calculate the areas of highest occupancy for virtual hatchlings
Monitoring Sites	Sandy Islet.
Timing	The first year of the GTMP.
Frequency	<ul style="list-style-type: none"> Modelling to be completed once. In the event that finer-scale bathymetric or oceanographic data becomes available at a later date, is collected during field surveys, or is required to improve model resolution, further dispersal modelling may be beneficial to refine modelled parameters and improve reportable parameter estimates.
Trigger Parameters	N/A: a stand-alone study that will be used to inform the design of acoustic receiver arrays (see Section 4.9) and determine the oceanographic conditions that are likely to increase the risk of hatchling dispersal to, and interaction with, Project-associated infrastructure.
Reportable Parameters	<ul style="list-style-type: none"> Extent of overlap between virtual hatchling core occupancy areas and the infrastructure and lighting footprints of the Project. Proportion of virtual hatchlings that reach Project-associated infrastructure and lighting footprints. Description of contributing environmental factors that increase the likelihood of hatchlings reaching Project-associated infrastructure.

4.9 Passive Acoustic Telemetry

The objectives, rationale, survey details, and parameters associated with the passive acoustic telemetry element of the GTMP are provided in **Table 11**.

Table 11: Overview of the passive acoustic telemetry element of the GTMP.

Passive Acoustic Telemetry	
Objective	Quantify the natural dispersal patterns of hatchling G-ScBr turtles under different environmental conditions and validate or refine the distribution of virtual hatchlings predicted from dispersal models (see Section 4.8) (KC5).
Rationale	Uniquely coded acoustic transmitters are small enough in size and weight to be deployed on hatchling marine turtles for in-water tracking (see Thums et al. 2016). Using the outputs of the virtual hatchling dispersal modelling (see Section 4.8), acoustic receivers will be deployed and acoustic transmitters used to passively track the behavioural parameters of G-ScBr hatchlings as they leave Sandy Islet. These movement data are required to ground-truth modelled dispersal patterns for virtual hatchlings and further quantify the in-water dispersal behaviour of G-ScBr hatchlings in order to fully resolve the likelihood of hatchlings from Sandy Islet interacting with Project-associated infrastructure.
Methods	<ul style="list-style-type: none"> • Design an acoustic receiver array based on virtual hatchling dispersal models, which includes receivers placed at key Project infrastructure locations (e.g. FPSO). • Complete necessary range testing experiments to confirm detection range and coverage of the array. • Deploy acoustic receivers to passively track hatchlings as they swim offshore. • Deploy oceanographic equipment (e.g. current meter) to measure physical parameters. • Release tagged hatchlings from the nesting beach under different environmental conditions (e.g. weather, ebbing and flowing tides), with a focus on the conditions predicted by virtual hatchling dispersal models to result in the highest likelihood of hatchling interaction with Project-associated infrastructure. • Download detection data from receivers prior to dismantling the array.
Monitoring Sites	Sandy Islet.
Timing	Peak hatching season.
Frequency	Minimum of one monitoring season over a minimum period of 14 days during the new moon phase, commencing in the second or third year of the GTMP. Additional monitoring seasons will be required should minimum sample sizes not be met during the first monitoring season, or virtual dispersal models require further refinement.
Sample Size	Minimum of 20 acoustically-tagged hatchlings released per treatment, minimum of 120 acoustically-tagged hatchlings released per monitoring season.
Trigger Parameters	<ul style="list-style-type: none"> • Alignment of in-field dispersal pattern records with virtual hatchling dispersal model outputs and validation of likely extent of interaction with Project-associated infrastructure.
Reportable Parameters	<ul style="list-style-type: none"> • Behavioural parameters of hatchlings (e.g. trajectories, rate of travel, mean direction, distance travelled, time spent in array). • Oceanographic parameters (e.g. current speed and direction, wind speed and direction, tidal height) and their influence on behavioural parameters.

4.10 Light Monitoring

The purpose, rationale, survey details, and parameters associated with the light monitoring element of the ALMP are provided in **Table 12**.

Table 12: Overview of the light monitoring element of the ALMP.

Light Monitoring	
Purpose	Establish a baseline of ambient light conditions that is biologically relevant for marine turtles (KC6).
Rationale	Light monitoring across the full 360° horizon is required to establish a reliable ambient lighting baseline for future monitoring comparisons and to verify light modelling predictions. These baseline data will also inform the interpretation of adult and hatchling turtle orientation and sea-finding behaviour data in a biologically relevant manner.
Methods	<p><i>Camera Deployment:</i> Light monitoring cameras, as recommended by the NLPG (Commonwealth of Australia 2020), consisting of a calibrated DSLR camera combined with a fisheye lens and with the capacity to capture imagery of light on the full 360° horizon will be deployed.</p> <p><i>Image Processing:</i> Overnight imagery will be processed using specialised software (e.g. Sky Quality Camera; Euromix Pty Ltd) to convert each image into a quantified isophote (i.e. light level) contour map. Quantified isophotes will be subdivided into 1° segments within the horizon view (0 – 30°). The mean light intensity value for each pixel will be calculated within each 1° segment and plotted as a radial line graph that is overlaid with the quantified isophote. The radial line graph will be used to identify the areas of highest light intensity along the horizon within view of hatchlings, with comparisons over subsequent seasons allowing for changes in light intensity and its source (based on its direction) to be identified.</p>
Monitoring Sites	Sandy Islet.
Timing	Peak nesting and hatching seasons during a new moon period (Commonwealth of Australia 2020).
Frequency	Every monitoring survey of the GTMP for a minimum of five nights with regular image capture intervals (i.e. 10 minutes) throughout each full monitoring night.
Sample Size	A minimum of one clear night of images per field survey.
Reportable Parameters	<ul style="list-style-type: none"> • Sector brightness (bearing will vary) for relevant light sources ($V_{mag}/arcsec^2$) • Whole-of-sky brightness ($V_{mag}/arcsec^2$) • 0 – 30° zenith brightness ($V_{mag}/arcsec^2$) • 60 – 90° horizon brightness ($V_{mag}/arcsec^2$) • Bearing range of identified individual/regional light sources • Environmental conditions

5 ADAPTIVE MANAGEMENT TRIGGERS

The monitoring methods outlined within the GTMP and ALMP will provide robust datasets that will support adaptive management responses for the Project based on:

- Changes in green turtle biologically important behaviours;
- Received light levels at Sandy Islet; and,
- Changes to availability of Sandy Islet turtle nesting habitat.

Ongoing data capture and analysis, alongside the continual refinement of the monitoring methods based on increasing familiarity with each field site, will allow for the knowledge gaps surrounding the biology of green turtles at Sandy Islet, and the relative importance of this nesting site to the G-ScBr stock, to be closed throughout the duration of the baseline monitoring period. From these datasets and after a minimum of four (ideally five) monitoring seasons, key reportable parameters and associated adaptive management triggers will be selected.

5.1 Selection of Key Reportable Parameters

Key reportable parameters will be selected at the completion of the final field survey of the baseline monitoring period and in consideration of the outcomes of power analyses conducted during the third year of monitoring (i.e. following field surveys in Season 2). The assignment of trigger values and/or corrective action conditions to the selected key reportable parameters at the end of the baseline monitoring period, rather than in an earlier year of Plan implementation, will allow time for:

- The logistics of accessing Sandy Islet and Browse Island during nesting and hatchling seasons to be refined given the remote nature of these sites;
- The current knowledge gaps surrounding the biology and ecology of nesting green turtles at Sandy Islet to be closed;
- The extent and repeatability of data capture possible at each study site per season to be understood; and,
- The ability of the complete baseline datasets to detect potential future impacts of the Project to be assessed.

In addition to eliminating current uncertainties surrounding the size and complexity of the final baseline datasets, selection of the key reportable parameters at this later stage of the Plan will also allow for external consultation with relevant stakeholders (e.g. DBCA), providing added confidence that any potential impacts associated with the Project on G-ScBr turtles will be able to be detected.

5.2 Trigger Values and Corrective Action Conditions

Trigger values and corrective action conditions will be determined following identification of key reportable parameters at the completion of the baseline monitoring period (minimum four, ideally five, years of monitoring).

Corrective action triggers will be established based on statistical deviations from baseline conditions for each key reportable parameter. Dependent on the outcome of the power analysis and the available baseline data, each trigger will be represented as a trend towards, or change beyond, a ± 1 , ± 2 , or ± 3 statistical deviation (e.g. standard deviation or median absolute deviation from median) from baseline conditions.

While the specifics of these values will be dependent on the final dataset and variation observed within it, as an example, the selected adaptive responses might be defined as follows:

- Alert: A trend towards the ± 1 statistical deviation limit for two consecutive years, or, a change beyond ± 1 statistical deviation from baseline conditions.
- Review: A change beyond ± 2 statistical deviation from baseline conditions.
- Action: A change beyond ± 3 statistical deviation from baseline conditions.

The aim of the initial response to activation of any trigger will be to determine whether the cause is attributable to the Project—i.e. it cannot be confidently attributed to natural variations in green turtle population trends at a regional level. If deemed to be Project-attributable, the associated response actions will be initiated according to the level of trigger activated. The following action would then be initiated in response to each trigger. For example:

- Alert: Conduct an internal investigation of existing data and other relevant information into cause for activation of the management trigger;
- Review: As for Alert, but additionally, conduct risk assessment to identify any potential risk of significant adverse impacts and conduct further data analysis, monitoring or studies if necessary to confirm actual or potential risk of significant adverse impacts; or,
- Action: As for review, but additionally, conduct a review of existing management measures and, where necessary, propose and implement additional management measures. Actions to offset any significant impacts may be required.

The tiered approach outlined above does not preclude early management action if a trigger is determined to be attributable to a stressor from the Project and/or represents a significant threat to the viability of the G-ScBr population.

6 REFERENCES

COMMONWEALTH OF AUSTRALIA (2020) National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds. Commonwealth of Australia, 2020.

FERREIRA, L.C., THUMS, M., FOSSETTE, S., WILSON, P., SHIMADA, T., TUCKER, A.D., PENDOLEY, K., WAAYERS, D., GUINEA, M.L., LOEWENTHAL, G., KING, J., SPEIRS, M., ROB, D. & WHITING, S.D. (2021). Multiple Satellite Tracking Datasets Inform Green Turtle Conservation at a Regional Scale. *Diversity and Distributions* 27: 249–266.

THUMS, M., WHITING, S.D., REISSER, J., PENDOLEY, K.L., PATTIARATCHI, C.B., PROIETTI, M., HETZEL, Y., FISHER, R. & MEEKAN, M.G. (2016). Artificial Light on Water Attracts Turtle Hatchlings during Their Near Shore Transit. *Royal Society Open Science* 3: 160142.

Appendix A: Infographic summarising the structure of the Plan.

MONITORING PLAN

Green Turtle Monitoring Program (GTMP)

Objective A: To investigate nesting turtle behaviour and habitat usage within Scott Reef and to establish a baseline data set for nesting turtles.

Objective B: To understand the key breeding parameters (e.g. nest abundance, incubation success, hatchling sea finding behaviour and post hatching dispersal) for green turtles at Scott Reef.

Objective C: To understand the relative importance of Sandy Islet as a nesting site for the G-ScBr green turtle stock.

Artificial Light Monitoring Program (ALMP)

Objective D: Establishing a baseline of ambient light conditions (prior to any project activities) during nesting season.

Objective E: Determining light intensity at Sandy Islet during nesting season during MODU and FPSO operations to verify modelling predictions and determine compliance with performance standards.

Key Component 1: Adult in-water behaviour.
Monitoring element: Satellite telemetry.

Key Component 2: Adult nesting and sea-finding behaviour.
Monitoring elements: Remote sensing, track census, capture-mark-recapture, and adult turtle track orientation.

Key Component 3: Hatchling (i.e., incubation) success.
Monitoring elements: Incubation success (marking, excavation, and elevation).

Key Component 4: Hatchling sea-finding behaviour.
Monitoring elements: Arena trials.

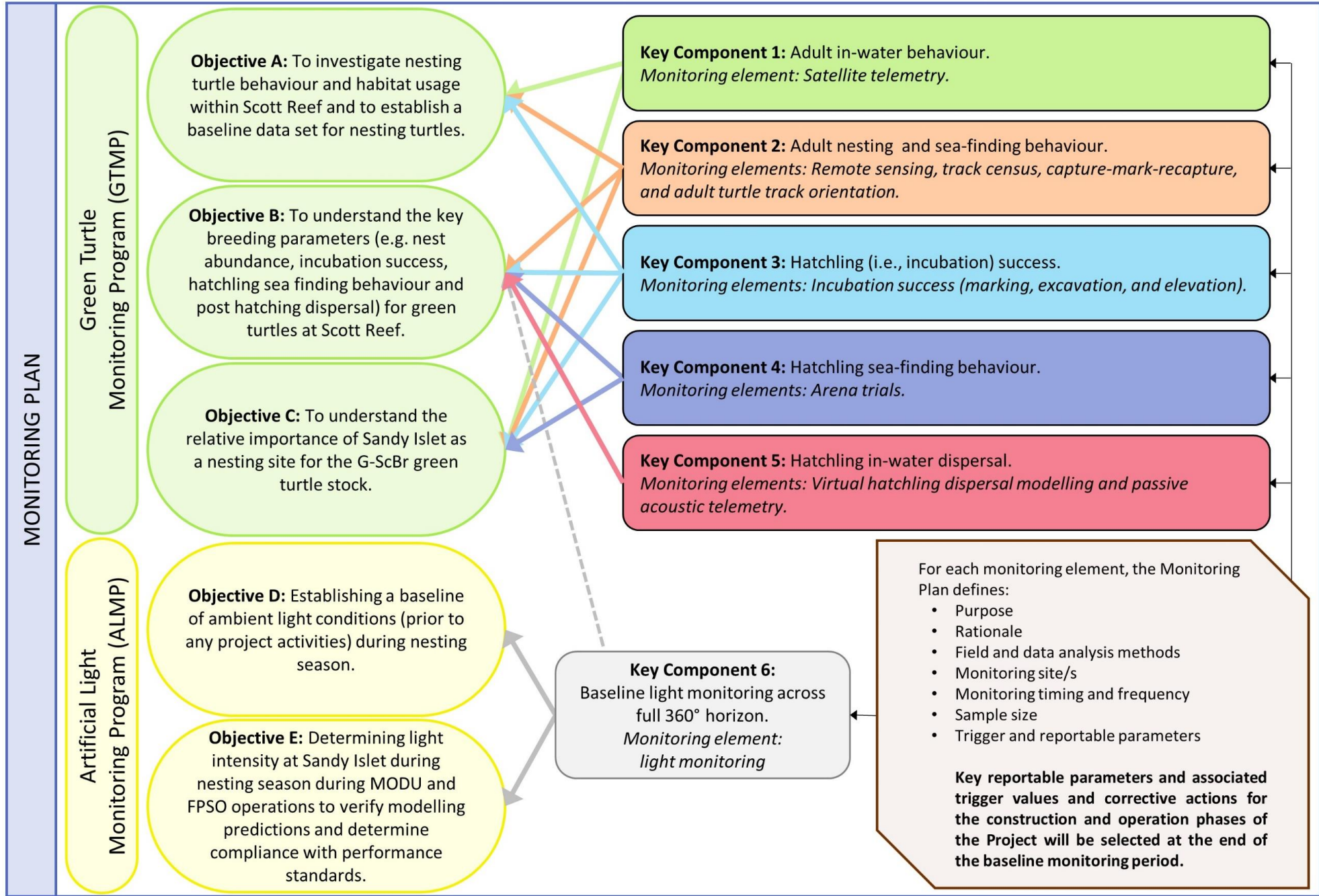
Key Component 5: Hatchling in-water dispersal.
Monitoring elements: Virtual hatchling dispersal modelling and passive acoustic telemetry.

Key Component 6:
Baseline light monitoring across full 360° horizon.
Monitoring element: light monitoring

For each monitoring element, the Monitoring Plan defines:

- Purpose
- Rationale
- Field and data analysis methods
- Monitoring site/s
- Monitoring timing and frequency
- Sample size
- Trigger and reportable parameters

Key reportable parameters and associated trigger values and corrective actions for the construction and operation phases of the Project will be selected at the end of the baseline monitoring period.



APPENDIX C SUBSIDENCE MONITORING PROGRAM

OBJECTIVE OF THE PROGRAM

The objective of the program will be to conduct a long term InSAR monitoring program to measure the rate of seabed subsidence in the vicinity of Sandy Islet (~within 5km) attributable to hydrocarbon extraction. A key interest is the determination of the area of Sandy Islet that is above LAT, as the purpose of this study is to understand if hydrocarbon production induced subsidence is causing a reduction in the available turtle nesting habitat (sand above high tide) at Sandy Islet.

Sandy Islet is typically featureless except for a dilapidated meteorological tower. The Islet varies in size, location, and elevation due to factors such as prevailing weather conditions and seasonal events (e.g. Cyclones). The final monitoring program design is expected to be capable of differentiating long term hydrocarbon extraction related subsidence from subsidence due to natural variation and environmental impact from natural events like storms.

Integrated Monitoring Approach

The natural sandy surfaces at Sandy islet are not suitable for making InSAR measurements due to low reflectivity and in particular the nature of shifting sands causing phase decorrelation. The hard rocky and stable surfaces at North/South Scott reefs in principle are suitable for InSAR subsidence estimates because of the resulting phase coherence. However, that is only feasible for areas that are exposed above the water level during the SAR acquisition. The reefs are only intermittently exposed above water (during low tides) and frequently submerged at medium or high tides. This is a specific challenge that requires a carefully tuned InSAR acquisition and processing strategy.

In order to compensate for these limitations an array of artificial corner reflectors shall be installed strategically across the islands and including Sandy Islet and the reefs. These reflectors still provide the benefit of nearly zero maintenance (after installation) with a more reliable utility as they are positioned above the highwater line and therefore provide measurements to a larger number of planned SAR acquisitions. The strong and reliable (coherent) reflection and frequent coverage helps to reduce noise sources for these locations

An integrated monitoring approach allows for an optimal combination of geodetic measurements that results in the mitigation of risks and limitations of individual methods while utilizing the strengths of others.

The integrated monitoring approach will include an integration of GNSS measurements as recorded at 2 Continuously Operating Reference Stations (CORS) with an array of passive retroreflectors located strategically around the reef.

The strength of the GNSS component is that the potential accuracy is high although it is a measurement of a single location. The value of the InSAR components of the monitoring program include the possibility to obtain relatively large numbers of measurements spatially without or minimal requirements of maintenance and human presence.

Continuously Operating Reference Station (CORS)

It is proposed to install one continuously operating reference station at Sandy Islet as well as a station at the Northern section of Scott Reef North, to accommodate accurate continuous differential GPS monitoring of gas field production related subsidence. The CORS will generate subsidence data that will supplement InSAR measurements and allow optimum integration with InSAR subsidence data.



Figure 9-1 - Example CORS that would be representative of that required for the subsidence monitoring program. Equipment would be mounted to a single pole. (Source – Unavco)

InSAR

The inSAR monitoring program will include the tasked acquisition of commercial SAR sensors. The minimum frequency of exactly repeated coverage will be 1 x per month from a SAR sensor resolution of better than 5 m wherever possible.

The precision and ultimately the accuracy of subsidence estimates from InSAR depend on many factors including:

1. The magnitude and spatio-temporal statistics of atmospheric effects in the data
2. The number of scenes used (per year) for the estimates
3. The actual phase coherence levels and statistics of intermittent exposure of natural reef surfaces (as discussed above)
4. The long-term stability of artificial reflectors and monuments

An increased frequency of SAR coverage may be required improve the precision of subsidence estimates. It should be noted that the actual accuracy of subsidence estimates assumes that there is real spatial variability of subsidence rates within the reefs (due to gas extraction) and that those estimates contain relevant information about the spatially varying subsidence rates caused by subsurface gas extraction.

The expected precision of locally estimated subsidence rate is better than 1 mm/yr LE90 when using all data SAR acquisitions available in any 1 year time period. This is based on the assumption of relatively stable subsidence rates during a 1 year time period. Details of precision and accuracy estimates will be an outcome of the detailed program design work.

Integration of all InSAR sources including corner reflectors and CORS and for a longer time period will lead to improved precision of local estimates. Moreover, it might be possible to use subsidence

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

estimates at multiple locations across the reefs to model the subsidence bowl and estimate the subsidence at the key location (Sandy Islet) at an enhanced accuracy. Addressing the various complexities and combination of factors listed above, providing a solid accuracy statement will be an outcome of detailed design work.

However, it is clear that all factors above are important and that it requires an excellent integrated InSAR program that allows estimation of very subtle rates of subsidence. The program will need to provide credible subsidence estimates with accuracy estimates (with e.g. 90% confidence levels). In case of the “0 subsidence” observation (in case no subsidence could be detected) credible accuracy estimates and confidence levels will be provided.

Natural Targets

Any natural targets and surfaces shall be used for future (and historical) SAR data if and when available at the Sandy islet and the surrounding reefs. Natural targets will be used wherever possible to generate maximum spatial and temporal content for InSAR monitoring.

Based on several samples of Sentinel-1 SAR imagery it is clear that reef surfaces are exposed during low tides (perhaps 10-20% of the time) and that suitable interferograms can be generated on exposed land surfaces for InSAR pairs. This is illustrated in Figure 2 and 3. It is likely that a higher frequency of measurement is possible by utilizing a smaller number of surfaces during slightly higher tides.

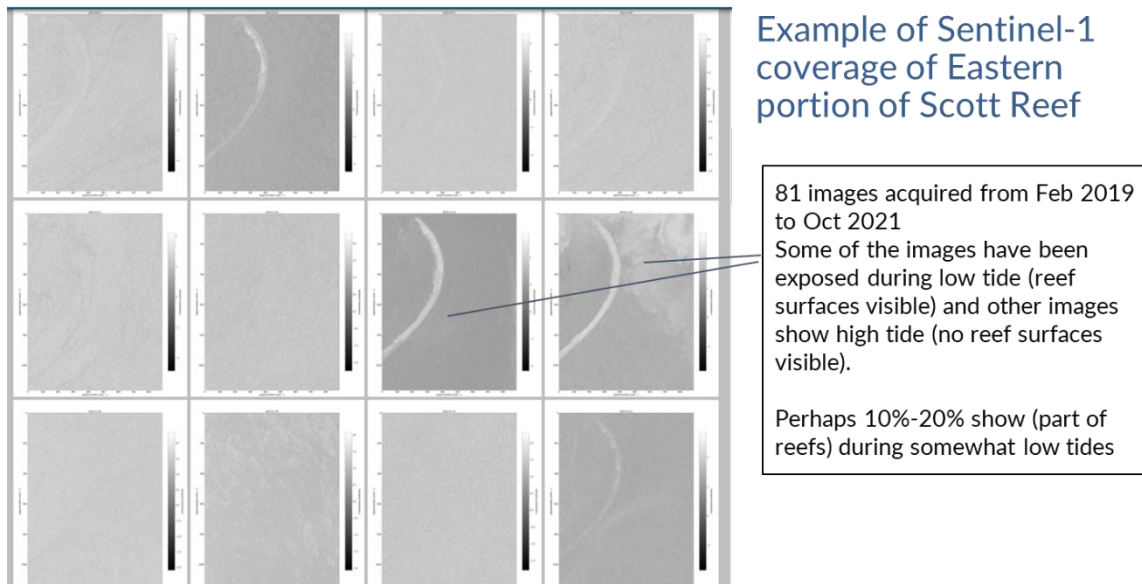
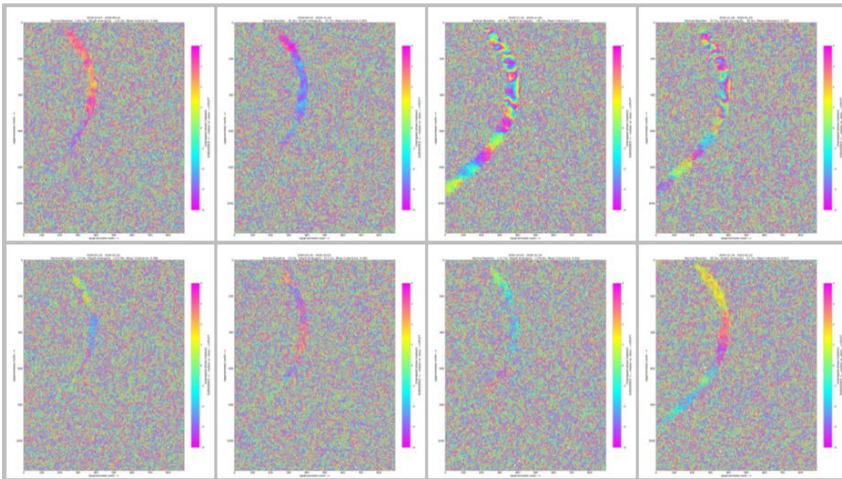


Figure 2 Examples of SAR images of the eastern portion of Scott Reef South (Sentinel-1 SAR ESA). Several indicated images show exposures at low tide.

Example of generation of SAR interferograms for pairs collected during low to modestly low tides



The hard exposed surfaces are clearly suitable as coherent reflector for InSAR purposes.

The operational extraction of information for subsidence measurement requires special attention as the information is only intermittently available.

Figure 3 Examples of interferograms of SAR pairs at low tide (and visible reef surfaces). The results confirm coherent phase information suitable for natural InSAR measurement purposes.

Artificial Targets

Artificial targets (corner reflectors) will be designed, installed and used to provide reliability, accuracy and spatial granularity to the subsidence monitoring program. The proposed number (and density) of reflectors will be based upon technical considerations (e.g. allowable maximum distance between individual targets) and any environmental constraints. A detailed overview of the design of the reflectors and will provide details of requirements for the foundations (construction, placement, location etc.) is to be developed.

Figure 4 provides an example of a reflector mounted on a piling that is mounted on a granite outcrop. Similar structures would be required to be in place at Scott Reef. The structure is expected to be of very solid construction suitable for long term exposure in the ocean environment. The foundation might involve shallow drilling of piling or mounting to large concrete blocks). Each target would be located approximately 5 km apart.



Figure 4 - Example corner reflector (in land based application). Source: University of Bergen, Norway.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

InSAR: Environmental Impact Assessment Summary

Corner reflectors foundations might involve destructive (e.g. shallow drilling of piling) or non-destructive methods (e.g. mounted on concrete blocks) depending on site location and conditions. Installation of this equipment will only be possible following dedicated survey of the installation zones and receipt of subsequent approvals. Installation of this equipment can be conducted with negligible impact to the receiving environment. Monitoring equipment will be targeted to be installed in habitats described (See Figure 5-22 of the EIS/ERD) as either shallow sand or Reef Flat. Total permanent disturbance associated with these activities which can be performed with small, shallow draught vessels, is expected to be less than 20 m². Temporary disturbance, which would be limited to low sensitivity environments (e.g. bare sand, rubble), will be less than 50m². Coral damage can likely be entirely avoided through site planning, as there is a high amount of flexibility in placement of corner reflectors.

Reporting

Deliverables include regular quarterly reports but will also include custom reports as required. Reporting shall include a full QA report including audit trail of processing decisions and technical details such as atmospheric noise reduction.

APPENDIX D HISTORIC SEDIMENT TEXTURE AND COMPOSITION AT SANDY ISLET

Summary of Smithers, S.S (2015) Sediment Texture and Composition at Sandy Islet, Scott Reef. Prepared for: Australian Institute of Marine Science (Western Australia).

Methods

Surface sediment samples were collected at Sandy islet during an AIMS research visit mid-October 2014. The cay was visited at low tide and samples (around 70g of sediment and a corresponding GPS coordinate and photographs) were collected from:

- across the island surface – sampling took place along nine separate cross-island transects;
- around the shoreline – at approximately 100 m intervals samples were collected from the toe of beach (where the beach meets the reef flat), mid beach, and near the high water (HW) mark; and
- from conspicuous sand deposits on the reef flat.

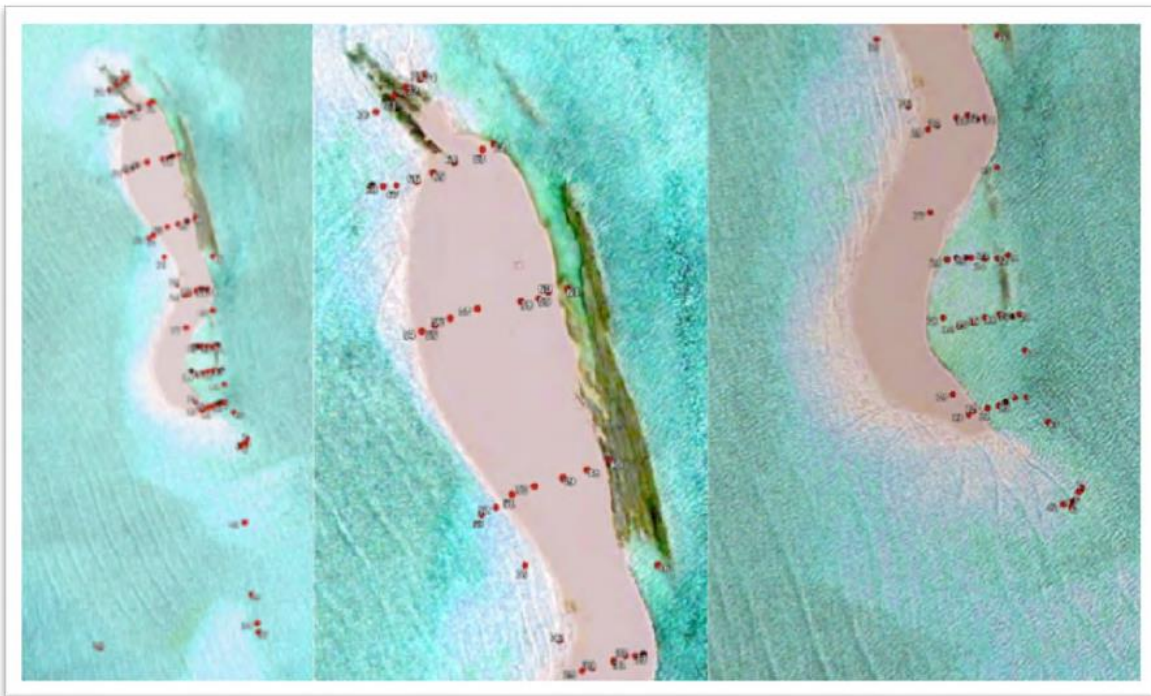


Figure 4: Sediment Sampling locations based on GPS co-ordinates provided by AIMS researchers.

The sediment texture was determined using a Rapid Sediment Analyser (RSA), which is a technique that allows the differentiation of sediments based on how rapidly they move through the water column. This was used over sieving, which only separates based on size and therefore does not account for the different density of biogenic carbonate shapes typically found in reef settings. To run the RSA sampling the following procedures are followed:

1. The original sediment sample collected was air-dried.
2. The air-dried sample was passed through a sample splitter to objectively split the sample into two representative subsamples
3. One of the subsamples was returned to the original sample bag to be used for constituent composition analysis
4. The other sample split was split again until a subsample of around 15g was achieved

5. The 15g sample is placed on a gate at the top of the instrument that is linked electronically to an analytical balance at the base of the instrument.
6. Once the RSA is activated the gate at the top opens and the balance at the bottom records cumulative weight at the base of the tube.
7. The software associated with instrument takes account of sediment density, water column height and temperature and calculates a grain size distribution.
8. A report sheet outlining the hydraulic grain size distribution, degree of sorting, skewness (above or below the mean grain size) and kurtosis (how 'peaky' the grain size curve is) for each sample.

The constituent composition of sediments documents the organisms responsible for the production of the material comprising the sediment in a given sample. The procedure followed for the analysis of the samples from Sandy Islet was:

1. Empty the air-dried sample split into a clear petri dish.
2. 'Smear' the sediments out so that a representative sample is visible as a single sediment layer across the base of the petri dish.
3. Place the petri dish under a binocular microscope and focus in so that the majority of sediment grains in the field of view are in focus.
4. Use attached microscope camera to take photo of field of view for each sample (e.g. Figure 5).
5. Photographs of each sample were imported into Corel Photo-Paint and each grain in the field of view identified and counted, to allow the relative proportion of all constituents in that subsample to be determined.

Results

Table 1: Sediment Texture Summary - Sandy Islet and Reef.

Sample ID	Latitude	Longitude	Geomorphological Setting (based on photographs only)	Gravels & Larger %	V Coarse Sand%	Coarse Sand%	Medium Sand %	Fine Sand %	Very Fine Sand %	Mud %	Mean Grainsize (microns)	Textural Class	Standard Deviation (sorting)	Skewness	Kurtosis
1	14°3.626'S	121°46.745'E	Gravelly shingly beach/spit	62.5	36.2	0.4	0.0	0.6	0.3	0.3	1724.79	vcsG	0.60 MWS	2.38	17.08
2	14°3.619'S	121°46.739'E	Gravelly shingly beach/spit	91.3	6.9	1.7	0.0	0.0	0.0	0.0	2184.06	G	0.39 WS	1.60	8.56
3	14°3.620'S	121°46.737'E	Gravelly shingly beach/spit	67.2	31.5	1.1	0.0	0.0	0.1	0.1	1925.87	vcsG	0.52 MWS	1.53	12.33
4	14°3.624'S	121°46.736'E	Gravelly shingly beach/spit	92.0	7.9	0.0	0.0	0.0	0.0	0.1	2283.75	G	0.35 WS	0.59	3.26
5	14°3.625'S	121°46.735'E	Gravelly shingly beach/spit	87.8	12.2	0.0	0.0	0.0	0.0	0.0	2257.7	vcsG	0.44 WS	0.33	2.43
6	14°3.627'S	121°46.734'E	Gravelly shingly beach/spit	60.3	39.7	0.0	0.0	0.0	0.0	0.0	1741.39	vcsG	0.47 WS	0.37	2.36
7	14°3.579'S	121°46.713'E	Lower beach	0.0	36.9	61.5	1.4	0.2	0.0	0.0	798.43	vCS	0.35 VWS	0.77	7.71
8	14°3.579'S	121°46.709'E	Beach	0.0	5.6	92.6	1.6	0.3	0.0	0.0	701.72	CS	0.26 VWS	2.88	17.91
9	14°3.582'S	121°46.704'E	Upper beach	0.0	31.9	65.7	1.1	0.3	1.0	0.7	751.61	vCS	0.44 WS	4.53	33.37
10	14°3.583'S	121°46.701'E	Reef island	0.0	23.0	73.7	2.9	0.4	0.0	0.0	708.09	vCS	0.37 WS	1.47	7.91
11	14°3.584'S	121°46.696'E	Reef island	1.1	56.2	42.0	0.6	0.1	0.0	0.0	866.27	Vcs	0.37 WS	-2.59	27.25
12	14°3.586'S	121°46.689'E	Upper beach	88.6	11.1	0.0	0.0	0.0	0.0	0.0	2195.78	vcsG	0.33 WS	0.41	3.82
13	14°3.587'S	121°46.688'E	Lower beach	39.5	58.5	1.3	0.8	0.0	0.0	0.0	1527.42	gVCS	0.48 WS	0.93	6.76
14	14°3.549'S	121°46.683'E	Mid beach	1.5	90.2	7.7	0.0	0.6	0.0	0.0	1094.15	VCS	0.42 WS	0.50	22.07
15	14°3.547'S	121°46.689'E	Upper beach	0.0	4.5	56.0	38.8	0.5	0.1	0.1	882.87	mCS	0.41 WS	-0.52	18.70
16	14°3.545'S	121°46.694'E	Reef island	0.2	47.8	49.0	1.6	1.3	0.0	0.0	807.54	vCS	0.43 WS	2.32	13.78
17	14°3.543'S	121°46.701'E	Reef island	6.1	89.5	4.1	0.0	0.3	0.0	0.0	1174.83	VCS	0.41 WS	-0.12	11.88
18	14°3.544'S	121°46.702'E	Spit/reef island.	1.2	65.7	31.8	0.6	0.2	0.5	0.2	912.13	Vcs	0.46 WS	2.09	19.91

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Sample ID	Latitude	Longitude	Geomorphological Setting (based on photographs only)	Gravels & Larger %	V Coarse Sand%	Coarse Sand%	Medium Sand %	Fine Sand %	Very Fine Sand %	Mud %	Mean Grainsize (microns)	Textural Class	Standard Deviation (sorting)	Skewness	Kurtosis
19	14°3.544'S	121°46.707'E	Spit/reef island.	6.4	75.0	16.9	1.0	0.1	0.4	0.4	1001.16	Vcs	0.52 MWS	2.43	21.18
20	14°3.544'S	121°46.710'E	Beach	5.1	88.1	5.5	0.3	0.2	0.8	0.8	1105.78	VCS	0.56 MWS	2.58	25.78
21	14°3.517'S	121°46.705'E	Beach	10.9	67.8	19.0	1.1	1.2	0.0	0.0	1026.62	gVcs	0.68 MWS	-0.37	6.45
22	14°3.519'S	121°46.701'E	Spit/reef island.	4.3	12.3	82.9	0.4	0.0	0.1	0.1	759.10	vCS	0.43 WS	-1.42	16.43
23	14°3.519'S	121°46.695'E	Spit/reef island.	3.2	70.3	21.9	2.3	2.3	0.0	0.0	939.13	Vcs	0.59 MWS	1.94	9.34
24	14°3.519'S	121°46.694'E	Reef island	14.8	77.7	5.9	1.0	0.0	0.6	0.6	1199.44	gVCS	0.54 MWS	2.54	21.09
25	14°3.519'S	121°46.689'E	Reef island	0.0	67.4	31.7	0.7	0.1	0.1	0.1	903.79	Vcs	0.34 VWS	2.04	17.94
26	14°3.519'S	121°46.686'E	Reef island	0.0	43.8	56.1	0.1	0.0	0.0	0.0	812.55	vCS	0.23 VWS	0.63	4.28
27	14°3.519'S	121°46.682'E	Beach	0.0	76.1	23.2	0.1	0.4	0.1	0.1	896.76	Vcs	0.32 VWS	5.20	52.35
28	14°3.520'S	121°46.678'E	Lower beach/water level	10.2	79.0	10.5	0.1	0.0	0.1	0.0	1117.47	gVcs	0.42 WS	0.11	11.46
29	14°3.465'S	121°46.669'E	Lower/mid Beach/Water Level	1.2	80.4	17.1	1.0	0.1	0.1	0.0	951.71	Vcs	0.38 WS	2.53	20.99
30	14°3.462'S	121°46.673'E	Upper beach/Reef Island	3.9	52.2	43.1	0.3	0.4	0.1	0.1	863.59	Vcs	0.42 WS	0.39	19.78
31	14°3.459'S	121°46.682'E	Gravelly upper beach	16.4	71.7	10.5	0.8	0.0	0.5	0.2	1222.36	gVcs	0.57 MWS	1.40	13.01
32	14°3.457'S	121°46.687'E	Intertidal / mid beach	0.0	45.5	49.9	2.1	1.6	0.8	0.5	781.71	vCS	0.55 MWS	2.74	14.82
33	14°3.458'S	121°46.691'E	Intertidal / mid beach	22.0	57.2	19.1	1.5	0.1	0.1	0.1	1141.27	gVcs	0.62 MWS	0.39	5.10
34	14°3.457'S	121°46.694'E	Intertidal / Lower beach	13.0	54.3	32.0	0.5	0.1	0.1	0.1	1003.14	gVcs	0.61 MWS	-0.68	5.32
35	14°3.895'S	121°46.534'E	Reef Flat – near crest	0.0	7.4	58.1	29.8	3.6	1.2	1.2	480.83	mCS	0.65 MWS	0.79	4.94
36	14°3.842'S	121°46.571'E	Reef flat	0.7	25.3	66.9	3.7	1.8	1.6	0.9	666.94	vCS	0.69 MWS	1.75	8.82
37	14°3.828'S	121°46.751'E	Sand spit	19.0	68.3	11.9	0.6	0.0	0.2	0.2	1177.17	gVcs	0.56 MWS	0.37	8.34
38	14°3.817'S	121°46.749'E	Sand spit	10.5	75.3	11.0	0.9	2.2	0.0	0.0	1061.20	gVcs	0.63 MWS	1.75	10.08

Sample ID	Latitude	Longitude	Geomorphological Setting (based on photographs only)	Gravels & Larger %	V Coarse Sand%	Coarse Sand%	Medium Sand %	Fine Sand %	Very Fine Sand %	Mud %	Mean Grainsize (microns)	Textural Class	Standard Deviation (sorting)	Skewness	Kurtosis
39	14°3.785'S	121°46.742'E	Beach/beachrock? Sand spit	21.3	62.1	15.8	0.1	0.3	0.4	0.3	1127.05	gVcs	0.57 MWS	1.29	11.60
40	14°3.381'S	121°46.680'E	Sand spit	7.0	66.5	24.8	1.0	0.0	0.7	0.6	962.36	Vcs	0.54 MWS	1.57	17.19
41	14°3.708'S	121°46.736'E	Beach/beachrock?	28.9	34.6	33.4	1.7	0.3	1.2	1.0	1160.80	gVcs	0.96 MS	0.54	5.15
42	14°3.624'S	121°46.729'E	Sand spit	36.7	57.1	4.6	0.0	1.1	0.6	0.4	1405.26	gVCS	0.70 MWS	2.53	15.43
43	14°3.587'S	121°46.720'E	Lower beach/water level	9.0	60.8	29.0	0.5	0.3	0.5	0.3	997.90	Vcs	0.62 MWS	1.21	11.05
44	14°3.558'S	121°46.710'E	Lower beach/water level	11.8	46.0	41.6	0.3	0.0	0.3	0.2	979.19	gVcs	0.66 MWS	-0.61	5.84
45	14°3.579'S	121°46.698'E	Lower beach/water level	1.7	73.3	23.5	0.7	0.3	0.5	0.3	956.00	Vcs	0.45 WS	3.00	24.00
46	14°3.421'S	121°46.698'E	Lower beach/water level	9.1	65.9	25.1	0.0	0.0	0.0	0.0	1005.51	Vcs	0.42 WS	-0.35	3.07
47	14°3.381'S	121°46.680'E	Reef island/beach?	11.1	67.4	18.3	2.2	0.0	1.0	0.9	1001.27	gVcs	0.65 MWS	1.98	15.09
48	14°3.384'S	121°46.671'E	Reef island	1.1	12.9	84.1	1.1	0.4	0.4	0.0	687.82	vCS	0.41 WS	1.57	15.91
49	14°3.387'S	121°46.661'E	Reef island	0.6	67.3	32.0	0.0	0.0	0.0	0.0	910.09	Vcs	0.32 VWS	0.07	3.65
50	14°3.390'S	121°46.649'E	Reef island	14.3	58.6	26.0	0.6	0.6	0.0	0.0	1033.94	gVcs	0.63 MWS	0.02	6.74
51	14°3.394'S	121°46.640'E	Reef island	0.0	46.8	51.9	0.7	0.3	0.4	0.3	814.01	vCS	0.35 VWS	5.02	43.47
52	14°3.399'S	121°46.633'E	Beach	11.8	84.2	2.9	0.0	0.0	1.1	0.8	1189.70	gVCS	0.56 MWS	4.12	33.01
53	14°3.402'S	121°46.628'E	Lower beach/water level	6.0	68.7	23.7	0.5	0.8	0.3	0.1	964.10	Vcs	0.50 WS	1.66	13.04
54	14°3.329'S	121°46.603'E	Lower beach/water level	17.4	46.0	35.4	0.9	0.0	0.4	0.2	1033.06	gVcs	0.66 MWS	-0.16	6.21
55	14°3.327'S	121°46.608'E	Beach	7.3	64.4	27.1	0.5	0.3	0.4	0.4	966.33	Vcs	0.53 MWS	1.53	16.76
56	14°3.324'S	121°46.615'E	Reef island	0.8	31.3	64.6	1.1	0.7	1.4	1.1	742.62	vCS	0.56 MWS	3.41	21.68
57	14°3.321'S	121°46.626'E	Reef island	4.3	43.7	50.9	0.9	0.1	0.0	0.1	853.32	vCS	0.47 WS	-0.11	10.30
58	14°3.318'S	121°46.644'E	Reef island	1.8	66.1	29.7	0.8	1.1	0.5	0.4	905.5	Vcs	0.53 MWS	3.02	19.97

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Sample ID	Latitude	Longitude	Geomorphological Setting (based on photographs only)	Gravels & Larger %	V Coarse Sand %	Coarse Sand %	Medium Sand %	Fine Sand %	Very Fine Sand %	Mud %	Mean Grainsize (microns)	Textural Class	Standard Deviation (sorting)	Skewness	Kurtosis
59	14°3.316'S	121°46.651'E	Beach	4.0	52.6	40.9	1.0	0.4	1.1	0.6	880.12	Vcs	0.65 MWS	1.38	13.79
60	14°3.314'S	121°46.655'E	Lower beach/water level	4.6	53.7	39.7	1.2	0.8	0.0	0.0	919.70	Vcs	0.57 MWS	-0.13	7.64
61	14°3.313'S	121°46.663'E	Lower beach/water level	12.6	54.2	30.0	1.5	0.4	1.3	0.7	976.71	gVcs	0.69 MWS	1.77	11.41
62	14°3.255'S	121°46.632'E	Lower beach/water level	39.5	33.2	27.1	0.2	0.0	0.0	0.0	1293.42	Vcs/csG	0.77 MS	-0.32	1.68
63	14°3.257'S	121°46.628'E	Beach	11.5	80.9	6.8	0.4	0.0	0.4	0.3	1180.52	gVcs	0.59 MWS	-0.20	14.70
64	14°3.262'S	121°46.617'E	Reef island	0.6	49.9	46.9	1.3	0.7	0.6	0.6	818.56	Vcs	0.52 MWS	2.80	17.85
65	14°3.266'S	121°46.608'E	Reef island	0.6	48.7	48.9	1.3	0.2	0.3	0.3	830.35	Vcs	0.43 WS	1.98	26.19
66	14°3.270'S	121°46.601'E	Reef island	2.2	39.2	55.2	2.5	0.4	0.4	0.4	789.42	vCS	0.52 MWS	1.63	12.00
67	14°3.272'S	121°46.593'E	Beach	10.2	63.5	25.0	0.7	0.3	0.3	0.3	1009.48	gVcs	0.60 MWS	-0.01	10.35
68	14°3.272'S	121°46.588'E	Lower beach/water level	8.4	65.5	23.7	0.5	0.8	1.1	1.0	964.01	Vcs	0.88 MWS	2.02	14.49
69	14°3.271'S	121°46.582'E	Lower beach/water level	28.1	50.7	17.1	0.0	0.9	3.2	1.9	1171.02	gVcs	0.95 MS	2.37	10.06
70	14°3.243'S	121°46.585'E	Lower beach/water level	31.4	56.5	12.0	0.0	0.0	0.2	0.2	1294.02	gVcs	0.62 MWS	0.37	6.89
71	14°3.237'S	121°46.592'E	Reef island/beachrock	25.0	61.5	12.2	0.6	0.2	0.5	0.3	1253.08	gVcs	0.65 MWS	1.17	9.51
72	14°3.234'S	121°46.597'E	Reef island/beachrock	22.2	73.4	3.9	0.4	0.0	0.0	0.0	1344.31	gVcs	0.46 WS	0.04	4.06
73	14°3.230'S	121°46.603'E	Reef island/beachrock	25.7	70.9	3.4	0.0	0.0	0.0	0.0	1381.45	gVcs	0.45 WS	0.24	3.76
74	14°3.227'S	121°46.605'E	Lower Beach/Water Level – possibly over beachrock outcrop	41.1	58.9	0.0	0.0	0.0	0.0	0.0	1619.90	gVCS	0.48 WS	-0.13	2.07
75	14°3.422'S	121°46.648'E	Lower beach/water level	15.3	77.5	6.8	0.0	0.3	0.2	0.3	1216.41	gVCS	0.51 MWS	1.41	14.59
76	14°3.451'S	121°46.660'E	Lower beach/water level	10.0	81.7	5.8	2.2	0.0	0.3	0.3	1166.26	gVCS	0.50 MWS	1.57	16.27
77	14°3.498'S	121°46.670'E	Lower beach/water level	11.6	78.0	8.8	0.9	0.3	0.5	0.3	1122.86	gVCS	0.54 MWS	2.08	16.67
78	14°3.545'S	121°46.676'E	Lower beach/water level	18.3	75.1	6.1	0.4	0.0	0.0	0.0	1315.93	gVCS	0.46 WS	-0.04	3.96

Sample ID	Latitude	Longitude	Geomorphological Setting (based on photographs only)	Gravels & Larger %	V Coarse Sand %	Coarse Sand %	Medium Sand %	Fine Sand %	Very Fine Sand %	Mud %	Mean Grainsize (microns)	Textural Class	Standard Deviation (sorting)	Skewness	Kurtosis
79	14°3.578'S	121°46.680'E	Lower beach/water level	47.4	51.0	0.6	0.0	0.4	0.0	0.0	1658.92	gVCS	0.54 MWS	0.76	7.35

Textural class codes:

G: gravel

vcsG: very coarse sandy gravel

csG: coarse sandy gravel

VCS: very coarse sand;

gVCS: gravely very coarse sand;

Vcs: very coarse sand also containing subsidiary but >10% coarse sand;

gVcs: gravely very coarse sand also containing subsidiary but >10% coarse sand;

CS: coarse sand

vCS: Coarse sand also containing subsidiary but >10% very coarse sand;

mCS: Coarse sand also containing subsidiary but >10% medium sand;

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Proposed Browse Project – Turtle Management Plan

Table 2: Constituent Composition Count Percentages - Sandy Islet and Reef. UID = Unidentified, CCA = Crustose Coralline Algae. Note unidentified sediments include those that could not be visually identified as of several possible constituents. For example, smaller sediments that have been 'polished' through abrasion and lost surface morphology are difficult to confidently identify. Specifically it can be very difficult to definitively classify smaller polished sediments as either coral or molluscan in origin.

Sample ID	Coral	CCA	Halimeda	Gastropod	Bivalve	UID Mollusc	Mollusc Total	Baculigypsiina	Amphistegina	Calcarina	Marginozora	Homotrema	UID-Forams	Forams Total	Echinoids	Alcyonarians	Bryzoans	Worm Tests	Crustacean	Unidentified	Other Total	Total	Geomorphological Setting (based on photographs only)	Notes from site photographs provided by AIMS
1	34.5	9.5	9.5	6.8	19.6	0.0	26.4	0.0	4.1	0.0	4.1	1.4	0.7	10.1	0.7	0.0	0.7	0.7	0.7	7.4	2.7	100.0	Gravelly shingly beach/spit	Collected from near HW on shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection.
2	55.2	7.5	3.7	14.9	6.7	0.0	21.6	0.0	0.0	0.0	2.2	0.7	0.0	3.0	1.5	0.0	3.0	1.5	0.7	2.2	6.7	100.0	Gravelly shingly beach/spit	Collected from near HW on shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection, site appears to be below HW.
3	50.0	12.5	3.9	12.5	6.3	0.0	18.8	0.0	5.5	0.0	0.8	0.8	0.0	7.0	0.8	0.0	0.8	1.6	0.8	3.9	3.9	100.0	Gravelly shingly beach/spit	Collected from near HW on shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection, site appears to be below HW.
4	53.1	9.7	9.0	11.7	4.1	0.0	15.9	0.0	0.0	0.0	0.7	0.7	0.7	2.1	0.0	0.0	1.4	0.7	0.0	8.3	2.1	100.0	Gravelly shingly beach/spit	Collected from shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection, site appears to be below HW.
5	41.0	13.3	2.4	14.8	11.4	1.0	27.1	0.0	2.9	0.0	0.5	1.9	1.0	6.2	0.0	0.0	5.2	0.0	0.5	4.3	5.7	100.0	Gravelly shingly beach/spit	Collected from shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection, site appears to be below HW.
6	29.8	14.5	6.0	16.2	9.4	7.2	32.8	0.0	3.4	0.0	1.3	3.8	1.3	9.8	0.0	0.0	1.7	0.4	0.4	4.7	2.6	100.0	Gravelly shingly beach/spit	Collected from shingle beach dominated with <i>Acropora</i> shingle and gravel surface lag. Recurved spit at time of collection, site appears to be below HW.
7	63.8	4.7	4.0	2.7	3.4	1.3	7.4	0.0	12.8	0.0	0.0	0.7	0.7	14.1	1.3	0.0	0.7	0.0	0.7	3.4	2.7	100.0	Lower beach	Sandy beach – lower down on beach.
8	49.0	13.0	3.0	2.0	22.0	1.0	25.0	0.0	7.0	0.0	0.0	2.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	100.0	Beach	Sandy beach – appears to still be in the intertidal.
9	63.9	3.2	1.3	2.6	8.4	0.0	11.0	0.0	16.1	0.6	0.0	0.6	0.0	17.4	0.0	0.6	0.0	0.0	0.6	1.9	1.3	100.0	Upper beach	Sand with isolated (storm washed) shingle and shells on surface.
10	64.6	4.0	0.0	2.5	9.1	0.0	11.6	0.0	10.1	0.0	0.5	1.5	1.0	13.1	1.0	0.5	0.0	0.0	0.0	5.1	1.5	100.0	Reef island	Sand – has appearance of wind blown.
11	65.0	5.7	2.4	2.4	0.8	0.8	4.1	0.0	7.3	0.8	0.0	1.6	1.6	11.4	0.8	0.0	0.0	0.0	0.0	10.6	0.8	100.0	Reef island	Sand – berm crest? Faint overwash swash line visible.
12	54.2	9.4	8.2	10.6	1.5	5.5	17.6	0.0	1.8	0.0	0.0	1.2	0.0	3.0	0.6	0.0	0.0	0.0	0.0	7.0	0.6	100.0	Upper beach	Gravel swash on upper beach?

Sample ID	Coral	CCA	Halimeda	Gastropod	Bivalve	UID Mollusc	Mollusc Total	Baculigypsiina	Amphistegina	Calcarina	Marginozora	Homotrema	UID-Forams	Forams Total	Echinoids	Alcyonarians	Bryzoans	Worm Tests	Crustacean	Unidentified	Other Total	Total	Geomorphological Setting (based on photographs only)	Notes from site photographs provided by AIMS
13	36.8	9.2	13.5	7.2	1.4	2.3	10.9	0.0	16.4	0.3	0.3	3.7	0.0	20.7	0.6	0.6	0.9	0.0	0.0	6.9	2.0	100.0	Lower beach	Gravels and coarse sand beachface. Mollusc fragments and shingle conspicuous.
14	67.0	8.5	3.8	2.8	2.8	6.6	12.3	0.0	0.9	0.0	0.0	0.9	0.0	1.9	0.0	0.0	0.0	0.0	0.0	6.6	0.0	100.0	Mid beach	Sandy Beach – above LWL in the intertidal.
15	63.3	5.8	2.9	2.2	6.5	2.2	10.8	0.0	10.8	0.0	0.0	0.0	0.0	10.8	0.7	0.0	0.0	0.0	0.0	5.8	0.7	100.0	Upper beach	Mostly sandy beach, with some coal and shell gravel at tidal swash line.
16	49.2	5.1	7.6	5.1	11.0	2.5	18.6	0.0	9.3	0.0	2.5	0.0	0.8	12.7	0.0	0.0	1.7	0.8	0.0	4.2	2.5	100.0	Reef island	Sand – dry at sampling. Rare gravels.
17	43.1	6.9	4.9	8.8	3.9	7.8	20.6	0.0	10.8	0.0	0.0	0.0	1.0	11.8	0.0	0.0	0.0	0.0	0.0	12.7	0.0	100.0	Reef island	Coarse sand/gravels. Looks to be above intertidal.
18	46.3	8.5	4.3	2.4	8.5	7.3	18.3	0.0	7.9	0.0	0.0	1.2	0.0	9.1	0.6	0.0	0.0	1.2	0.6	11.0	2.4	100.0	Spit/reef island.	Upper swash or possibly washover? Coarse sand and shell/shingle gravels.
19	32.9	10.6	6.2	3.7	5.6	16.1	25.5	0.0	11.8	0.0	0.0	1.2	0.6	13.7	0.0	1.2	0.6	1.9	0.0	7.5	3.7	100.0	Spit/reef island.	Upper swash? Coarse sand and shell/shingle gravels.
20	49.2	5.9	4.2	3.4	5.1	16.1	24.6	0.0	2.5	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.8	12.7	0.8	100.0	Beach	Mid beach swash line? Possible behind a beachrock outcrop?
21	42.6	6.6	6.6	2.5	1.6	7.4	11.5	0.0	16.4	0.0	0.0	4.1	0.0	20.5	0.0	0.8	0.0	0.0	0.0	11.5	0.8	100.0	Beach	Sandy mid or lower beach? Note that on satellite image extensive beachrock outcrop on this shore at this point.
22	48.3	5.7	9.2	1.1	0.6	6.3	8.0	0.0	17.8	0.0	0.0	1.7	0.0	19.5	0.6	0.0	0.6	1.1	0.0	6.9	2.3	100.0	Spit/reef island.	Upper swash? Coarse sand and shell/shingle gravels.
23	35.2	8.6	7.8	7.8	0.8	10.9	19.5	0.0	14.8	0.0	0.8	1.6	0.8	18.0	0.0	0.8	0.8	0.0	0.0	9.4	1.6	100.0	Spit/reef island.	Upper swash – washover or HAT? Coarse sand and shell/shingle gravels.
24	36.5	6.7	6.7	17.3	1.0	15.4	33.7	0.0	4.8	0.0	0.0	1.0	1.0	6.7	1.0	0.0	0.0	0.0	0.0	8.7	1.0	100.0	Reef island	Sand – dry at sampling. Some gravels.
25	34.1	6.1	8.5	4.9	1.8	23.8	30.5	0.0	9.1	0.0	0.0	1.2	0.6	11.0	0.0	0.0	0.0	0.0	0.0	9.8	0.0	100.0	Reef island	Sand – dry at sampling. Rare gravels.
26	42.1	1.3	11.3	4.4	1.3	14.5	20.1	0.0	10.1	0.0	0.0	0.6	0.6	11.3	0.0	1.9	0.0	0.0	0.0	11.9	1.9	100.0	Reef island	Upper swash or possibly washover? Coarse sand and shell/shingle gravels.
27	33.7	4.7	13.6	6.5	7.7	10.1	24.3	0.0	9.5	0.0	0.0	1.8	0.0	11.2	0.0	0.0	0.0	0.0	0.0	12.4	0.0	100.0	Beach	Sandy beach – mid intertidal?
28	34.6	6.0	11.3	6.8	0.8	11.3	18.8	0.0	11.3	0.8	0.0	0.8	1.5	14.3	0.0	0.0	0.0	0.0	0.0	15.0	0.0	100.0	Lower beach/water level	Gravelly (small) and coarse sand lag over sand beach. Conspicuous mollusc fragments.
29	26.1	7.0	13.9	7.8	0.9	19.1	27.8	0.0	10.4	0.0	0.0	1.7	0.0	12.2	0.0	0.0	0.0	0.0	0.0	13.0	0.0	100.0	Lower/mid Beach/Water Level	Coarse to medium sands, rare gravels.
30	38.0	5.3	9.1	5.9	0.5	12.3	18.7	0.0	14.4	0.5	0.0	0.0	0.0	15.0	0.0	0.5	0.0	0.0	0.5	12.8	1.1	100.0	Upper beach/Reef Island	Mostly medium to coarse sands. – backbeach?
31	21.2	7.5	8.0	5.7	0.0	14.6	20.3	0.0	25.5	0.0	0.0	1.9	0.5	27.8	0.9	0.0	0.5	0.0	0.5	13.2	1.9	100.0	Gravelly upper beach	Coarse / gravelly beachface.
32	34.0	4.4	12.8	8.9	0.0	14.8	23.6	0.0	13.3	0.5	0.0	0.5	1.0	15.3	0.0	0.5	0.0	0.0	0.0	9.4	0.5	100.0	Intertidal / mid beach	Sandy beach face.
33	44.5	4.2	7.6	8.4	0.0	9.2	17.6	0.0	7.6	0.0	0.0	0.0	1.7	9.2	0.0	0.0	0.0	0.0	0.0	16.8	0.0	100.0	Intertidal / mid beach	Sandy beach face.

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Proposed Browse Project – Turtle Management Plan

Sample ID	Coral	CCA	Halimeda	Gastropod	Bivalve	UID Mollusc	Mollusc Total	Baculigypsina	Amphistegina	Calcarina	Marginopora	Homotrema	UID -Forams	Forams Total	Echinoids	Alcyonarians	Bryozoans	Worm Tests	Crustacean	Unidentified	'Other' Total.	Total	Geomorphological Setting (based on photographs only)	Notes from site photographs provided by AIMS
34	27.2	3.5	11.4	3.5	0.0	10.5	14.0	0.0	24.6	0.0	0.0	0.9	0.9	26.3	0.0	0.9	0.9	0.0	0.0	15.8	1.8	100.0	Intertidal / Lower beach	Sandy beach face with scattered gravels – possibly behind a beachrock outcrop.
35	29.4	1.6	16.7	0.8	0.0	16.7	17.5	0.0	11.1	0.0	0.8	1.6	2.4	15.9	0.8	0.0	1.6	0.0	0.0	16.7	2.4	100.0	Reef Flat – near crest	Reef flat in microatoll zone. Sandy patches in coral rubble
36	33.2	4.4	10.7	5.4	0.0	7.3	12.7	0.0	20.0	0.0	1.5	1.0	0.5	22.9	0.0	1.5	0.0	1.0	0.5	13.2	2.9	100.0	Reef flat	As above.
37	29.5	7.7	26.9	3.8	0.0	6.4	10.3	0.0	5.1	0.0	0.0	1.3	1.3	7.7	0.0	0.0	0.0	0.0	0.0	17.9	0.0	100.0	Sand spit	Sand spit to south of cay – conspicuous mollusc lag on surface. Spit appears to have bioturbator burrows on surface, suggesting some depth for infaunal mollusc habitat. Algae on surface – suitable for grazers.
38	40.7	3.3	15.4	7.7	0.0	15.4	23.1	0.0	4.4	0.0	2.2	2.2	0.0	8.8	0.0	0.0	0.0	2.2	0.0	6.6	2.2	100.0	Sand spit	As above
39	28.8	3.0	21.2	6.1	0.0	18.2	24.2	0.0	9.8	0.0	0.0	0.0	0.0	9.8	0.0	1.5	0.0	0.0	0.0	11.4	1.5	100.0	Beach/beachrock? Sand spit	Sandy spit. Rippled Sands, lower intertidal.
40	35.8	3.7	15.7	2.2	0.0	14.2	16.4	0.0	11.2	0.0	1.5	0.0	0.0	12.7	0.0	0.0	0.0	0.0	0.0	15.7	0.0	100.0	Sand spit	Sandy Spit to south of cay. Lower beach above rippled sands.
41	30.2	2.2	14.7	5.3	4.4	14.7	24.4	0.0	17.8	0.0	0.0	0.4	0.0	18.2	0.0	0.9	0.4	0.0	0.0	8.9	1.3	100.0	Beach/beachrock?	Sandy Spit to south of cay – closer to the island. Lower beach from rippled sands?
42	25.7	1.0	11.9	7.9	1.0	23.8	32.7	0.0	16.8	0.0	0.0	2.0	0.0	18.8	0.0	1.0	0.0	0.0	0.0	8.9	1.0	100.0	Sand spit	Sandy Spit to south of cay – Rippled sands?
43	33.9	2.6	8.7	11.3	0.9	16.5	28.7	0.0	13.9	0.0	0.0	0.9	0.0	14.8	0.9	1.7	0.0	0.0	0.0	8.7	2.6	100.0	Lower beach/water level	Lower beach – above toe of beach.
44	29.8	3.1	13.3	7.6	0.9	17.8	26.2	0.0	15.1	0.0	0.9	0.0	0.0	16.0	0.4	0.4	0.0	0.0	0.0	10.7	0.9	100.0	Lower beach/water level	Lower beach – above toe of beach.
45	30.0	0.8	9.2	5.4	0.0	16.2	21.5	0.0	20.0	0.0	0.0	3.8	0.0	23.8	0.0	0.8	0.0	0.0	0.0	13.8	0.8	100.0	Lower beach/water level	Lower beach – above toe of beach. Lower beach – above toe of beach.
46	23.0	4.5	14.0	4.5	0.4	16.9	21.8	0.0	23.9	0.0	0.8	1.2	0.4	26.3	0.0	0.8	0.4	0.0	0.0	9.1	1.2	100.0	Lower beach/water level	
47	21.0	2.5	14.3	8.4	0.0	16.0	24.4	0.0	25.2	0.0	1.7	0.8	0.0	27.7	0.0	0.0	0.0	0.0	0.0	10.1	0.0	100.0	Reef island/beach?	Upper beach behind beachrock outcrop?
48	27.0	0.0	16.4	3.5	0.4	9.7	13.7	0.0	31.0	0.0	0.4	1.3	0.4	33.2	0.0	0.0	0.0	0.0	0.0	9.7	0.0	100.0	Reef island	Reef island surface
49	33.6	2.0	14.8	1.3	0.0	16.8	18.1	0.0	12.8	0.7	0.0	0.7	0.0	14.1	0.7	0.0	0.0	0.0	0.0	16.8	0.7	100.0	Reef island	Reef island surface
50	25.0	0.0	13.7	4.2	0.0	25.6	29.8	0.0	17.9	0.0	0.6	0.6	0.6	19.6	0.0	0.0	0.0	0.0	0.0	11.9	0.0	100.0	Reef island	Reef island surface
51	29.9	0.0	14.5	1.7	0.0	20.7	22.4	0.0	16.2	0.4	0.0	0.0	0.4	17.0	0.0	0.0	0.0	0.4	0.0	15.8	0.4	100.0	Reef island	Reef island surface - berm?
52	17.5	3.8	21.3	16.3	0.0	13.8	30.0	0.0	11.3	0.0	0.0	0.0	0.0	11.3	1.3	0.0	0.0	0.0	0.0	15.0	1.3	100.0	Beach	Upper beach
53	20.6	2.6	17.4	5.2	0.0	12.9	18.1	0.0	21.3	0.0	0.0	0.0	0.0	21.3	0.0	0.0	0.0	0.0	0.0	20.0	0.0	100.0	Lower beach/water level	Lower beach – above toe of beach.

Sample ID	Coral	CCA	Halimeda	Gastropod	Bivalve	UID Mollusc	Mollusc Total	Baculigypsina	Amphistegina	Calcarina	Marginopora	Homotrema	UID -Forams	Forams Total	Echinoids	Alcyonarians	Bryozoans	Worm Tests	Crustacean	Unidentified	'Other' Total.	Total	Geomorphological Setting (based on photographs only)	Notes from site photographs provided by AIMS
54	12.3	0.9	12.7	10.4	0.0	16.5	26.9	0.0	30.7	0.9	1.9	2.4	3.3	39.2	0.0	0.0	0.9	0.0	0.0	7.1	0.9	100.0	Lower beach/water level	Lower beach – above toe of beach.
55	16.3	5.4	13.0	8.2	0.0	20.1	28.3	0.0	19.0	0.0	0.0	1.6	0.5	21.2	0.0	0.0	0.0	0.5	0.0	15.2	0.5	100.0	Beach	Lower beach – just above toe.
56	12.4	3.1	17.1	3.9	0.8	18.6	23.3	0.0	31.8	0.0	1.6	0.8	1.6	35.7	0.0	0.0	0.0	0.0	0.0	8.5	0.0	100.0	Reef island	Upper beach/Berm?
57	20.4	2.2	10.5	2.2	0.0	16.6	18.8	0.0	19.3	0.0	0.6	1.1	0.0	21.0	0.0	0.0	0.0	0.0	0.0	27.1	0.0	100.0	Reef island	Reef island surface
58	20.7	4.7	14.0	6.7	0.0	26.7	33.3	0.0	10.0	0.0	0.0	0.7	0.7	11.3	0.0	0.0	0.0	0.7	0.0	15.3	0.7	100.0	Reef island	Reef island surface
59	18.2	2.7	13.6	2.7	0.0	19.5	22.3	0.0	23.2	0.9	0.5	0.9	0.5	25.9	0.0	0.0	0.0	0.0	0.0	17.3	0.0	100.0	Beach	Upper Beach – behind beachrock outcrop.
60	15.0	2.1	17.1	7.0	0.5	11.8	19.3	0.0	26.2	0.5	1.1	0.5	1.6	29.9	0.0	0.0	0.5	0.5	0.0	15.5	1.1	100.0	Lower beach/water level	Behind beachrock outcrop
61	21.7	3.9	19.7	3.3	0.0	13.8	17.1	0.0	23.7	0.0	3.3	0.0	0.0	27.0	0.7	0.0	0.0	0.0	0.0	9.9	0.7	100.0	Lower beach/water level	Behind beachrock outcrop
62	19.7	2.3	13.6	3.0	0.0	17.4	20.5	0.0	24.2	0.0	1.5	3.0	0.0	28.8	0.8	0.8	0.0	0.0	0.0	13.6	1.5	100.0	Lower beach/water level	Lower beach/water level
63	22.9	5.5	22.9	8.3	0.9	17.4	26.6	0.0	9.2	0.0	0.0	0.0	0.0	9.2	0.0	0.0	0.0	0.0	0.0	12.8	0.0	100.0	Beach	Lower beach/water level
64	20.7	4.8	20.0	2.1	0.0	15.9	17.9	0.0	20.0	0.0	0.0	0.7	0.7	21.4	0.0	0.0	0.0	0.0	0.0	15.2	0.0	100.0	Reef island	Gravelly sand beach?
65	19.5	1.6	18.7	0.0	0.0	24.4	24.4	0.0	19.5	0.8	0.0	4.1	0.8	25.2	0.8	0.0	0.8	0.0	0.0	8.9	1.6	100.0	Reef island	Upper beach/reef island surface?
66	19.0	4.8	18.1	2.9	0.0	12.4	15.2	0.0	25.7	0.0	0.0	1.0	0.0	26.7	0.0	0.0	0.0	1.0	0.0	15.2	1.0	100.0	Reef island	Beach face?
67	22.2	2.1	19.6	5.3	0.0	16.9	22.2	0.0	16.4	0.0	0.0	0.0	0.5	16.9	0.0	0.0	0.0	0.0	0.0	16.9	0.0	100.0	Beach	Beach face?
68	21.5	4.7	23.4	6.5	0.9	16.8	24.3	0.0	9.3	0.0	1.9	2.8	0.9	15.0	1.9	0.0	0.9	0.0	0.0	8.4	2.8	100.0	Lower beach/water level	Lower beach/water level
69	22.9	8.6	22.9	11.4	0.0	7.1	18.6	0.0	12.9	0.0	2.9	1.4	0.0	17.1	0.0	0.0	0.0	0.0	0.0	10.0	0.0	100.0	Lower beach/water level	Lower beach/water level
70	24.4	4.9	18.3	7.3	0.0	18.3	25.6	0.0	13.4	0.0	0.0	2.4	0.0	15.9	0.0	0.0	0.0	0.0	0.0	11.0	0.0	100.0	Lower beach/water level	Lower Beach/Water Level – possibly with beachrock outcrop?
71	14.6	2.5	22.3	4.5	0.0	21.7	26.1	0.0	21.0	0.6	1.3	0.0	1.3	24.2	0.0	0.0	0.0	0.0	0.0	10.2	0.0	100.0	Reef island/beachrock	Beach face?
72	21.9	7.0	19.3	9.6	0.0	17.5	27.2	0.0	12.3	0.9	0.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	11.4	0.0	100.0	Reef island/beachrock	Beach face?
73	20.0	8.8	12.5	12.5	0.0	16.3	28.8	0.0	11.3	0.0	1.3	5.0	0.0	17.5	0.0	0.0	0.0	0.0	0.0	12.5	0.0	100.0	Reef island/beachrock	Beach face – beachrock outcrop?
74	22.4	8.4	17.6	12.4	0.0	24.0	36.4	0.0	3.2	0.0	0.0	2.4	0.0	5.6	0.8	0.4	0.0	0.0	0.0	8.4	1.2	100.0	Lower Beach/Water Level – possibly over beachrock outcrop shown on satellite	Lower beach / beachrock outcrop?

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Sample ID	Coral	CCA	Halimeda	Gastropod	Bivalve	UID Mollusc	Mollusc Total	Baculigypsina	Amphistegina	Calcarina	Marginopora	Homotrema	UID -Forams	Forams Total	Echinoids	Alcyonarians	Byzoans	Worm Tests	Crustacean	Unidentified	'Other' Total	Total	Geomorphological Setting (based on photographs only)	Notes from site photographs provided by AIMS
																							image	
75	23.4	4.4	10.9	5.8	0.0	19.0	24.8	0.0	19.0	0.0	0.0	0.7	0.0	19.7	0.0	0.0	0.7	0.0	0.0	16.1	0.7	100.0	Lower beach/water level	Lower beach – above toe of beach.
76	24.7	3.4	15.7	9.0	0.0	16.9	25.8	0.0	12.4	0.0	0.0	4.5	0.0	16.9	1.1	0.0	0.0	0.0	0.0	12.4	1.1	100.0	Lower beach/water level	Lower beach – above toe of beach.
77	12.7	4.0	16.0	2.7	0.0	18.0	20.7	0.0	28.7	0.7	1.3	0.7	1.3	32.7	0.7	0.7	0.0	0.7	0.7	11.3	2.7	100.0	Lower beach/water level	Lower beach – above toe of beach.
78	43.7	4.2	9.9	5.6	0.0	14.1	19.7	0.0	2.8	0.0	0.0	1.4	1.4	5.6	0.0	0.0	0.0	1.4	0.0	15.5	1.4	100.0	Lower beach/water level	Lower beach – above toe of beach.
79	29.6	5.6	23.9	9.9	0.0	14.1	23.9	0.0	7.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	100.0	Lower beach/water level	Lower beach – above toe of beach.

Table 3: Average Constituent Composition Count Percentages of all Samples Collected in each Geomorphological Zone and for All Grains Counted across all 79 Samples. UID = Unidentified. CCA = Crustose Coralline Algae. Note unidentified sediments include those that could not be visually identified as of several possible constituents. For example, smaller sediments that have been 'polished' through abrasion and lost surface morphology are difficult to confidently identify. Specifically it can be very difficult to definitively classify smaller polished sediments as either coral or molluscan in origin.

ZONE	Coral	CCA	Halimeda	Gastropod	Bivalve	UID_M	Mollusc Total	Baculigypsina	Amphistegina	Calcarina	Marginopora	Homotrema	UID-F	Foram Total	Echinoderm	Alcyonarian	Bryozoan	Worms	Crustacean	UID	Other total	Number of samples/grains
Reef Flat	31.7	3.3	13.0	3.6	0.0	10.9	14.5	0.0	16.6	0.0	1.2	1.2	1.2	20.2	0.3	0.9	0.6	0.6	0.3	14.5	2.7	2
Gravelly Spit	42.2	11.6	5.6	13.2	9.8	1.9	24.9	0.0	2.7	0.0	1.5	1.8	0.7	6.7	0.4	0.0	2.3	0.7	0.5	5.1	3.9	6
Sand Spit	32.1	3.5	17.9	5.4	0.2	16.0	21.6	0.0	9.9	0.0	0.7	0.9	0.2	11.8	0.0	0.6	0.0	0.4	0.0	12.1	0.9	5
Beachrock	18.2	5.4	19.1	8.0	0.0	19.1	27.1	0.0	16.0	0.6	0.9	1.1	0.6	19.1	0.0	0.0	0.0	0.0	0.0	11.1	0.0	3
Lower Beach	26.7	4.6	14.4	6.8	0.5	14.2	21.5	0.0	17.6	0.2	0.7	1.6	0.6	20.7	0.4	0.3	0.3	0.1	0.1	11.0	1.2	23
Beach	37.4	5.5	10.5	6.1	2.9	11.6	20.6	0.0	13.0	0.2	0.0	0.9	0.3	14.4	0.2	0.2	0.1	0.0	0.1	11.0	0.6	18
Reef Island	34.1	4.0	11.0	4.0	2.1	14.2	20.3	0.0	15.9	0.1	0.4	1.1	0.6	18.0	0.2	0.2	0.2	0.3	0.0	11.6	1.0	22
AVERAGE of TOTAL GRAINS COUNTED	32.8	5.2	12.0	6.3	2.3	12.6	21.2	0.0	14.3	0.1	0.5	1.2	0.5	16.7	0.3	0.3	0.4	0.2	0.1	10.8	1.2	79/11953

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

APPENDIX E EFFECTS OF BEACH NOURISHMENT ON SEA TURTLE NESTING AND REPRODUCTIVE SUCCESS

This document is protected by copyright. No part of this document may be reproduced, adapted, transmitted, or stored in any form by any process (electronic or otherwise) without the specific written consent of Woodside. All rights are reserved.

Controlled Ref No: BD0006AH0000008

Revision: 5

Page 92 of 92

Uncontrolled when printed. Refer to electronic version for most up to date information.

EFFECTS OF BEACH NOURISHMENT ON SEA TURTLE NESTING AND REPRODUCTIVE SUCCESS

TECHNICAL NOTE

SEPTEMBER 2024



PREPARED FOR:
PENDOLEY ENVIRONMENTAL
12A PITT WAY
BOORAGOON, WA 6154
+61 8 9330 6200



PENDOLEY
ENVIRONMENTAL

PREPARED BY:
ECOLOGICAL ASSOCIATES, INC.
P.O. BOX 405
JENSEN BEACH, FLORIDA 34958-0405
+1 772 334 3729
WWW.ECOLOGICAL-ASSOCIATES.COM



TECHNICAL NOTE

Effects of Beach Nourishment on Sea Turtle Nesting and Reproductive Success

Prepared by:
Ecological Associates, Inc.
P.O. Box 405
Jensen Beach, FL 34958
+1 772 334 3729

www.ecological-associates.com



For:
Pendoley Environmental
12A Pitt Way, Booragoon, WA 6154
+61 8 9330 6200
www.penv.com.au



September 2024

Effects of Beach Nourishment on Sea Turtle Nesting and Reproductive Success

Introduction

Sandy beaches found across the globe perform critical social and ecological functions. Along developed coastlines, they protect upland properties from storm and tidal surges and buffer winds during tropical storms and other severe weather events. Each year, beaches attract millions of tourists who contribute billions of dollars to local economies (e.g., see Houston, 2013). They also support unique assemblages of flora and fauna and in temperate and tropical zones provide critical nesting habitat for several globally imperilled species of sea turtles. Thus, it is not surprising that considerable effort and financial resources are directed toward maintaining the quality of sandy beaches, particularly in an era of climate change and rising sea levels.

In the United States (U.S.), beach nourishment has been used increasingly as a way of mitigating erosion and is a preferred alternative to shoreline armouring (e.g., seawalls and rock revetments) which often exacerbates erosion. Beach nourishment typically involves the harvesting of submerged marine sediments from a “borrow” area, placement of those sediments on an eroded shoreline (usually via pipeline), and then mechanically distributing the dredged material into a pre-determined template based on volumetric requirements for the project. Alternatively, sand may be mined from an upland source and trucked to the project site. In some geographic regions, dredged sand is sometimes used to create new islands for development or enhance existing beaches for ecotourism. In Australia, beach sand has been taken from seaward portions of the beach and mechanically moved landward to fill low lying areas, address unique geomorphological conditions, and enhance sea turtle nesting habitat (Smithers and Dawson, 2023).

Beach nourishment has been employed in the U.S. to restore eroded beaches for over 100 years (Elko *et al.*, 2021). Over 1.5 billion cubic yards (1.15 billion m³) of sand have been placed in over 475 coastal communities. More than 3,200 individual nourishment projects have taken place, with the majority occurring in California, Florida, New Jersey, North Carolina, New York, and

Louisiana. Beach nourishment projects are governed by federal and state regulatory permits which obligate the permittee to meet various environmental conditions for the protection of species listed under the U.S. Endangered Species Act (ESA).

All five species of sea turtles that utilize U.S. beaches for nesting are listed as either threatened or endangered under the ESA, and thus require special protections during coastal construction projects. Their protected status has given rise to numerous studies to assess the effects of beach nourishment on nesting activity. The loggerhead sea turtle (*Caretta caretta*) is by far the most abundant species nesting on U.S. beaches, and Florida hosts the largest nesting aggregation of loggerheads in the world (Ceriani *et al.*, 2019). Consequently, most studies assessing the effects of beach nourishment on sea turtles have focused on loggerheads in Florida. However, a few studies have also included green turtles (*Chelonia mydas*), as their numbers in the U.S. are increasing. Data for leatherbacks (*Dermochelys coriacea*), hawksbills (*Eretmochelys imbricata*), and Kemp's ridleys (*Lepidochelys kempii*), all of which nest in relatively low numbers in the U.S., are generally lacking.

Reine (2022) conducted a comprehensive literature review of the effects of beach nourishment on sea turtles. Although he presented considerable information related to factors affecting nesting and reproductive success globally, including Australia, he apparently did not uncover any information specific to beach nourishment projects outside the U.S.

This technical note summarizes known or potential effects of beach nourishment on sea turtle nesting behavior and reproductive success on mainland and barrier island beaches. For the reasons noted above, it is biased towards studies of loggerheads nesting in the U.S. Nevertheless, it may provide relevant insight into the design of nourishment projects to minimize impacts to other species nesting both within the U.S. and in other geographic regions. Recommendations are provided for post-construction monitoring to evaluate the response of sea turtles to newly built beaches. This is critical for identifying areas of needed improvements and establishing a baseline against which to assess impacts from future projects. Much of the information contained

in this paper is derived from the following sources: National Research Council (1995), Crain *et al.* (1995), and Reine (2022). Additional relevant citations are included where appropriate.

Sea Turtle Nesting Behavior

The sea turtle nesting season varies among species and geographic regions. In temperate areas, it is largely confined to the warm summer months but in tropical areas often extends over a much longer time frame. During the nesting season, an adult female ready to nest (individuals typically nest every two to three years) will return to her natal beach or a nearby beach and crawl ashore at night (the Kemp's ridley is a notable exception). Nesting females require a warm, sandy environment sufficiently above the reach of tides in which to deposit their eggs. She will nest several times each season. In Australia, green turtles typically nest every 3-8 years and produce on average 7 clutches a year at a mean re-nesting interval of 12-14 days, depending on location; Limpus *et al.*, 2003; Perez *et al.*, 2024. The cues used by turtles to select a nest site are not fully understood, but beach slope seems to have a major influence, at least for loggerheads. In the U.S., both loggerheads and leatherbacks tend to spread their nests across the entire width of the beach. On the relatively narrow and more steeply sloped beaches of central and southeast Florida, the majority of loggerhead nests tend to be located mid-beach (Ernest *et al.*, In Press; Gravelle and Wyneken, 2022), while on the flatter beaches of southwest Florida they tend to be concentrated higher on the beach near supra-littoral vegetation (Garmestani *et al.*, 2000). Green and hawksbill turtles tend to nest at higher elevations, often in vegetation (Horrocks and Scott, 1991; NMFS and USFWS, 1998; Turkozan *et al.*, 2011). Thus, inferences regarding the effects of beach nourishment on the nesting behavior of loggerheads may not apply to species that typically select different nest sites or nest in areas where beaches are shaped differently than those in southeast Florida.

The nesting process is stereotypical among species with slight deviations. After emerging from the ocean, a female turtle unencumbered by obstacles or disturbances, will begin ascending the beach. Once an appropriate nest site is selected, she will excavate an egg chamber, lay her eggs,

cover the clutch of eggs with sand, and return to the ocean. She will typically nest several more times during the nesting season. During the incubation period, sediments surrounding the clutch must have sufficient porosity to allow for gas exchange in and out of the egg chamber and adequate moisture content to ensure proper embryonic development. The vertical vacillation of the saltwater wedge beneath the beach during tidal cycles effectively establishes a pumping mechanism for gas movement in and out of the egg chamber (Goforth and Carthy, 2022). If there is insufficient sand cover above the water table, eggs within lower portions of the egg chamber may be inundated during high tides; hatching success may be substantially reduced, depending on the timing, frequency, and duration of egg chamber inundation. Temperatures within the clutch and surrounding sediments influence both the incubation period and the sex of hatchlings. Warmer temperatures accelerate the incubation period, and temperatures above a certain threshold skew the sex ratio toward females. After a period of approximately six to eight weeks, hatchlings emerge from their nests and orient to the ocean using celestial light cues.

Potential Impacts of Beach Nourishment on Sea Turtles

There are four principal aspects of beach nourishment potentially impacting sea turtles for projects involving a marine borrow site: dredging of the borrow area to obtain sand for the project, the suitability of that dredged material as nesting habitat, the mechanical placement and subsequent distribution of the dredged sand on the beach, and the design/shape of the built beach. This technical note only considers impacts associated with the built beach (*i.e.*, it does not address potential injuries to turtles in the water caused by dredging). These impacts are also applicable to projects involving upland borrow sites.

Although beach nourishment may expand sea turtle nesting habitat, it does not necessarily result in increased nesting. Almost all nourishment projects in the U.S. result in a reduction in nest densities and nesting success (percentage of all turtle crawls onto the beach resulting in nests) during the first year or two following construction (Trindell *et al.*, 1998). This has been variously attributed to high sediment compaction, increased escarpment formation (steep vertical ledges

on the beach), and changes in the cross-sectional profile of the built beach. As discussed below, the quality of material placed on the beach can affect the ability of turtles to excavate an egg chamber of appropriate dimensions and can alter the incubation environment of developing embryos. Changes in beach profile can affect nesting success and nest placement.

Sediment Characteristics

Ensuring that sediments used for nourishment are compatible with those found on native beaches is essential to maintaining the suitability of the project site as nesting habitat. Sediment grain size and composition largely contribute to the quality of the built beach: suitable sediments allow for adequate gas exchange in and out of the egg chamber, do not alter the normal incubation temperature of the clutch, and do not cause excessive beach compaction. Compaction (hardness) typically results when sediments are transferred to the beach via pipeline. The sand/seawater slurry that arrives on the beach causes a homogenous distribution of sediments. Larger particles tend to layer with fine particles lodging between them, thus creating a brick-and-mortar effect. As the beach dries, it hardens, and depending on the composition of sediments and the amount of fine particles present, it may become highly compact; in severe cases it becomes concreted. In the U.S., built beaches are typically mechanically tilled immediately following construction to minimize compaction.

High sediment compaction can affect a turtle's ability to construct an egg chamber of appropriate dimensions and/or may inhibit gas, nutrient, and moisture movement in and out of the egg chamber. On highly concreted beaches, turtles may abandon their nesting attempts altogether. Compact sediments overlaying the egg chamber may prevent or slow hatchlings from emerging from the nest. Insofar as the color of sediments used for nourishment projects affects incubation temperatures, sediments that differ greatly in color from native sands may alter hatchling sex ratios.

In the U.S., the Army Corps of Engineers has established criteria for sediments used in nourishment projects to minimize the impacts noted above, the principal tenets of which are summarized below:

- Beach compatible fill must maintain the general characteristics and functionality of the material naturally occurring on the project beach and in the adjacent dune system.
- The placed sediment must be similar in color and grain size distribution (sand grain frequency, mean and median grain size, and sorting coefficient) to the material in the historic beach sediment at the site, and must not contain:
 - a. greater than 5%, by weight, silt, or clay,
 - b. greater than 5%, by weight, fine gravel,
 - c. coarse gravel or cobble material in a percentage or size greater than found on the native beach, and
 - d. construction debris, toxic material, or other foreign matter, or material that will result in cementation of the beach.

Beach Design

Nesting sea turtles rely on exogenous cues (thermal, olfactory, visual, tactile, etc.) they perceive as they emerge from the ocean and begin ascending the beach in search of a nest site. On mainland and barrier island beaches, studies have shown that the shape of the built beach (width, slope, and elevation) can substantially affect loggerhead nesting behavior and nest placement (Ernest and Martin, 1999; Ernest *et al.*, In Press; Brock *et al.*, 2007). Of the beach variables studied to date, slope appears to be the most influential.

On the central and southeast coast of Florida, high density nesting beaches for loggerheads and green turtles tend to be relatively narrow and steeply sloped. However, beach nourishment projects in this region typically result in wide, flat beaches with an elevated berm and a relatively steep foreshore slope between the berm and waterline. Invariably, nesting success for both loggerhead and green turtles declines on these nourished beaches for the first year or two post

construction (Trindell *et al.*, 1998). On the constructed berm, odds of loggerhead nesting increase as slopes increase and decrease considerably when negative slopes are encountered. LiDAR data collected from a beach in east central Florida showed that the greater the change in slope on a nourished beach from a natural profile, the greater the effect on loggerhead nesting behavior (Long *et al.*, 2011). Consequently, beaches should be designed and constructed to mimic, as close as possible, the cross-sectional profile of pre-existing or adjacent natural beaches. It should be noted that responses of loggerheads to beach nourishment may vary on beaches that tend to be naturally flatter, such as those on the southwest coast of Florida (Garmestani *et al.*, 2000).

Wide, flat nourished beaches undergo appreciable changes during storms and rough sea conditions as the profile equilibrates to a more naturally sloped profile under the influence of local hydrodynamic forces. As sand erodes along the seaward edge of the berm, steep escarpments (scarps) often form that can prevent turtles from accessing suitable habitat farther landward. Encounters with scarps often cause turtles to abandon their nesting attempts, thereby contributing to reduced nesting success. Scarp formation is often exacerbated when incompatible sediments, particularly those containing a large proportion of fine-grained particles, are placed on the beach.

Studies have shown that loggerheads in southeast Florida use only a small portion of the new habitat available to them on newly nourished beaches, while green turtles continue to place most of their nests near the dune, although in lower numbers (Brock *et al.*, 2007). Placement of a relatively large proportion of loggerhead nests near the waterline results in a greater number being washed out as the beach equilibrates to a more natural profile. Reduced nesting success and a higher incidence of nest washouts results in lower hatchling production.

Artificial beachfront lighting interferes with the natural lighting cues used by emergent hatchlings to orient and quickly navigate to the ocean after leaving the nest. If they become disoriented, they are more susceptible to predation and exhaustion. Lighting from upland development may be more visible to turtles on wide, flat nourished beaches than on the naturally sloped beaches

that preceded them. Consequently, hatchling disorientations have increased on some beaches following nourishment (e.g., see Brock *et al.*, 2007).

Construction-related Impacts

During a nourishment project, nesting turtles may be injured by vehicles or equipment operating on the beach, trapped in deep ruts, or prevented from reaching preferred nest sites by pipelines. Nests on the beach may be buried by nourishment sand or crushed by heavy equipment. Compacted sediments and scarps within constructed areas of the beach can interfere with nesting, while nighttime construction lighting can disorient hatchlings and disrupt nesting activity on adjacent darker beaches. Because of these potential impacts, it is preferable to construct beach nourishment projects outside of the sea turtle nesting season, although that is not always feasible. (In the U.S., construction is sometimes permitted during the early part of the nesting season when nesting activity is relatively low.) Similarly, almost all nesting occurs at night, and thus it is preferable to construct nourishment projects during daylight hours only. Special precautions, as recommended below, are needed if work is to occur around the clock.

Unique Aspects of Proposed Project at Sandy Islet, Australia

Sandy Islet is a small (approximately 700 m long by 130 m wide at its maximum), unvegetated, low-lying, sand cay located on Scott Reef approximately 450 km north of Broome on Australia's northwest coast. The cay is comprised of unconsolidated sediments derived from the skeletal remains of organisms comprising and inhabiting the adjacent reef. Because of its location, small size, and low elevation, its landform is highly dynamic, changing in response to sediment supply, wind, waves, and sea level conditions (Smithers, 2015). Although most portions of the island are marginally above sea level, some areas remain emergent even during the highest tides. These higher elevations provide critical nesting habitat for green sea turtles, the only species known to nest on the island. Green turtles nesting on Sandy Islet belong to a discrete genetic stock with little genetic exchange with other rookeries (Commonwealth of Australia, 2017; Whiting *et al.*, 2018). In its most recent assessment, the Marine Turtle Specialist Group of the International

Union for Conservation of Nature (IUCN) assessed green turtles as endangered globally (<https://www.iucn-mtsg.org/statuses>). Green turtles are listed as vulnerable under Australia's Environment Protection and Biodiversity Conservation Act 1999.

Proposed liquid natural gas (LNG) extraction in the vicinity of Scott Reef has raised concerns about the potential for subsidence of the seabed supporting the reef and associated impacts to sea turtle nesting habitat on Sandy Islet. Proposed mitigation measures for the project include placement of sediments on the island to augment habitat losses resulting from LNG extraction.

As noted earlier, beach nourishment studies performed to date have involved remediation of erosion on mainland and barrier island beaches. There are no known precedents for assessing potential impacts from sand placement on oceanic islets to mitigate habitat loss due to subsidence. The only relatable work took place on Raine Island on the northern Great Barrier Reef complex off Australia's northeast coast. There, sediments were taken from seaward portions of the beach and used to fill low-lying areas subject to overwash and seawater ponding during high tides. This "reprofiling" effort was intended to boost green turtle hatchling production which had been in recent decline. However, the Raine Island project provides little guidance for proposed beach nourishment work on Sandy Islet. Raine Island is unique in its geomorphology and causes of sediment loss. Reductions in hatchling production were caused by the declining depth of sand above the underlying water table, the absence of aerial and tidal sediment transfer to replenish sand losses, and the reworking of sediments by an extraordinarily high number of green turtles nesting on the island (Smithers and Dawson, 2023). Furthermore, even though Raine Island is an oceanic cay, it has several physical elements common to mainland and barrier island beaches: a relatively steep foreshore slope, an elevated berm, and a sandy beach backed by a dune and dune vegetation. Thus, cues used by sea turtles for nest placement at most global sites, including Raine Island, may not be present at low-lying, unvegetated Sandy Islet. Consequently, to ensure that proposed mitigation measures for Sandy Islet are successful, a better understanding of its geomorphology and current nesting and nest distribution patterns are essential.

Key information needed to support beach nourishment on Sandy Islet includes, but is not limited to, the following:

- Existing sediment characteristics (composition, grain size, porosity, color, etc.), sediment budget, and sediment compaction,
- Nesting habitat morphology, including elevations,
- Sediment depth above the underlying water table,
- Quantification of annual nesting by species,
- Current nesting success (percentage of turtle crawls onto the dry sandy beach that result in nests) by species,
- Distribution of nests within available habitat, identifying areas supporting highest nest densities,
- Current hatching success (percentage of eggs in clutch that produce hatchlings which successfully emerge from the nest),
- Mean and maximum clutch depths, and
- Emergent hatchling orientation patterns.

It is recognized that much of the information related to sea turtle nesting on the island may be difficult or unrealistic to obtain because of the study site's remoteness. However, the greater the understanding of factors influencing current nesting and reproductive success on the island, the greater the potential for successfully remediating habitat losses to subsidence. To empirically evaluate the success of remediation actions, similar information should be collected from at least one comparable control site, if available. Data collected before and after nourishment from both Sandy Islet and the control site(s) provide an optimal design for assessing impacts.

Recommendations for Minimizing Impacts to Sea Turtles Resulting from Beach Nourishment

Based on years of research by government agencies, academia, and the private consulting sector, and drawing upon protective measures incorporated into regulatory permits for beach

nourishment projects in the U.S., the following guidelines are recommended for minimizing impacts to nesting and hatchling sea turtles on Sandy Islet.

1. Sediments placed on the beach should mimic as closely as possible the grain size, composition, and color of native sands within the project area.
2. The shape of the built beach (cross-sectional beach profile) should mimic, to the extent practicable, the morphology of the native beach. In particular, the design should:
 - i. Ensure there is sufficient sand cover above the underlying water table to avoid inundation of the egg chamber during high tides. The mean depth of a green turtle egg chamber is approximately 0.8 m below the beach surface; however, individual clutches may be deeper (Limpus *et al.*, 2003). Thus, a minimum sand depth of 1.0 m above the water table at high tide would be a reasonable target.
 - b. Minimize the potential formation of a mid-beach trough. These shallow areas are subject to seawater ponding during high tides and contribute to reduced hatchling success.
 - c. Minimize the potential for formation of negative slopes which tend to increase the odds of loggerheads abandoning their nesting attempt on newly built beaches in southeast Florida (Ernest *et al.*, In Press).
3. To the extent possible, construction should be performed outside the sea turtle nesting season. If construction must take place during any portion of the nesting season, measures should be taken to minimize impacts to nesting turtles and their nests:
 - a. Trained sea turtle monitors should patrol the construction footprint (including equipment staging areas if applicable) each morning prior to any construction activity.
 - b. Nests potentially affected by construction activities should be relocated to a safe, suitable, nearby location outside the construction footprint. The relocation area should be unaffected by tidal inundation, predation, or artificial illumination. It is recognized that relocation may not be a viable option for Sandy Islet, as the entire

island would likely be subject to construction activities, and the movement of eggs to a distant hatchery would be logistically impractical.

- c. Nests within the project area likely unaffected by construction should be conspicuously marked for avoidance.
4. If nourishment is to occur at any time between dusk and dawn, the following additional precautions should be taken:
 - a. Sand placement and operation of heavy equipment should be confined to as small an area as practicable.
 - b. Highly skilled staff should monitor beaches within the construction footprint at night for the presence of nesting turtles or emergent hatchlings.
 - c. Construction operations should be suspended if a nesting turtle or hatchling enters the construction area and should not resume until the turtle has returned to the ocean and any resultant nest relocated.
5. Construction lighting should be minimized and focused solely on the active work area. Lights should be positioned, directed downward, and laterally shielded to prevent illumination of adjacent beaches.
6. Upon completion of construction and removal of equipment and materials from the beach, sediment compaction of placed sand should be measured. Areas exhibiting compaction levels substantially exceeding pre-nourishment levels should be mechanically tilled.
7. Any escarpments present following completion of construction should be mechanically knocked down before the contractor leaves the site.
8. All construction materials and equipment should be removed from the beach as quickly as possible after completion of construction, tilling, and scarp knockdowns, as they may pose obstacles to nesting and hatchling turtles.
9. Following completion of construction, the nourished beach should be monitored by trained technicians to document nesting activity and reproductive success. This program should include:
 - a. Surveys to document nest counts by species.

- b. Marking and monitoring of nests to determine nest fate (hatched, washed out, damaged by another nesting turtle, etc.) and reproductive success (percentage of eggs that produce hatchlings which successfully emerge from the nest).
 - c. If applicable, nighttime evaluations to document lighting from offshore sources that directly or indirectly illuminate the nourished nesting beach.
 - d. Documentation of hatchling disorientations and identification of causal light sources.
10. Periodic surveys should be conducted to identify and remediate new escarpment formations. Scarp remediation (knockdown) must be conducted in a manner that prevents harm to any nests that may be present.

Given the unique nature of Sandy Islet (small size, lack of suitable nearby relocation sites, etc.), an alternative protective measure for work that must be conducted during the nesting season might be to erect an exclusion barrier around the perimeter of the island to prevent nesting turtles from coming ashore during construction. This would allow construction to occur around the clock. If sand placement and related construction activities are of short duration (< 2 weeks), the project would potentially affect only one nesting cycle. However, this approach is not without harm, as some turtles may deposit their eggs in the ocean if repeatedly dissuaded from nesting (e.g. before the barrier is removed; Limpus *et al.*, 2003). The optimum approach for minimizing impacts to sea turtles potentially resulting from this unique project would be to perform work completely outside of the nesting season or at least confine it to the early portion of the season when nesting is minimal.

Conclusion

Impacts to sea turtles can be minimized through careful planning, smart beach design/engineering, use of appropriate and high-quality sediment, thoughtful construction practices, and implementation of appropriate minimization measures during construction. Robust monitoring and data collection both pre- and post-construction are also critical and will

allow development of programmatic improvements to minimize impacts to sea turtles during subsequent nourishment events.

Literature Cited

- Brock, K.A., Reece, J.S., and Ehrhart, L.M., 2007. The effects of artificial beach nourishment on marine turtles: differences between loggerhead and green turtles. *Restoration Ecology*, 17(2), 297-307.
- Ceriani, S.A., Casale, P., Brost, M., Leone, E.H., and Witherington, B.E., 2019. Conservation implications of sea turtle nesting trends: Elusive recovery of a globally important loggerhead population. *Ecosphere*, 10. <https://doi.org/10.1002/3cs2.2936>
- Commonwealth of Australia, 2017. Recovery plan for marine turtles in Australia 2017-2027. Department of the Environment and Energy, Canberra. 154p.
- Crain, D.A., Bolten, A.B., and Bjorndal, K.A., 1995. Effects of beach nourishment on sea turtles: review and research initiatives. *Restoration Ecology*, 3(2), 95-104.
- Elko, N., Briggs, T.R., Benedet, L., Robertson, Q., Thomson, G., Webb, B., and Garvey, K. 2021. A century of U.S. beach nourishment. *Ocean and Coastal Management*, 199. <https://doi.org/10.1016/j.ocecoaman.2020.105406>
- Ernest, R.G. and Martin, R.E., 1999. Martin County Beach Nourishment Project Sea Turtle Monitoring and Studies, 1997 Annual Report and Final Assessment. Jensen Beach, Florida: Ecological Associates, Inc., Report, 96p.
- Ernest, R.G., Martin, R.E., Desjardin, N.A., Scriptor, M.J., Scarola, J.C., Kim, H., and Trindell, R. In Press. Changes in loggerhead sea turtle nesting behavior on a nourished beach in southeast Florida. *Journal of Coastal Research*.
- Garmestani, A.S., Percival, H.F., and Rice K.G., 2000. Nest-site selection by the loggerhead sea turtle in Florida's Ten Thousand Islands. *Journal of Herpetology*, 34(4), 504-510.
- Goforth, K.M. and Carthy, R.R., 2022. Tidally-driven gas exchange in beaches: implications for sea turtle nest success. *Journal of Coastal Research*, 38(3), 523-537.
- Gravelle, J. and Wyneken, J., 2022. Resilient eggs: highly successful loggerhead sea turtle nesting sites vary in their characteristics. *Frontiers in Ecology and Evolution*, 10:853835, 14p.

- Horrocks, J.A. and Scott, N.M., 1991. Nest site location and nest success in the hawksbill turtle *Eretmochelys imbricata* in Barbados, West Indies. *Marine Ecology Progress Series*, 69, 1-8.
- Houston, J.R., 2013. The value of Florida beaches. *Shore and Beach*, 81(4), 4-11.
- Limpus, C.J., Miller, J.D., Parmenter, C.J., and Limpus, D.J., 2003, The green turtle, *Chelonia myda*, population of Raine Island and the northern Great Barrier Reef: 1843-201. *Memoirs of the Queensland Museum*, 49(1), 349-440.
- Long, T.M., Angelo, J., and Weishampel, J.F., 2011. LiDAR-derived measures of hurricane- and restoration-generated beach morphodynamics in relation to sea turtle nesting behaviour. *International Journal of Remote Sensing*, 32(1), 231-241.
- NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service), 1998. Recovery Plan for U.S. Pacific Populations of the Hawksbill Turtle (*Eretmochelys imbricata*). National Marine Fisheries Service, Silver Spring, Maryland. 83p.
- National Research Council, 1995. Beach Nourishment and Protection. Washington, D.C.: National Academy Press. 334p.
- Perez, M., Limpus, C., Shimada, T., McDonald, S., Coffee, O., Hinchcliffe, E., and Hamann, M. 2024. Inter-nesting habitat use by green turtles *Chelonia mydas* in the Great Barrier Reef. *Endangered Species Research*, 54, 225-238.
- Reine, K.J., 2022. A Literature Review of Beach Nourishment Impacts on Marine Turtles. Vicksburg, Mississippi: U.S. Army Engineer Research and Development Center, Environmental Laboratory, Waterways Experiment Station, ERDC/EL TR-22-4, 71p.
- Smithers, S., 2015. Sediment Texture and Composition at Sandy Islet, Scott Reef: Description and Preliminary Interpretation. Unpublished Report to the Australian Institute of Marine Science. College of Marine and Environmental Science, James Cook University (Queensland, Australia), 28p + Appendices.
- Smithers, S.G. and Dawson, J.L., 2023. Beach reprofiling to improve reproductive output at the world's largest remaining green turtle rookery: Raine Island, northern Great Barrier Reef. *Ocean and Coastal Management*, 231(2023), 106385.
- Trindell, R., Arnold, D., Moody, K, and Morford, B., 1998. Post-construction marine turtle nesting monitoring results on nourished beaches. In: Tait, L.S. (compiler), *Rethinking the Role of Structures in Shore Protection. Proceedings of the 11th Annual National Conference on Beach Preservation Technology* (St. Petersburg, Florida), pp. 77-92.

- Turkozan, O., Yamamoto, K., and Yilmaz, C., 2011. Nest site preference and hatching success of green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtles at Akyatan Beach, Turkey. *Chelonian Conservation and Biology*, 10(2), 270-275.
- Whiting, S., Tucker, T., Pendoley, K., Mitchell, N., Bentley, B., Berry, O., FitzSimmons, N., 2018. Final Report of Project 1.2.2 prepared for the Kimberley Marine Research Program, Western Australian Marine Science Institution, Perth, Western Australia, 146 p.