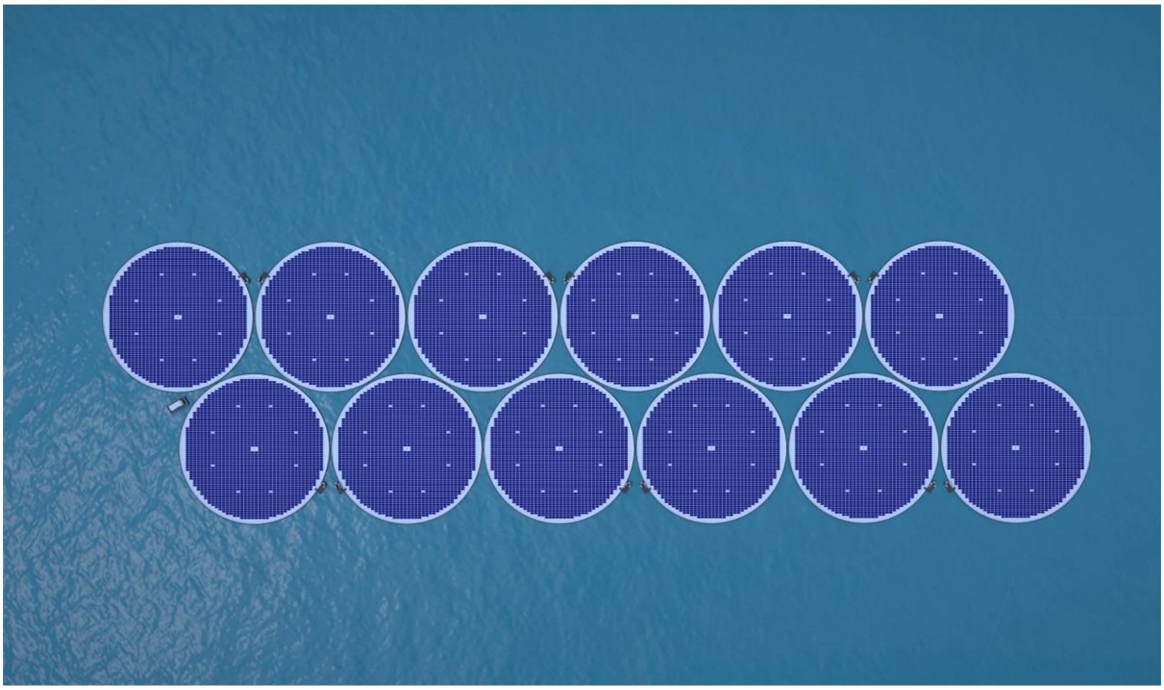
Nearshore Floating Photovoltaic (PV) Farm at Pulau Sebarok

Environmental Study Report



Sunseap Energy Ventures PL

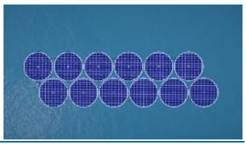
November 2023

The expert in **WATER ENVIRONMENTS**

Nearshore Floating Photovoltaic (PV) Farm at Pulau Sebarok

Environmental Study Report

Draft Report



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1 Introduction

1.1 Project Background

Sunseap Energy Ventures PL (Sunseap) intends to design and deploy a near-shore Floating Photovoltaic (FPV) system at Pulau Sebarok in Singapore (the Project). DHI Water & Environment (S) Pte Ltd (DHI) has been commissioned by Sunseap to carry out a Feasibility and Environmental Study (the Study) for the Project.

DHI has prepared this Environmental Impact Assessment (EIA) report to document the planned works; detail the existing environmental baseline conditions and receptors; analyse the impacts; assess the significance level; and then recommend mitigation, monitoring and management measures to reduce the level of impact to meet the environmental quality objectives for the Project, if any.

1.2 EIA Objectives

The objectives of this EIA study include:

- providing scientific information and assessment on the nature and extent of the potential environmental impacts arising from the Project
- recommending a robust Environmental Management and Monitoring Plan (EMMP) framework for the construction phase, based on the predicted impacts
- consulting relevant government agencies and stakeholders, obtaining approval for the proposed development’s environmental study

1.3 Report structure

This EIA Document is structured as follows:

- Section 1 – Introduction
- Section 2 – Project Description
- Section 3 – Environmental Laws, Standards and Guidelines
- Section 4 – EIA Approach
- Section 5 – Environmental Baseline
- Section 6 – Prediction and Evaluation of Environmental Impacts (Construction)
- Section 7 – Prediction and Evaluation of Environmental Impacts (Operation)
- Section 8 – Impact Significance Summary
- Section 9 – Environmental Management Framework
- Section 10 – Conclusions
- Section 11 – References

2 Project Description

The Project is a grant project under the collaboration between Energy Market Authority (EMA) of Singapore and the Korea Institute of Energy Technology Evaluation and Planning (KETEP), in short, the EMA-KETEP Partnership. Sunseap, with the support of Solar Energy Research Institute of Singapore (SERIS), has been awarded this grant to deploy a nearshore floating photovoltaic (PV) platform with energy storage at Pulau Sebarok. Sunseap has signed an agreement to work with Vopak Terminals on a commercial basis, to decarbonise their energy consumption on Sebarok with plans to deploy two (2) floating solar modules approximately 290 m off the south-east tip of Pulau Sebarok. The system is expected to generate an energy output of 1.2-megawatt peak to support energy demand on the island (Figure 2.1).

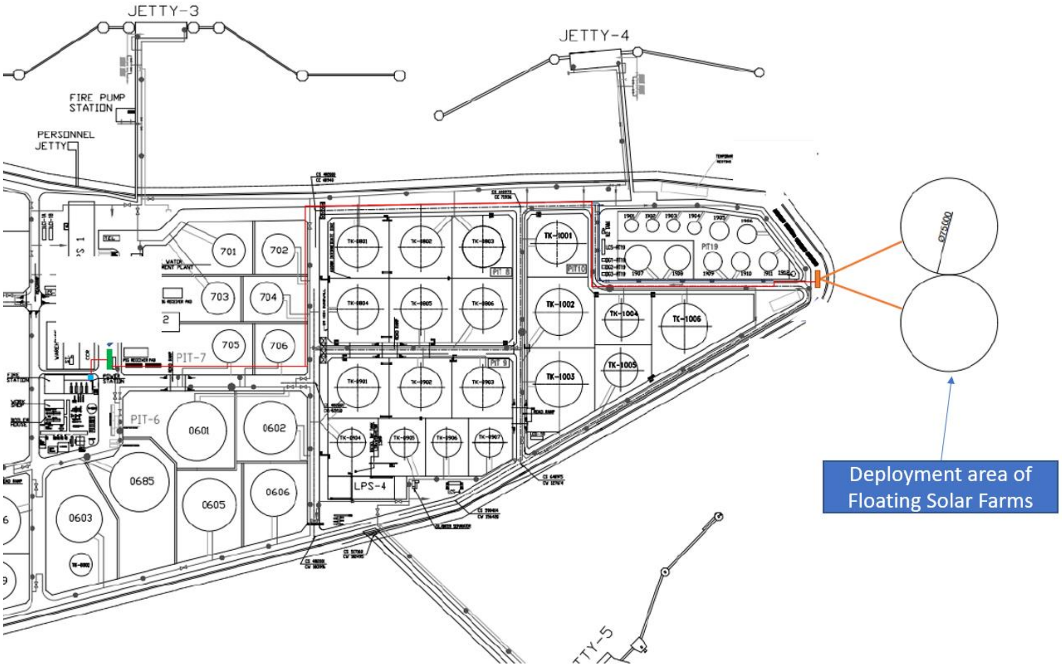

Figure 2.1 Proposed floating photovoltaic (PV) modules (Source: Client, 2022)

2.1 Project Area

The Project is located south of Pulau Sebarok, an island off the southern shores of Singapore which covers 46.8 ha and is predominantly used for storage and transhipment of oil (Figure 2.2). The nearest neighbouring island is Pulau Semakau to its west. North of Pulau Sebarok lies uninhabited Pulau Jong, and to its southern extent the Monggok Sebarok reef can be found.

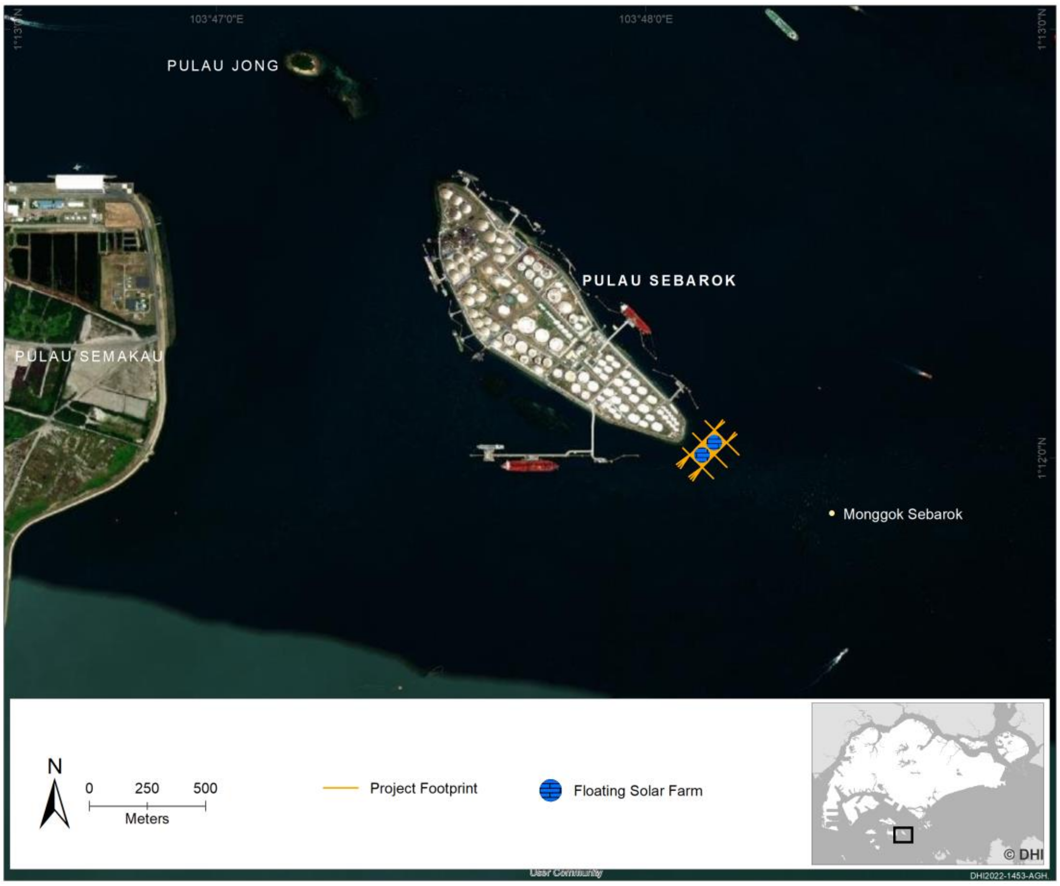

Figure 2.2 Project area.

2.2 Project Design

Sunseap intends to deploy two Ocean Sun Floating Photovoltaics (FPV) farms in the waters off the southern shoreline of Pulau Sebarok. The Ocean Sun system is an innovative installation, consisting of a 75 m floating buoyancy ring fitted with a hydro-elastic membrane (Figure 2.3 and Figure 2.4). Male keder strips are welded on the membrane. The photovoltaic (PV) modules are fitted with a maritime-grade aluminium female keder and are slid into position and secured by crimping. This facilitates simple installation and replacement of the modules.

Each floater has a diameter of 75 m, and the diameter of the membrane is 72 m, an area of approximately 0.44 hectares. The floaters are anchored to the seabed through a mooring system that consists of mooring ropes and concrete sinkers. There will be no anchor to the shoreline.

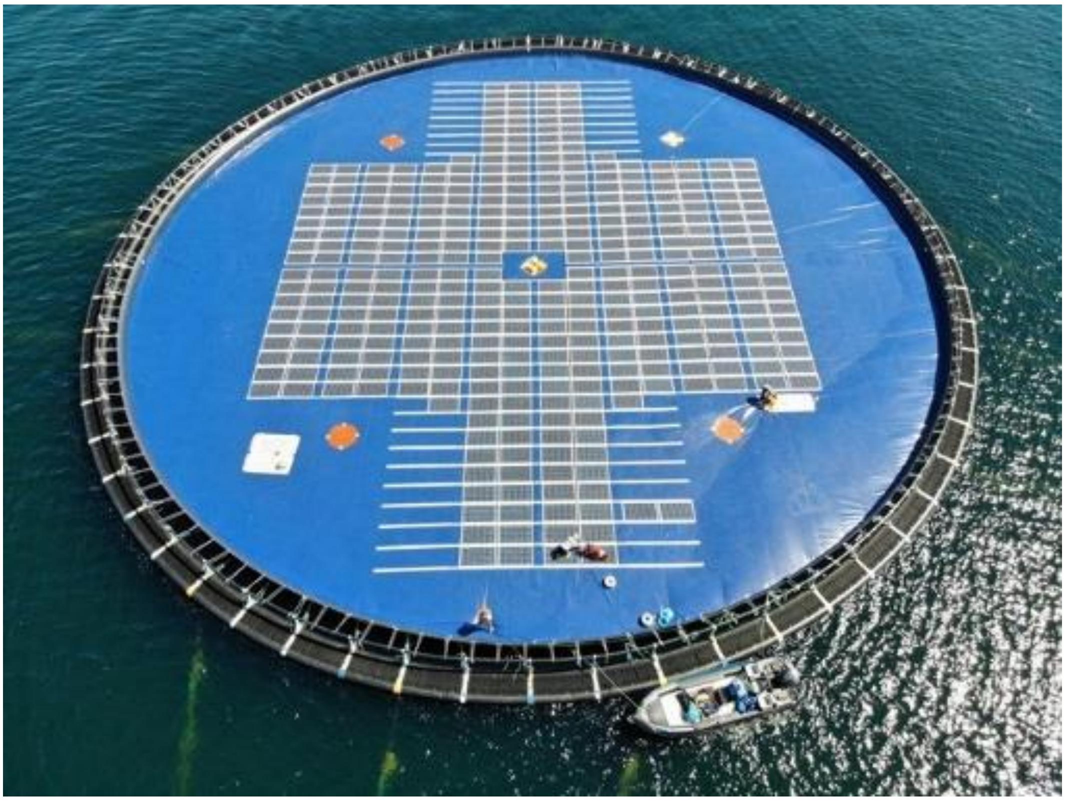

Figure 2.3 Configuration of the FPV farm (Ocean Sun) to be deployed at the identified site (Source: Ocean Sun)

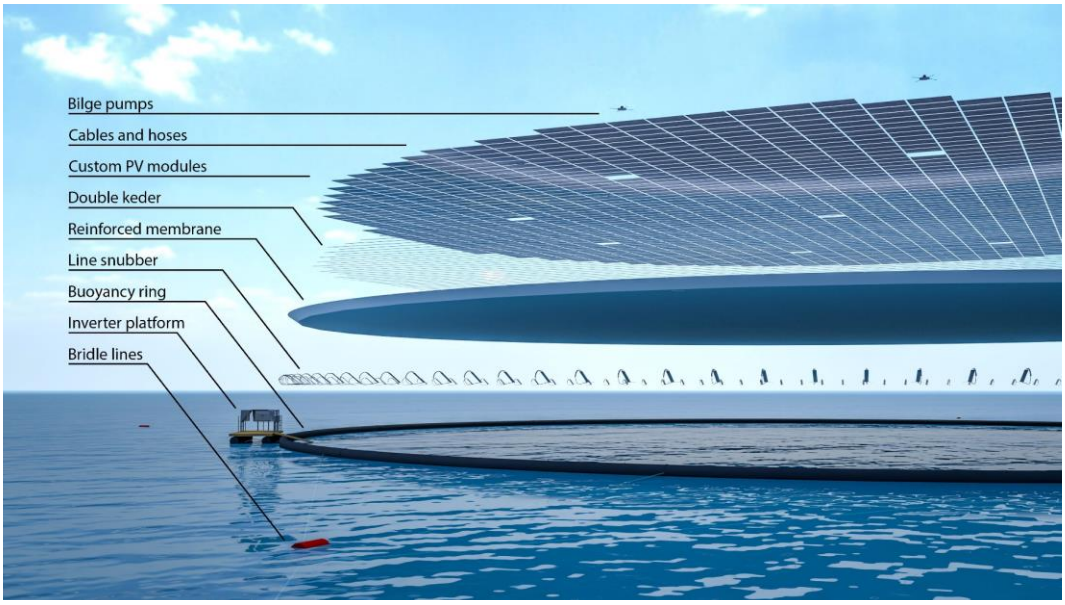

Figure 2.4 Ocean Sun photovoltaic technology (Source: Ocean Sun)

The following information on the layout and specifications is derived from the Mooring System Analysis Report provided by Client in July 2022.

2.2.1 General layout and specifications

The outer diameter of one floater is 75 m, and the diameter of the membrane is 72 m. Each floater consists of the floatation HDPE (high density polyethylene) pipes, the hydroelastic membrane, PV modules and inverters. Additionally, brackets, cabling and connection ropes are part of the floater. The floater is a double ring with ø400mm HDPE pipes with SDR (standard dimension ratio) 26 as a base case configuration. The two HDPE rings are connected by 48 brackets with a relative distance of 4.8 meters. Connection ropes attach the membrane to the HDPE pipes.

The floatation pipes are made of HDPE 100 quality, with an assumed tensile strength of minimum 25 MPa (MegaPascal), and a modulus of elasticity of minimum 1000 MPa at the rated temperature, based on available datasheets from HDPE water pipe suppliers by Konti Hydroplast[1] on water supply polyethylene pipes.

Inverters and combiner boxes are fixed to the handrail which again is fixed to the inner ring via dedicated brackets. The inverters have a weight of approximately 180 kg, and a wind fetch area of 1.4 m x 0.5 m.

The thin, hydroelastic membrane is tied into the floatation pipes with 144 connecting ropes. The mass per unit area of the membrane is 0.975 kg/m^2. The design drawings of the OS-75 system show in detail the design of the connecting ropes. The maximum forces in the connecting ropes are documented to be lower than the breaking strength of the membrane attachment point.

The main component of the PV system, the c-Si (crystalline silicon) PV modules are attached to the membrane with aluminium profiles which slide into keders that are welded on the membrane. Up to 1,819 panels with a weight of 23 kg each will be attached to the membrane.

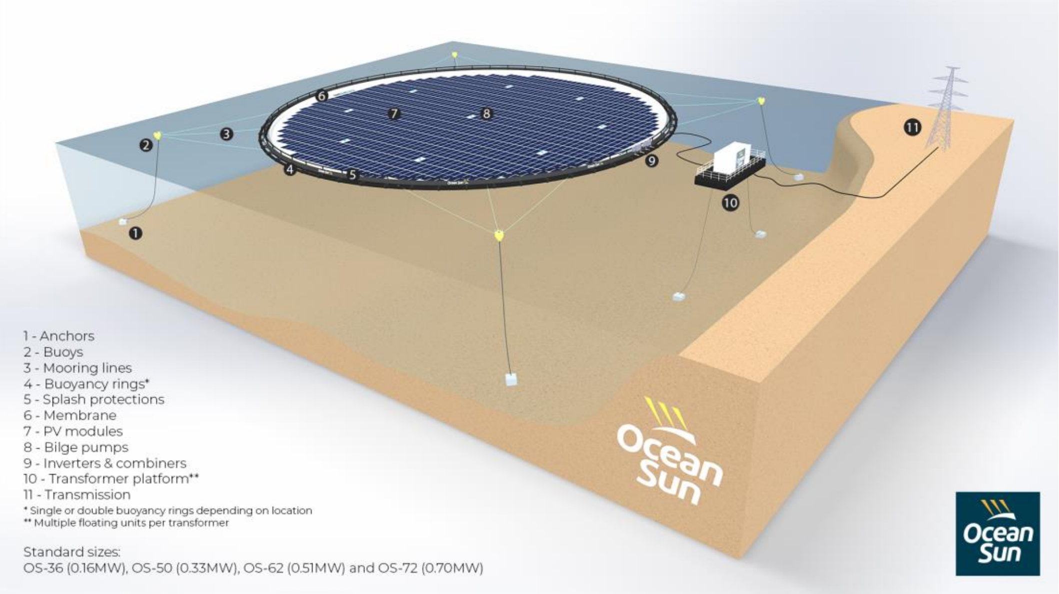

Figure 2.5 General layout and specifications of floater (Source: Ocean Sun).

The two OS-75 floaters are structurally connected with a fender consisting of a soft rubber tire and chains, to provide an area efficient system layout. Three fenders are considered between the floaters. The distance between the fenders is 1.6 meters. Fenders should be visually inspected during regular operation and maintenance.

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[1] Konti Hydroplast, "Water supply polyethelene pipes" https://konti-hidroplast.com.mk/pdf/vodovod/Broshura%20Water%20Pipes_EN.pdf.

2.2.2 Mooring lines

The modular systems will be anchored in place with 16 mooring lines made up of mooring chain and fibre ropes (Figure 2.6). The selection of the mooring materials qualities takes into consideration the required minimum breaking load, axial stiffness and weight of analysed mooring components as well as local factors such as ultraviolet (UV) degradation and water quality.

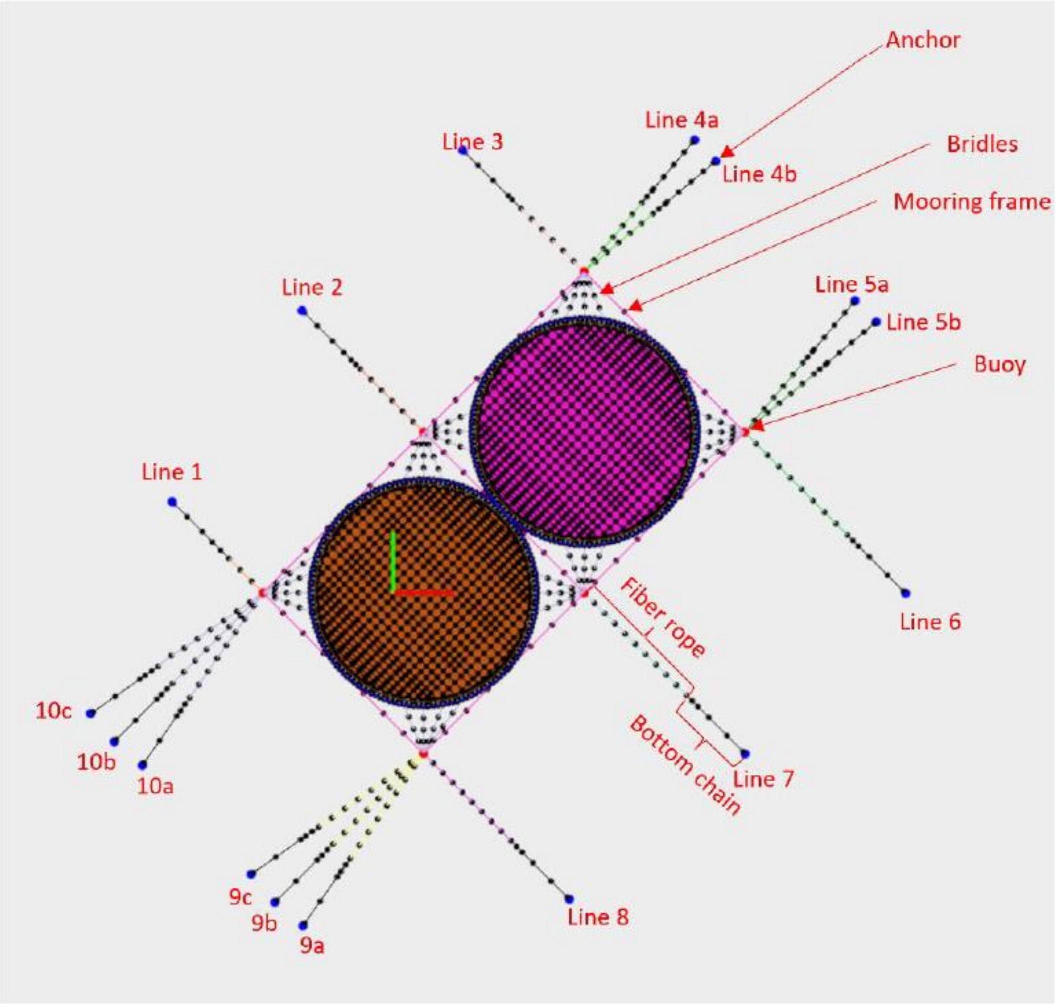


Figure 2.6 General overview of the mooring system layout. Red markers indicate buoys. Blue dots represent anchor positions (Source: Mooring system analysis report. July 2022. Client).

Figure 2.7 shows an example of how the anchor, bottom chain, buoy, bridle lines and floater are connected. The different components are explained below.

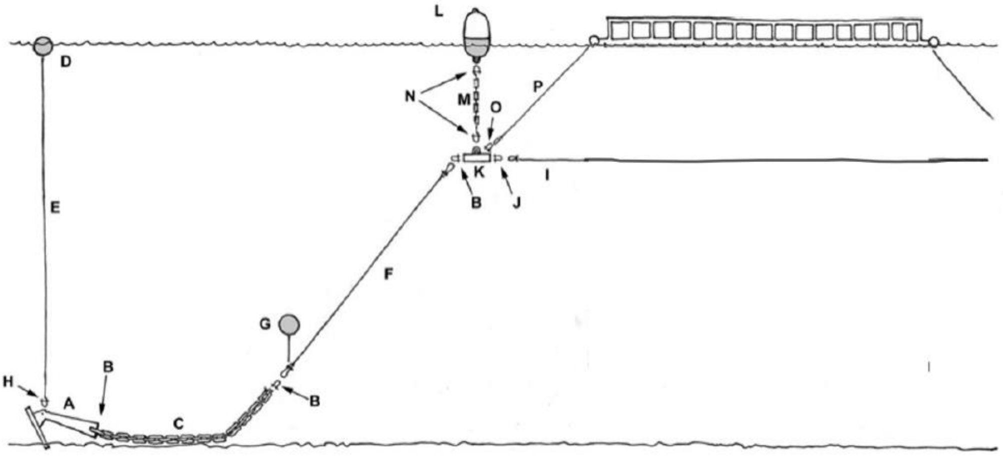


Figure 2.7 Illustration of mooring schematic (Image: Francesco Cardia, 2017; Source: Mooring system analysis report, July 2022, Client)

Table 2.1 Description of the components illustrated in Figure 2.7.

Components	Description
A	Anchor. Dead weight
B, J, O, N	Shackles
C	Bottom chains
D, E	Anchor marker buoy (optional)
F	Mooring rope
G	Deep water buoy (optional)
I	Frame rope
K	Corner plate/coupling plate
L	Mooring buoy
M	Buoy chain (sometimes integrated in mooring buoy as a beam)
P	Bridle ropes

2.2.3 Anchor / Clump / Sinker

Up to sixteen anchors will be deployed to support the mooring lines. The anchors will be made in different sizes and tonnage using concrete mixture. The sizes and dimension of the anchors are shown in Table 2.2.

Table 2.2 Dimension of anchors based on weights

Size	Width (mm)	Length (mm)
4 tonnes	1320	1320
5 tonnes	1350	1350
6 tonnes	1400	1400
7 tonnes	1450	1450
9 tonnes	1600	1600
12 tonnes	1750	1750

2.3 Project Installation

In terms of deployment, the Ocean Sun FPV farm would be towed to the designated area where PV modules would be installed in situ as shown in Figure 2.8. No heavy marine machineries and equipment are required for the installation; thus, no spill of oil and grease is expected.

Figure 2.8 Installation of PV modules on the hydro-elastic membrane of the Ocean Sun system (Source: Client, 2021).

2.4 Project Operation

The FPV farm comes equipped with nine bilge pumps distributed on the membrane surface to ensure effective rainwater dispersion. It will require some maintenance such as removal of debris and cleaning, likely with sea water. As this is a research/pilot project, the maintenance and cleaning needs frequency is still uncertain. For the first year of deployment, the maintenance activity is planned for quarterly in order to understand the cleaning needs of the farm. The maintenance activity will involve usage of chemical cleaning solution (when necessary) and wastewater discharges to the sea. The operation team will also need to perform regular inspection and maintenance of inverters and transformers. Once the floater and membrane are installed, it is fully safe to walk on the surface, thus, operators can easily access the whole system and efficiently perform operation and maintenance in situ.

A marine electrical cable (transmission cable) will transmit the harvested solar energy from the PV system to Pulau Sebarok. It is understood that the cables will be laid on floats to float at the water surface.

2.5 Project Timeframe

The Project consists of two main phases, which are described in Table 2.3 below.

Table 2.3 Overview of the Project

Stage of the Project	Action	Schedule
Construction	• Launching of modular system to site from land • Installation of PV modules, inverters, and anchoring system	Two (2) weeks
Operation	• Electricity production • Maintenance	Twenty (20) years

3 Environmental Laws, Standards and Guidelines

This section describes the EIA framework in Singapore as well as the relevant laws, standards and guidelines to this Study.

There is a selection of regulations and laws that are of relevance to the execution of the environmental feasibility and the subsequent EIA analyses. Existing acts and guidelines seen as ‘environmentally’ relevant are discussed in Section 3.2 and 3.3.

In addition to the above-mentioned applicable regulations, national goals or strategies and ratified international conventions are also of relevance to the legal framework (Section 3.4). The aforementioned environmental legislation, as well as other relevant laws and established ‘tolerance limits’ are described in more detail in the sections that follow.

3.1 EIA Process in Singapore

Singapore adopts a systematic framework to determine and mitigate the potential impact of any new development on the environment. Environmental considerations are an important part of the planning evaluation process, and planning approvals are granted to development proposals only when they have met the requirements imposed by the relevant regulatory agencies. If the impact on the environment could be significant, an environmental study will be required to assess in greater detail the full impact and develop more extensive mitigating measures.

The EIA Framework in Singapore comprises the use of a set of screening criteria to identify projects that agencies require more in-depth assessment, and a planning process that allows for EIA and public disclosure when needed. The process is illustrated in Figure 3.1 and summarized in Table 3.1.

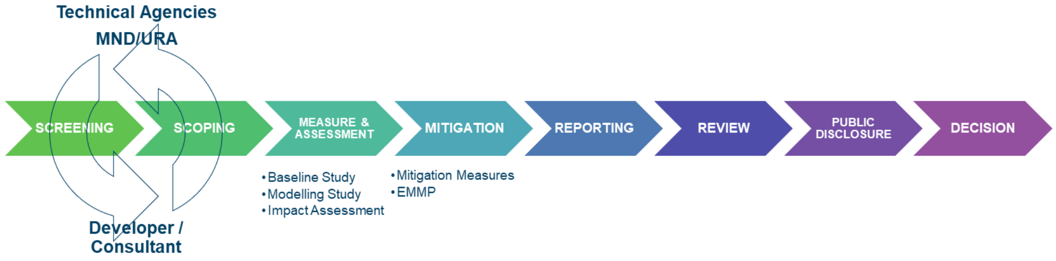


Figure 3.1 An illustration of EIA procedures in Singapore. Stakeholder engagement is project dependent and can take place at various stages of the study.

Table 3.1 Objectives of key EIA stages in Singapore

EIA Stage	Objectives
Screen	To identify and recommend whether an Environmental Study is required and propose a stakeholder engagement plan for the Project.
Scope	To identify environmental pressures/changes arising from the Project and environmental sensitive receptors (ESRs) that may be affected by them and on that basis, determine assessment scope (spatial and temporal boundaries, impacts to be assessed) and formulate EIA approach and methodology. This stage has been completed for this study.

EIA Stage	Objectives
Measure	To describe the baseline conditions and the identified ESRs in potential impact zone of the Project, either through field surveys or desktop literature searches and data analysis.
Assess	To classify significance of impacts through assessment of magnitude and duration of environmental pressures in relation to tolerance limits of the ESRs, taking into account the importance of the receptors and their recoverability from the impacts.
Manage & Mitigate	To outline management and engineering measures are required to mitigate the impacts to an as-low-as-reasonably-practicable level (ALARP) and monitoring regime for construction phase to ensure that impacts are managed accordingly.
Report & Consult	To prepare and submit the Environmental Impact Assessment Report; consultation (with the TAs and the public); and approval by URA and MND.
Engage	To engage relevant stakeholders (socio-economic receptors, interest groups, etc.) to obtain feedback on scoping, impact findings and monitoring requirements – stakeholder engagement requirement varies depending on scale of development, sensitivity of the Project area, among other factors.

3.2 Relevant Singaporean Acts

Several Singaporean Acts are applicable to this study. These include, but are not limited to, the following:

- Planning Act (revised 1998). An act to provide for the planning and improvement of Singapore and for the imposition of development charges on the development of land and for purposes connected therewith.

- Environmental Protection & Management Act 1999 (revised 2002). Covers pollution control including noise, hazardous substances, trade effluent & air quality (including ozone depleting substances, or ODS). Implemented by NEA (Pollution Control Department - PCD);

- Environmental Public Health Act 1987 (revised 2002). Covers general waste, dangerous substances, and hazardous wastes. Implemented by NEA;

- Maritime and Port Authority of Singapore Act 1996 (revised 1997). Establishes the Marine and Port Authority (MPA) of Singapore to provide for its functions and powers. Also covers regulation and control navigation within the limits of the port and the approaches to the port. Implemented by MPA;

- Merchant Shipping (Civil Liability and Compensation for Oil Pollution) Act 2008 (revised 2010). Covers penalties for oil spills from any vessel. Implemented by MPA;

- Prevention of Pollution of the Sea Act 1990 (revised 1999). An act to put into effect the International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978, and to other international agreements relation to the prevention, reduction and control of pollution of the sea and pollution from ships, and generally for the prevention reduction and control of pollution to the sea (MARPOL). Implemented by MPA; and

- Energy Conservation Act (Amendment) 2017. An Act to mandate energy efficiency requirements and energy management practices to promote energy conservation, improve energy efficiency and reduce environmental impact.

3.3 Relevant Regulations and Guidelines

Regulations and guidelines of relevance to the Project include, but are not limited to, the following:

- National Parks Board Biodiversity Impact Assessment (BIA) Guidelines 2020;
- NEA Hazardous Waste (Control of Export, Import and Transit) Regulations 1998 (revised 2000). Covers transport of hazardous waste (BASEL permits);
- NEA Environmental Protection and Management (Hazardous Substances) Regulations 1999 (revised 2008);
- NEA Code of Practice on Pollution Control (2013);
- NEA Code of Practice on Environmental Health (2017);

3.4 Conventions, Treaties and Protocols

Singapore has ratified or acceded to the following key international conventions, treaties and protocols of relevance to this EIA:

- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, the "London Convention" in short;
- International Regulations for Preventing Collisions at Sea 1972 (Colregs) are published by the International Maritime Organization (IMO);
- International Convention for the Safety of Life at Sea (SOLAS), most recent amendment dates from May 2011;
- Kyoto Protocol to the UNFCCC 1997;
- MARPOL 73/78: International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978. ("MARPOL" is short for marine pollution and 73/78 short for the years 1973 and 1978.);
- UN Convention on Biological Diversity 1992;
- United Nations Convention on the Law of the Sea (UNCLOS) 1982, also called the Law of the Sea Convention or the Law of the Sea treaty; and

3.5 International Guidelines

Some aspects of the Project are not covered by existing Singapore regulations. For example, the Singapore guidelines do not specify certain water quality standards or guidelines. In accordance with usual EIA practices, where National standards are not available, relevant international standards such as the World Bank (which includes the International Finance Corporation, or IFC) guidelines will be applied. DHI will also apply other relevant international benchmarks and our own well-established port and marine ecology related tolerance limits as appropriate. The standards and guidelines used within the assessment process will be further detailed within the EIA Report.

3.5.1 World Bank / IFC

In general, the EIA will reference where IFC Performance Standard 1: Assessment and Management of Environmental and Social Risks are relevant. More specifically, the EIA may reference IFC Performance Standards, including:

- Performance Standard 3: Pollution Prevention and Abatement;
- Performance Standard 4: Community Health, Safety and Security;
- Performance Standard 6: Biodiversity Conservation and Sustainable Natural Resource Management; and

The IFC Performance Standards are strengthened by a set of Environmental Health and Safety (EHS) Guidelines which provide additional supporting material to assist with improving compliance with the standards and improving project performance. Those which may apply for this Project include:

- Energy conservation
- Wastewater and ambient water quality;
- Hazardous materials management; and
- Waste management.

3.5.2 Other International Guidelines

Other internationally accepted policies and guidelines may be referenced and applied as a basis for assessing impacts. The following, amongst others, have been identified for this Project:

- European Union Guidance on EIA (European Commission 2001);
- The European Commission's Integrated Pollution, Prevention and Control (IPPC) General Principles of Monitoring, 2003;
- Association of Southeast Asian Nations Marine Water Quality Criteria (ASEAN 2008) for assessing water quality;
- IUCN Red List of Threatened Species for assessing the vulnerability of species. Under this classification scheme, globally threatened species have been categorised as Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened or Least Concern;
- Singapore Red Data Book (Davison et al., 2008) for assessing the vulnerability of species in Singapore. Under this classification scheme, locally threatened species have been categorised as Globally Extinct, Presumed Nationally Extinct, Critically Endangered, Endangered, Vulnerable, Near Threatened or Least Concern.

It should be noted that this list is not exhaustive, and specific standards and guidelines may be referenced throughout the relevant sections of the EIA Report.

4 EIA Scope and Approach

4.1 Study Scope

Environmental screening for the Nearshore FPV Farm at Sebarok took place between October and December 2021. Consultation for assessment scope for this EIA was between April and May 2021, with Urban Redevelopment Authority (URA) and relevant Technical Agencies (TAs), i.e., Maritime and Port Authority of Singapore (MPA), National Environment Agency (NEA), National Parks Board (NParks) and Singapore Food Agency (SFA).

The potential impacts from the Project were identified at this stage through developing a Scoping Matrix for the Project. The methods undertaken to develop the Scoping Matrix include working closely with the client to understand the Project design and its approach to construction and operation, and thereby identifies potential environmental pressures. At the same time, carrying out a desktop study for the study area in combination with consultation with relevant agencies (i.e., URA and TAs), to understand the social, economic, and ecological receptors in the area. The pressures and receptors are then tabulated in Scoping Matrix and interactions between them are sought and to be assessed in the EIA study.

The scoping matrix for the Project is presented in Table 4.1. The baseline study and impact analysis and assessment in this EIA was then scoped based on these identified impacts. The present report discusses and documents outcome from these tasks.

Sediment plume was initially anticipated to be one of the pressures (or environmental changes) arising from the Project. It is related to the deployment of concrete sinkers for the anchoring system and their movements during operation. DHI’s baseline survey however finds that the seabed in the project site is a mixture of substrates (rocks) and coral rubbles. This impact was later scoped out from the study, due to the non-silty characteristic of the seabed here.

The panel is made of high-density polyethylene (HDPE) and are designed to withstand offshore conditions. The technology used in the panel has been verified by internationally recognized certification bodies. Therefore, potential impact arising from the material of the PV panels is scoped out of this EIA.

Impacts from the energy storage system (ESS) is scoped out of this study as the system is located in the middle of Sebarok island that is fully built-up and stores huge inventory of hazardous materials. The existing risk of oil spill is huge, which the ESS for this project will not change the risk level, noting that environmental impact assessment is all about assessing *change*.

Additionally, the ESS has three layers of containment to prevent chemicals from leaking (Figure 4.1). The electrolyte of the ESS is stored in polypropylene tanks and the tanks are double walled. The container of the ESS forms the third layer of protection with the inner walls of the container lined with acid resistive coating. Leakage sensors are installed between the tanks to detect any electrolyte spillage which will shut down the battery and alert the operators. Sunseap will be applying license for the ESS with NEA.

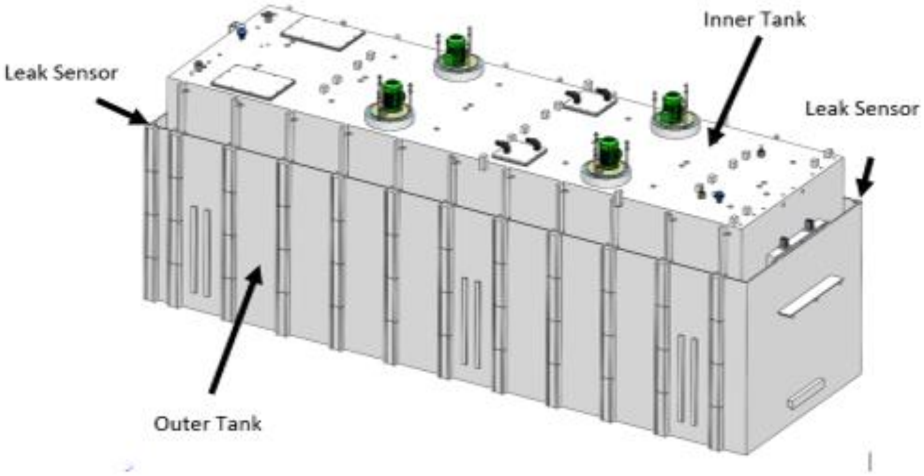


Figure 4.1 Illustration of ESS equipped with containment measures to mitigate spillage of chemicals (Source: Client, 2023)

Table 4.1 Scoping matrix for the FPV installation (updated based on baseline survey findings).

Environmental Pressures	**Environmental Receptors**					
	Fairway and Navigation	**Jetties**	**Corals**	**Marine Fauna**	**Benthic Habitat**	**Avifauna**
Physical presence / Disturbance	L		S L[2]	L[1]	S L[2]	L[4]
Light penetration				L		
Water temperature				L		
Water quality[3]			L	L		
Electromagnetic field				L		

- Pressures = changes in environmental parameters resulting from the Project. Receptors = social, economic, or ecological features that may be affected by the pressure.
- S = Short-term impacts – normally associated with construction activities. L = Long-term impacts – normally associated with project design and footprint.

[1] related to marine cable: entanglement risk toward mobile marine fauna and scouring effect on intertidal area

[2] related to concrete sinkers: direct loss of macrobenthos within their direct footprint

[3] related to light shading effect, change in dissolved oxygen level (resulting from change in water temperature), biofouling of the membrane in contact with water, and washing/maintenance of the FPV farm

[4] due to reflective surface of FPV panels

4.2 Study Approach

DHI's overall workflow to environmental impact assessment is illustrated in Figure 4.2. This section offers to elaborate on the approach for Measure, Assess and Manage stages.

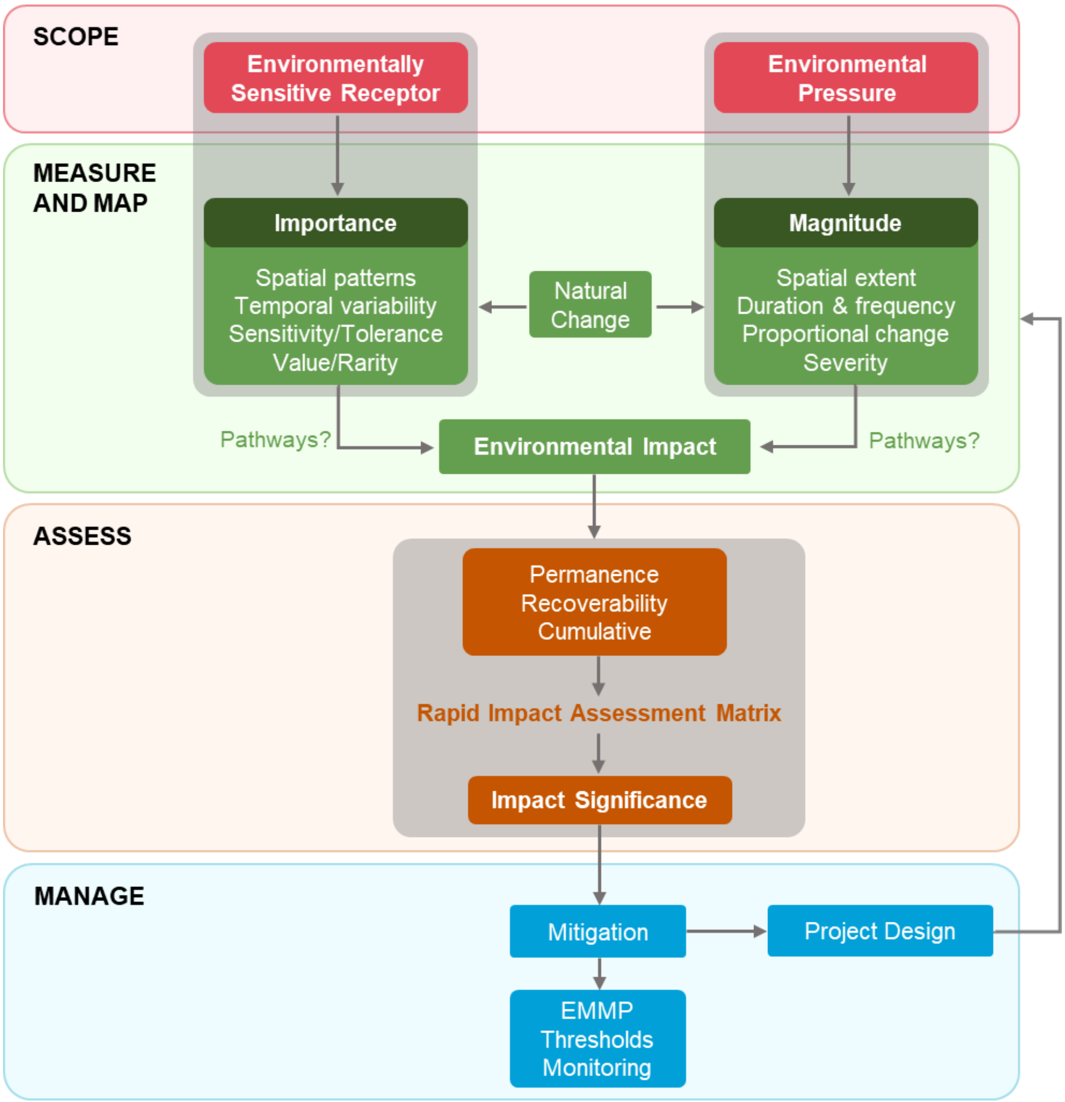


Figure 4.2 DHI's overall workflow for the impact assessment process.

4.2.1 Measurement

The EIA requires relevant inputs on the existing environmental receptors and pressures. It also requires reliable prediction of the future conditions when the Project is constructed and in operation. This section outlines DHI's approach to the Environmental Baseline Study (EBS) and to prediction of effects from the development of interest.

4.2.1.1 Baseline Condition

The primary objective of the EBS is to gather sufficient understanding of the existing environmental conditions at and around the proposed development area for several purposes:

- understanding the presence and conditions of sensitive receptors in the study area
- establishing environmental baseline conditions
- collecting data for model setup and calibration

The above activities will support the subsequent impact assessment task. The scope of this baseline study was established based on the receptors earlier identified and the impacts that need to be assessed in this EIA.

The baseline conditions will be established through a combination of physical surveys and a thorough desktop review of other data and information available or to be made available to DHI. Such information can be in-house data held by DHI from internally funded research projects (e.g., Automatic Identification system (AIS) data) or can come from agencies associated with other environmental studies. The physical surveys conducted for this study, including their methodologies, are described in Section 5.

4.2.1.2 Impact Prediction

Multiple methods are employed in this study to predict the level of changes likely arising from the construction and operation phases of the Project. It is important to note that at this stage, the assessment merely describes the magnitude of the environmental changes or effects of the Project. The methodologies are outlined in the impact assessment sections (Section 6 and Section 7).

Quantitative assessment methods are used where possible, to provide good understanding of magnitude of potential changes arising from the Project. They include:

- Hydrodynamic thermal modelling to assess the thermal impacts potentially arising from the change in water temperature due to the sheltering effect of the photovoltaic cells.
- Geographic information system (GIS) calculation and mapping of direct loss of habitats.

The rest of the pressures identified for this EIA are assessed qualitatively guided by the various definitions of Rapid Impact Assessment Matrix (RIAM), coupled with knowledge from relevant literature, guidelines, expert opinion and past project experiences.

4.2.2 Assessment

4.2.2.1 Assessment Method

All the identified impacts will be assessed using the Rapid Impact Assessment Matrix (RIAM), originally developed by Pastakia & Jensen (1998). RIAM allows for a holistic, rapid and easily comparable presentation and summary of the overall project impacts, which ultimately aids in pinpointing the most significant impacts predicted, in accordance with the broad definitions presented in Table 5.2. Besides the reduction in assessment subjectivity as compared to other methodologies, RIAM also accounts for the presence of impacts that may be cumulative in nature. The Biodiversity Impact Assessment (BIA) Guidelines of Singapore (National Parks Board, 2020) recommends the use of RIAM as one of three approved methods for assessing and summarizing the overall significance of impacts.

Table 4.2 Broad definitions of impact significance levels. Impacts can be either negative or positive.

Impact Significance	Broad Definition
No Impact	Changes are significantly below physical detection level and below the reliability of numerical models, so that no change to the quality or functionality of the receptor will occur.
Slight Negative or Positive	Changes can be resolved by numerical models and are detectable in the field, which may cause slight and localised nuisance or disruption of daily activities.
Minor Negative or Positive	Changes can be resolved by numerical models and are likely to be detected in the field, which may cause stress to a portion of the population at endurable levels, but at a spatial scale that is unlikely to have any secondary consequences.
Moderate Negative or Positive	Changes can be resolved by numerical models and are obviously detectable in the field, which may cause significant stress to a large portion of population and would likely disrupt the quality and functionality of the receptor.
Major Negative or Positive	Changes are highly detectable in the field and are likely to be related to significant habitat loss. Major impacts are likely to have secondary influences beyond the area of assessment.

RIAM translates qualitative standard definitions of evaluation criteria into semi-quantitative ordinal scores which are then used to calculate Environmental Scores (ES), via the formula:

$$Environmental\ Score\ (ES) = I\ \times M\ \times (P + R + C)$$

The five evaluation criteria (variables) used in the formula are defined as:

(I) Importance – This defines the importance of the sensitive receptor identified, which is assessed against spatial or political boundaries, socio-economic value, intrinsic quality, or the degree of rarity.

(M) Magnitude – Impact Magnitude or Magnitude of change is based on the relationship between the analysed physio-chemical, biological, or socio-economic deviation from baseline conditions and the relevant environmental standards, benchmarks, guidelines, or tolerance limits (see Section 4.2.2.2). Importantly, the Magnitude value should reflect the magnitude of change experienced at a particular sensitive receptor. In this way, the impact pathway is considered, i.e., whether there is a spatial and/or temporal overlap between the environmental change and receptor. Positive or negative impacts are represented though positive or negative ordinal scores for Magnitude respectively.

(P) Permanence – This defines whether an impact is temporary or permanent, i.e. a measure of the temporal status of the loss/change.

(R) Recoverability – The score expresses whether the receptor can recover from the impact, either unassisted or via mitigation measures. Recoverability is also a measure of the control over the effect (i.e., can it be mitigated).

(C) Cumulative Impact – This is a measure of whether the effect will have a single direct impact or whether there will be a cumulative effect over time.

The approach of RIAM is therefore to couple the potential impact Magnitude experienced at the sensitive receptor(s) of interest, with a concurrent assessment of receptor Importance, impact Permanence, Recoverability, and Cumulative potential.

The multiplication of Magnitude and Importance in the formula ensures that the weight of each evaluation criteria is expressed and is individually able to significantly influence the resultant ES. The summation of Permanence, Importance, and Cumulative ensures that these criteria are represented collectively, but do not have a large influence on the resultant ES individually.

The standard (generic) definitions of each evaluation criteria, and the associated ordinal scores used to calculate ES, are shown in Table 4.3. To account for the wide variability and context-specificity of sensitive receptors and predicted environmental impacts (pressures), the generic definitions of Importance and Magnitude in Table 4.3 will be customized and made specific for sensitive receptors and predicted environmental impacts respectively, with justifications elaborated in each assessment in Section 6 and 7.

Table 4.3 Evaluation criteria and the associated standard definitions and ordinal scores used in the calculation of Environmental Scores.

Evaluation Criteria	Standard Definitions	Ordinal Score
Importance*	Important to national/international interests	5
	Important to regional/national interests	4
	Important to areas immediately outside the local condition	3
	Important to the local conditions (within a large direct impact area)	2
	Important only to the local condition (within a small direct impact area)	1
Magnitude*	Major positive benefit or change	+4
	Moderate positive benefit or change	+3
	Minor positive benefit or change	+2
	Slight positive benefit or change	+1
	No change/status quo	0
	Slight negative disadvantage or change	-1
	Minor negative disadvantage or change	-2
	Moderate negative disadvantage or change	-3
	Major negative disadvantage or change	-4
Permanence	Temporary or short-term change.	2
	Permanent change or long-term; value and/or function unlikely to return.	3
Recoverability	Recoverable or controllable through EMMP	2

Evaluation Criteria	Standard Definitions	Ordinal Score
	Irrecoverable	3
Cumulatively	Impact can be defined as non-cumulative/single (not interaction with other impacts).	2
	Presence of obvious cumulative/cascading effect that will affect other projects or activities or trigger secondary impacts.	3

* Definitions and scorings of Importance and Magnitude will be customised for all identified sensitive receptors and environmental impacts respectively in Section 6 and 7.

For each identified environmental impact affecting a sensitive receptor, an ES will be calculated. The ES are then banded together and ranked in range bands as presented in Table 4.4, which are then translated to Impact Significance – the reported output of the impact assessment process.

Table 4.4 Range bands of ES and the associated Impact Significance used in RIAM.

Environmental Scores (Range Bands)	Impact Significance Translated from Environmental Scores
116 to 180	Major positive change/impact
81 to 115	Moderate positive change/impact
37 to 80	Minor positive change/impact
7 to 36	Slight positive impact
-6 to +6	No impact/Status quote/Not applicable
-7 to -36	Slight negative change/impact
-37 to -80	Minor negative change/impact
-81 to -115	Moderate negative change/impact
-116 to -180	Major negative change/impact

4.2.2.2 Assessment Criteria

Ranking Magnitude of change requires knowledge of relevant environmental standards, benchmarks, guidelines, or tolerance limits of the sensitive receptors – the assessment criteria. This EIA adopts various assessment criteria from the above-mentioned laws, standards and guidelines. The criteria specific to definite levels with respect to water quality and sediment quality are listed in the following sections.

For other environmental aspects which do not have a definite limit of impact (e.g., ecological and biodiversity receptors), DHI will assess qualitatively based on knowledge from international literature, standards, guidelines, expert opinion and past project experiences such as standards which have been adopted for previous EIA studies in Singapore and validated against long-term environmental monitoring and management projects undertaken for multiple Singapore government agencies. The identified tolerance limits allow for a level of detail that will enable the results of the short- and long-term impact assessments to be quantified in terms of magnitude and scale of impact on each individual receptor.

Currents and Navigation

Marine navigation is susceptible to changes in current fields. Definitive tolerance limits relevant to the effects of changes in current on navigation is not available, as the significance of changes in current speed and direction depends on the usage of the specific water area.

Marine Facilities

Navigation channels, berthing areas and jetties are susceptible to incremental sedimentation, which may result in increased maintenance costs associated with maintenance dredging.

In the field, redistribution mechanisms such as the effect of propeller wash and the inherent accuracy limits of bathymetric surveys make detecting small incremental changes to sedimentation against background variability very difficult, with a potential measurable change typically being taken as about 150 mm (Engineer Research and Development Center, 2003). A limit of 150 mm/year has thus been set as the lower limit for measurable change labelled as ‘Minor Change,’ and other limits set are presented in Table 4.5.

It is noted that there is presently a degree of uncertainty in the suitability of 50 mm/year reflecting ‘No Impact’. Although this is well below the limit that can be reliably measured in the field, some facility operators claim realised impacts for changes in the order of 10 mm/year or less. Whilst standard practice cannot support the determination of such low limits, the fact that claims have been made on changes falling in the ‘Slight’ or ‘No Impact’ categories must be flagged as a risk factor for stakeholder engagement and ongoing relationships with neighbouring facilities with the application of the proposed tolerance limits for EIA purposes.

Table 4.5 Tolerance limits for marine facilities to changes in sedimentation (i.e. from background levels)

Magnitude	Definitions
No Change	Less than 50 mm/year
Slight Negative Change	Between 50 to 150 mm/year
Minor Negative Change	Between 150 to 300 mm/year
Moderate Negative Change	Between 300 to 500 mm/year
Major Negative Change	More than 500 mm/year

Water Quality

The Association of Southeast Asian Nations Marine Water Quality Criteria (ASEAN MWQC, 2008) provides a framework aimed at protecting ASEAN coastal waters from the effects of pollution. The ASEAN MWQC have been developed to provide guidance on a set of common approaches and methodologies that address marine water quality issues within the ASEAN region. As there are currently no available guidelines for water quality within Singapore waters, the ASEAN MWQC are applied as a locally relevant benchmark.

The ASEAN MWQC were developed by ASEAN scientists during the period from 1992 to 1997, through study of relatively 'good' marine water quality (European Union Water Framework Directive-EU WFD). The ASEAN MWQC focuses on a range of known pollutants such as heavy metals, suspended solids, nutrients and bacteria for assessment of marine water quality but does not include other key water quality parameters. Therefore, in the absence of local or ASEAN guidelines, other international guidelines are included (e.g., US EPA Aquatic Life Ambient Quality Criteria, 2016 and EU Water Framework Directive 2006/44/EC).

Table 4.6 presents the applicable marine water quality criteria from ASEAN MWQC and other international guidelines.

Table 4.6 Applicable water quality marine criteria as for ASEAN MWQC and other international guidelines.

Parameter	ASEAN MWQC	International Guidelines
Secchi disc depth	-	-
Turbidity	-	-
Salinity	-	-
pH	-	Changes in pH should not be outside 6.5 to 9.0 (shallow and productive coastal and estuarine areas)*
Temperature	Increase not more than 2°C above the maximum ambient temperature	-
Dissolved oxygen, DO	> 4 mg/L	≥ 70% weekly average saturation on farm^ or Based on two daily measurements (preferably around 6am and 3pm) < 5% weekly samples below 2 mg/L^
Total suspended solids, TSS	Permissible 10% maximum increase over seasonal average concentration	-
Ammonia, as NH_3-N	< 70 µg/L	-
Nitrite, as NO_2-N	< 55 µg/L	-
Nitrate, as NO_3-N	< 60 µg/L	-
Phosphate, as PO_4-P	< 15 µg/L	-
Total nitrogen, TN	-	Permissible limit of 1.5 mg/L for Class I (virtually undisturbed, natural aquatic system, all intended uses are supported by waters of this use class)$^{\&}$
Total phosphorus, TP	-	Permissible limit of 0.1 mg/L for Class I (virtually undisturbed, natural aquatic system, all intended uses are supported by waters of this use class)$^{\&}$
Oil and grease	< 0.14 mg/L	-

Parameter	ASEAN MWQC	International Guidelines
Chlorophyll-*a*	-	-
Faecal coliform	< 100 MPN/100 mL (for coastal recreational activities)	-
Enterococci	< 35 cfu/100 mL (for coastal recreational activities)	

** US EPA AWQC, 2016*

& *Directive 75/440/EEC*

^ ASC, 2019

Marine Ecology and Biodiversity

At present, only tolerance limits associated with suspended sediments and sedimentation have been defined for corals, seagrasses, and mangroves. As such, a literature review was conducted to allow an assessment of the impacts identified in the scoping exercise on the different floral and faunal groups found in the study area. Assessment of impacts arising from the development are thus carried out using expert opinion based on current research findings to support the qualitative assessment.

5 Environmental Baseline

5.1 Existing Environmental Receptors

Based on DHI's extensive in-house receptor database and a desktop review of public information, environmental features within the vicinity of the Project area are shown in Figure 5.1. Those that are identified as potentially affected by the Project, also known as environmental receptors, are described in Table 5.1.

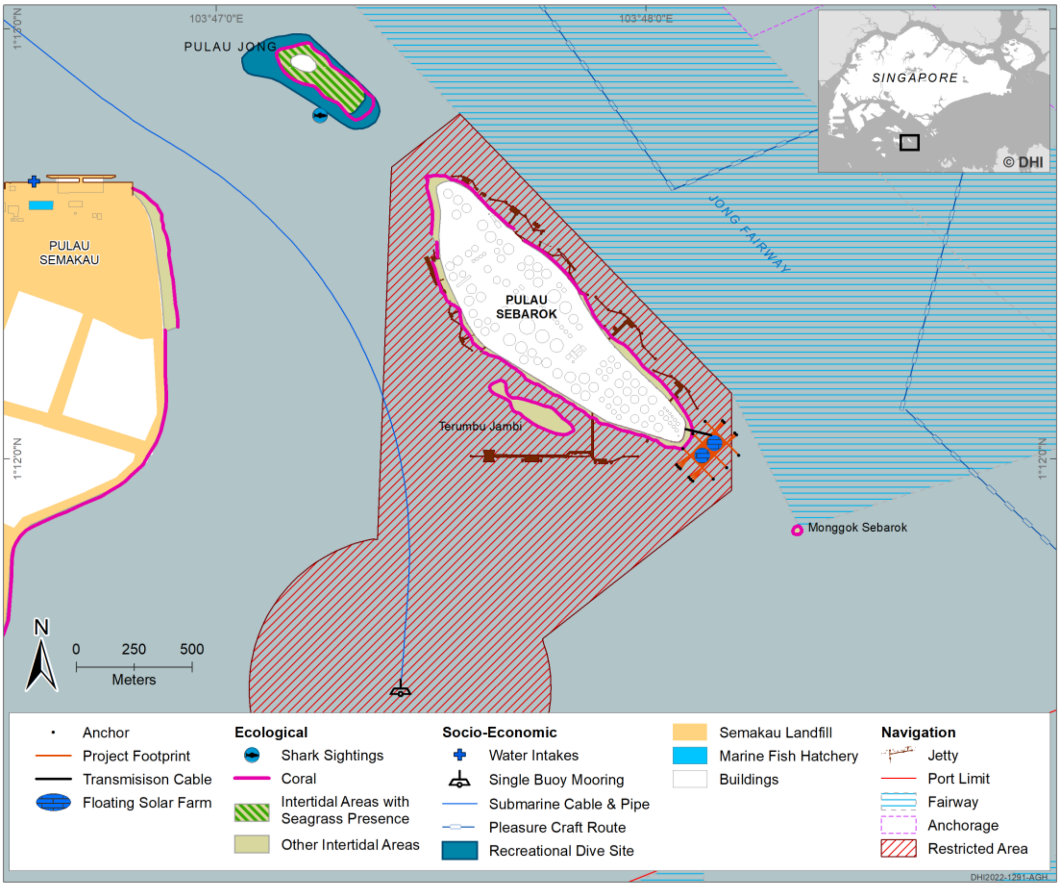


Figure 5.1 Overview of environmental features in the study area.

Table 5.1 Description of environmental receptors to the Project. Other environmental features not listed here have been screened out due to their distance.

Environmental Receptor	Description
Marine jetties	• Shoreline of Pulau Sebarok densely populated with terminals and jetties for vessel transit, berthing, and departing. • Management of jetties distributed among three terminal operators – Vopak, Petro China, Cleanseas. • Jetties in close proximity to the Project (southern shoreline) largely managed by Vopak. The nearest jetties are 125 m (OSV4, to the east of the landing point) and 237 m (OSV5, to the west) away from the project footprint.

Environmental Receptor	Description
Marine fairways and navigation	Adjacent to the Project area is the Jong Fairway (127 m away) and Singapore Strait (1.8 km away). The main marine traffic around the Project area comprises of vessels travelling to and from Pulau Sebarok
	The Project footprint is within the MPA-designated restricted area around Pulau Sebarok extending up to 1.3 km to the Shell Single Buoy Mooring (SBM) towards the southwest of the Project area. Vessels are prohibited from anchoring and mooring within the area.
Ecological receptors	Pulau Sebarok and the surrounding islands are known to be rich in coral habitats. Corals are found fringing Pulau Sebarok, Terumbi Jambi (0.5 km away from project footprint), Pulau Jong (2.2 km away from project footprint), and Pulau Semakau (2.3 km away from project footprint). Corals are also found in Monggok Sebarok (at a distance of 0.5 km from project footprint) – the reef forms the base of the Sebarok beacon. The FPV is located at a distance of 8.7 km from the edge of the reef slope of Pulau Sebarok. While two anchor points are located within the reef crest of Pulau Sebarok.
	Presence of intertidal habitats have also been documented on these islands, but seagrass habitats had only been observed on Pulau Jong, located 2.2 km away from the Project footprint.
	Macrobenthic communities and the seafloor within and around the Project footprint.
	Marine fauna sightings have been documented in the area, including but not limited to, a diverse range of fishes, turtles, marine mammals, and sharks. Sighting recorded at Pulau Jong located 2.2 km away from Project footprint and at Three Sisters Island, 3.7 km towards eastward of the Project site.
	Avifauna (resident and migratory birds) of the general study area.

5.2 Physical Characteristics

This section describes the metocean characteristics of the potential deployment area for the FPV project. These understandings are built into modelling temperature changes that may arise from the solar panels.

5.2.1 Bathymetry

At the floating PV location, the water depth varies from 8 to 16 meters below Chart Datum (CD) as shown in Figure 5.2. The water depth is approximately -14 mCD at the centre of the two floaters, while the depth of the anchoring points varies between 4 and 20 meters below CD.

This bathymetry data was obtained from different sources gathered in DHI’s database. The data were combined to produce a consistent bathymetry dataset covering the entire study area. To obtain such a consistent dataset, common references were applied. The horizontal reference adopted for the study was longitude, latitude geographical coordinates (WGS-84 datum), while the vertical reference was in Chart Datum (CD).

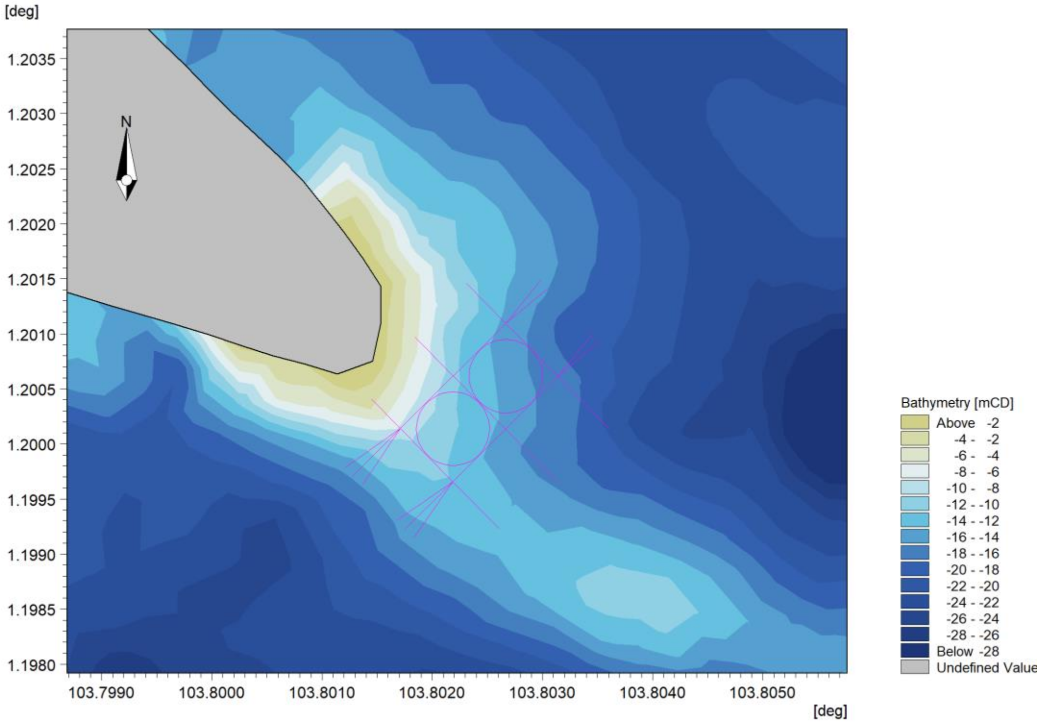


Figure 5.2 Bathymetry in the vicinity of the Project area

5.2.2 Winds

Wind condition at the study site is relatively strong as it is located offshore. NEA wind station at Pulau Semakau was assessed to understand the wind condition at the Project site. It is the nearest NEA wind station with available long-term data. The data is available from 2009 to 2018 at 1-minute temporal resolution at an altitude of 10 m above mean sea level (mMSL), with few gaps in the dataset. The 1-min wind speeds were interpolated to 10-minute averages using a moving-average technique for further analysis. The most frequent wind comes from the north (about 21% of the time) and the strongest wind comes from the west (up to 24 m/s), as can be seen in Figure 5.3 and Table 5.2.

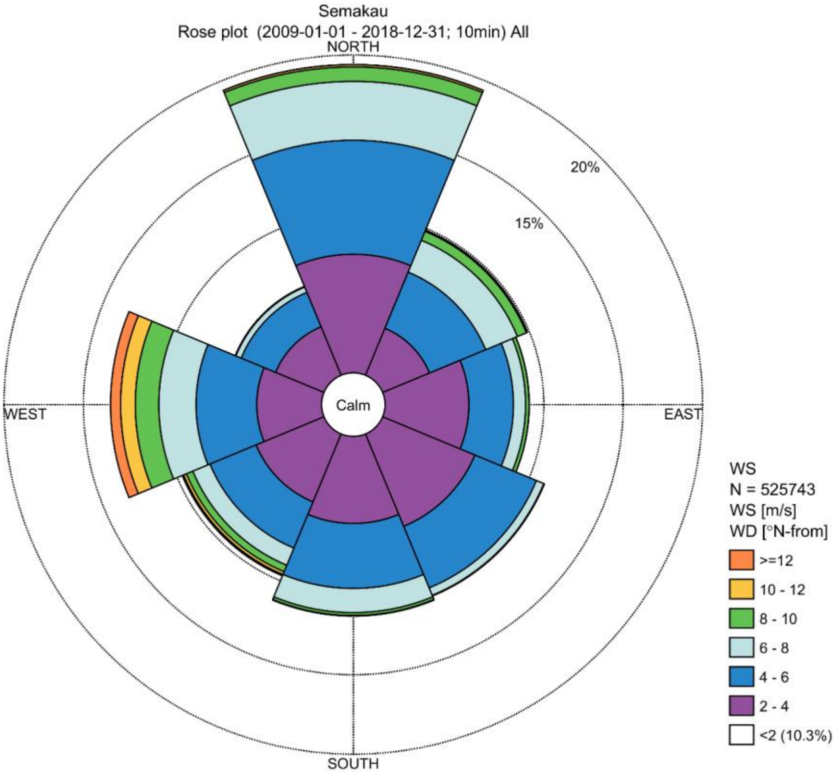
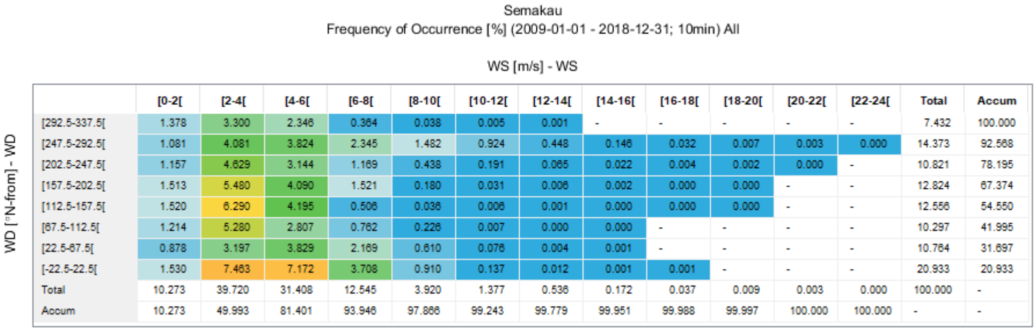


Figure 5.3 Wind rose (10-min average) at Semakau wind station

Table 5.2 Occurrence table of wind speed and wind direction at Semakau wind station



Semakau
Frequency of Occurrence [%] (2009-01-01 - 2018-12-31; 10min) All

WS [m/s] - WS

WD [°N-from] - WD	[0-2[	[2-4[	[4-6[	[6-8[	[8-10[	[10-12[	[12-14[	[14-16[	[16-18[	[18-20[	[20-22[	[22-24[	Total	Accum
[292.5-337.5[	1.378	3.300	2.346	0.364	0.038	0.005	0.001	-	-	-	-	-	7.432	100.000
[247.5-292.5[	1.081	4.081	3.824	2.345	1.482	0.924	0.448	0.146	0.032	0.007	0.003	0.000	14.373	92.568
[202.5-247.5[	1.157	4.629	3.144	1.169	0.438	0.191	0.065	0.022	0.004	0.002	0.000	-	10.821	78.195
[157.5-202.5[	1.513	5.480	4.090	1.521	0.180	0.031	0.006	0.002	0.000	0.000	-	-	12.824	67.374
[112.5-157.5[	1.520	6.290	4.195	0.506	0.036	0.006	0.001	0.000	0.000	0.000	-	-	12.556	54.550
[67.5-112.5[	1.214	5.280	2.807	0.762	0.226	0.007	0.000	0.000	-	-	-	-	10.297	41.995
[22.5-67.5[	0.878	3.197	3.829	2.169	0.610	0.076	0.004	0.001	-	-	-	-	10.764	31.697
[-22.5-22.5[	1.530	7.463	7.172	3.708	0.910	0.137	0.012	0.001	0.001	-	-	-	20.933	20.933
Total	10.273	39.720	31.408	12.545	3.920	1.377	0.536	0.172	0.037	0.009	0.003	0.000	100.000	-
Accum	10.273	49.993	81.401	93.946	97.866	99.243	99.779	99.951	99.988	99.997	100.000	100.000	-	-

5.2.3 Currents

Strong current prevails around Pulau Sebarok with mean current speeds ranging between 0.5m/s and 1.0m/s, and maximum current speed going up to 1.8 m/s. Figure 5.4 shows the snapshot of current field around Pulau Sebarok during maximum west going and east going current during Northeast monsoon. The island bifurcates the current and it generates eddies behind the island. East going current is in general stronger with maximum current is up to 1.8m/s occurring at the area southwest of the island. This characteristic implies a good flushing capacity of the area which is an advantage in terms of water quality, but a disadvantage in terms of mooring design.

Mean annual total current rose extracted around the study area (floating PV) is presented in Figure 5.5, whilst the directional occurrence percentages are shown in Table 5.3. The directionality indicates a strong influence of tidal current which consists of two main current directions: easterly and south-westerly going currents.

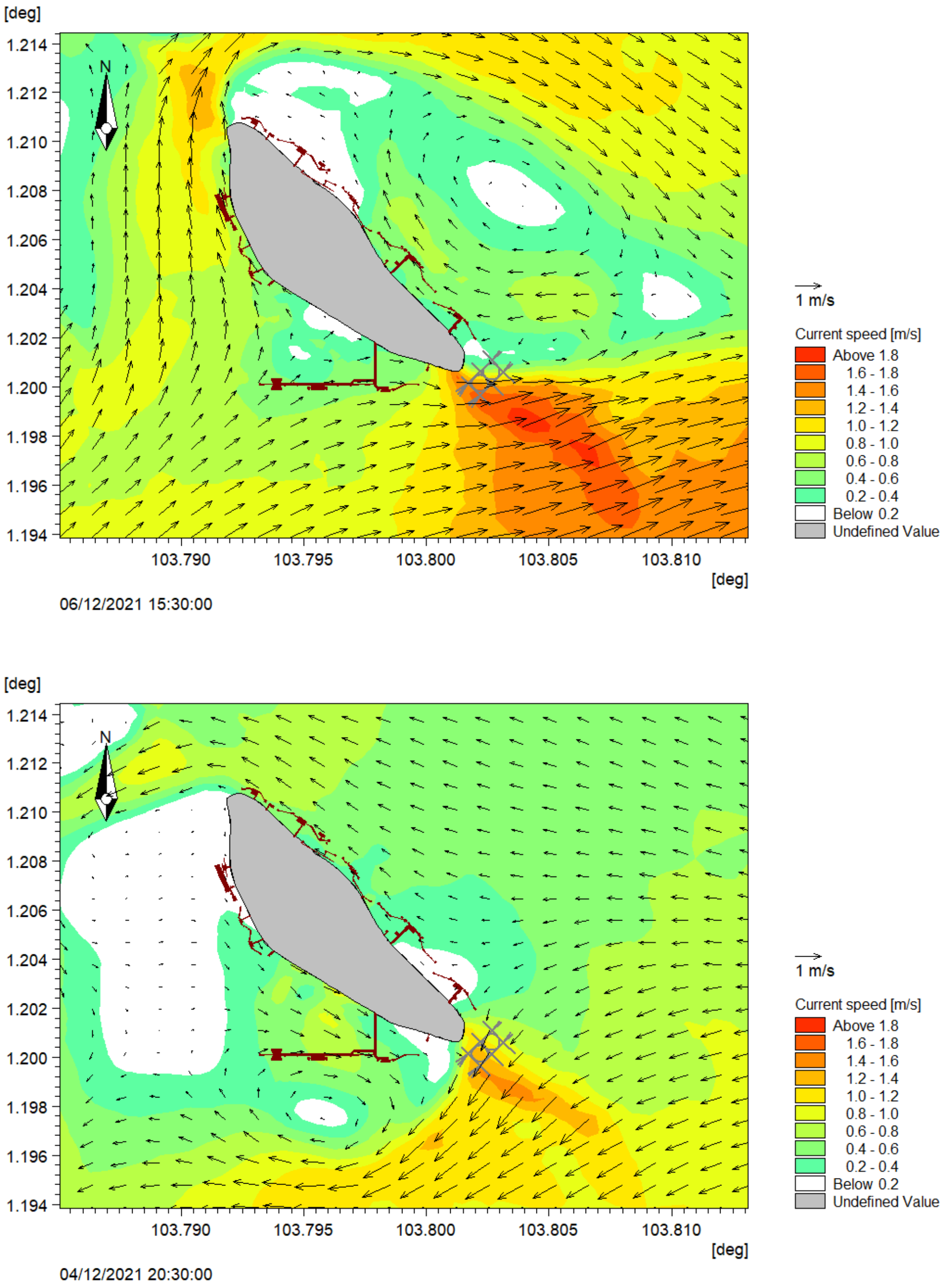


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Figure 5.4 Snapshot of current vectors around Pulau Sebarok during strong east going current (top) and west going current (bottom)

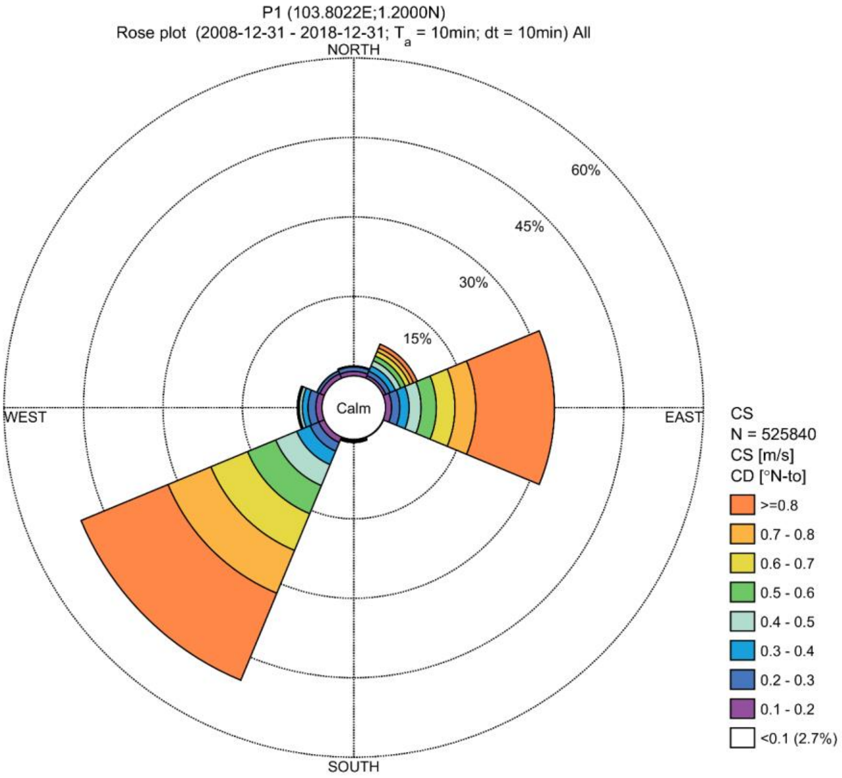
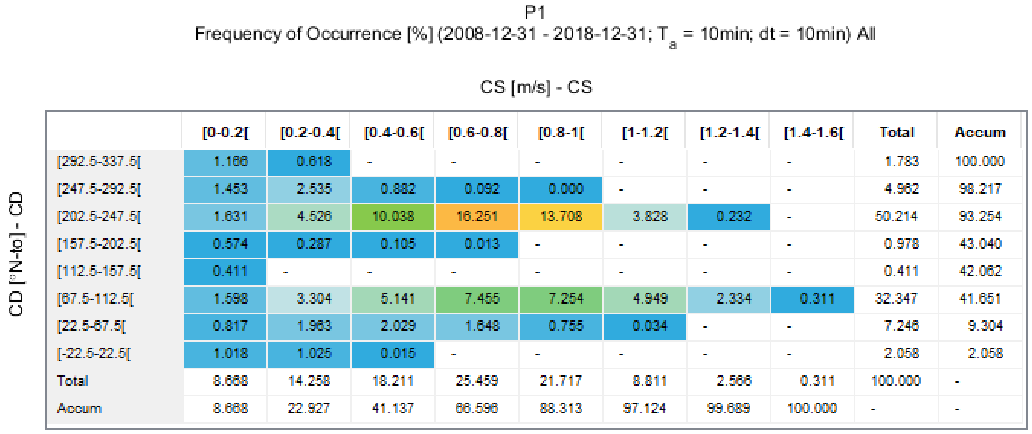


Figure 5.5 Current rose plot from 10 years hindcast model carried out in the MetOcean study /1/

Table 5.3 Occurrence table of total current speed and current direction at study area /1/



P1
Frequency of Occurrence [%] (2008-12-31 - 2018-12-31; T_a = 10min; dt = 10min) All

CS [m/s] - CS

CD [°N-to] - CD	[0-0.2[	[0.2-0.4[	[0.4-0.6[	[0.6-0.8[	[0.8-1[	[1-1.2[	[1.2-1.4[	[1.4-1.6[	Total	Accum
[292.5-337.5[	1.166	0.618	-	-	-	-	-	-	1.783	100.000
[247.5-292.5[	1.453	2.535	0.882	0.092	0.000	-	-	-	4.962	98.217
[202.5-247.5[	1.631	4.526	10.038	16.251	13.708	3.828	0.232	-	50.214	93.254
[157.5-202.5[	0.574	0.287	0.105	0.013	-	-	-	-	0.978	43.040
[112.5-157.5[	0.411	-	-	-	-	-	-	-	0.411	42.062
[67.5-112.5[	1.598	3.304	5.141	7.455	7.254	4.949	2.334	0.311	32.347	41.651
[22.5-67.5[	0.817	1.963	2.029	1.648	0.755	0.034	-	-	7.246	9.304
[-22.5-22.5[	1.018	1.025	0.015	-	-	-	-	-	2.058	2.058
Total	8.668	14.258	18.211	25.459	21.717	8.811	2.566	0.311	100.000	-
Accum	8.668	22.927	41.137	66.596	88.313	97.124	99.689	100.000	-	-

5.2.4 Waves

The wave climate in Singapore waters is dominated by locally generated wind waves and swell of low amplitude entering the Singapore Straits, primarily from the South China Sea for eastern Singapore and the Malacca Straits for western side. While no wave measurements are available within the vicinity of the Project area, long-term hindcast wave modelling has been conducted as part of the MetOcean Study /1/, providing wave estimates at the Project area.

Annual wave rose and the corresponding occurrence table at the Project site are presented in Figure 5.6 and Table 5.4. Scatter diagram of significant wave height (H_{m0}) versus peak wave period (T_p) at the extraction point are given in Figure 5.7. The corresponding occurrence tables are provided in Table 5.5.

The wave rose indicates that the study area is dominated by the south-westerly waves (occurring approximately 24 % of the time) followed by the north-easterly waves. Strongest waves are coming from southwest sector with the magnitude of the significant wave height is up to 1.6m. Figure 5.7 and Table 5.5 indicate that the waves are dominated by the wind waves with small portion of swell waves with lower amplitude.

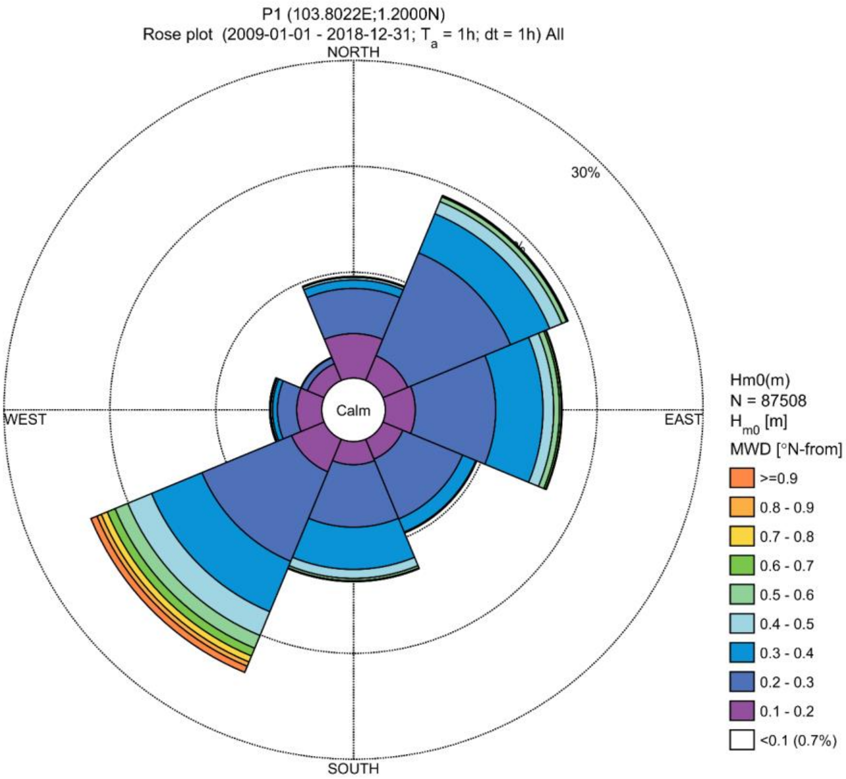
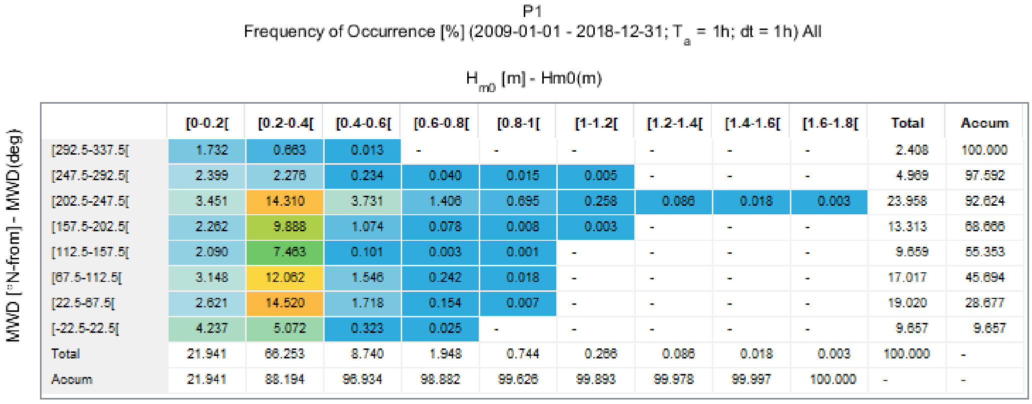


Figure 5.6 Wave rose at the Project site (direction: coming from)

Table 5.4 Occurrence table of significant wave height (H_{m0}) and mean wave direction (MWD) at the Project site



P1
Frequency of Occurrence [%] (2009-01-01 - 2018-12-31; T_a = 1h; dt = 1h) All

H_{m0} [m] - Hm0(m)

MWD [°N-from] - MWD(deg)

	[0-0.2[	[0.2-0.4[	[0.4-0.6[	[0.6-0.8[	[0.8-1[	[1-1.2[	[1.2-1.4[	[1.4-1.6[	[1.6-1.8[	Total	Accum
[292.5-337.5[	1.732	0.663	0.013	-	-	-	-	-	-	2.408	100.000
[247.5-292.5[	2.399	2.276	0.234	0.040	0.015	0.005	-	-	-	4.969	97.592
[202.5-247.5[	3.451	14.310	3.731	1.406	0.695	0.258	0.086	0.018	0.003	23.958	92.624
[157.5-202.5[	2.262	9.888	1.074	0.078	0.008	0.003	-	-	-	13.313	68.666
[112.5-157.5[	2.090	7.463	0.101	0.003	0.001	-	-	-	-	9.659	55.353
[67.5-112.5[	3.148	12.062	1.546	0.242	0.018	-	-	-	-	17.017	45.694
[22.5-67.5[	2.621	14.520	1.718	0.154	0.007	-	-	-	-	19.020	28.677
[-22.5-22.5[	4.237	5.072	0.323	0.025	-	-	-	-	-	9.657	9.657
Total	21.941	66.253	8.740	1.948	0.744	0.266	0.086	0.018	0.003	100.000	-
Accum	21.941	88.194	96.934	98.882	99.626	99.893	99.978	99.997	100.000	-	-

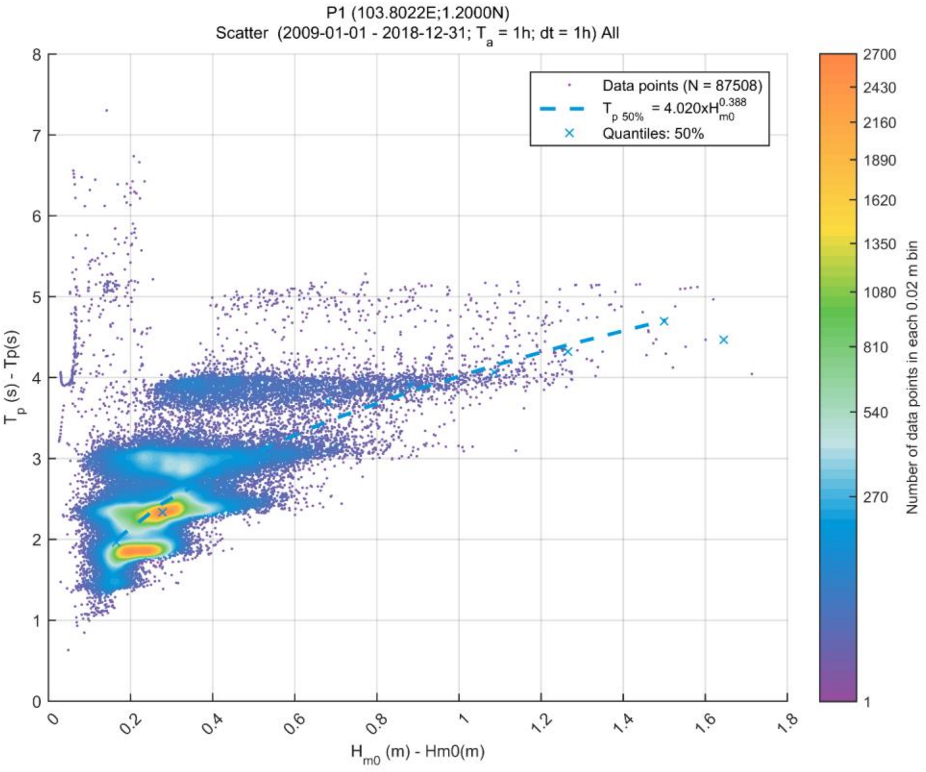
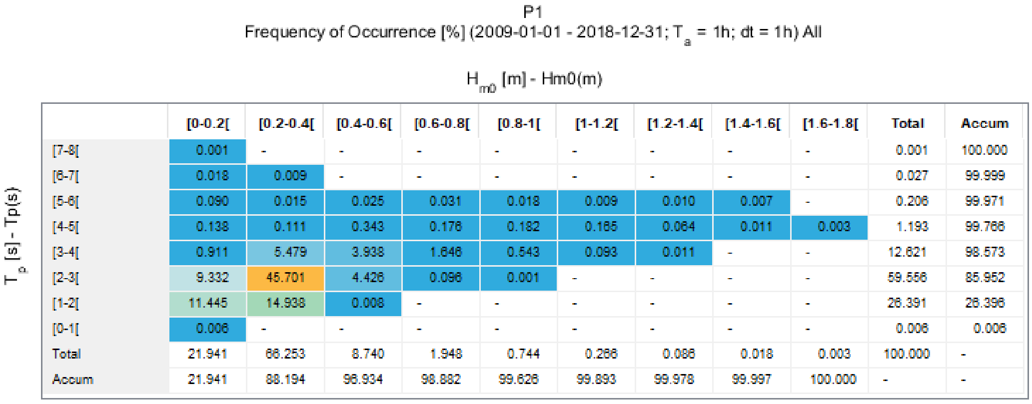


Figure 5.7 Scatter plot of H_{m0} versus T_p at the Project site. X-axis represents the significant wave height (H_{m0}) and y-axis represents the peak wave period (T_p)

Table 5.5 Occurrence table of significant wave height (H_{m0}) and peak wave period (T_p) at Project site



P1

Frequency of Occurrence [%] (2009-01-01 - 2018-12-31; T_a = 1h; dt = 1h) All

H_{m0} [m] - Hm0(m)

T_p [s] - Tp(s)	[0-0.2[	[0.2-0.4[	[0.4-0.6[	[0.6-0.8[	[0.8-1[	[1-1.2[	[1.2-1.4[	[1.4-1.6[	[1.6-1.8[	Total	Accum
[7-8[	0.001	-	-	-	-	-	-	-	-	0.001	100.000
[6-7[	0.018	0.009	-	-	-	-	-	-	-	0.027	99.999
[5-6[	0.090	0.015	0.025	0.031	0.018	0.009	0.010	0.007	-	0.206	99.971
[4-5[	0.138	0.111	0.343	0.176	0.182	0.165	0.064	0.011	0.003	1.193	99.766
[3-4[	0.911	5.479	3.938	1.646	0.543	0.093	0.011	-	-	12.621	98.573
[2-3[	9.332	45.701	4.426	0.096	0.001	-	-	-	-	59.556	85.952
[1-2[	11.445	14.938	0.008	-	-	-	-	-	-	26.391	26.396
[0-1[	0.006	-	-	-	-	-	-	-	-	0.006	0.006
Total	21.941	66.253	8.740	1.948	0.744	0.266	0.086	0.018	0.003	100.000	-
Accum	21.941	88.194	96.934	98.882	99.626	99.893	99.978	99.997	100.000	-	-

5.3 Water Quality

A one-off in situ and ex situ water quality sampling was carried out at one location as shown in Figure 5.8. Sampling was conducted on 12 August 2022, during both flood and ebb tide. In-situ measurements was throughout the water column at one-meter interval from surface to one-meter above the seabed, whereas water samples were collected at 1 m below water surface.

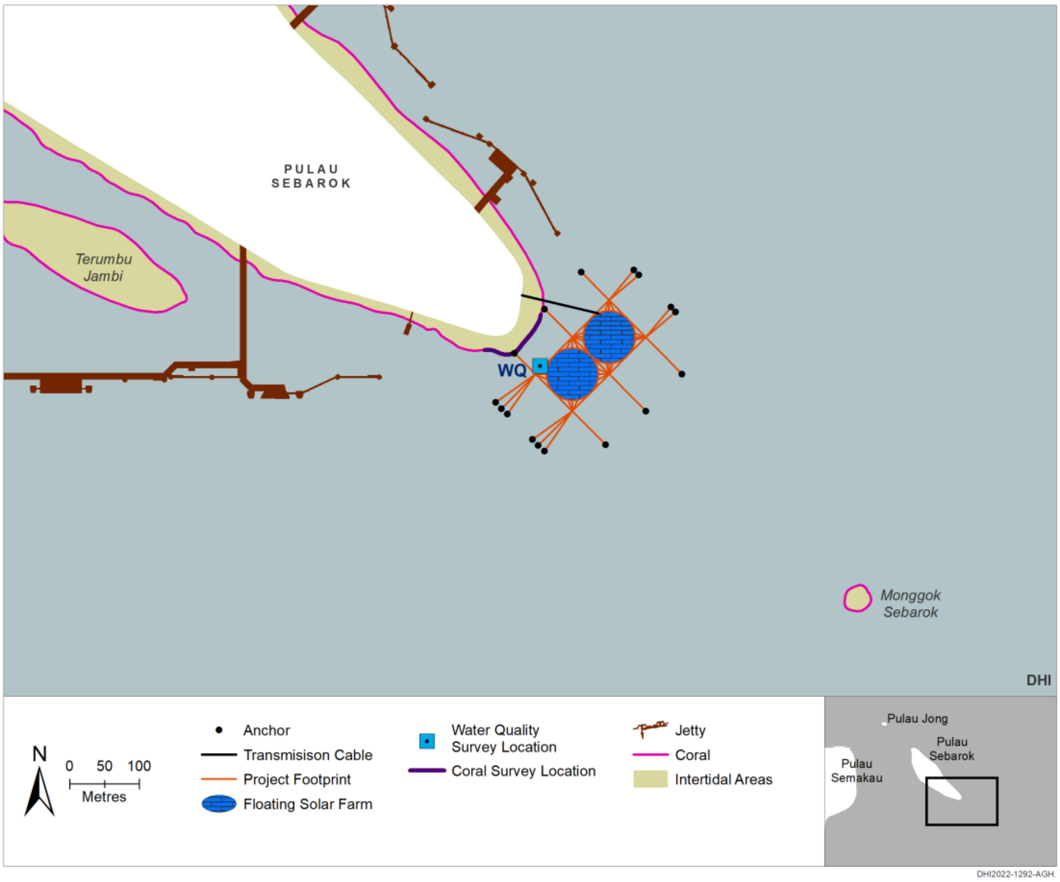


Figure 5.8 Water sampling location.

5.3.1 In-situ Measurements

Temperature readings taken at one meter intervals throughout the water column in the water quality station during flood and ebb tides ranged from 29.80 – 29.97 ˚C with the highest temperature readings during flood is 29.97˚C and during ebb is 29.90˚C. Salinity ranged from 29.62 psu – 29.95 psu with highest reading during flood is 29.64 psu and during ebb is 29.95 psu. pH is a measure of the acidity or alkalinity in an aqueous solution. pH measurements taken during flood and ebb tide ranged from 8.03 – 8.05 with highest values of 8.04 during flood and 8.05 for ebb tide.

Dissolved oxygen (DO) is the amount of gaseous oxygen in water which is a direct indicator of water's ability to support life. The DO measurements ranged from 5.80 mg/L – 5.95 mg/L with minimum values of 5.81 mg/L recorded during flood tide and 5.80 mg/L recorded during ebb tide. DO measurements are above the ASEAN MWQC limit of 4 mg/L indicating acceptable water quality with respect to DO.

Secchi disc depth and turbidity readings provide an indication on the water clarity in the baseline assessment. A large value of Secchi disc depth translates to a higher water clarity and lower turbidity indicates poor water clarity. Secchi depth values ranged from 2.3 m – 3.0 m. Turbidity values ranged from 0.95 NTU – 2.52 NTU and maximum values were 1.56 NTU and 2.52 NTU. Neither measurement has an ASEAN MWQC or international guideline however, both results indicate that the waters in the area are generally clear, with high visibility.

The baseline values presented here follow similar trends as water quality samples collected around Pulau Semakau in 2019 (DHI, 2020). For the previous study ten sampling locations were used to collect baseline water quality. A brief summary of the results are as follows:

- Temperature range: 28.7 ˚C – 29.0 ˚C
- Salinity range: 32.0 psu – 32.1 psu
- pH range: 8.15 – 8.18
- Dissolved oxygen range: 6.08 mg/L – 6.29 mg/L
- Turbidity range: 1.14 NTU – 6.05 NTU
- Secchi depth range: 2.6m – 4.5m

Water quality values from the previous 2020 EIA and the current Project are comparable though not identical. In particular the Secchi depth, turbidity and DO maximum values are lower in the present study relative to the previous EIA (DHI, 2020).

5.3.2 Ex-situ Results

The laboratory results for the water samples collected during flood and ebb tides at the surface and bottom depths are presented in Table 5.6. In general, the water quality in areas within Project site is relatively good as indicated by concentrations of nutrients that fall within the ASEAN MWQC limit. Total suspended sediment (TSS) concentrations in the Project site are also low with concentration around 6.1 – 6.10 mg/L during flood and 8.20 – 8.5 mg/L during ebb tide.

Table 5.6 Laboratory analysis results

Test Parameter	Unit	WQ01 Flood (Surface)	WQ01 Flood (Bottom)	WQ01 Ebb (Surface)	WQ01 Ebb (Bottom)	ASEAN MWQC
Total Ammoniacal as NH_3-N + NH_4-N	mg/L	<0.01	0.018	0.020	0.015	<0.07
Nitrate as NO_3-N	mg/L	0.050	0.049	0.048	0.047	<0.06
Nitrite as NO_2-N	mg/L	0.013	0.010	0.014	0.010	<0.055
Phosphate as PO_4-P	mg/L	<0.01	<0.01	<0.01	<0.01	<0.015
Total Phosphorus as TP	mg/L	0.018	0.028	0.025	0.027	0.1*
Total Nitrogen as TN	mg/L	0.27	0.28	0.11	0.15	1.5*
Oil & Grease by FTIR	mg/L	<0.1	<0.1	0.11	<0.1	<0.14
Chlorophyll-a	µg/L	0.35	0.40	0.37	0.25	-
Total Suspended Solids as TSS	mg/L	6.10	6.60	8.50	8.20	≤10% increase over seasonal average concentration

Note: * EU Water Framework Directive 75/440/EEC

5.4 Seabed Condition

Spot verification was carried out to establish the seabed condition within the study area, as shown in Figure 5.9. In general, the seabed condition showed mixture of coral rubbles and rocky substrates at all three observation locations (Figure 5.10).

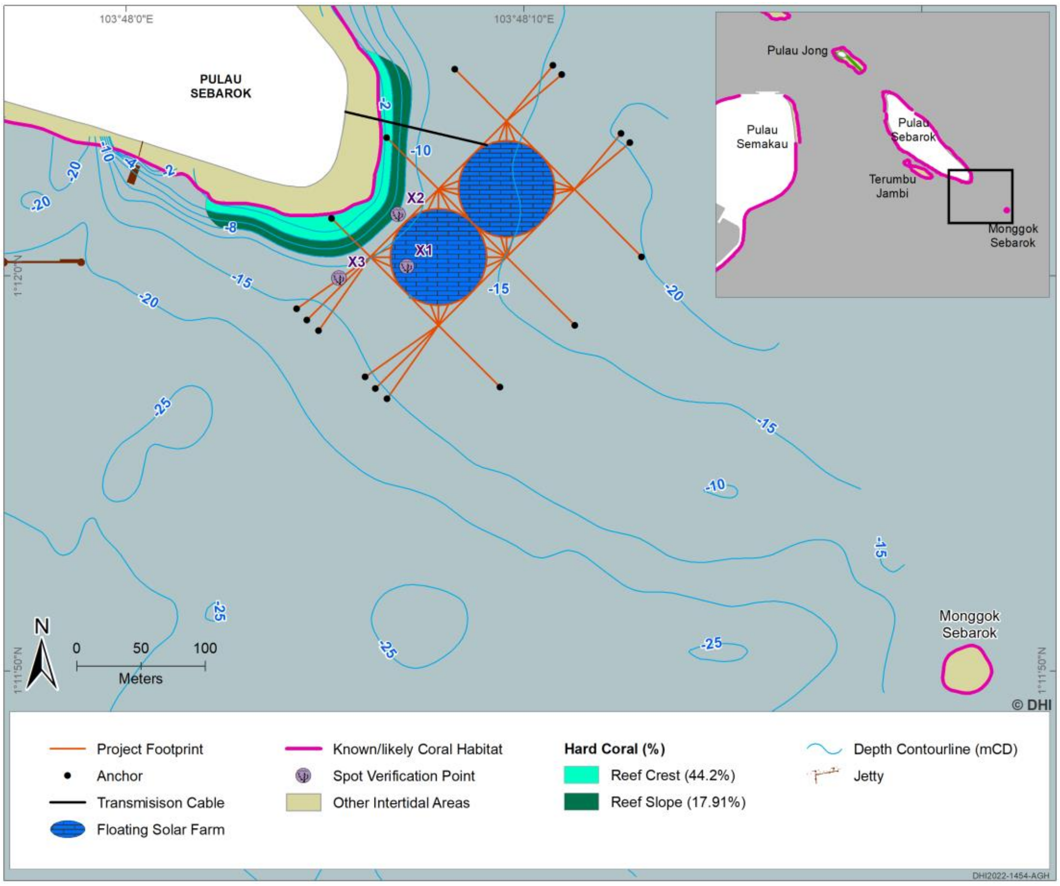


Figure 5.9 Seabed verification carried out within the study area.

Figure 5.10 Seabed condition observed on the Project area around the lower reef area.

5.5 Ecology and Biodiversity

This section describes the findings from the ecological baseline surveys at Sebarok island.

5.5.1 Corals

A coral survey was conducted at the southern tip of Pulau Sebarok as shown in Figure 5.11 on 19 August 2022. During the surveys, it was found that the reef was generally limited to the shallow areas fringing Pulau Sebarok, and hard coral communities were observed growing along the reef crest and reef slope. Beyond this, the lower reef zone was characterised by gorgonians, ahermatypic corals, sponges and other associated heterotrophs. A summary of the results for each zone is presented in the following sections. Detailed survey information, methods, and data are further presented in the Appendix A of this report.

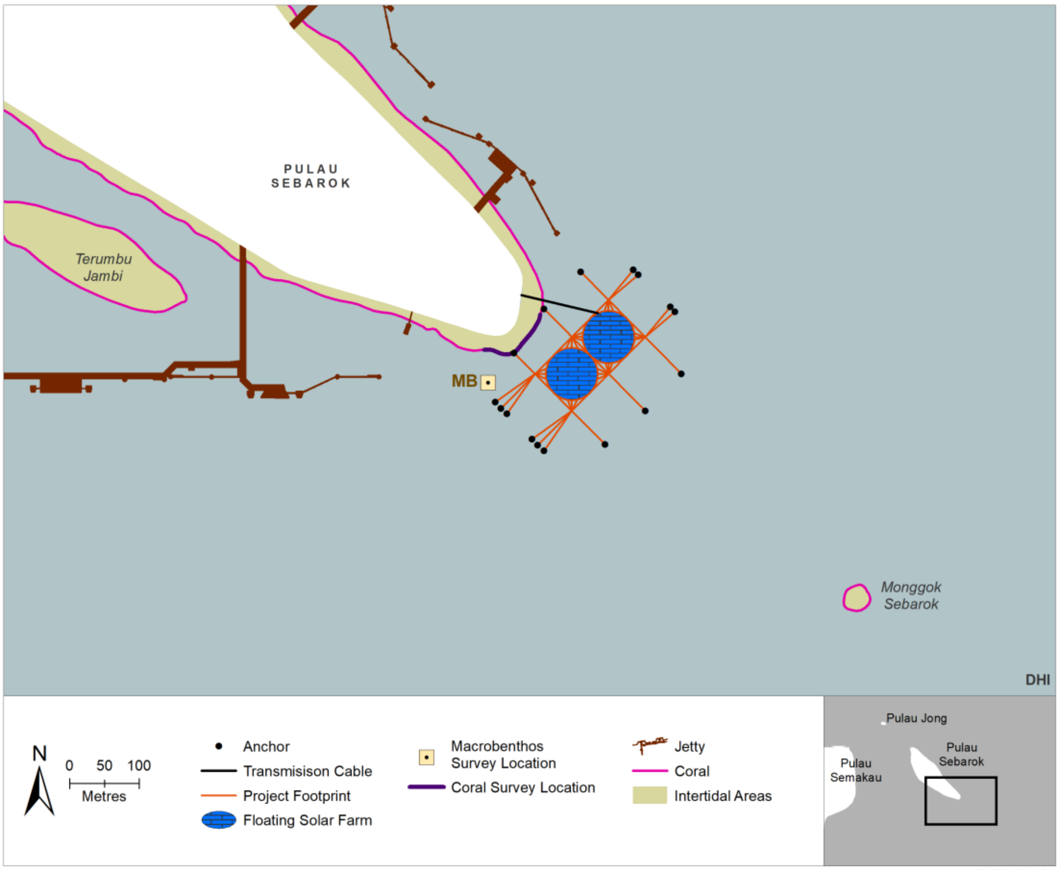


Figure 5.11 Ecological survey area

Figure 5.12 presents the coral reef distribution and percentage (%) of live hard coral cover in the area extrapolated from the findings and survey observation. The reef crest where corals are most diverse and abundant has a percentage of live hard coral cover of up to 44.2% and followed by 17.91% at the reef slope area. Lower reef area mainly comprised of consolidated substrate whereby corals such as hard corals, sea fans, black corals, bryozoans and whip corals were less commonly observed.

Detailed description of the coral condition such as diversity and abundance at reef crest, reef slope and lower reef area are presented in the following subsections.

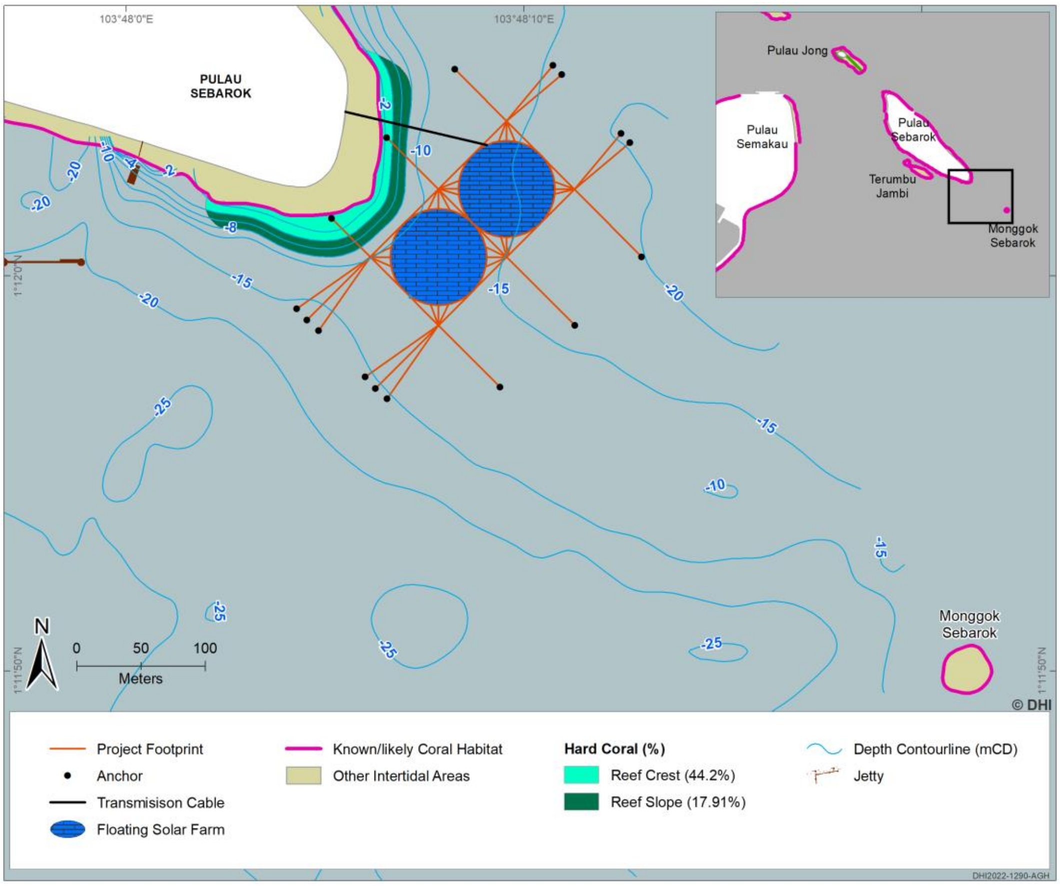


Figure 5.12 Percentage of live hard coral cover

5.5.1.1 Reef Crest

Substrate Composition

The subtidal environment at the reef crest consists of a manmade rock revetment, on which a healthy and diverse coral reef has established itself. During the Line Intercept Transect (LIT) survey of the reef crest, hard coral was the dominant benthic category, with a percentage cover of 44.20 % ± 8.57 (SE) (Figure 5.13).

Sponge was the second most dominant live benthic category, making up 5.16 % ± 0.69 (SE) cover (Figure 5.13). Other fauna, mainly zoanthids and anemones, had a percentage cover of 2.76 % ± 1.59 (SE). Soft coral made up 1.53 % ± 1.03 (SE) cover (Figure 5.13), and was comprised of *Dendronephthya* spp., *Sarcophyton* spp., *Lobophytum* spp. And *Sinularia* spp. There was also a low percentage of macroalgae (0.87 % ± 0.40 (SE)) (Figure 5.13),

Among the non-living benthic categories recorded at the reef crest, rubble was the most dominant (23.03 % ± 7.53 (SE)), followed by dead coral (21.59 % ± 4.07 (SE)) and less than 1% of rock, sand and silt combined.

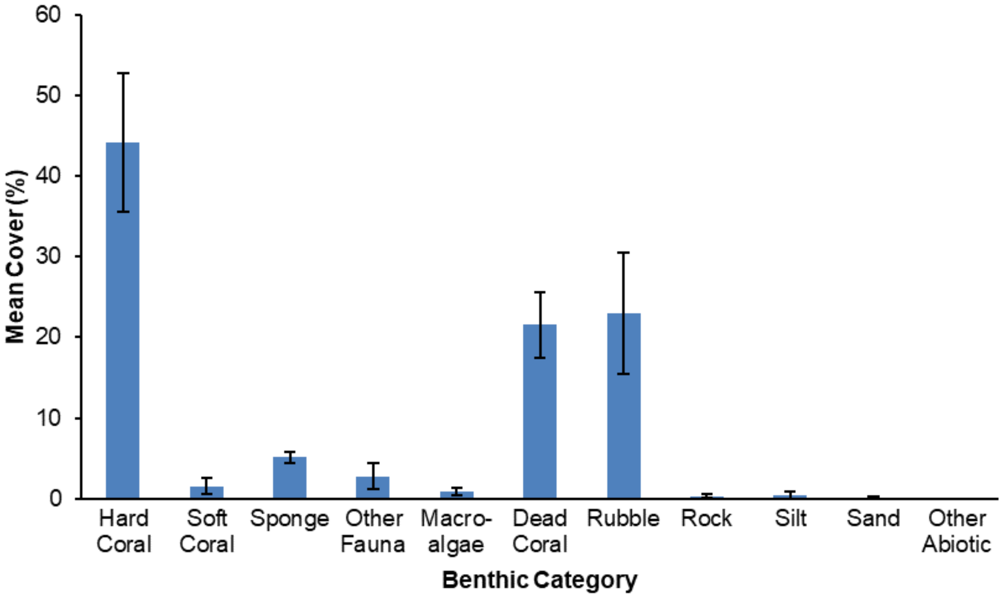


Figure 5.13 Mean percentage cover (%) and standard error (± SE) of benthic categories recorded during the LIT survey at the reef crest

Hard Coral Growth Forms

Coral growth forms reflect the life history strategy of a colony, and the same species of coral can exhibit different growth forms in their lifetime or under different environmental conditions (Todd, 2008). Therefore, different sites may be characterised by different growth form compositions, depending on abiotic parameters.

During the survey of the reef crest, foliose corals were the most dominant hard coral growth form, making up 20.24 % ± 5.00 (SE) % of cover observed (Figure 5.14). Submassive, massive, branching and encrusting hard coral growth forms accounted for 8.07 % ± 2.89 (SE), 5.19 % ± 1.52 (SE), 4.97 % ± 1.92 (SE), 4.44 % ± 1.54 (SE) cover respectively (Figure 5.14). There were small percentages of branching *Acropora* (1.09 % ± 0.78 (SE)) and mushroom corals (0.20 % ± 0.20 (SE)) also observed within the transects (Figure 5.14).

In total, there were seven hard coral growth forms observed during the reef crest survey. Foliose corals were by far the dominant growth form at the reef crest (Figure 5.14), and their dominance is expected as Singapore's reefs tend to be dominated primarily by these fast-growing hard corals (Chua and Chou, 1991; Goh and Chou, 1993).

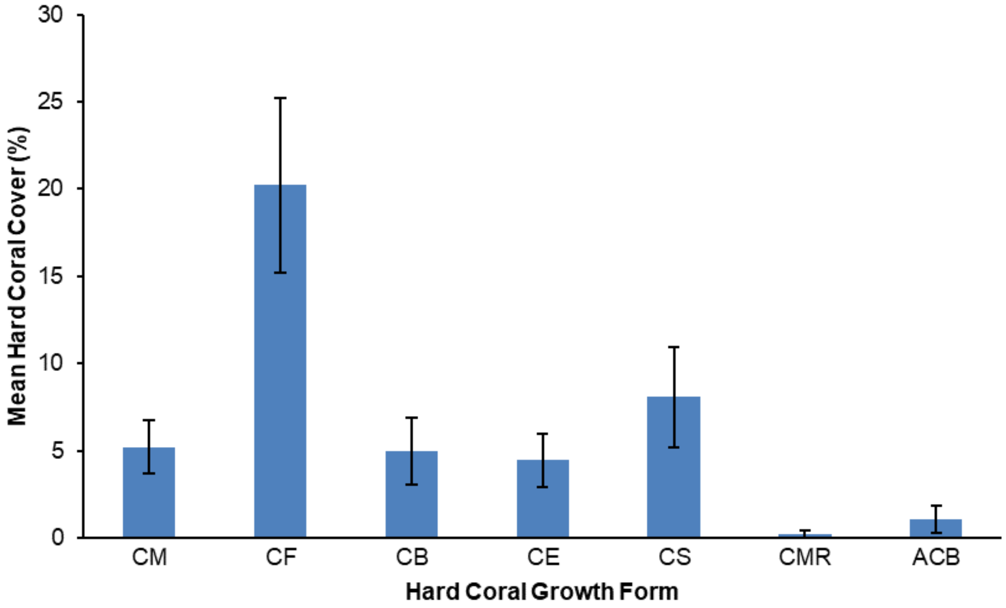


Figure 5.14 Mean percentage hard coral cover (%) and standard error (± SE) of hard coral growth forms recorded during the LIT survey at the reef crest (CM: Massive Coral; CF: Foliose Coral; CB: Branching Coral; CE: Encrusting Coral; CS: Submassive Coral; CMR: Mushroom Coral; ACB: *Acropora* Branching Coral)

Hard Coral Size

The size of hard corals provides an indication for the age of the colony, as their diameter increases progressively with age. Larger colonies also contribute disproportionately more to coral reproduction (Hall and Hughes, 1996). As such, size class distributions can reveal the general age of a coral community while differences in distribution suggest corresponding differences in reproductive output. The modal size class recorded at the time of the survey was size class 4 (25 – 50 cm in diameter), which made up to a total of 32.65 % ± 0.46 (SE), % of colonies (Figure 5.15). Most hard coral colonies were from size classes 3 – 6 (10 – 100 cm), making up 83.67 % of all hard corals. In addition, 16.33 % ± 0.59 (SE) of recorded colonies were in size class 7 (>100 cm). The largest size class 7 corals were of the genera *Porites*, *Heliopora*, *Pachyseris*, *Montipora*, and *Hydnophora.*

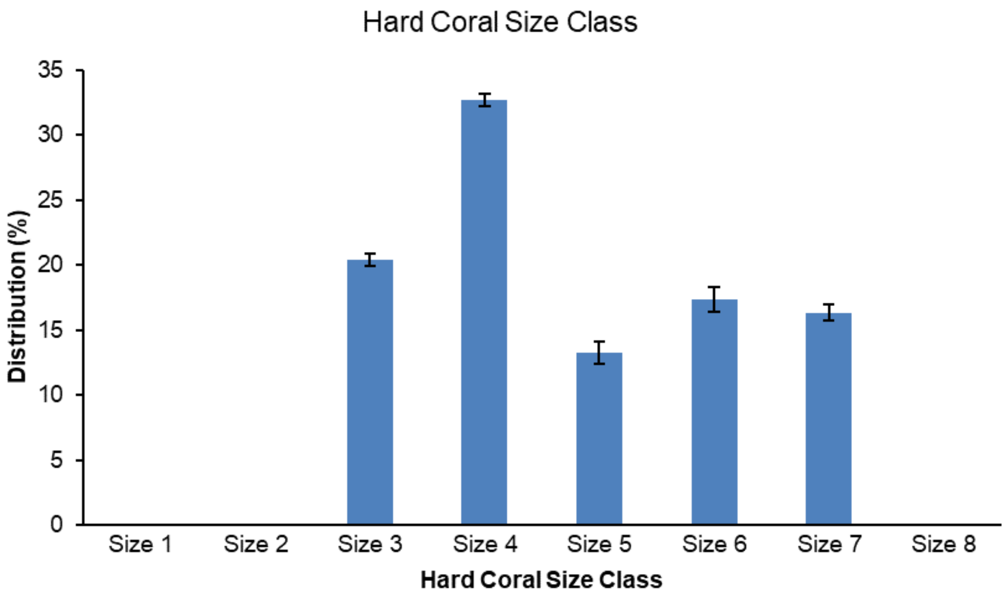


Figure 5.15 Distribution (%) and standard error (± SE) of hard coral size classes recorded during the LIT survey at the reef crest

Coral Diversity

For the reef crest a total of 98 hard coral colonies from 24 genera were recorded. *Heliopora* spp. was the most common genus by occurrence (20 colonies), while *Montipora* spp. was the most common genus by percentage cover (17.65 % of hard coral cover). Furthermore, an additional 10 hard coral genera were also observed in the vicinity of the survey transects along the reef crest.

Table 5.7 Hard coral diversity summary for all live hard corals recorded during the LIT survey at the reef crest

Hard Coral Diversity Summary	
Total Hard Coral Percentage Cover	44.20
Total Number of Genera	24
Total Number of Colonies	98
Most Common Genus (By Occurrence)	*Heliopora*
Occurrence	20
Most Common Genus (By Percentage Cover)	*Montipora*
Percentage Cover	17.65

Overview of the reef environment at the reef crest

Heliopora spp., most common hard coral genus by occurrence at the reef crest

Large stand of branching coral, *Acropora* sp.

Montipora spp., most common hard coral genus by percentage cover at the reef crest

School of parrotfish foraging along the reef crest

A

large hard coral bommy, *Porites* sp.

Large anemone with family of clown anemonefish, *Amphiprion ocellaris* (VU)

Egg case of a shark or ray

Figure 5.16 Representative photos from the LIT survey at the reef crest

5.5.1.2 Reef Slope

Substrate Composition

The subtidal environment at the reef slope was characterised by a steeply sloping reef, with patches of hard coral bommies and dead coral interspersed with stretches of loose rubble. During the LIT survey of the reef slope, it was found that among the living benthic categories, hard coral was the most dominant benthic category, with a percentage cover of 17.91 % ± 2.69 (SE) (Figure 5.17).

The macroalgal component comprised of coralline algae, making up 1.72 % ± 0.90 (SE) cover, while other benthic fauna, comprised of zoanthids, sea fans, sea whips, corallimorphs and a sea star, made up 1.37 % ± 1.16 (SE) cover (Figure 5.17). Soft coral made up 0.50 % ± 0.50 (SE) cover (Figure 5.17), and was comprised of *Sarcophyton* spp.

Among the non-living benthic categories recorded at the reef slope, rubble was the most dominant (53.60 % ± 5.07 (SE)), followed by dead coral (20.08 % ± 3.05 (SE)), sand (3.82 % ± 1.42 (SE)), and rock (0.66 % ± 0.66 (SE) (Figure 5.17).

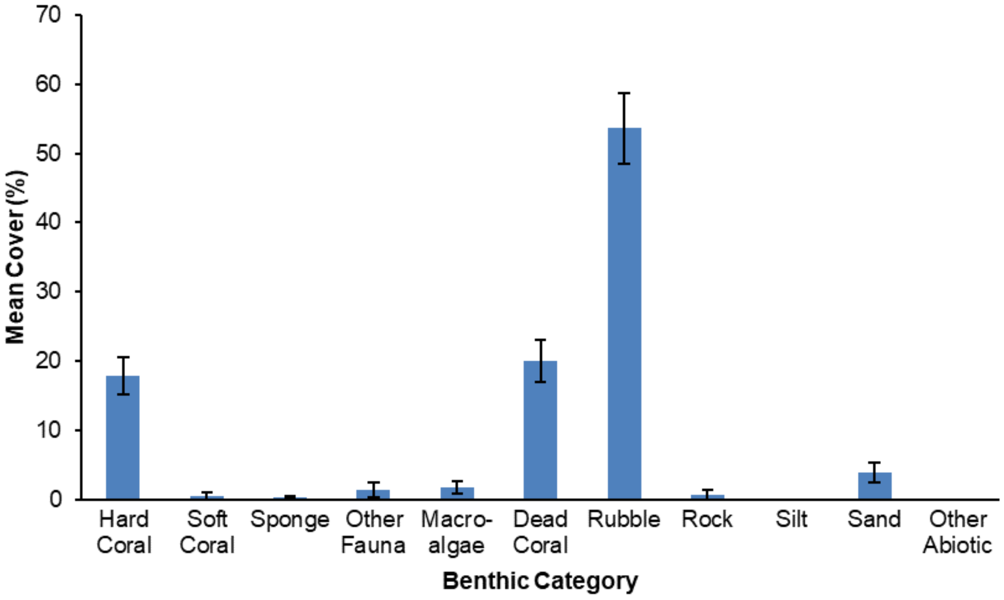


Figure 5.17 Mean percentage cover (%) and standard error (± SE) of benthic categories recorded during the LIT survey at the reef slope

Hard Coral Growth Forms

During the survey of the reef slope, encrusting corals were the dominant hard coral growth form observed, making up 6.56 % ± 1.42 (SE) % of cover observed (Figure 5.16). Massive, submassive, foliose and mushroom hard coral growth forms accounted for 4.51 % ± 2.19 (SE), 3.14 % ± 1.36 (SE), 2.64 % ± 1.25 (SE) and 1.06 % ± 0.87 (SE) cover respectively (Figure 5.16). In total, there were five hard coral growth forms observed during the reef slope survey.

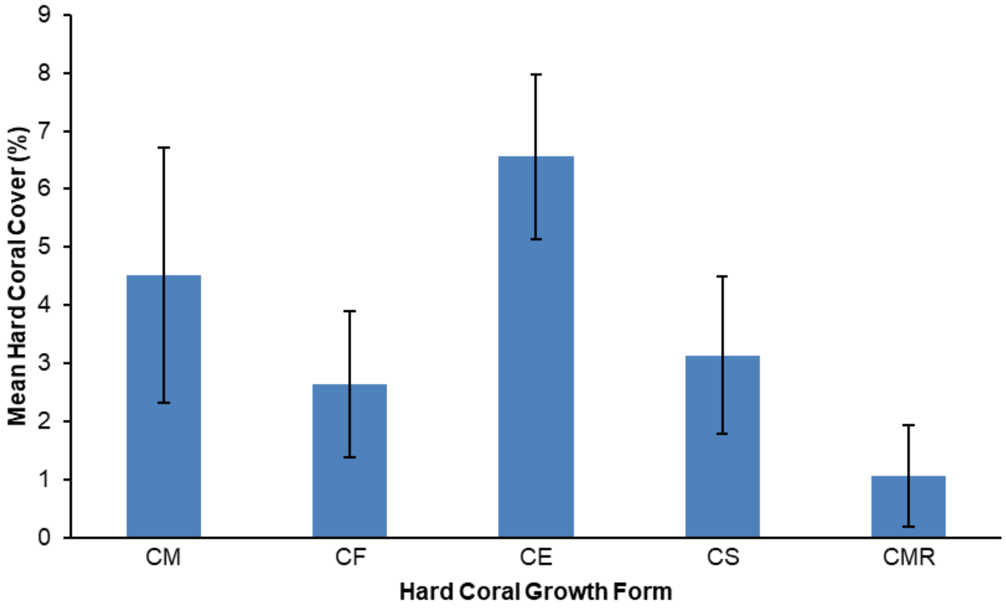


Figure 5.18 Mean percentage cover (%) and standard error (± SE) of hard coral growth forms recorded during the LIT survey at the reef slope (CM: Massive Coral; CF: Foliose Coral; CB: Branching Coral; CE: Encrusting Coral; CS: Submassive Coral; CMR: Mushroom Coral; ACB: *Acropora* Branching Coral)

Hard Coral Size

At the time of the reef slope survey, the modal size class was size class 4 (25 – 50 cm in diameter), which made up to a total of 48.33 % ± 1.31 (SE), % of colonies (Table 5.8). Most hard coral colonies were from size classes 3 – 4 (10 – 50 cm), making up 81.67 % of all hard corals. In addition, 5.00 % ± 0.36 (SE) of recorded colonies were in size class 6 (75-100 cm), and 5.00 % ± 0.36 (SE) of recorded colonies were in size class 7 (>100 cm). These large size class 6 and 7 corals were of the genera *Heliopora*, *Leptastrea, Montipora*, *Astreopora* and *Oxypora.*

Table 5.8 Size class distributions for all live hard corals recorded during the LIT survey at the reef slope

Hard Coral Size Class	No. of Colonies	%	SE
Size 1 (<5cm)	0	0.00	0.00
Size 2 (5-10cm)	1	1.67	0.18
Size 3 (10-25cm)	20	33.33	0.75
Size 4 (25-50cm)	29	48.33	1.31
Size 5 (50-75cm)	4	6.67	0.33
Size 6 (75-100cm)	3	5.00	0.36
Size 7 (>100cm)	3	5.00	0.36
Size 8 (Stand >100cm)	0	0.00	0.00

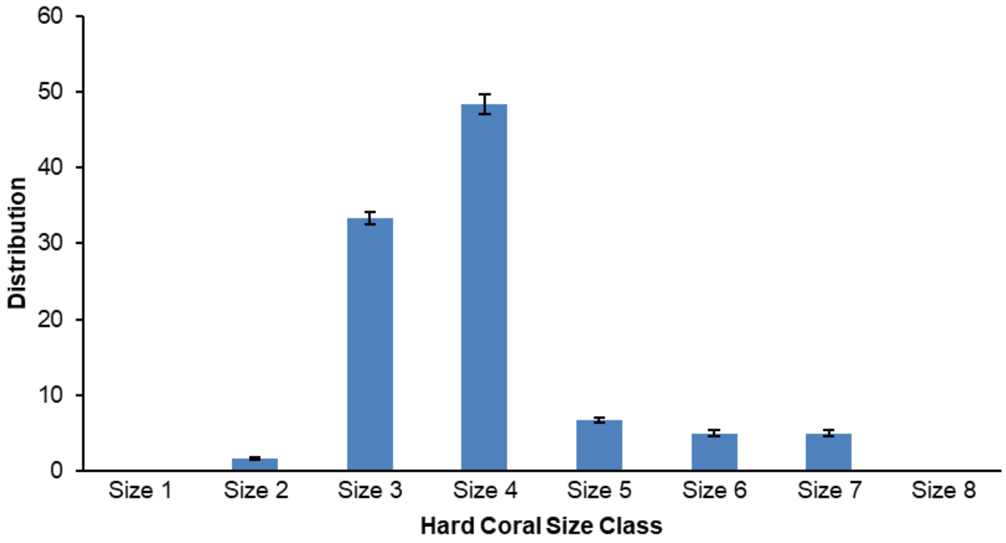


Figure 5.19 Distribution (%) and standard error (± SE) of hard coral size classes recorded during the LIT survey at the reef slope

Coral Diversity

For the reef crest a total of 60 hard coral colonies from 22 genera were recorded. *Favites* spp. was the most common genus by occurrence (10 colonies), as well as by percentage cover (12.90 % of hard coral cover). Furthermore, an additional 16 hard coral genera were also observed in the vicinity of the survey transects along the reef slope.

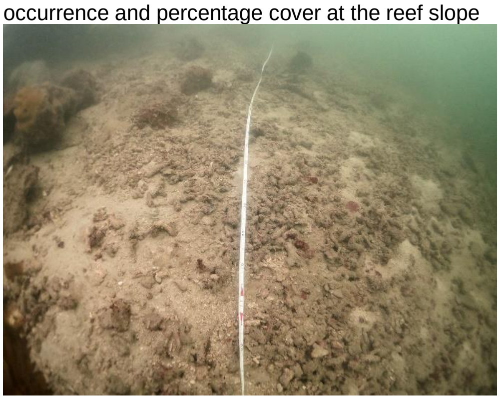
Table 5.9 Hard coral diversity summary for all live hard corals recorded during the LIT survey at the reef slope

Hard Coral Diversity Summary	
Total Hard Coral Percentage Cover	17.91
Total Number of Genera	22
Total Number of Colonies	60
Most Common Genus (By Occurrence)	*Favites*
Occurrence	10
Most Common Genus (By Percentage Cover)	*Favites*
Percentage Cover	12.90

Overview of the reef environment at the reef slope

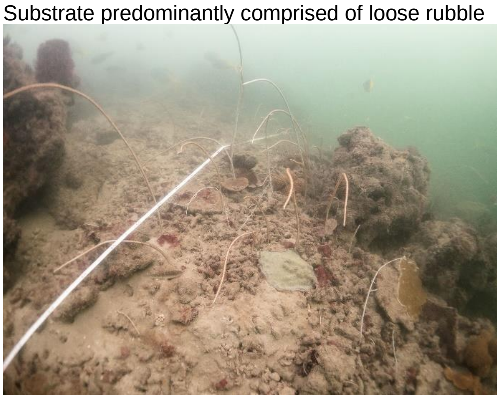
Favites spp., most common hard coral genus by occurrence and percentage cover at the reef slope

Submassive coral, *Madracis* sp.



Substrate predominantly comprised of loose rubble

Large sea fan on the reef slope



Sea whips, *Junceella* spp.

Sixbar angelfish, *Pomacanthus sexstriatus*

Longfin batfish, *Platax teira*

Figure 5.20 Representative photos from the LIT survey at the reef slope

5.5.1.3 Lower Reef

The lower reef was surveyed utilising a horizontal visual quadrat transect as opposed to the LIT method used for the reef crest and slope. The horizontal visual quadrat transect is better suited for areas where the dominant growth forms are organisms such as gorgonians and sponges, etc.

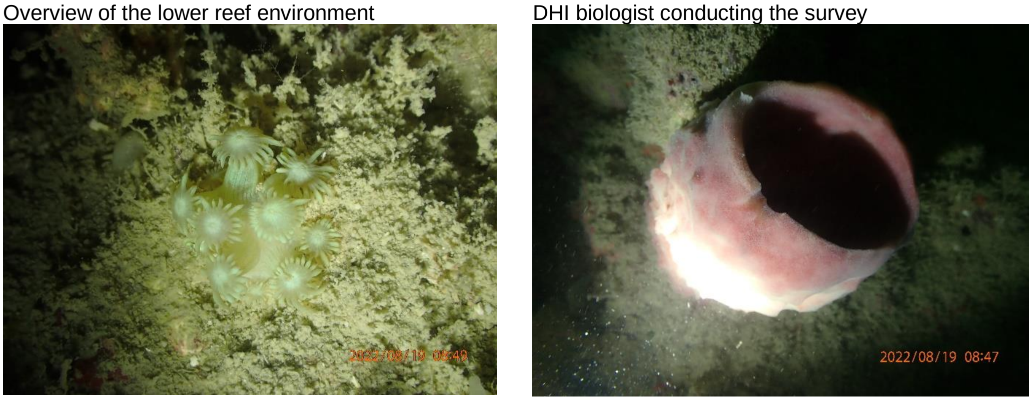
Results showed a partially consolidated (32.22 % ± 5.93 (SE)) substrate with a mean target organism density of 5.22 ± 2.98 (SE) individuals m^{-2}. Sponges (2.17 ± 0.45 (SE) individuals m^{-2}), ahermatypic corals (1.50 ± 0.44 (SE) individuals m^{-2}) and ascidians (0.61 ± 0.18 (SE) individuals m^{-2}) accounted for more than 80% of the target individuals recorded. Hard corals, sea fans, black corals, bryozoans, and whip corals were less commonly observed, with mean densities under 0.4 individuals m^{-2} (Table 5.12).

Table 5.10 Mean abundance and standard error for each target organism group recorded during the HVQT surveys at Pulau Sebarok

Benthos	**Density (individuals/m^2)**	
	Mean	**SE**
Sea Fan	0.22	0.17
Whip Coral	0.11	0.08
Black Coral	0.11	0.08
Soft Coral	0.00	0.00
Hard Coral	0.39	0.16
Ahermatypic Coral	1.50	0.44
Sponge	2.17	0.45
Ascidian	0.61	0.18
Bryozoan	0.11	0.08
Substrate Consolidation	**Cover (%)**	
	Mean	**SE**
Total consolidation	**32.22**	**5.93**

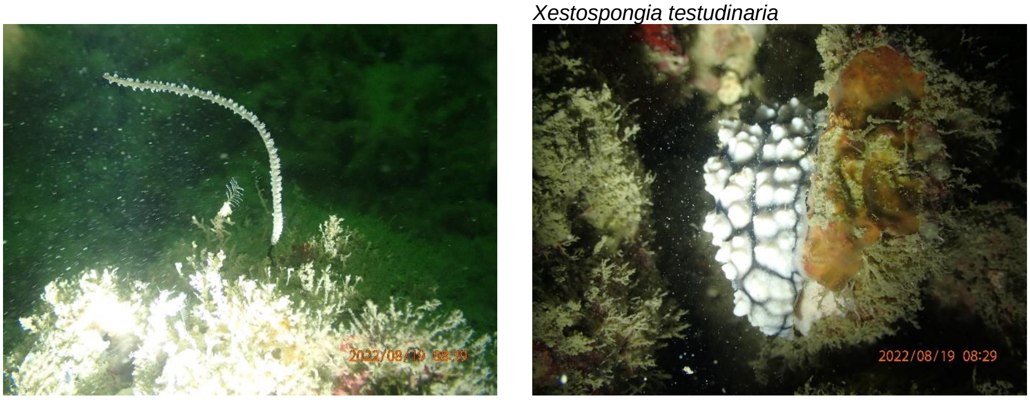
Overview of the lower reef environment

DHI biologist conducting the survey



Submassive hard coral, *Goniopora* sp.

Barrel sponge,
Xestospongia testudinaria



Sea whip, *Cirrhipathes* sp.

Pimply nudibranch,
Phyllidiella pustulosa

Figure 5.21 Representative photos during HVQT surveys at the lower reef

5.5.1.4 Species of Concern

Table 5.11 lists all species encountered during the coral surveys which are listed in the Singapore Red Data Book (RDB) and have local conservation status. A full list of all encountered species is shown in Appendix A.

Table 5.11 List of all encountered species which are listed on the Singapore Red Data Book

No	Functional Group	Scientific Name	Common Name	Status*	Notes*
1	Hard Coral	*Acropora acuminata*	N/A	VU	RDB3
2	Hard Coral	*Fimbriaphyllia divisa*	Frogspawn Coral	VU	RDB3
3	Hard Coral	*Hydnophora grandis*	Spine Coral	NT	RDB3

No	Functional Group	Scientific Name	Common Name	Status*	Notes*
4	Hard Coral	*Montipora foliosa*	Cabbage Coral	NT	RDB3
5	Hard Coral	*Pavona cactus*	Cactus Coral	VU	RDB3
6	Hard Coral	*Pavona decussata*	Cactus Coral	NT	RDB3
7	Hard Coral	*Psammocora nierstraszi*	Boulder Sandpaper Coral	VU	RDB3
8	Fish	*Amphiprion frenatus*	Tomato Anemonefish	VU	RDB2
9	Fish	*Amphiprion ocellaris*	False Clown Anemonefish	VU	RDB2
10	Others	*Chicoreus ramosus*	Ramose Murex	EN	RDB2
11	Others	*Junceella gemmacea*	Sea Whip	EN	RDB2
12	Others	*Mauritia arabica*	Arabian Cowrie	VU	RDB2

*Note: VU – Vulnerable; NT – Near-Threatened; EN – Endangered; RDB3 – Red Data Book version 3; RDB2 – Red Data Book version 2.

5.5.2 Macrobenthos

A macrobenthos survey was conducted on 12 August 2022. The survey location is presented in Figure 5.22. Grab sampling was unsuccessful in the initial proposed location (i.e. Old MB) as the sample collected comprised mostly of coral rubbles and rocks. Spot verification was carried out to determine the seabed condition (Figure 5.23) before selecting the new location (New MB).

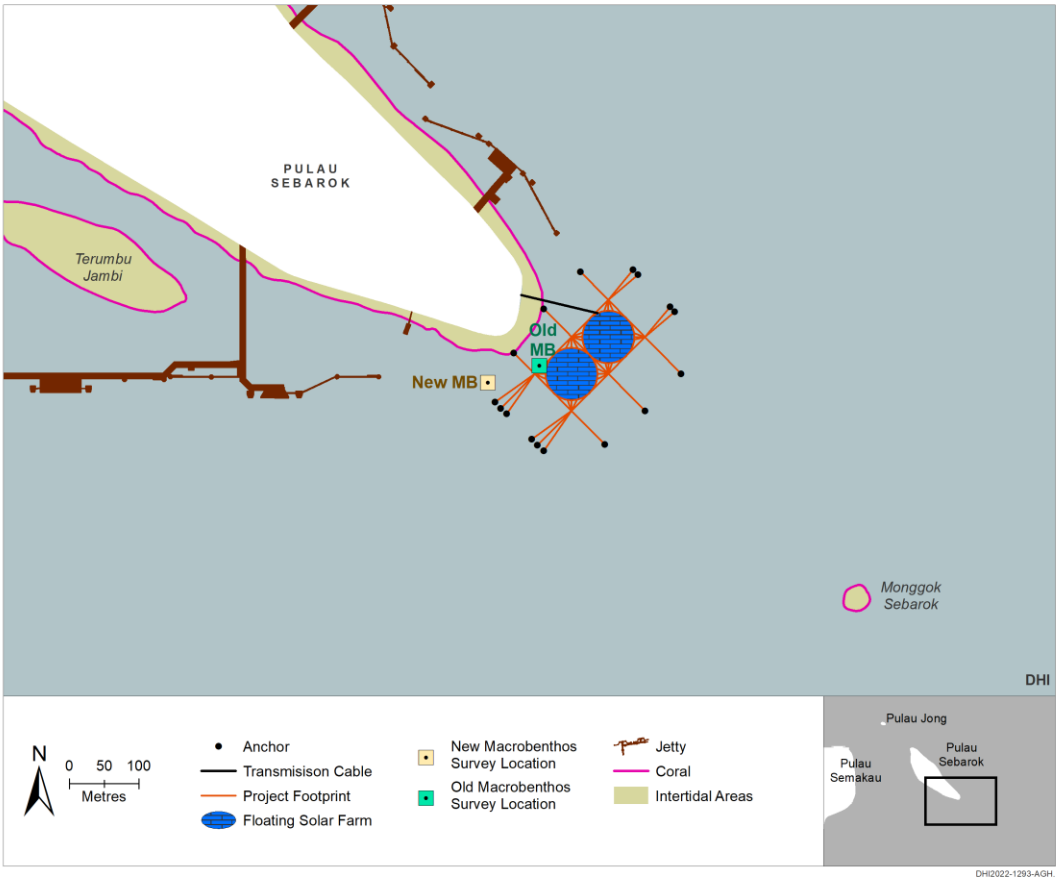


Figure 5.22 Macrobenthos survey location.

Figure 5.23 Mixture of coral rubbles and rocks collected at Old MB station.

A total of 95 individual organisms were recorded from the three grab samples at the sampling station. The mean density recorded was 502.65 individuals/m^2 ± 51.54 (SE). Nine taxonomic classes were observed, including Hydrozoa, Demospongiae, Ascidiacea, Anthozoa, Ophiuroidea, Maxillopoda, Bivalvia, Oligochaeta and Malacostraca. Out of these recorded classes, Hydrozoa was the most abundant with 243.39 individuals/m^2. The sediment collected from the sampling station consisted of rubble and was collected at a depth of 15 m at the time of the survey.

Table 5.3 Mean density distribution across the taxonomic classes at the sampling station

Taxonomic Class	Mean Density (individuals/m^2)
Demospongiae	158.73
Hydrozoa	243.39
Maxillopoda	10.58
Anthozoa	21.16
Ascidiacea	37.04
Ophiuroidea	15.87
Bivalvia	5.29
Oligochaeta	5.29
Malacostraca	5.29
Mean Total	**502.65**
Total Standard Error	**51.54**

Demospongiae

Hydrozoa

Maxillopoda

Anthozoa

Ascidiacea

Ophiuroidea

Bivalvia

Oligochaeta

Malacostraca

Figure 5.24 Representative photos from the 9 classes of organisms recorded from the sampling station

5.5.3 Plankton

The sampling of both phytoplankton and zooplankton was carried out alongside the water quality surveys at the same sampling point (Figure 5.8). Phytoplankton samples were collected using a water sampler at the surface (1 m) and 1 m above the seabed, and for zooplankton a vertical plankton tow was used to sample the water column (2 m above seabed to the surface).

5.5.3.1 Phytoplankton

The results for total abundance of phytoplankton are presented in Table 5.12. Phytoplankton density observed at WQ1 ranges from 3.30 to 22.15 cells/ml, with the higher densities of phytoplankton recorded during flood tide (14.90-22.15 cells/ml).

The most abundant species encountered during the baseline survey was *Skeletonema* sp., with density of 8.10 cells/ml and 16.70 cells/ml during flood tide, at surface and near bottom respectively. Dinophyceae, commonly known as dinoflagellates, were also encountered during the baseline monitoring, but at very low densities (between 0.30 and 0.60 cells/ml).

Shannon Wiener index (*H*) is used to assess the species diversity of the phytoplankton community at WQ1. *H* is characterized by values between 0 and 5, with a higher *H* value representing higher species diversity amongst the community. The baseline survey results indicate that *H* is characterized by values between 1.12 (flood tide, near seabed) and 2.42 (ebb tide, near seabed), indicating relatively low phytoplankton diversity during the monitoring. Higher *H* values are observed during ebb tide and lower ones during flood tide.

Evenness Index (E_H) provides information related to the distribution of organisms and is characterised by values between 0 and 1, with higher E_H values corresponding to more equal distribution of organisms amongst present species. EH is characterised by values between 0.40 and 0.94, indicating the phytoplankton community in the study area is rather equally distributed.

Table 5.12 Total abundance (in cell/mL), Shannon Wiener Index (H) and Evenness (EH) values from phytoplankton analysis.

Tide	**Depth**	**TOTAL Density (cells/ml)**	**Shannon-Wiener (H')**	**Equitability (Eh)**
Flood	Surface	14.90	1.81	0.62
Flood	Bottom	22.15	1.12	0.40
Ebb	Surface	5.10	2.33	0.86
Ebb	Bottom	3.30	2.42	0.94

5.5.3.2 Zooplankton

Monitoring of zooplankton was done during flood and ebb tides at WQ01. Total abundance was 2,771.95 org/m^3 and 1,747.17 org/m^3 during flood and ebb tide respectively. This aligns with observation for phytoplankton that higher abundance is observed during flood tide.

The class Copepoda was observed to be the most abundant, with a total of 2,217.56 org/m^3 during flood tide and 1,478.37 org/m^3 during ebb tide. Within the class, the species that was found of the highest abundance is *Paracalanus* sp. during flood tide (932.38 org/m^3) and *Oithona* sp. during ebb tide (492.79 org/m^3). All zooplankton species observed in the table have been previously observed in Singapore (Schmoker *et al.,* 2014).

Table 5.13 Total abundance (in org/m^3), Shannon Wiener Index (H) and Evenness (EH) values from zooplankton analysis.

Tide	**TOTAL Density (org/m^3)**	**Shannon-Wiener (H')**	**Equitability (Eh)**
Flood	2,771.95	1.88	0.68
Ebb	1,747.17	2.02	0.84

5.5.4 Marine Megafauna

In general, marine megafauna are known as whales, dolphins and dugongs, sharks, rays and sea turtles. In Singapore, identification of marine megafauna can be difficult due to turbid waters. Additionally, marine megafauna spends most of their time submerged and surface only every few minutes. Most of the information gathered in literature was from reported sightings of these animals. As shown in the Figure 5.25 there is no reported or sighted marine megafauna within the Project area, which could be due to lack of foraging area as well as Project area is within and surrounded by busy marine navigation area, where marine megafauna would tend to avoid.

The closest reported or sighted marine megafauna were around islands to the north and east of Pulau Sebarok such as Pulau Semakau, Pulau Jong and Sister's Islands Marine Park. Sister's Islands Marine Park is located more than 3 km eastward from the Project area and further divided by the busy Jong Fairway navigation lane. More sightings of marine megafauna in these areas could be due to suitable marine habitat such as availability of food/foraging grounds.

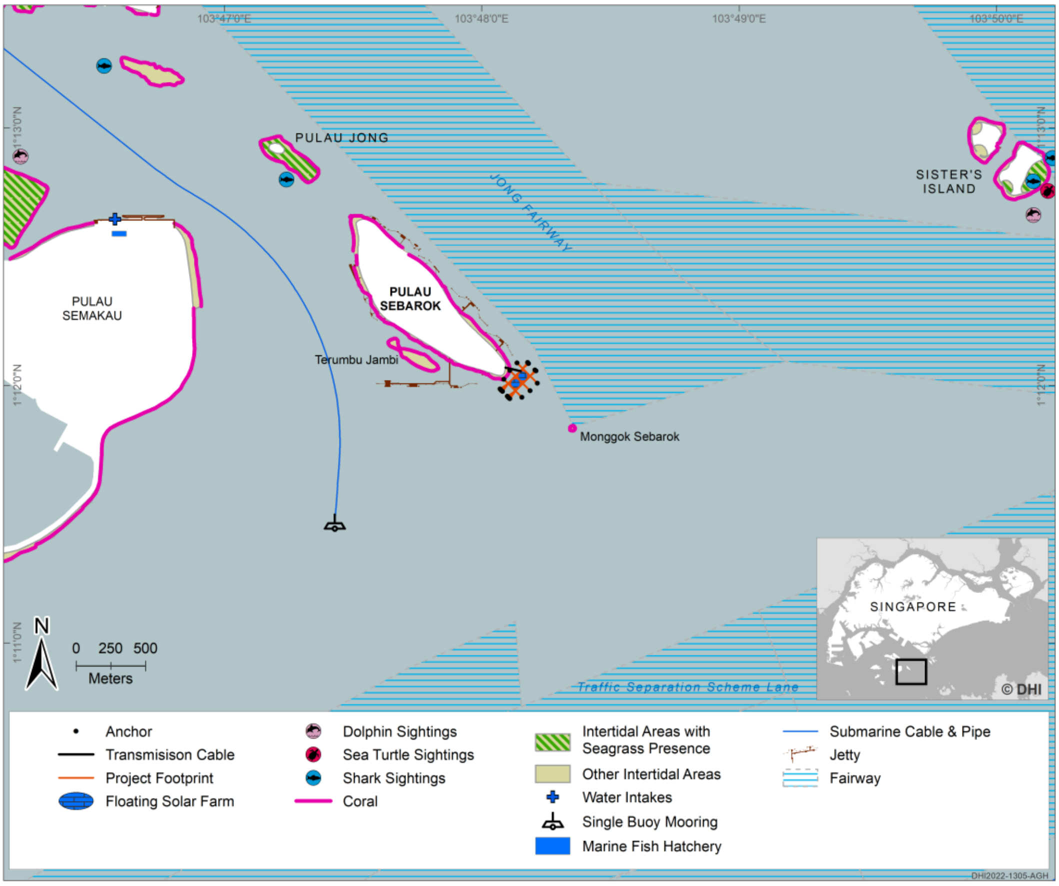


Figure 5.25 Marine megafauna sighted or reported within the Project area.

5.5.5 Avifauna

The avifauna of Pulau Sebarok include migratory and resident species. Shorebirds are migratory birds that fly mainly along shorelines and feed in mudflats and wetlands along their migratory paths (eBird, n.d.). The East Asian-Australasian Flyway (EAAF) is the main migration route for shorebirds wintering in Singapore and other Southeast Asian countries (Figure 5.26) (EAAFP) (Li et al., 2020). Some research has shown that Singapore may be an intersection for the EAAF and the Central Asian Flyway (CAF), another main Flyway for migratory birds (Li et al., 2020). While many migratory shorebirds travel through Singapore, the main stopover locations include Sungei Buloh, Seletar Dam, Mandai Mudflats and Pulau Ubin as these locations are ideal for breeding and feeding (iNatrualist, n.d.). Singapore is also home to roughly 153 resident avian species which breed/freed throughout the mainland and islands in ideal habitats (Figure 5.28).

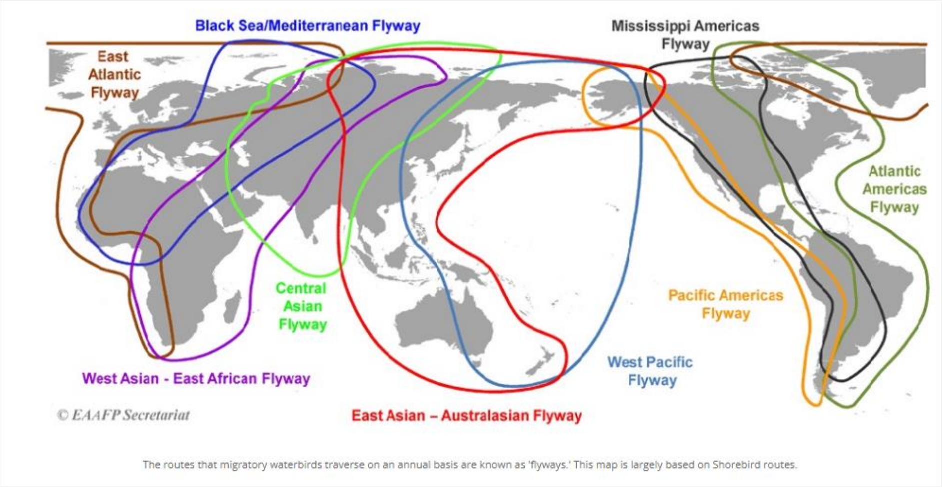


Figure 5.26 Map of the nine flyway routes used by migratory waterbirds and shorebirds. *Source:* (EAAFP, 2018)

Figure 5.27 shows the land classification of Singapore from buildings to vegetated areas and marshes. Pulau Sebarok is classified as 'buildings' and 'impervious surfaces' as it is mainly used for storage and transhipment of oil (Gaw et al., 2019). There are many ideal natural habitats within Singapore for avian species to thrive however, some species do exist within man-made infrastructure. While Pulau Sebarok may not be an ideal natural habitat for avian feeding/breeding, local and migratory species may still find refuge within the industrial areas or pass the island on their migratory routes. No opportunistic sighting of birds was recorded during DHI's marine surveys.

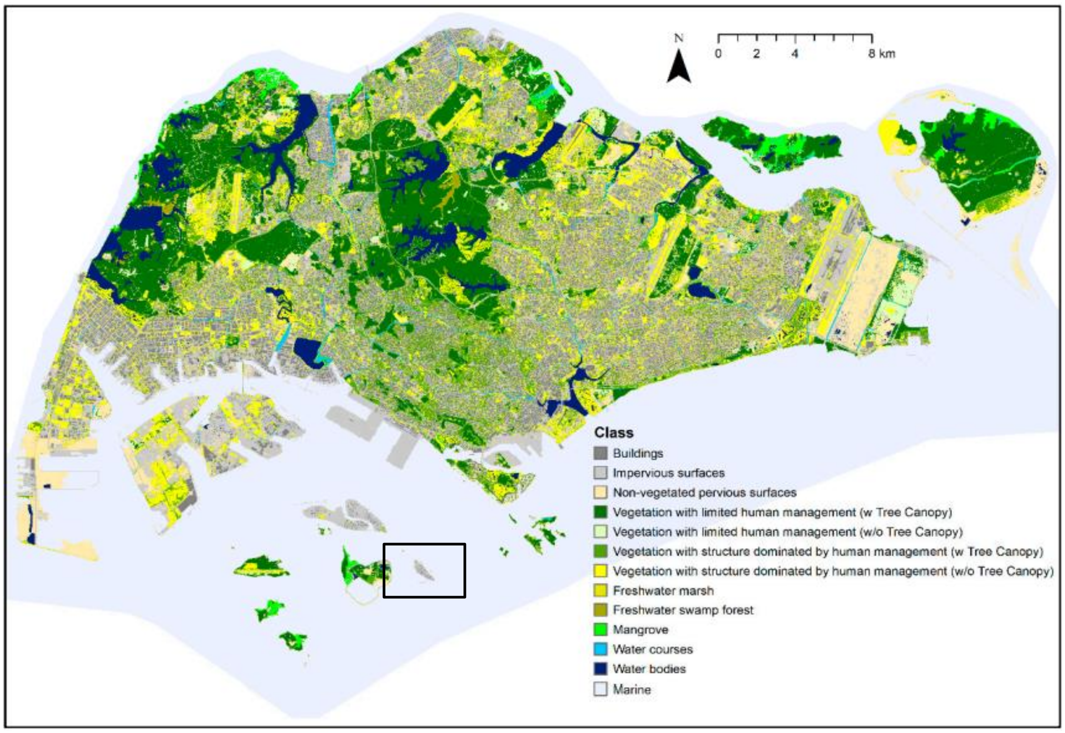


Figure 5.27 Land classification of Singapore from satellite images taken from 2003 – 2018. Pulau Sebarok indicated in the black square. *Source: Gaw, Yee, and Richards, 2019.*

Figure 5.28 Observed avian species in Singapore from 1990 – 2022 (Source: eBird, n.d.)

5.6 Maritime Transport and Infrastructure

5.6.1 Marine Jetties

The shoreline of Pulau Sebarok is densely populated with terminals and jetties for vessel transit, berthing and departing. Figure 5.29 shows the jetties that are within the proximity of the Project site, which are mainly around Pulau Sebarok. The management of these jetties is distributed among three terminal operators, they are Vopak, Petro China and Cleanseas. Each of the jetty names and their respective terminal operators are presented in Table 5.14.

The jetties located at the southern shoreline, closest to the Project site are largely managed by Vopak (Figure 5.29). The distance of the Project site to the nearest jetty, which is OSV 4 is approximately 125 m, followed by OSV 5 at 237m.

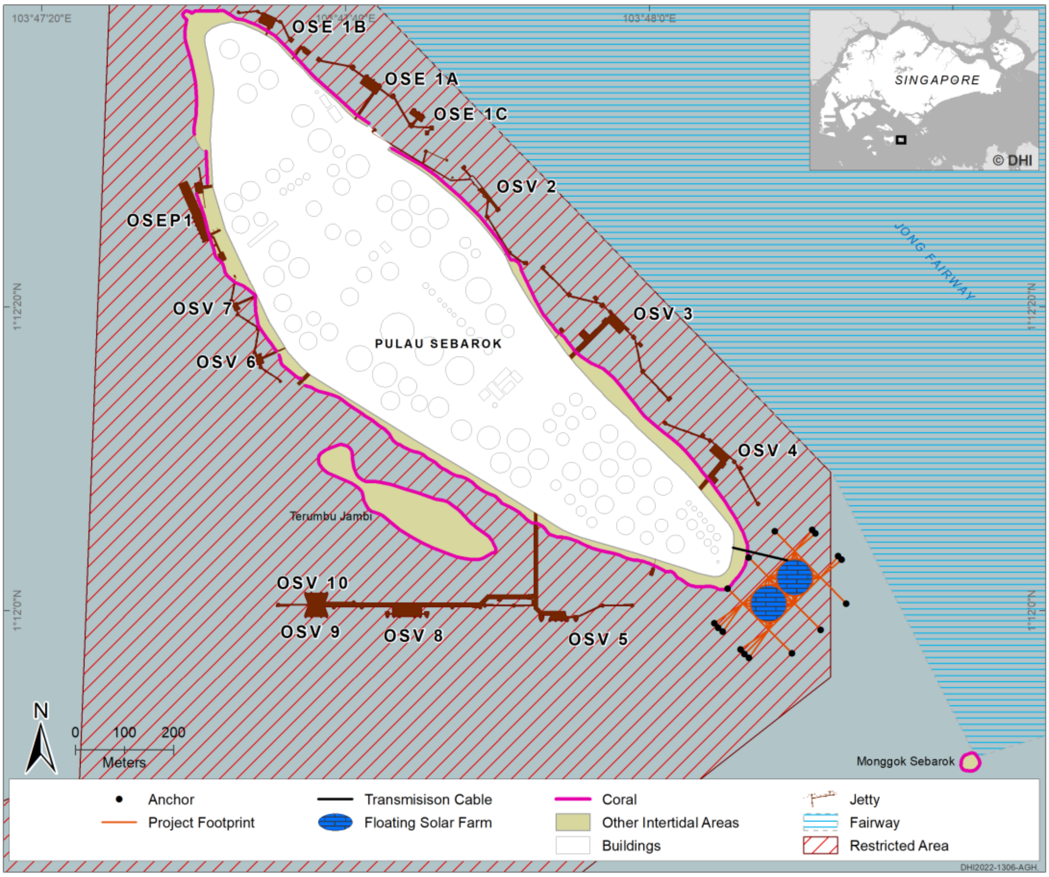


Figure 5.29 Jetties within the proximity to the Project site are mainly around Pulau Sebarok.

Table 5.14 Jetty names and respective terminal operators.

Jetty Name	Terminal Operator
OSV2, OSV3, OSV4, OSV5, OSV6, OSV7, OSV8, OSV9, OSV10	Vopak
OSE1A, OSE1B, OSE1C	Petro China
OSEP1	Cleanseas

5.6.2 Navigation and Anchorage

The Project site is adjacent to Jong Fairway and Singapore Strait, some of the busiest navigation channels around Singapore waters. Hence, the island is not just a destination for vessels, but also a close neighbour to a large proportion of traffic plying the main routes.

Maritime and Port Authority of Singapore (MPA) has designated a buffer around the island extending to the Shell Single Buoy Mooring (SBM) towards the southwest as a restricted area. Vessels are prohibited from anchoring and mooring within the area.

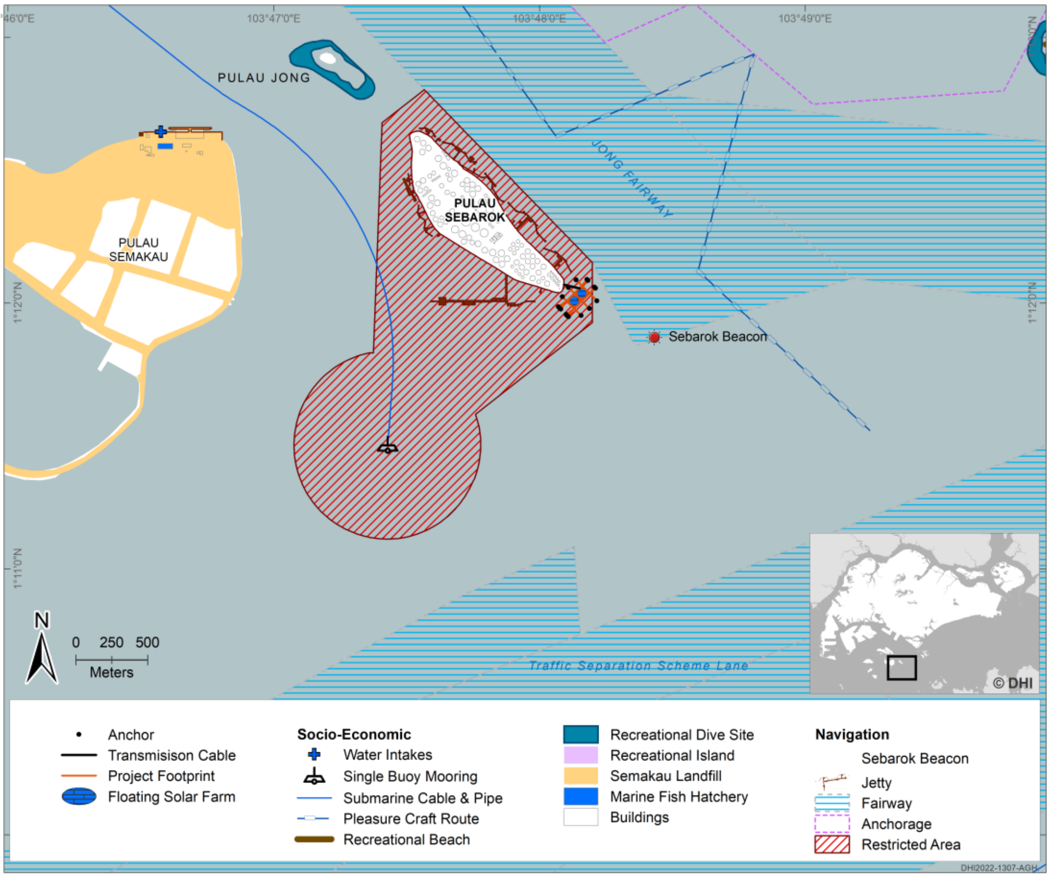


Figure 5.30 Socioeconomic receptors around study area.

6 Construction Phase Impacts

During construction phase, only one potential impact is predicted, i.e., physical disturbance to marine fauna in the deployment area (see Section 4.1).

6.1 Impacts on Marine Ecology and Biodiversity

6.1.1 Relevant Sensitive Receptors

The identified sensitive receptors that may be affected due to short-term impacts arising from the Project are corals located on Pulau Sebarok, and the benthic organisms found within the Project vicinity.

6.1.2 Evaluation Framework

This assessment is conducted qualitatively based on expert judgement guided by the definitions in RIAM framework.

6.1.3 Impact Assessment

The installation of anchoring points will involve the placement of concrete sinkers. Due to the currents in the area, it is expected that some adjustments will be needed to the concrete sinkers before they are in their final location. During the installation process, these adjustments could involve the dragging of concrete sinkers across the seabed, causing ancillary damages to the seabed and possibly affecting the corals and other benthic organisms. Furthermore, two of the concrete sinkers are located on the reef crest, where 44.3% live coral cover was recorded during the baseline survey. As such, any unnecessary adjustments made before the placement of the concrete sinkers could have direct impacts on these coral habitats. It is noted that the presence of these concrete sinkers could also present opportunity for colonisation of corals and other epibenthos requiring hard substrates to establish in the future. As such, the overall effect from the installation of anchoring points is assessed to be a Minor Negative change, given that it’s likely measurable in the field.

6.1.4 Proposed Mitigation Measures

The proposed mitigation measures include:

- Careful placement of the concrete sinkers during installation should be considered to ensure that there is minimal impact on the seabed. This could involve dropping the concrete sinkers into their exact final location instead of dragging it across the seabed into its final location.
- Concrete sinkers to be shifted as far away from coral habitats as possible, and at minimum, a few metres away from any coral habitat to avoid scouring. Where unavoidable, as much as possible, place the two concrete sinkers in the coral habitat with less coral coverage.
- Carry out a pre-construction coral survey to confirm there are no corals at the new concrete sinker locations. If concrete sinkers cannot be shifted away from the coral habitat, relocation of the affected corals is recommended.

6.1.5 Impact Summary

The deployment of the FPV at Sebarok may result in some ancillary damage to the coral and the benthic habitats in the project area. This impact is assessed to be Minor Negative, but mitigation measures have been recommended to reduce it to Slight Negative.

Table 6.1 RIAM results for impact from Near-shore FPV at Sebarok on marine ecology and biodiversity.

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation							With Mitigation		
		I	M	P	R	C	ES	Impact Significance	M	ES	Residual Impact Significance
Habitat damage	Corals	4	-2	2	2	2	-48	Minor Negative	-1	-24	Slight Negative
	Benthic organisms	2	-2	2	2	2	-24	Slight Negative	-1	-12	Slight Negative

7 Operation Phase Impacts

Operation phase of the Near-shore FPV project is predicted to cause several impacts to the environmental receptors in its vicinity, including maritime traffic and marine ecology and biodiversity. This section analyses, discusses and assesses these impacts.

7.1 Impacts on Marine Ecology and Biodiversity

7.1.1 Relevant Sensitive Receptors

As described in Section 5.4, corals and macrobenthos can be found within the Project vicinity and are considered receptors that may be affected by the long-term impacts arising from the Project (Figure 7.1). There are no marine fauna sightings documented around the Project area, the nearest documented sightings are 2.2 km away from the Project area at Pulau Jong. Additionally, avifauna of national concern have been sighted on Pulau Semakau, located 2.3 km westward of the Project area.

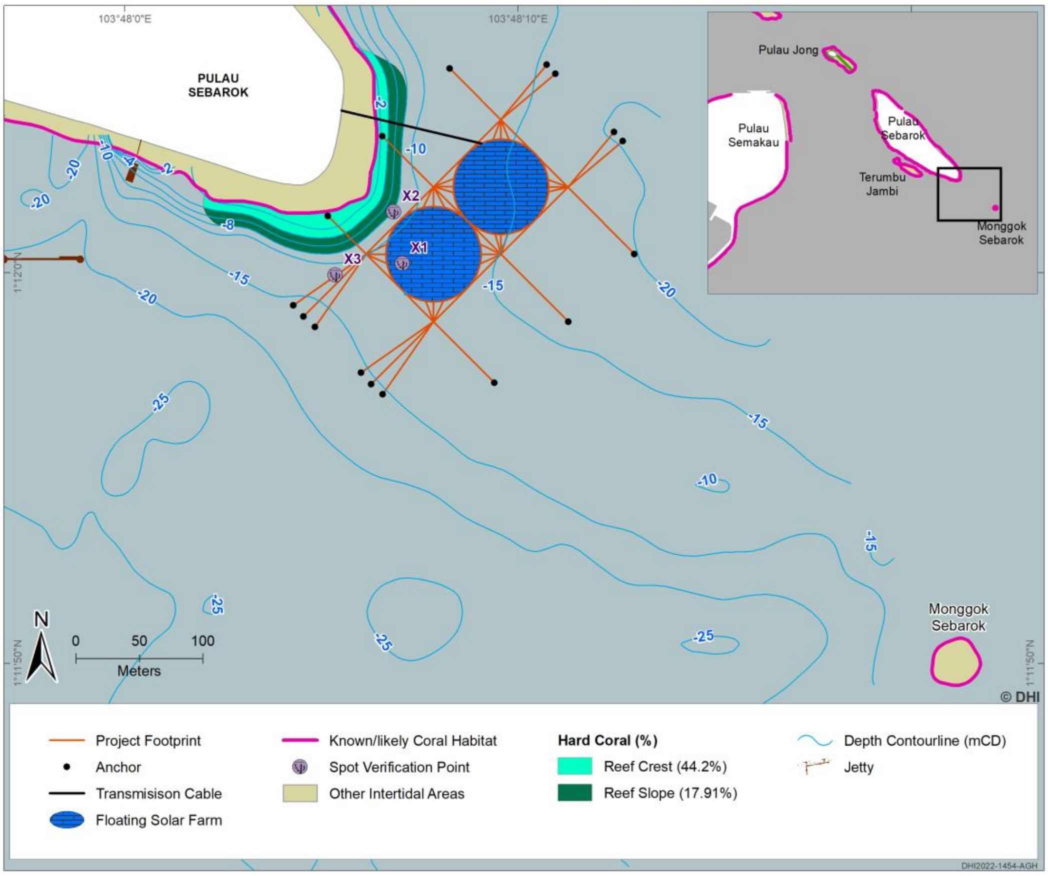


Figure 7.1 Overview of known environmental receptors in the study area. Hard coral cover presented in the figure are based on the LIT surveys carried out for the Project extrapolated over the reef area.

7.1.2 Evaluation Framework

The Project is predicted to impact marine ecology and biodiversity in the study area in multiple ways. That includes direct loss of coral and macrobenthos habitats, reduction in light penetration in the water column, change in water temperature and water quality, and emission of electromagnetic field. Most of these effects are analysed and assessed qualitatively based on expert judgement, except for thermal effects of the FPV.

DHI adopts DHI's MIKE 3 Flexible Mesh (FM) Hydrodynamic (HD) model for the numerical modelling of temperature changes underneath the FPV. This is a highly versatile modelling system that resolves effect on hydrostatic pressure, flows, salinity, temperature, density and turbulence within the modelling domain. Details of this model can be found in Appendix B.

The 3D thermal model was carried out for two scenarios (baseline and final) to assess the changes due to the FPV farm existence. Both scenarios were run for 14 days during Northeast (NE) and Southwest (SW) monsoon.

7.1.3 Impact Assessment

7.1.3.1 Direct loss of habitat

There will be a maximum direct loss of 3 m^2 of subtidal/benthic habitat due to the placement of the concrete sinkers at each location. Additionally, the bottom chains lying on the seabed will also scour the surface due to tidal forces. If the movement of the cables occur frequently, this would also equate to habitat loss as marine organisms are unable to colonise the substrate. According to current design plans, two of the anchors are found in depths suitable for coral habitat.

Additionally, beacons are expected to be installed just off the shoreline of Pulau Sebarok for navigational safety. The exact placement or design (floating or anchored) of these beacons is currently unknown but could potentially be placed in existing coral habitat. If the beacons are anchored into the sediment, this would result in further direct losses of habitat.

This extent of habitat loss is assessed to be Minor Negative change.

It is worth highlighting that the introduction of the concrete sinkers and cables connected to the FPV can provide new substrate for benthic species to colonise, and so function as an artificial reef. Careful design considerations for the concrete sinkers, such as increasing the topographical complexity by including crevices and pits instead of smooth surfaces, can further enhance the potential for substrate provision (Clark and Edwards, 1994; Firth et al., 2014). With the provision of new substrates, the impact to the coral habitat due to the concrete sinkers and cables could be mitigated with potential to growth through recolonisation.

7.1.3.2 Entanglement and collision risk (marine megafauna)

The presence of the floating electrical cables and anchoring cables connected to the Project, and the FPV itself, may pose an entanglement or collision risk to surface-dwelling or pelagic marine fauna such as sharks, sea turtles, dolphins, and dugongs. This could be further compounded, in the case of the electrical cables, if the emission of EMFs attracts marine fauna. Entanglement can cause injury or even mortality if the animal cannot get free. In the present case, collision is unlikely to cause serious injury, given that the FPV is a floating, moored system with less resistance than a fixed, immovable object and less likelihood of collision compared to a moving object like a vessel.

Given that the anchoring cables are well-spaced, the risk of entanglement is likely low. However, the presence of the electrical cables and the FPV on the surface is likely to pose a slightly higher risk. While the presence of internationally listed species of conservation significance (e.g. dugong) have been detected in the area, these have not occurred around Pulau Sebarok itself. As Pulau Sebarok is surrounded by busy shipping channels, it is likely that marine fauna presently avoids the island. As there are no known foraging grounds near Pulau Sebarok either (e.g. seagrass meadows), the probabilities of marine fauna encountering the cables associated with the Project is low. Thus, there is a Slight Negative change arising from entanglement and collision risks associated with the Project.

7.1.3.3 Reduction in light availability (shading)

In the longer term, the physical presence of the FPV may cause some effects to the health and functioning of subtidal, intertidal, and macrobenthic habitat due to the reduction in light availability caused by the shading effect of the physical structure. A reduction of light availability can also reduce surface phytoplankton production, causing knock-on effects for other organisms that depend on them.

The presence of the FPV will cause a light deficit directly beneath it. The area covered by the FPV is 0.88 ha (~ 1 football field), and the area with a light deficit could potentially be greater depending on the angle of the sun. The light deficit could impact on photosynthesising organisms, including corals. However, the FPVs are located 8.6 m away from the nearest coral habitats recorded during the baseline surveys. As such, there is unlikely to be any appreciable impact from the reduction in light availability on coral habitats.

A secondary effect of reduced light availability is declination in primary production and food availability for organisms that feed on phytoplankton such as zooplankton, small fish, and crustaceans (Hooper at al., 2021). This could in turn impact other marine fauna that feed on these primary consumers, including many benthic organisms.

As there are currently few existing FPVs globally, empirical studies on their impacts are limited. In a modelled simulation of the effects of FPVs on net primary production in three locations within the North Sea, Karpouzoglou et al. (2020) found that there was less than 10% reduction in primary production when there was approximately 20% FPV coverage of the study area. In contrast, detrimental impacts on primary production were observed when coverage increased to approximately 40% (Karpouzoglou et al., 2020). However, the exact areal extent this equates to is unclear, and was not specified in the study. The authors also found that the changes in net primary production were highly related to the site characteristics, including the amount of mixing and stratification. In well-mixed locations, the light deficit was partially compensated by platform friction and wind shielding, while in the stratified location, it was intensified (Karpouzoglou et al., 2020).

The area covered by the proposed FPVs has good water exchange, thus potentially bringing in phytoplankton from surrounding waters, and low density of benthic organisms. There is likely No Impact on marine fauna in terms of a reduction in food sources.

7.1.3.4 Increase in ambient water temperatures

Effect of solar panels

Installation of the floating structure with some parts being submerged at a very low draft is not expected to change the hydrodynamic flow pattern i.e., current speed and direction around the floating PV. Based on the information provided by the client, The floater is a double ring with ø400mm HDPE pipes.

The model plots for maximum, 95th percentile and mean temperature at the surface layer for baseline during NE and SW monsoon and their respective difference plots (the value obtained from the scenario model result subtracted by the baseline model result) are presented in Figure 7.2 and Figure 7.3.

Only temperatures at surface layers are used in this assessment. The baseline survey conducted for this EIA recorded Secchi disc depth of 2.6 m to 4.5 m while the water depth is 10 m to 14 m, indicating that light only penetrates the top water layer. The bottom layer receives very limited sunlight from the surface hence reduction of which is not anticipated to affect the bottom layer. Indeed, model results for bottom layer shows -0.01 °C change in 95th percentile temperature at bottom layer, this is likely within the range of model uncertainty. The model plot for temperature change at the bottom layer can be found in Appendix B.

It is apparent from the model plots that in all monsoons, the predicted temperature change due to the presence of the FPV panel is less than 0.1°C for maximum, 95th percentile and mean temperature, suggesting that overall temperature distribution is not affected by the presence of the FPV panel. Additionally, this is within the ASEAN MWQC allowable limit of less than 2°C increase above the maximum ambient temperature.

During daytime, the FPVs indeed will have overall cooling effect on the water column. Solar radiation is the only source of energy in this system. It will be absorbed by the FPVs and converted to electricity. The FPVs could be heated up during that process, which may warm up the top layer of water. But this amount of heating is less than the direct heating by solar radiation in absence of FPVs, as part of the received energy has been converted to another form.

At night, in absence of solar radiation, hence absence of the direct heating, a concern arises during the agency consultation process for this study regarding the heat accumulation in the panels during hot days may release into the water column at night. It is noted that with the strong ambient currents in the area (up to 1.6 m/s), any temporary change in water column underneath the PV panels will be dispersed quickly by the ambient water resulting in insignificant change in temperature.

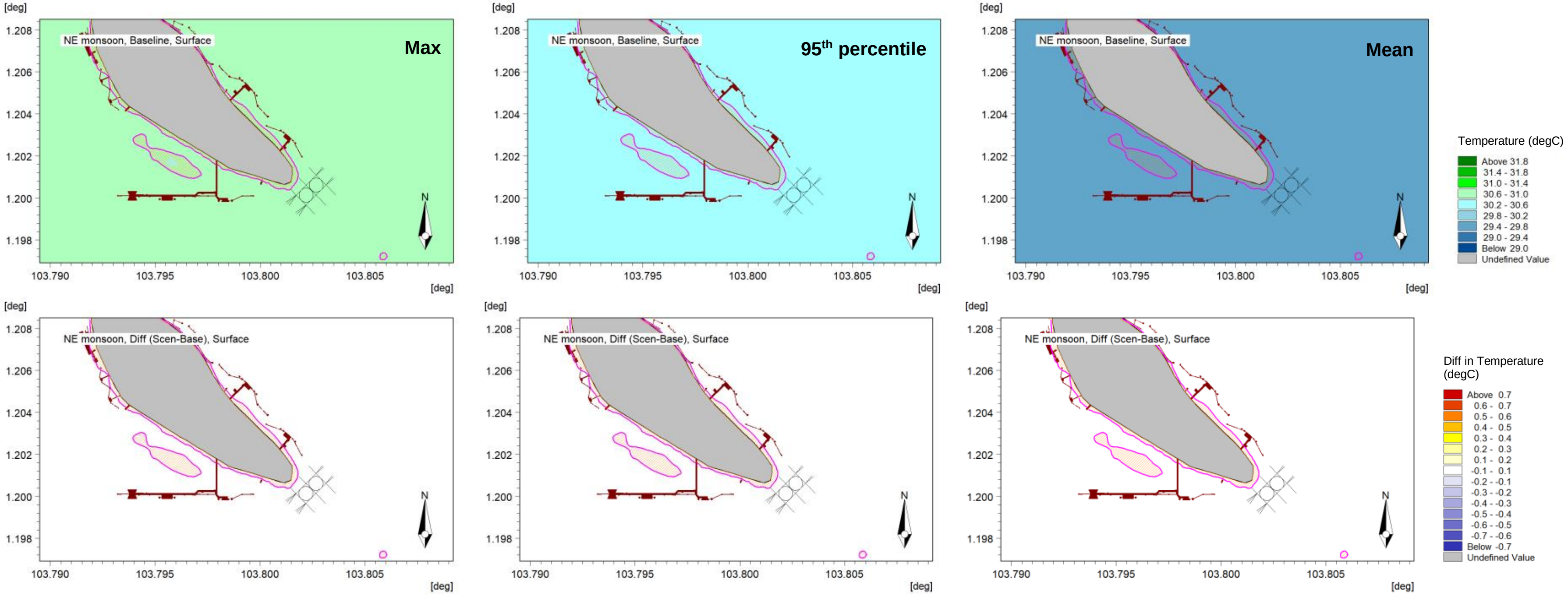


Figure 7.2 Temperature over 14 days at the surface, during northeast monsoon. Top: Baseline. Bottom: Predicted change arising from Project. Left: Max. Middle: 95th percentile. Right: Mean.

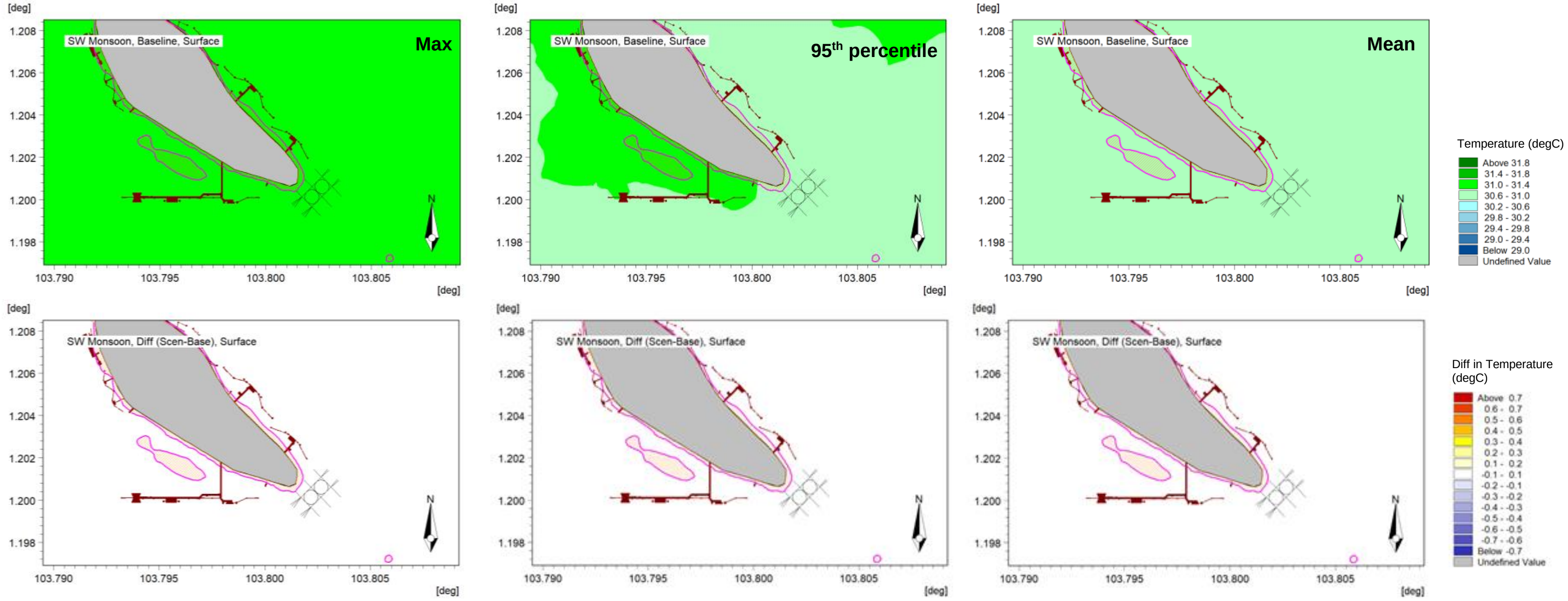


Figure 7.3 Temperature over 14 days at the surface, during southwest monsoon. Top: Baseline. Bottom: Predicted change arising from Project. Left: Max. Middle: 95th percentile. Right: Mean.

Effect of cable

Increases in ambient water temperatures are also expected due to the heat emitted from the cables transporting the electrical energy. However, there have been very few field measurements of this increase. Temperature measurements were taken from subsea cables (buried at approximately 1 m depth) originating from an offshore wind array in Nysted, Denmark, and showed a maximum temperature increase of about 2.5ºC at 50 cm directly below the cable (Meißner et al., 2006). However, at the sediment surface, temperatures were largely similar to the reference site that had no subsea cables. Temperature increases can modify the chemical and physical properties of the substratum, such as the oxygen concentration profile (redox interface depth) and cause physiological changes in benthic organisms (OSPAR Commission, 2008; Taormina et al., 2018). These are described in detail for each faunal group below.

Effect on Corals

It is now well-established that elevated temperatures can lead to coral bleaching, where corals lose their zooxanthellae, and that bleaching events are happening at increasing frequency on coral reefs globally (Coles and Brown, 2003). Additionally, corals that bleach become more susceptible to disease and mortality (Whelan et al. 2017). Coral Reef Watch (CRW) established by the National Oceanic and Atmospheric Administration (NOAA) issues coral bleaching alerts when the sea surface temperature is 1ºC higher than the highest climatological monthly mean, equating to 31ºC in Singaporean waters (NOAA, 2022).

Vulnerability to thermal stress can be genera-specific in both scleractinian (hard) and soft corals. It was previously reported that *Acropora* and *Pocillopora* spp. are the most susceptible to heat stress, while others such as *Cyphastrea*, *Turbinaria*, and *Galaxea* are more resistant (Marshall and Baird, 2000). However, a survey of bleached corals in Singaporean waters during an ocean warming event (30.6ºC) found corals from the genera *Goniastrea*, *Platygyra*, and *Porities* to be the most affected (Chou et al., 2016). These results were also in line with previous observations from the 2010 major bleaching event in Singapore and Peninsular Malaysia (Guest et al., 2012). Field observations in the upper Gulf of Thailand found mass bleaching of hard and soft corals when water temperatures reached a maximum of approximately 5.7ºC above normal conditions (Chavanich et al., 2009). However, 95% of the bleached soft coral (*Sarcophyton* spp.) population recovered within 4 months and were able to survive. In an experimental study, *S. ehrenbergi* was found to be the most resilient to heat stress, surviving temperatures of 34ºC (6ºC above the control of 28ºC) for more than 39 hours (Strychar et al., 2005). In contrast, *Sinularia* sp. were able to survive prolonged exposure of 32ºC, but mortality was observed within 24 hours at 34ºC. Lastly, *Xenia* sp. started to bleach at temperatures less than 30ºC (Strychar et al., 2005).

Coral bleaching alerts are triggered in Singapore when sea surface temperatures are 1ºC higher than the highest climatological monthly mean, equating to 31ºC. However, these temperatures are currently being recorded occasionally, with maximum temperatures during the SW monsoon ranging from 30.8-31.1ºC.

A 0.1°C increase due to the FPV would not thus exceed the coral bleaching alert threshold. Furthermore, the increase in ambient temperature is expected to be limited to within the immediate vicinity of the FPV and is unlikely to cause any negative impacts to the corals found on Pulau Sebarok.

On the other hand, increases in ambient temperatures from the cables could potentially be higher. This would be especially detrimental where the cables make landfall in the vicinity of coral habitats or in the intertidal areas during low tide where there is less water exchange. As the corals are mainly found in subtidal habitats, the good flushing in the area is likely able to remove the excess heat and prevent any major detrimental impacts. A slight negative impact is thus expected on corals that can be found in shallower waters, where flushing may not be as frequent.

Effect on Benthic organisms

The effects of thermal stress on other benthic organisms are not as well-studied or understood compared to corals. Elevated sea surface temperatures have been linked to the local extinction of the majority of echinoderm species (such as sea stars and urchins) on a Brazilian coral reef, with no recovery observed two years after (Attrill et al., 2004). Tropical bivalves were also found to have a narrower range of thermal tolerance limits compared to temperate species, suggesting that tropical species are less adapted to temperature variations (Compton et al., 2007). A separate study on two sea urchin species also showed a narrow upper tolerance limit of up to 3.66ºC above ambient temperatures for *Echinometra lucunter*, and up to 5.67ºC for *Diadema antillarum* (Sherman 2015).

As the minimal increase in ambient temperatures associated with the presence of the FPVs are only expected on the surface, benthic organisms located at depths of 15m are unlikely to be impacted. Temperature increases are also expected from the electrical cables through heat loss, although these losses are expected to be localised around the cable. Additionally, since the cables are expected to be floating on the water surface, any increases are also unlikely to impact benthic organisms. Furthermore, the strong currents in the Project vicinity could equate to quicker heat dissipation, lowering the magnitude of any negative impact due to temperature increases. As such, no significant impacts are expected to the benthic organisms from increases in ambient temperatures.

7.1.3.5 Changes in water quality

Operation of the solar power farm is expected to alter water quality (at varying degree) in the vicinity through several ways:

- Scouring of the seabed (by the concrete sinkers) and shoreline (by the cable), resulting in resuspension of the seabed
- Alteration of dissolved oxygen level as a result of reduced photosynthesis and lower water temperature
- Biofouling of the membrane where the FPV modules sit
- Discharges from maintenance (e.g., washing) of the FPV farm

The seabed in the study area has been established through DHI’s baseline survey to comprise mostly rocks and coral rubbles. Increase in suspended sediment resulting from scouring will not be assessed.

Dissolved oxygen level

Dissolved oxygen is important to many forms of aquatic life. This water quality parameter may be indirectly altered by the FPV’s shading effect. Reduced photosynthesis due to the lack of light penetration potentially results in less oxygen release into the water column. On the other hand, lower water temperature due to shading increases oxygen solubility. The net change is dependent on extent of shading, abundance of phytoplankton and level of flushing in the area.

As mentioned in Section 2.2, each floater has a diameter of 75 m, and the diameter of the membrane is 72 m. Two floaters will have the longest span of 150 m covering an area of approximately 0.88 hectares. With the average current speed in the order of 1 m/s (as described in Section 5.2.3), it is estimated that this will result in a flushing/residence time in the order of hours instead of days. New Zealand considers less than 3 days as short residence time, which is equivalent to good flushing (LAWA, 2022).

The baseline study established that phytoplankton in the area is low and that flushing in the area is strong. These together substantiate there will be no change to dissolved oxygen level in the water.

Biofouling of membrane in contact with water

Biofouling of the FPV membrane in contact with the water can lead to oxygen depletion when the biofouling organisms die off. However, with good flushing in the Project area, this is unlikely to affect the benthic organisms located 15 m below the FPV. Additionally, other mobile fauna will be able to move away from the oxygen depleted area. The FPV membrane proposed to be used is also designed to be resistant to biofouling. To date, it has been deployed in more eutrophic waters and has experienced very little biofouling. As such, there is likely no impacts to water quality arising from biofouling of the FPV membrane.

Washing/maintenance of the FPV farm

There are likely to be changes in water quality associated with the maintenance of the FPV. This could be in the form of chemicals or detergents (when necessary) used during the washing of the FPVs, or the use or accidental release of oil or chemicals from maintenance boats during the cleaning process. Phosphates in detergents have been shown to lead to freshwater algal blooms, which then release toxins and deplete oxygen availability upon decomposition (Cohen and Keiser, 2017). Detergents have also been shown to damage gill functions in freshwater fish species (Fiorelini Pereira et al., 2017). While less is known about their impacts on marine species, it stands to reason that there would be similar negative impacts. However, chemical detergents are unlikely to be used for cleaning as the FPV membrane is unlikely to experience high levels of biofouling. Instead, only water will be used for cleaning.

Any chemical or oil spill near the Project could spread to a wider area due to the water movement in the area. In relation to effect of phosphates, the negative effects associated with oil in the marine environment is much more established. These can include lethal or sublethal toxicity to a wide range of fauna ranging from plankton to marine mammals, and fouling and degradation of marine habitats (Murphy et al., 2016).

It is noted that the waters around Pulau Sebarok is highly trafficked by vessels of all sizes. Therefore, risk of oil spill already exists. It is also anticipated that maintenance operation for the FPV will likely be by small boats, hazardous material inventories are therefore small. In combination with the probable annual cleaning frequency, the FPV cleaning activities are assessed causing No Change to Slight Change in terms of oil spill risk to marine habitats in the study area.

7.1.3.6 Electromagnetic field (EMF)

The electromagnetic field (EMF) generated around the marine cables could have direct impacts on marine species which are known to be sensitive to electromagnetic fields. This includes rays, sharks, fishes, mammals, turtles, molluscs, and crustaceans. EMF emitting from marine power cable may at a local scale alter predator/prey interaction, induce behaviour effects, affect species navigation/orientation capabilities, and cause physiological and developmental effects.

Many marine animals can be sensitive to electromagnetic fields (EMFs) in the marine environment or have the potential to detect them (Gill et al., 2014). Of the marine fauna found in Singaporean waters, this includes elasmobranchs (sharks, skates, and rays), cetaceans (whales, dolphins, and porpoises), crustaceans, molluscs, echinoderms, bivalves, and polychates (Kirschvink et al., 1986; Lohman and Lohman, 1996; Willows 1999; Tricas and Sisneros, 2004; Everitt 2008). However, the interaction between anthropogenic EMF and marine fauna is highly complex and still poorly understood (Gill et al., 2014).

Elasmobranchs

Elasmobranchs can be sensitive to alternating electric fields from 1 to 10 Hz, but also a broad response bandwidth from 0.01 to 25 Hz (Normandeau et al., 2011). Similarly, behavioural responses to direct current and modulated electric fields are likely at frequencies up to 8 Hz (Normandeau et al., 2011). Some species of bottom-dwelling elasmobranchs (e.g., small-spotted catshakrs, *Scyliorhinus canicular*, or thornback rays, *Raja clavata*) have been observed to be attracted to or exhibit increased movement when AC cables were powered (Normandeau et al., 2011). While no direct behavioural data have been reported, sharks and rays are likely to detect, respond, and possibly show avoidance behaviours to DC cable systems (Yano et al., 2000). In the event of avoidance behaviour, movement between important areas such as feeding, mating, and nursery areas could be prevented, thus causing long-term detrimental impacts. However, mesocosm studies have also showed that the impacts of EMF can be highly species-specific, and even specific to individuals, making it difficult to draw generalisations across elasmobranchs (Gill et al., 2009). There are also substantial gaps between the interaction of pelagic elasmobranchs and submarine cables, making it harder to evaluate impacts at the population scale for elasmobranchs.

The electrical cables used in this Project are expected to float at the water surface, where they will be less likely to be encountered by elasmobranchs which are generally pelagic or bottom-dwelling. However, there is currently insufficient information about the impact of EMFs on elasmobranchs, although they are likely to be able to detect such changes. As no conclusive negative impacts have been shown in previous experiments and given the low occurrence of elasmobranchs in the Project vicinity, no significant impacts are expected to elasmobranchs from changes in the electromagnetic field due to the Project.

Cetaceans

Less is known about the impacts of EMF on cetaceans, although they are known to be sensitive to changes in geomagnetic fields. (Gill et al., 2012). Mass strandings in sperm whales (*Physeter macrocephalus*) have been found to be associated with disruptions and changes in the Earth’s magnetic field, which occurs during solar storms (Vanselow et al., 2017). Given the difficulties of conducting controlled experiments on cetacean species, thresholds for EMF exposure are unavailable. However, previous correlation studies between cetacean strandings and geomagnetic minima suggests that cetaceans are likely to be able to detect DC magnetic fields within the vicinity of 50 m above and 68 m horizontally across from an “average” cable (Normandeau et al., 2011). The behavioural and physiological impacts from this detection, however, is unknown. Additionally, previous studies have shown the Guiana (*Sotalia guianensis*; Czech-Damal et al., 2012), and Bottlenose dolphins (*Tursiops truncates*; Hunttner et al., 2021) to be capable of electrosensing, indicating that cetaceans could be impacted by anthropogenic EMFs. Czech-Damal et al. (2012) found that the Guiana dolphin was capable of detecting electric fields with a stimulus below 10 µV/m, and had an absolute detection threshold of 460 µV/m. At these exposure levels, the Guiana dolphins were attracted to the electric field (Czech-Damal et al., 2012). However, the consequence of this attraction is unclear. Given that cetaceans frequent the water surface more often in order to breathe, they are likely to come in contact with the electrical cables more often. Yet, there is also minimal information that currently exists on EMFs impacts on cetaceans. Given the low occurrence of cetaceans in the Project vicinity, and the limited area of influence (most likely < 100m from the cable) no significant impacts are expected to cetaceans from changes in the electromagnetic field due to the Project.

Benthic organisms

Exposure to a static magnetic field for several weeks had no impact on a range of invertebrates (prawns, crabs, and mussel). Furthermore, mussels exposed for 3 months during their reproductive period saw no significant changes in their reproductive indices, indicating that MF exposure had no detrimental impacts (Bochert and Zettler, 2004). Behavioural responses in invertebrates have been mixed, with some studies showing repulsion (Ernst and Lohmann, 2018) or attraction (Scott et al., 2018) to artificial magnetic fields, while others have found no responses (Love et al., 2017). Studies on polychaetes have only been conducted on a single species, *Hediste diversicolor*, and have found no attraction nor repulsion towards artificial magnetic fields (Bochert and Zettler, 2006; Jakubowska et al., 2019). Exposure potentially caused an increase in bioturbation activity (i.e., more upward, and downward migrations), but not emergence above the sediment surface (Jakubowska et al., 2019). However, the consequences of these behavioural responses are unclear. The electrical cables used in this Project are expected to float on the water surface, away from benthic organisms (at a maximum depth of 15 m). Previous field measurements have recorded a ~80% reduction in electric field (< 200 µV/m) within 12 m (Meißner et al., 2006). As no conclusive negative impacts have been shown in previous studies and given the low density of benthic organisms in the Project vicinity, no significant impacts are expected to the benthic organisms from changes in the electromagnetic field due to the Project.

7.1.3.7 Reduction in foraging area and collision risk (avifauna)

The physical presence of the FPV can also have impacts on avifauna in or passing through the area. Avifauna can collide with the FPV due to polarised light pollution and/or as a result of mistaking large arrays of PV panels for water (Horváth et al., 2009; Lovich and Ennen, 2011).

The area covered by the FPV is 0.88 ha (~ 1 football field), causing a reduction of foraging area for species that dive for food. However, such species have not been noted in the immediate vicinity of the Project area. As such, there is unlikely to be an impact on the availability of foraging areas as a result of the FPV.

There is currently no distinct pattern in types of bird species negatively impacted by PV panels and collision causalities (McCary, 1986; Kagan et al., 2014; Jenkins et al., 2017). However, there are clear qualitative indications that water birds can be attracted to and collide with PV panels. This is because of polarised light pollution (PLP) creating a “lake effect” on the surface of the PV panels leading birds to mistake the panels for open water (Horváth et al., 2009; Lovich and Ennen, 2011; Jenkins et al., 2017; Hathcock, 2018). PLP is polarised light reflected from artificial surface interfering with natural patterns of polarised light experienced by organisms (Hathcock, 2018). The “lake effect” can thus lead to increased mortality in avifauna species. However, the occurrence of avifauna on Pulau Sebarok is low, likely as a result of minimal available habitat. While species of concern have been sighted on nearby Pulau Semakau, it is unlikely that these species would migrate to Pulau Sebarok due to the absence of feeding and roosting habitat. However, they may fly over Pulau Sebarok while in transit to Sisters’ Island. As such, there is a potential Slight Negative impact from collision risk due to the FPV.

7.1.3.8 Habitat alteration (avifauna)

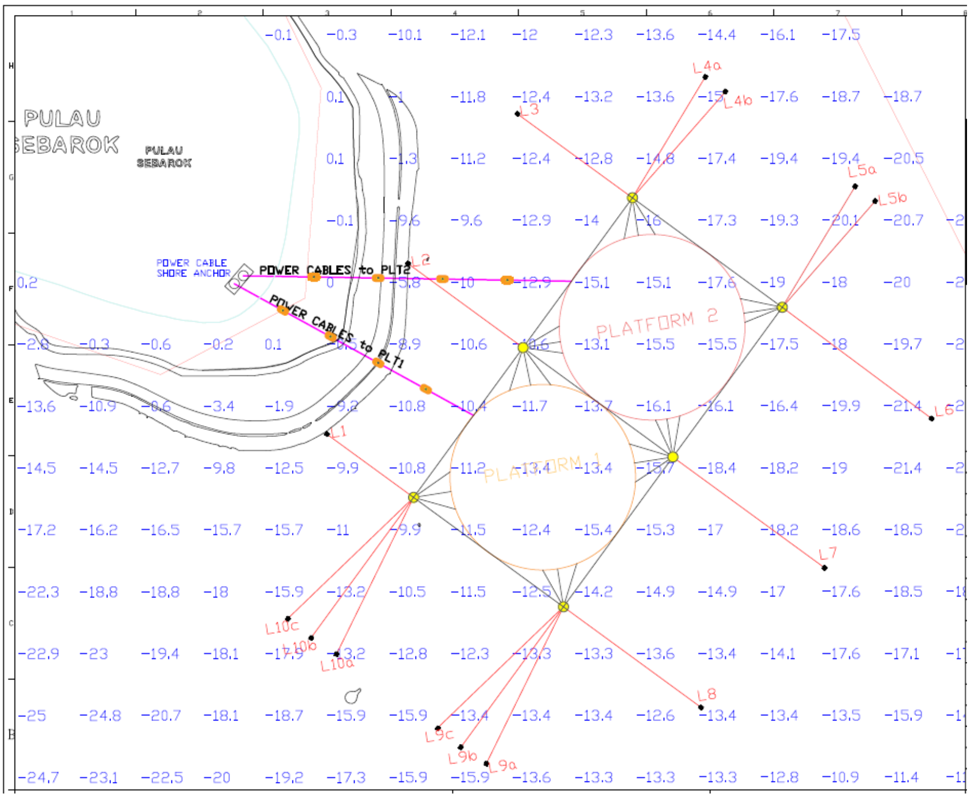
PV panels also have a potential impact on avifauna (birds), although avian interactions and related impacts to PV panels are not well understood (Hathcock, 2018). BirdLife South Africa does provide a list of possible PV avian impacts and mitigation measures. Displacement of sensitive species from their habitat is noted to be common with PV panels construction. While these Ocean Sun FPV farms are deployed offshore and habitat loss will be minimal, impact to birds is still possible (Hanneline, n.d.). It is noted that PV panels are less reflective than Concentrated Solar Power (CSP) which mitigates the chance of avian attraction and collision, but the potential impact is still present. BirdLife South Africa states that birds are likely to nest and perch on PV panels which can attract more birds to the area, increasing risk (Hanneline, n.d.). In 2016 PUB (Singapore’s National Water Agency) and the Economic Development Board (EDB) launched a one megawatt-peak floating PV testbed at Tengeh Reservoir (roughly north-west Singapore). They reported that there has been no significant impact on wildlife (PUB, n.d.).

PV panels can also indirectly impact avifauna by degrading or altering habitat. However, because of the offshore location and size of the Ocean Sun floaters there is less concern for avian habitat degradation and more concern for habitat alteration. Avifauna can potentially create nests on the PV panels, and the attraction of insects to the panels can also attract avifauna (Hanneline, n.d.; Horváth, 2009). Risk of birds nesting and perching on the PV panels is increased because nesting/resting areas are limited offshore, and the PV panels could act as a refuge for migrating or breeding species (Hanneline, n.d.). However, the creation of nests on the FPV could lead to panel obstruction (Hanneline, n.d.). Due to the presence of insectivorous avifauna of note in the Project vicinity which could transit over Pulau Sebarok, there is the potential for a Minor Negative impact arising from habitat alteration.

7.1.4 Proposed Mitigation Measures

The proposed mitigation measures for impacts to marine ecology and biodiversity include but are not limited to:

- Mitigation measures outlined in Section 6.1.4.
- Concrete sinkers to be shifted as far away from coral habitats as possible, and at minimum, a few metres away from any coral habitat to avoid scouring. Where unavoidable, as much as possible, place the two concrete sinkers in the coral habitat with less coral coverage. Taking this into consideration, a new mooring plan is established and is shown below:



- The optimisation of the two concrete sinkers indicated that the new locations are right at the border of the coral slope (see above). However, as the exact extent of the corals is uncertain, it is recommended that a coral mapping exercise be undertaken before the deployment of the concrete sinkers. If corals are found at the intended locations, it is proposed that the sinkers be moved further away from the nearest corals, taking into account potential scouring beyond the footprint. However, if this is not possible, then relocation of the corals is recommended.

- Design of mooring lines especially at the two points within the reef crest should avoid excess slack between the bottom chains and the concrete sinker/anchor to minimise the chains from scouring the seabed.
- Consider designing the concrete sinkers in a way to enhance the potential for substrate provision, such as increasing the topographical complexity by including crevices and pits instead of smooth surfaces.
- Ensure sufficient weight of the concrete anchors to avoid scouring of the seabed during operation
- Install floating instead of anchored navigational safety beacons. While this reduces the direct footprint of the beacon, anchors keeping the floating beacons in place will still result in some scouring.
- Ensure safe practices during cleaning process to lower the risk of oil spills from vessels, standby emergency response kit. Necessary content of the emergency response kit includes absorbent pads, pillows and socks, disposable personal protective equipment (PPE), and disposable bin to contain contaminated materials.
- Anti-reflective coating on FPV panels to minimise reflection and "lake-effect" on avifauna

7.1.5 Impact Summary

Table 7.1 RIAM results for impact from Near-shore FPV at Sebarok on marine ecology and biodiversity.

Predicted Impact	**Sensitive Receptors**	**Predicted Impacts Without Mitigation**							**With Mitigation**		
		I	**M**	**P**	**R**	**C**	**ES**	**Impact Significance**	**M**	**ES**	**Residual Impact Significance**
Direct loss of habitat and scouring	Benthic organisms	2	-2	3	2	3	-32	Slight Negative	0	0	No Impact
	Corals	4	-2	3	2	3	-64	Minor Negative	-1	-32	Slight Negative
Entanglement / collision risk	Marine megafauna	5	-1	3	2	2	-35	Slight Negative	-1	-35	Slight Negative
Reduction in light availability, reduction of food source	Marine fauna	2	0	3	3	3	0	No Impact	0	0	No Impact
Water temperature change	Corals	4	-1	3	3	3	-36	Slight Negative	-1	-36	Slight Negative
	Benthic organisms	2	0	3	3	3	0	No Impact	0	0	No Impact
Alteration of dissolved oxygen level in water	Marine fauna	4	0	3	2	3	0	No Impact	0	0	No Impact
Water quality alteration due to biofouling	Marine fauna	4	0	3	2	3	0	No Impact	0	0	No Impact

Predicted Impact	**Sensitive Receptors**	**Predicted Impacts Without Mitigation**							**With Mitigation**		
		I	**M**	**P**	**R**	**C**	**ES**	**Impact Significance**	**M**	**ES**	**Residual Impact Significance**
Water quality changes related to system maintenance	Marine fauna and habitats	5	-1	2	2	3	-35	Slight Negative	-1	-35	Slight Negative
EMF emission	Elasmobranchs	4	-1	3	3	3	-36	Slight Negative	-1	-36	Slight Negative
	Cetaceans	4	-1	3	3	3	-36	Slight Negative	-1	-36	Slight Negative
	Benthic organisms	2	-1	3	3	3	-18	Slight Negative	-1	-18	Slight Negative
Reduction in foraging areas	Avifauna	5	0	3	3	3	0	No Impact	0	0	No Impact
Collision risk	Avifauna	5	-1	3	2	2	-35	Slight Negative	-1	-35	Slight Negative
Habitat alteration	Avifauna	5	-1	3	3	2	-40	Minor Negative	-1	-40	Minor Negative

7.2 Fairway and Navigation

7.2.1 Relevant Sensitive Receptors

The identified sensitive receptor that may be affected by the Project is the vessels coming in and out to the jetties at the south of Pulau Sebarok. To understand this receptor, one (1) year of AIS data was extracted to assess the impact to the traffic conditions in the area. Instead of more recent years, 2019 data was chosen as the representative year since the subsequent pandemic is expected to have decreased the volume of marine traffic. Findings from this analysis is presented below.

Data on vessel traffic in and around the Project area was collected from DHI's AIS database, which is updated real time by DHI as an internal support service for various DHI activities. The AIS data of 2019 shows the marine traffic at the southernmost area of Pulau Sebarok is very busy as noticeable with the dense overlay of tracks (Figure 7.4) but it does not cut across the Project area. The AIS data shows the traffic within the Project area is lesser in density as can be seen in Figure 7.4 with the lighter traffic tracks going across the project area.

Besides traffic density, a large proportion of tracks around Pulau Sebarok are of the vessels size classes (<100 m LOA) and tracks cutting across the Project area are mostly of the small vessels size classes (<50 m LOA). The larger vessels classes (>50 m LOA) tend to keep to the wider navigation channels. Notice that the dense overlay of tracks is beyond the Sebarok beacon to the south. This implies there are some navigational constraints, particularly for larger ships passing through this southern area.

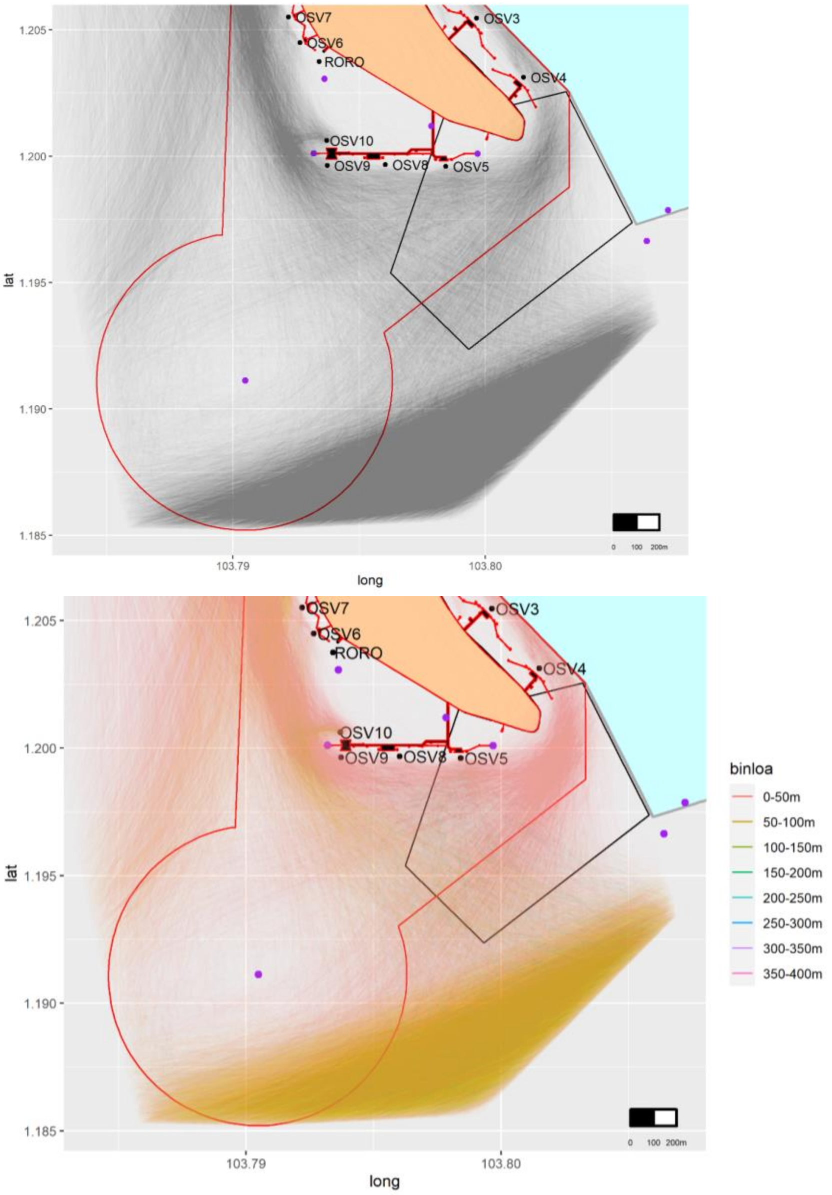


Figure 7.4 Typical traffic patterns around south of Pulau Sebarok (AIS data of entire 2019) overlaid with Project area (black polygons), navigation marks (purple points), fairways (blue polygon), and restricted areas (red polygon). Top image shows regular routes; Bottom image colours the routes by vessel size classes.

7.2.2 Evaluation Framework

The presence of the FPV takes up sea space which may otherwise be available for navigation and may be result in navigation safety to vessel manoeuvring in the vicinity. The assessment of these impacts is qualitative, based on experience and expert judgement.

7.2.3 Impact Assessment

This assessment comprises three parts, including impact on small vessels and large vessels that approach or depart from a jetty along Sebarok shoreline and impact on passing vessels.

Small Vessels Movement

It is typical of the smaller vessel sizes (<50 m LOA) to comprise of ferries, pilot vessels, port tenders, tugs, and other ancillary craft. These are likely to be the vessels which aid berthing operations at the Sebarok jetties and perform other miscellaneous activities such as cargo and personnel transfers. Due to their small size and shallow draught, they are ubiquitous throughout the study area (Figure 7.5).

The presence of small vessels is noticeably everywhere, which implies that such small craft are highly manoeuvrable and able to navigate safely around any obstacle in the sea. This is clearly present in that they steer around existing navigational marks (e.g., Sebarok beacon).

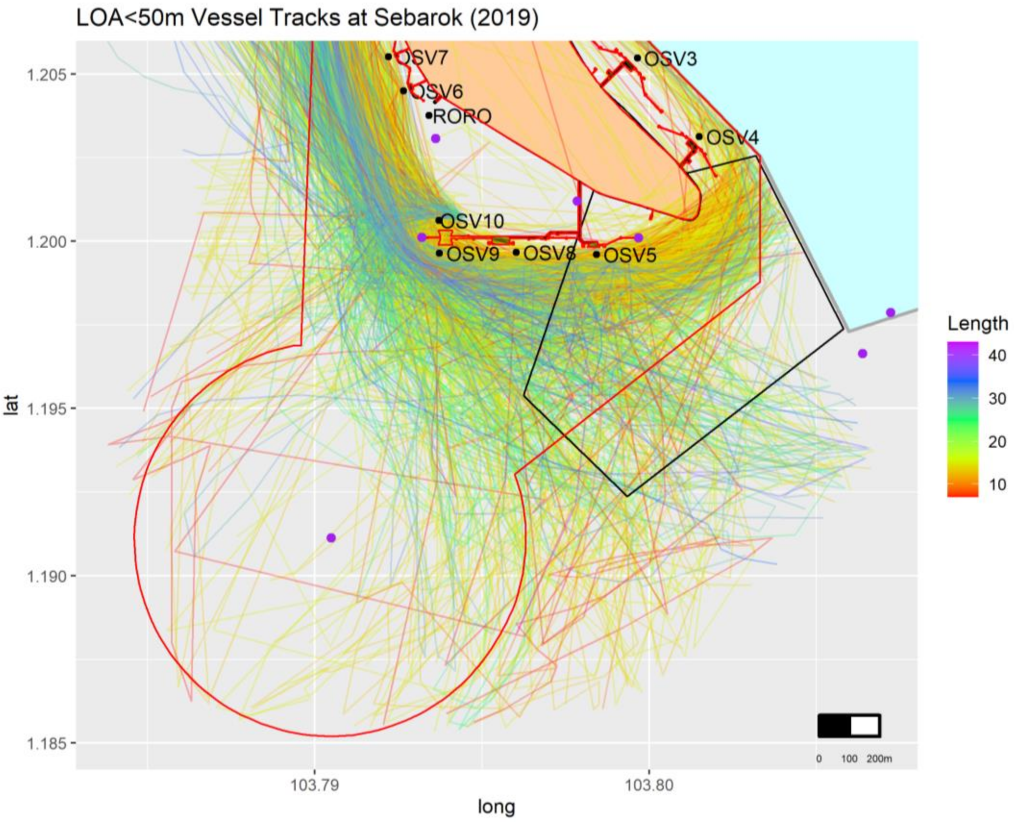


Figure 7.5 Incoming and outgoing movements at jetties OS3 to OSV10. Data extracted for vessels at LOA <50 m.

Large Vessels Movements

Contrary to the small sizes, the larger vessels (>50 m LOA) have clearer patterns, appearing to follow the navigation routes identified, i.e., Jong Fairway and Singapore Strait. Deeper draughts necessitate a wider clearance around Pulau Sebarok as can be seen from the distinct gap between the southwestern route nearby to Project area and the island. This route on approach to the southern jetties (OSV5, OSV8, OSV9, OSV10) shows the large vessels movement do not cut across the Project area. They instead occupy the southern portion of the Project area, leaving most of it untouched. It seems that the preferred approach for these vessels is to come south of Sebarok beacon instead of passing between the beacon and island. Again, such behaviour is typical of larger vessels as they attempt to avoid the shallow spots around Sebarok beacon. However, it was noted at the start of this section that the space between the beacon and island is used as a frequent route. This route is explored in the following.

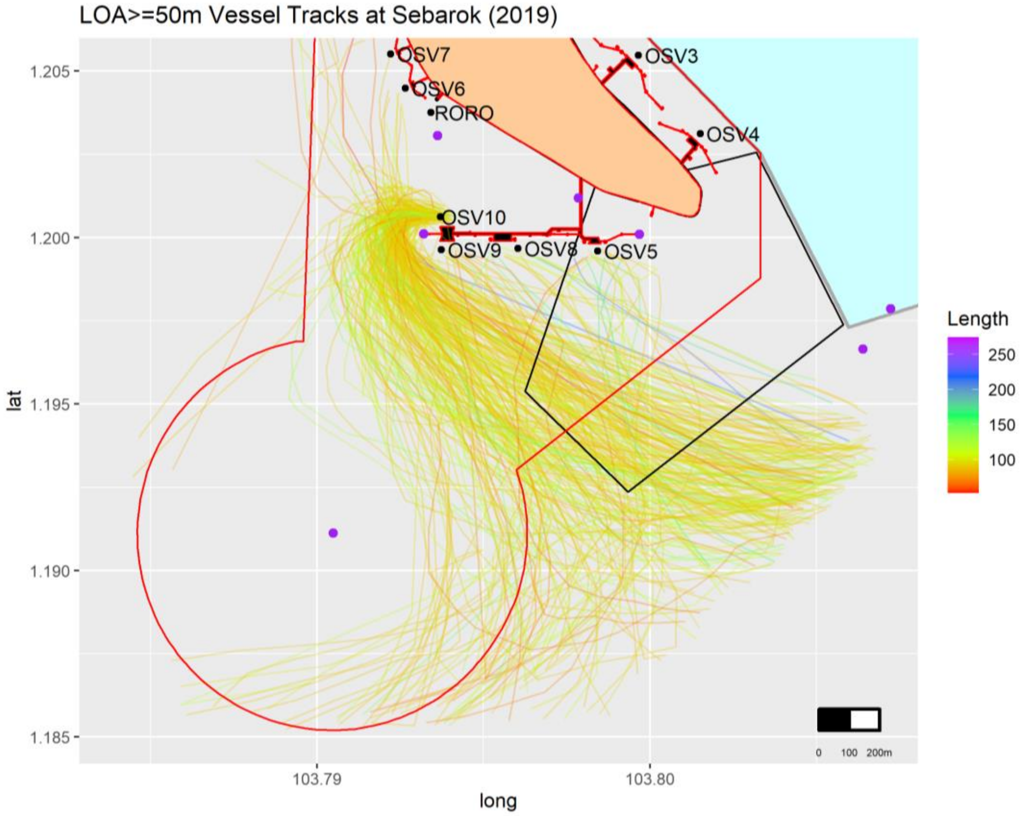


Figure 7.6 Incoming and outgoing tracks at jetties OSV3 to OSV10. Data extracted for vessels of LOA >=50 m.

Passing Vessels

Passing vessels which do not use the jetties at Sebarok followed the general routes which include cutting through the Project area. As noted above, the southern route through Project area comprised mostly of smaller vessels (<50 m LOA) as these were not constrained by draught and could pass between Sebarok beacon and the island without fear of grounding. The most important observation here, is the size of vessels which are all small. Thus, similar conclusions can be made for these passing vessels and those small vessels approaching the island. Their high manoeuvrability enables swift reactions to any marine obstacles.

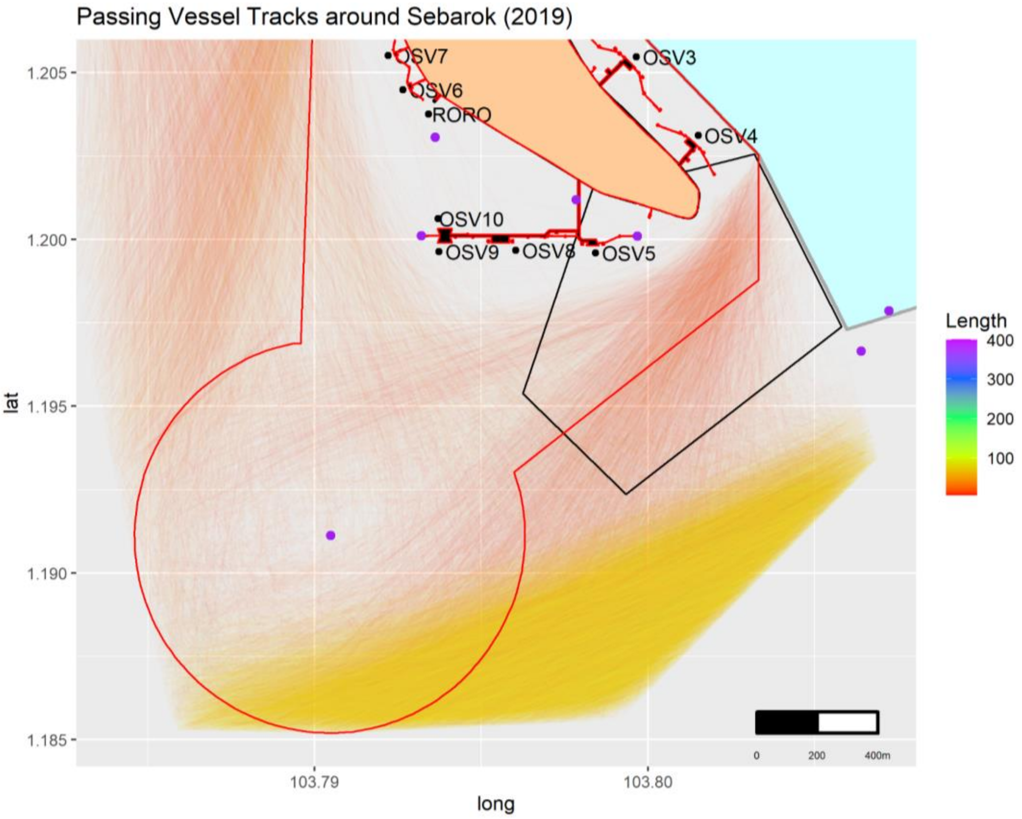


Figure 7.7 Passing vessel tracks around Project area (polygon in black outline).

7.2.4 Proposed Mitigation Measures

The proposed mitigation measures for impact to navigation safety include but not limited to:

- A Port Marine Notice shall be obtained for the Project and navigation charts updated
- Installation of navigation aids around the FPV and notified by port notices.
- Consultation with MPA during the planning process
- Implementation of regulatory requirements by MPA.

7.2.5 Impact Summary

In summary, small vessels (<50 m LOA) are highly manoeuvrable and should easily avoid deployed FPVs if marked with clear navigation aids and notified by port notices. Large vessels (>50 m LOA) rarely pass close to Pulau Sebarok and only come in proximity when berthing at the island jetties.

The traffic of vessels of 50 m LOA and above do not cut across the Project area, where it can conclude that the Project footprint will not affect the navigation safety to the large vessels.

Recognizing the movements of smaller vessels around the south of Pulau Sebarok, the presence of FPV will require additional navigation marks and implementation of regulatory requirements by MPA such as buffer zones and mooring, in the area to minimise allision risk by small passing/approaching/departing vessels.

Table 7.2 RIAM results for impact from Near-shore FPV at Sebarok on fairway and navigation.

Predicted Impact	**Sensitive Receptors**	**Predicted Impacts Without Mitigation**							**With Mitigation Measures**		
		I	**M**	**P**	**R**	**C**	**ES**	**Impact Significance**	**M**	**ES**	**Residual Impact Significance**
Impact to navigation safety	Marine vessels in vicinity	3	-2	3	2	2	-42	Minor Negative	-1	-21	Slight Negative

8 Decommissioning Phase Impacts

8.1 Impacts on Marine Ecology and Biodiversity

8.1.1 Relevant Sensitive Receptors

The post-operation phase of the near-shore FPV project is predicted to cause impacts on any flora and fauna which may have previously been impacted by the presence of the FPV. This could include benthic fauna which have colonised the project-related structures, or flora and fauna already found within the project area as described in Section 5.4.

8.1.2 Evaluation Framework

The decommissioning and removal of the near-shore FPV is predicted to impact marine ecology and biodiversity mainly through the physical act of structure removal. These are analysed and assessed qualitatively based on expert judgement. All other environmental conditions are returned to the natural state (pre-project) and thus no impacts are expected to occur.

8.1.3 Impact Assessment

8.1.3.1 Habitat damage during structure removal

As with the installation of the concrete sinkers, the removal of the concrete sinkers could potentially cause scouring of the benthic habitat if any of the sinkers are dragged across the seabed before being lifted. This would in turn cause ancillary damages to the seabed and potentially affect corals and other benthic organisms. Given that two of the concrete sinkers are located on the reef crest, there is a potentially Minor Negative change due to the removal of the project-related structures. This can potentially be mitigated by ensuring that concrete sinkers are immediately lifted without any dragging, or to leave the concrete sinkers in place (subject to navigational impact assessment, Section 8.2).

8.1.3.2 Loss of new artificial habitat

The concrete sinkers could have provided new substrate for benthic species such as corals (in shallower depths) or molluscs and crustaceans (in greater depths), and their removal could be detrimental. This is unlikely to be the case at greater depths as the baseline density of benthic organisms is low. The impact could be greater at shallower depths due to the potential of colonisation by coral species of conservation significance. The loss of habitat is thus assessed to be a Minor Negative change. However, this can be mitigated by either transplanting the corals and/or other organisms attached to the sinkers or leaving the concrete sinkers in place (subject to navigational impact assessment, Section 8.2).

Additionally, the PV panels themselves could potentially attract avifauna either through provision of roosting/nesting space or attraction of prey items such as insects. It was previously noted that there are insectivorous avifauna of note within the Project vicinity which could transit over Pulau Sebarok. The removal of the PV panels thus equates to the loss of potential habitat for avifauna and decrease in prey items. However, the occurrence of avifauna near Pulau Sebarok is low, due to the absence of good quality habitat. While avifauna may transit over the project area, better quality habitat at nearby Pulau Semakau is more likely to be chosen. Nevertheless, the occurrence of avifauna of international conservation significance leads to a potential for a Minor Negative impact to arise from the removal of the PV panels.

8.1.4 Proposed Mitigation Measures

The proposed mitigation measures include:

- Careful removal of concrete sinkers, ensuring they are immediately lifted without any drag
- Leaving the concrete sinkers in place, especially the ones located within the coral reef crest
- Removal and transplantation of benthic organisms found to be growing on concrete sinkers
- Relocation of nests found on PV panels to other suitable nesting sites

8.1.5 Impact Summary

Table 8.1 RIAM results for impact from Near-shore FPV at Sebarok on marine ecology and biodiversity.

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Residual Impact Significance
Habitat damage	Corals	4	-2	2	2	2	-48	Minor Negative	0	0	No Impact
	Benthic organisms	2	-2	2	2	2	-24	Slight Negative	0	0	No Impact
Loss of new artifical habitat	Benthic organisms	2	-2	3	3	2	-32	Slight Negative	0	0	No Impact
	Corals	4	-2	3	3	2	-64	Minor Negative	0	0	No Impact
	Avifauna	5	-1	3	3	2	-40	Minor Negative	-1	-40	Minor Negative

8.2 Impacts on Fairway and Navigation

8.2.1 Relevant Sensitive Receptors

The identified sensitive receptor that may be affected by the decommissioning of the near-shore FPV Project is the vessels coming in and out to the jetties at the south of Pulau Sebarok which have previously been impacted by the presence of the FPV as described in Section 7.2.

8.2.2 Evaluation Framework

The decommissioning of the FPV will involve the removal of the farm structure, mooring and concrete sinkers from the sea space which may affect the navigation safety to vessel manoeuvring in the vicinity. The assessment of these impacts is qualitative, based on experience and expert judgement.

8.2.3 Impact Assessment

Small Vessels Movement

No impact to the small vessels' movement is expected with the removal of FPV. However, the intention to retain the two concrete sinkers around the depth of -2 mCD to -4 mCD, adjacent to the P. Sebarok seawall may post as a navigation risk for small vessels sizes (<50 m LOA) which are ubiquitous throughout the study area.

Large Vessels Movements

No impact to the larger vessels (>50 m LOA) is expected, as they appeared to stay within the navigation routes identified, i.e., Jong Fairway and Singapore Strait. The removal of the FPV and the retaining of the two concrete sinkers nearby P. Sebarok seawall will not affect the navigation of these large vessels, because as shown in Section 7.2.3, the large vessels movement do not cut across the Project area and tends to avoid shallow area.

Passing Vessels

No impact to the passing vessels comprised mostly of smaller vessels (<50 m LOA) is expected from the removal of the FPV. Similarly with small vessels, the two concrete sinkers remaining between the depth of -2 mCD to -4 mCD may post as a navigation risk such as grounding as they are constrained by draught and could navigate at shallower area.

8.2.4 Proposed Mitigation Measures

The proposed mitigation measures for impact to navigation safety include but not limited to:

- A Port Marine Notice to be obtained for the removal of the Project and navigation charts updated
- Consultation with MPA regarding retaining any concrete sinkers in the seabed
- Installation of navigation aids around the two concrete sinkers and notified by port notices

8.2.5 Impact Summary

Predicted Impact	**Sensitive Receptors**	**Predicted Impacts Without Mitigation**							**With Mitigation Measures**		
		I	**M**	**P**	**R**	**C**	**ES**	**Impact Significance**	**M**	**ES**	**Residual Impact Significance**
Impact to navigation safety	Marine vessels in vicinity	3	-1	3	2	2	-21	Slight Negative	0	0	No Impact

9 Impact Significance Summary

This section summarises possible significant impacts arising during the installation phase of the Project. Alongside the identified impacts, suitable mitigation measures and established best management practices are recommended.

Table 9.1 Impact significance summary table for Near-shore FPV Farm at Sebarok.

Report Section	Predicted Impact	Receptor	Impact Significance	ES	I	M	P	R	C	Management and Mitigation Measures	Residual Impact
Construction Phase											
Marine Ecology and Biodiversity											
6.1.3	Ancillary habitat damage due to installation process of the placement of concrete sinkers.	Corals	Minor Negative	-48	4	-2	2	2	2	• Careful placement of the concrete sinkers to avoid ancillary habitat damage. • As much as possible, place the two concrete sinkers in the coral habitat in areas with less coral coverage. • Pre-construction coral survey to establish the affected corals due to the placement of the concrete sinkers and to relocate the affected corals • Consider shifting the concrete sinkers away from corals areas	Slight Negative
		Benthic organisms	Slight Negative	-24	2	-2	2	2	2		Slight Negative
Operation Phase											
Marine Ecology and Biodiversity											

Report Section	Predicted Impact	Receptor	Impact Significance	ES	I	M	P	R	C	Management and Mitigation Measures	Residual Impact
7.1.3.1	Direct loss of habitat due to concrete sinker and scouring from the movement of the concrete sinkers and bottom chains	Corals	Minor Negative	-64	4	-2	3	2	3	• Design of mooring lines to avoid excess slack to minimise the chains from scouring the seabed. • Consider design the concrete sinkers in a way to enhance the potential for substrate provision, such as increasing the topographical complexity by including crevices and pits instead of smooth surfaces. • Ensure sufficient weight of the concrete anchors to avoid scouring of the seabed during operation • Install floating instead of anchored navigational safety beacons.	Slight Negative
		Benthic organisms	Slight Negative	-32	2	-2	3	2	3		No Impact
7.1.3.2	Entanglement and collision risk	Marine megafauna	Slight Negative	-35	5	-1	3	2	2	Not required.	Slight Negative
7.1.3.3	Reduction of food source due to reduction in light availability (shading)	Marine fauna	No Impact	0	2	0	3	3	3	Not required.	No Impact
7.1.3.4	Water temperature change	Corals	Slight Negative	-36	4	-1	3	3	3	Not required.	Slight Negative
		Benthic organisms	No Impact	0	2	0	3	3	3	Not required.	No Impact

Report Section	Predicted Impact	Receptor	Impact Significance	ES	I	M	P	R	C	Management and Mitigation Measures	Residual Impact
7.1.3.5	Alteration in dissolved oxygen level	Marine fauna	No Impact	0	4	0	3	2	3	Not required.	No Impact
7.1.3.5	Biofouling of membrane in contact with water	Marine fauna	No Impact	0	4	0	3	2	3	Not required.	No Impact
7.1.3.5	Water quality changes related to system maintenance	Marine fauna and habitats	Slight Negative	-35	5	-1	2	2	3	• Ensure safe practices during cleaning process to lower the risk of oil spills from vessels, standby emergency response kit. • Use eco-labelled detergents, benchmarked against Singapore and international guidelines for cleaning the FPV modules	Slight Negative
7.1.3.6	Impact of electromagnetic field (EMF)	Elasmobranchs	Slight Negative	-36	4	-1	3	3	3	Not required.	Slight Negative
		Cetaceans	Slight Negative	-36	4	-1	3	3	3	Not required.	Slight Negative
		Benthic organisms	Slight Negative	-18	2	-1	3	3	3	Not required.	Slight Negative
7.1.3.7	Reduction in foraging areas	Avifauna	No Impact	0	5	0	3	3	3	Not required.	No Impact
7.1.3.7	Collision risk	Avifauna	Slight Negative	-35	5	-1	3	2	2	Best management practice such as anti-reflective coating on the PV panels to minimise reflection	Slight Negative
7.1.3.8	Habitat alteration	Avifauna	Minor Negative	-40	5	-1	3	3	2	Not required.	Minor Negative

Report Section	Predicted Impact	Receptor	Impact Significance	ES	I	M	P	R	C	Management and Mitigation Measures	Residual Impact
Fairway and Navigation											
7.2.3	Impact to vessels movement and navigation safety	Marine navigation	Minor Negative	-42	3	-2	3	2	2	• Installation of navigation aids • Port Marine Notice to be obtained and navigation charts to be updated • Consultation with MPA during planning process and implementation of the regulatory requirements	Slight Negative
Post Operation/Decommissioning Phase											
Marine Ecology and Biodiversity											
8.1.3.1	Habitat damage during structure removal	Corals	Minor Negative	-48	4	-2	2	2	2	Careful removal of concrete sinkers, ensuring they are immediately lifted without any drag.	No Impact
		Benthic organisms	Slight Negative	-24	2	-2	2	2	2		No Impact
8.1.3.2	Loss of new artificial habitat	Benthic organisms	Slight Negative	-32	2	-2	3	3	2	Removal and transplantation of benthic organisms found to be growing on concrete sinkers.	No Impact
		Corals	Minor Negative	-64	4	-2	3	3	2	Leaving the concrete sinkers in place, especially the ones located within the coral reef crest	No Impact
		Avifauna	Minor Negative	-40	5	-1	3	3	2	Relocation of nests found on PV panels to other suitable nesting sites	Minor Negative
Fairway and Navigation											

Report Section	Predicted Impact	Receptor	Impact Significance	ES	I	M	P	R	C	Management and Mitigation Measures	Residual Impact
8.2.3	Impact to vessels movement and navigation safety	Marine navigation	Slight Negative	-21	3	-1	3	2	2	• Installation of navigation aids • Port Marine Notice to be obtained and navigation charts to be updated • Consultation with MPA regarding retaining concrete sinkers in seabed	No Impact

10 Environmental Management Framework

This section outlines mitigation, monitoring and management measures applicable for the Project. Based on the impact assessment, there are no high potential adverse effects from the Project activities that warrants environmental management and monitoring during the construction, operation and decommissioning phase. The majority of the impacts are Slight to Minor Negative in nature. In addition to mitigation measures described for each of the identified impacts in Section 6, Section 7 and Section 8, best management practices that are common across installation, operation and decommissioning of FPV farm in marine water are to be implemented for the Project.

However, it is noteworthy that majority of the impacts are associated with marine ecology and biodiversity especially coral habitats. In order to mitigate the impacts to coral habitats, new mooring plan was established by optimising the mooring layout to stay outside of coral reefs to reduce the impact of direct loss of marine habitat. As such, a pre-construction marine habitat (i.e., coral and benthic fauna) survey to confirm the corals and benthic fauna presence at the new concrete sinker locations is proposed. This should be followed with quarterly marine habitat monitoring for up to a year (at least) after deployment to document any potential impacts arising from the project.

As the Project sits within a restricted zone whereby anchoring and mooring of vessels are prohibited, planning process of the deployment of the FPV farm should include consultation with MPA to ensure impact to navigation is mitigated in accordance with the regulatory requirements. Additionally, MPA to also be consulted for the planning process of the decommissioning of the FPV farm.

11 Conclusion

In order to assess the environmental impact of installing a near-shore Floating Photovoltaic (FPV) system south of Pulau Sebarok, baseline surveys for identified environmental receptors such water quality, marine ecology and biodiversity as well as predictive modelling of water quality was carried out. This was accompanied by an impact assessment of the proposed activities.

The baseline surveys revealed that the physico-chemical water quality within the Project area is within the acceptable ASEAN MWQC limits and when compared against other previously published literature, the water quality values in the area generally has similar characteristics. The marine ecological receptors surveyed showed high percentage cover of hard corals along the reef crest and reef slope at the coastline of Pulau Sebarok. The seabed below the FPV footprint is a mixture of coral rubbles and rocks with no coral or seagrass communities. No sensitive receptor was observed at the intertidal area and the plankton community was generally low in abundance and diversity.

The Project site is adjacent to Jong Fairway and Singapore Strait, some of the busiest navigation channels around Singapore waters. The site is also sits within the MPA designated restricted area whereby vessels are prohibited from anchoring and mooring within the area. The nearest jetty to the Project site is OSV 4 at Pulau Sebarok facing the Jong Fairway, at approximately 125m from the Project site.

The environmental impacts due to the deployment of the FPV farm, are mostly Slight Negative, with one issue assessed as Minor Negative. The Slight Negative impacts include impact to water quality due to resuspension of sediments and impact of the suspended plumes to the marine ecology and biodiversity. On the other hand, habitat damage due to placement of concrete sinkers is expected to be of Minor Negative because two of the anchor points are within an area with live coral cover of up to 44.3%. With careful placement of the sinkers during installation and potential of the sinkers acting as artificial reef to encourage recolonisation, the damage to the habitat can be minimised. In addition, taking into account the potential impact to the corals, a new mooring plan has been established to reduce the damage to the habitat by optimising the location of the two concrete sinkers to stay outside of the coral reefs. This further mitigate the impact to the coral habitats.

Meanwhile, the environmental impacts identified during the operation of the FPV farm is impact mainly due to the physical presence. Slight Negative impact significance is predicted for direct loss of habitat due to concrete sinkers and bottom chains, increase of suspended sediments to coral and benthic organisms, impact to water quality due to maintenance works, impact to the marine fauna due to increase in ambient temperatures and impacts to marine navigation in the area. Minor Negative impact significant is predicted for marine fauna and biodiversity due to direct loss of habitat due to installation of navigation beacons, and entanglements or collision risk to biodiversity such as marine megafauna and avifauna. The removal of the FPV farm is the key potential environmental impact identified for the decommissioning phase. Impacts to marine ecology and biodiversity due to the loss of newly created habitat and to the navigation around the area are Minor to Slight Negative.

Each of these impacts have been assessed and specific mitigation measures to address the impacts has been recommended in Section 6, Section 7 and Section 8. There is no specific environmental monitoring to be implemented as impacts are minor to slight in nature. However, the proposed new mooring plan to optimise the two concrete sinkers to stay outside of the coral reefs in order to reduce the impact of direct loss of marine habitat will need to be verified. As such, a pre-construction marine habitat (i.e., coral and benthic fauna) monitoring to assess the corals and benthic fauna presence at the new concrete sinker locations is proposed. This is followed with quarterly marine habitat monitoring for up to a year after deployment to ensure impact to marine habitat is reduced with the optimisation of the concrete sinkers. In addition, best management practices that are common to deployment and operation of FPV farm should still be implemented.

Overall, the environmental impact levels due to the Project are not considered significant, in the sense that they are all able to be managed or mitigated.

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