Proposed Enhancement Jetty Works at Ubin Living Lab, Pulau Ubin

Environmental Impact Assessment Report (Final)

National Parks Board

Environmental Impact Assessment Report

December 2023

The expert in WATER ENVIRONMENTS

This report has been prepared under the DHI Business Management System certified by Bureau Veritas to comply with ISO 9001 (Quality Management), ISO 14001 (Environmental Management), ISO 45001 (Occupational Health and Safety Management) and bizSAFE STAR

Proposed Enhancement Jetty Works at Ubin Living Lab, Pulau Ubin

Environmental Impact Assessment Report (Final)


Ubin Living Lab, Pulau Ubin

Prepared for	National Parks Board
Represented by	Mr Konrad Teo

Project manager	Cheok Zi Yu
Quality supervisor	Le Thi Phuong Thao

Project number	61802820
Approval date	15 December 2023
Revision	06
Classification	Confidential

DHI Water & Environment (S) Pte Ltd • 2 Venture Drive • #18-18 Vision Exchange • Singapore• 608526
Telephone: +65 67776330 • Telefax: +65 67773537 • dhi@dhi.com.sg•

CONTENTS

1 Introduction ... 1
1.1 Background ... 1
1.2 EIA Objectives ... 2

2 Project Description ... 3
2.1 Project Location ... 3
2.2 Project Design ... 4
2.3 Project Timeline (2024 onwards) ... 6

3 Environmental Laws, Standards and Guidelines ... 7
3.1 EIA Process in Singapore ... 7
3.2 Relevant Singaporean Acts ... 8
3.3 Relevant Singapore Regulations and Guidelines ... 9
3.4 Applicable International Guidelines ... 9
3.4.1 World Bank / IFC ... 10
3.4.2 Other International Guidelines ... 10
3.5 Conventions, Treaties and Protocols ... 11

4 EIA Scope and Approach ... 12
4.1 Study scope ... 12
4.1.1 Spatial and Temporal Scope ... 12
4.1.2 Assessment Scope ... 13
4.1.2.1 Environmental Pressures ... 13
4.1.2.2 Sensitive Receptors ... 13
4.1.2.3 Potential Impacts ... 15
4.2 Study Approach ... 17
4.2.1 Measurement ... 17
4.2.1.1 Baseline Conditions ... 17
4.2.1.2 Impact Prediction ... 23
4.2.2 Assessment ... 27
4.2.2.1 Methodology ... 27
4.2.2.2 Assessment Criteria ... 30
4.2.3 Management and Mitigation ... 31
4.3 Reporting Flow ... 32

5 Construction Phase (Short-Term) Impacts ... 33
5.1 Coastal Dynamics ... 33
5.1.1 Relevant Key Receptors ... 33
5.1.2 Baseline Conditions ... 33
5.1.3 Evaluation Framework ... 48
5.1.4 Result and Discussion ... 51
5.1.5 Coastal Dynamics Summary ... 58
5.2 Sediment Plume ... 59
5.2.1 Relevant Key Receptors ... 59
5.2.2 Baseline Conditions ... 59
5.2.3 Evaluation Framework ... 62
5.2.4 Results and Discussion ... 63
5.2.5 Sediment Plume Summary ... 66
5.3 Pollutant Release ... 67
5.3.1 Relevant Key Receptors ... 67

5.3.2 Baseline Conditions ... 67
5.3.2.1 Seabed Sediment Quality ... 67
5.3.2.2 Heavy Metals in Sediment ... 69
5.3.2.3 Cyst ... 69
5.3.2.4 Marine Water Quality ... 70
5.3.3 Evaluation Framework ... 92
5.3.4 Results and Discussion ... 93
5.3.5 Pollution Release Summary ... 94
5.4 Air Quality ... 95
5.4.1 Relevant Key Receptors ... 95
5.4.2 Baseline Conditions ... 95
5.4.2.1 Local Monitoring Data ... 95
5.4.2.2 Secondary Data ... 102
5.4.3 Evaluation Framework ... 105
5.4.4 Results and Discussion ... 107
5.4.5 Air Quality Impact Summary ... 108
5.5 Airborne Noise ... 109
5.5.1 Relevant Key Receptors ... 109
5.5.2 Baseline Conditions ... 109
5.5.3 Evaluation Framework ... 115
5.5.4 Results and Discussion ... 118
5.5.5 Airborne Noise Summary ... 121
5.6 Underwater Noise ... 122
5.6.1 Relevant Key Receptors ... 122
5.6.2 Baseline Conditions ... 122
5.6.3 Evaluation Framework ... 127
5.6.4 Results and Discussion ... 127
5.6.5 Underwater Noise Summary ... 128
5.7 Marine Ecology and Biodiversity ... 129
5.7.1 Environmental Baseline, Relevant Key Receptors and Pressures ... 129
5.7.1.1 Intertidal Surveys ... 129
5.7.1.2 Subtidal Surveys ... 136
5.7.2 Evaluation Framework ... 140
5.7.3 Results and Discussion ... 147
5.7.4 Mitigation Measures ... 151
5.7.5 Marine Ecology and Biodiversity Impact Summary ... 156
5.8 Terrestrial Ecology and Biodiversity ... 157
5.8.1 Environmental Baseline, Relevant Key Receptors and Pressures ... 157
5.8.1.1 Terrestrial Flora ... 157
5.8.1.2 Terrestrial Fauna: Transect Survey ... 159
5.8.1.3 Terrestrial Fauna: Camera Trapping ... 162
5.8.2 Evaluation Framework ... 164
5.8.3 Results and Discussion ... 164
5.8.4 Mitigation Measures ... 166
5.8.5 Terrestrial Ecology and Biodiversity Impact Summary ... 168
5.9 Marine Navigation ... 170
5.9.1 Relevant Key Receptors and Pressures ... 170
5.9.2 Evaluation Framework ... 170
5.9.3 Results and Discussion ... 171
5.9.4 Marine Navigation Impact Summary ... 172
5.10 Aquaculture ... 173
5.10.1 Relevant Key Receptors and Pressures ... 173
5.10.2 Evaluation Framework ... 173
5.10.3 Results and Discussion ... 174
5.10.4 Mitigation Measures ... 176
5.10.5 Aquaculture Impact Summary ... 176
5.11 Socio-economic ... 178

5.11.1 Relevant Key Receptors and Pressures ... 178
5.11.2 Evaluation Framework ... 178
5.11.3 Results and Discussions ... 180
5.11.4 Mitigation Measures ... 182
5.11.5 Socio-economic Impact Summary ... 184
5.12 Transboundary Impact ... 185
5.12.1 Relevant Key Receptors and Pressures ... 185
5.12.2 Evaluation Framework ... 186
5.12.3 Results and Discussions ... 186
5.12.4 Transboundary Impact Summary ... 187

6 Post-Construction Phase (Long-Term) Impacts ... 188
6.1 Hydrodynamics ... 188
6.1.1 Relevant Key Receptors ... 188
6.1.2 Environmental Baseline ... 188
6.1.3 Evaluation Framework ... 188
6.1.4 Results and Discussion ... 190
6.1.5 Hydrodynamics Summary ... 208
6.2 Ship Wake ... 209
6.2.1 Relevant Key Receptors ... 209
6.2.2 Evaluation Framework ... 209
6.2.3 Results and Discussion ... 218
6.2.4 Ship Wake ... 236
6.3 Propeller Wash-Induced Sediment Plume ... 237
6.3.1 Relevant Key Receptors ... 237
6.3.2 Evaluation Framework ... 237
6.3.3 Results and Discussion ... 238
6.3.4 Propeller wash-induced Sediment Plume Summary ... 241
6.4 Marine Biodiversity and Shorelines ... 242
6.4.1 Relevant Key Receptors and Pressures ... 242
6.4.2 Evaluation Framework ... 242
6.4.3 Results and Discussion ... 242
6.4.4 Mitigation Measures ... 246
6.4.5 Marine Biodiversity and Shorelines Impact Summary ... 247
6.5 Terrestrial Biodiversity ... 249
6.5.1 Relevant Key Receptors and Pressures ... 249
6.5.2 Evaluation Framework ... 249
6.5.3 Results and Discussion ... 249
6.5.4 Mitigation Measures ... 250
6.5.5 Terrestrial Biodiversity Impact Summary ... 251
6.6 Marine Navigation ... 252
6.6.1 Relevant Baseline Features, Key Receptors and Pressures ... 252
6.6.1.1 Environmental Baseline ... 252
6.6.2 Evaluation Framework ... 258
6.6.3 Results and Discussion ... 259
6.6.4 Marine Navigation Impact Summary ... 260
6.7 Aquaculture ... 261
6.7.1 Relevant Key Receptors and Pressures ... 261
6.7.2 Assessment Framework ... 261
6.7.3 Results and Discussions ... 261
6.7.4 Mitigation Measures ... 263
6.7.5 Aquaculture Impact Summary ... 264
6.8 Socio-economic ... 265
6.8.1 Relevant Key Receptors and Pressures ... 265
6.8.2 Evaluation Framework ... 265
6.8.3 Results and Discussion ... 265

6.8.4 Mitigation Measures ... 266
6.8.5 Socio-economic Impact Summary ... 266
6.9 Transboundary Impacts ... 267
6.9.1 Relevant Key Receptors and Pressures ... 267
6.9.2 Evaluation Framework ... 267
6.9.3 Results and Discussions ... 267
6.9.4 Transboundary Impact Summary ... 268
6.10 RIAM Impact Significance Summary ... 269
6.10.1 Construction Phase ... 269
6.10.2 Post-Construction Phase ... 273

7 Environmental Management Framework ... 277
7.1 Environmental Quality Objectives ... 277
7.2 Environmental Monitoring and Management Plan ... 277
7.2.1 EMMP Roles and Responsibilities ... 278
7.2.1.1 Employer ... 278
7.2.1.2 Contractor ... 278
7.2.1.3 Environmental Control Officer ... 278
7.2.1.4 Environmental Specialists ... 279
7.2.1.5 EMMP Consultant ... 279
7.3 Environmental Monitoring ... 279
7.4 Grievance Management ... 281
7.5 Management of Change ... 281
7.6 Environmental Auditing ... 282
7.7 Non-Compliance and Remedial Action ... 282
7.8 Environmental Impact Register ... 282

8 Conclusion ... 287

9 References ... 289

FIGURES

Figure 1.1 Location of the proposed development ... 1
Figure 2.1 Pulau Ubin visitor information map (Source: NParks, 2020) ... 3
Figure 2.2 Plan view of the proposed jetty and arrival pavilion, including the proposed working space around the jetty (Source: PAL Consultancy) ... 4
Figure 2.3 Construction equipment types to be used for the development (Top: for trimming of seabed; Middle: for micro piling; Bottom: for marine piling) ... 5
Figure 3.1 An illustration of the EIA Process in Singapore. The relevance and requirement of stakeholder engagement are project-dependent and can take place at various stages of the study ... 7
Figure 4.1 Overview of known environmental receptors in the study area ... 14
Figure 4.2 DHI's approach to environmental scoping, impact assessments and environmental management ... 17
Figure 4.3 Hierarchy of mitigation strategy adopted in this EIA ... 31
Figure 5.1 Bathymetric map of the Johor Strait, including the area of interest (black box) ... 34
Figure 5.2 Location of the ADCP deployment (ADCP1) as well as the current transects ... 35
Figure 5.3 Rose plot of current speed and direction ... 35
Figure 5.4 Rose plot of wave speed and direction ... 37
Figure 5.5 Time series of current speed (top) and current direction (bottom) measurements at ADCP1 ... 38
Figure 5.6 Time series of significant wave height (top), wave direction (middle) and wave time period (bottom) measurements at ADCP1 ... 39

Figure 5.7. Overview of area of interest in June 2022 imagery with digitised shoreline from June 2012 (red line) overlaid. Areas of focus A., B., C., and D. indicated by grey boxes. The proposed jetty is indicated by white lines 40
Figure 5.8. Area of focus A. Images show shoreline position change around the proposed jetty location from 2012 to 2022. The shoreline position from 2012 was digitised and then overlaid on the subsequent shoreline images. The 2012 shoreline position is indicated in red for all images. The proposed jetty is indicated by white lines 41
Figure 5.9. Area of focus B. Northwest point of Pulau Ketam with signs of erosion from June 2012 to June 2022. The largest deviation from the 2012 shoreline is approximately 24 m, indicated by the yellow dashed line 42
Figure 5.10. Area of focus C. Narrow area of Pulau Ketam from June 2012 to June 2022 42
Figure 5.11. Area of focus D. southeast of the proposed jetty site. Signs of erosion can be seen from June 2012 to June 2022 within the grey box 43
Figure 5.12. Close-up view of the eroded area in area D. Red path indicates the 2012 shoreline. Yellow dashed line highlighting a channel formed detaching the extension from the island 43
Figure 5.13. Overall shoreline erosion of Pulau Ubin based on satellite image analysis (Source: Surbana Jurong (SJ), 2015) 44
Figure 5.14 Shoreline survey segments along Pulau Ketam and Pulau Ubin 45
Figure 5.15 Dense and mature mangrove species along the shoreline of Pulau Ketam (top left and right); exposed sandy sediment along the shoreline of Pulau Ketam (bottom left); and infrastructure extending to the shoreline (bottom right) 45
Figure 5.16 Sandy shoreline of Ketam Beach surrounded by rocks and dense vegetation (top); mature and dense mangrove species (bottom) 46
Figure 5.17 Area near the proposed jetty location (top); shoreline of the Living Fisher Village with the rocky vegetated shoreline and man-made access point (bottom) 47
Figure 5.18 Dense and mature mangrove and terrestrial vegetation (top left); variation in sediment type along the shoreline (top right); unregulated man-made structure with garbage along the shore (bottom left); evidence of scarped shoreline erosion (bottom right) 48
Figure 5.19 DHI's calibrated and validated Singapore Straits' model domain and bathymetry. The location of the study area with 25 m resolution in the model is indicated by the red box 49
Figure 5.20 Baseline (top) and Construction Phase (bottom) profile for assessment of hydrodynamic impacts. The Construction Phase profile includes two (2) piling locations (i.e., Pile 1 and Pile 2) and two (2) trimming locations (i.e., TR1 in the seabed and TR2 in the shoreline) with a trimming volume of 200 m^3 each 50
Figure 5.21 Mean current speed during NE monsoon in El Niño (left column) and La Niña (right column) years, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios 52
Figure 5.22 Difference in mean current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon in El Niño (left column) and La Niña (right column) years 52
Figure 5.23 Mean current speed during NE monsoon (left) and SW monsoon (right) in the Neutral year, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios 53
Figure 5.24 Difference in mean current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon (left) and SW monsoon (right) in the Neutral year 53
Figure 5.25 95th percentile current speed during NE monsoon in El Niño (left column) and La Niña (right column) years, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios 54
Figure 5.26 Difference in 95th percentile current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon in El Niño (left column) and La Niña (right column) years 54

Figure 5.27 95th percentile current speed during NE monsoon (left) and SW monsoon (right) in the Neutral year, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios 55
Figure 5.28 Difference in 95th percentile current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon (left) and SW monsoon (right) in the Neutral year 55
Figure 5.29 Slackwater duration (Current speeds <0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña 57
Figure 5.30 Slackwater duration (currents <0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon 58
Figure 5.31. Hand auger sediment core location (top left), an example of the extraction process (top right), and final sample (bottom) 60
Figure 5.32 Location for terrestrial sediment (HA1) sample 61
Figure 5.33 Scenario for the sediment plume modelling, involving two (2) trimming areas and four (4) piling locations. Black points indicate the location of sediment release from the works 63
Figure 5.34 Mean incremental SSC from piling and trimming works during El Niño year, NE monsoon 64
Figure 5.35 95th percentile incremental SSC from piling and trimming works during El Niño year, NE monsoon 64
Figure 5.36 Percentage of time in exceedance of 5 mg/l for SSC in the study area, during El Niño year, NE monsoon 65
Figure 5.37 Percentage of time in exceedance of 10 mg/l for SSC in the study area, during El Niño year, NE monsoon 65
Figure 5.38 Percentage of time in exceedance of 25 mg/l for SSC in the study area, during El Niño year, NE monsoon 66
Figure 5.39 Location of the marine sediment quality survey point (SQ1) 67
Figure 5.40 Operation of Van Veen grab sampler 68
Figure 5.41 Sediment profiles at SQ1 showing the particle size distribution of sediments found 68
Figure 5.42 Locations of marine water quality survey (WQ01-03) 70
Figure 5.43 Median temperature results across all three (3) locations with error bars 74
Figure 5.44 Median pH results across all three (3) locations with error bars 75
Figure 5.45 Median salinity results across all three (3) locations with error bars 76
Figure 5.46 Median turbidity results across all three (3) locations with error bars 77
Figure 5.47 Turbidity profiles for each water quality station (note that the x- and y- axes ranges vary for each plot) 77
Figure 5.48 Median dissolved oxygen results across all three (3) locations with error bars 78
Figure 5.49 Maximum Secchi disc depth results across all three (3) locations 79
Figure 5.50 TSS concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides 82
Figure 5.51 Total nitrogen (TN), Total Ammoniacal Nitrogen (TAN), Nitrate and Nitrite concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides 83
Figure 5.52 Total Phosphorous (TP) (top) and phosphate (bottom) concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides 84
Figure 5.53 BOD_5 concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides 85

Figure 5.54 Chlorophyll-a concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 86
Figure 5.55 Faecal coliform concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 87
Figure 5.56 Enterococci concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 88
Figure 5.57 Arsenic concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 89
Figure 5.58 Cadmium concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 89
Figure 5.59 Chromium concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 90
Figure 5.60 Copper concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 90
Figure 5.61 Nickel concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 91
Figure 5.62 Zinc concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides.......... 91
Figure 5.63 Location of baseline ambient air quality monitoring station (AQ1) 96
Figure 5.64 Air monitoring set-up on-site 97
Figure 5.65 Measured 24-hour average concentrations of $PM_{2.5}$ at AQ1 99
Figure 5.66 Measured 24-hour average concentrations of PM_{10} at AQ1 99
Figure 5.67 Measured hourly concentrations of $PM_{2.5}$ at AQ1 100
Figure 5.68 Measured hourly concentrations of PM_{10} at AQ1 100
Figure 5.69 Measured hourly concentrations of NO_2 at AQ1.......... 100
Figure 5.70 Measured hourly concentrations of CO at AQ1 101
Figure 5.71 Measured 8-hour average concentrations of CO at AQ1 101
Figure 5.72 Measured 8-hour average concentrations of O_3 at AQ1.......... 102
Figure 5.73 Locations of baseline airborne noise monitoring stations (SN1, SN2 and N1)..... 110
Figure 5.74 Continuous noise monitoring data recorded at N1, noise criteria for type c) other premises.......... 113
Figure 5.75 Location of underwater noise monitoring station (UN1) 122
Figure 5.76 Passing vessel recorded by AIS data between 22 November and 06 December 2022. Label A represents the underwater noise monitoring area UN1 124
Figure 5.77 Sound pressure level distribution over time (top) and spectrograms of the 1/3 octave band-analysis (bottom) for UN1. The colour legend presented on the right side of the spectrogram indicates the sound pressure level (SPL) in decibels (dB); the vertical axis on the left side of the spectrogram indicates the frequency band in hertz (Hz). Label A indicates the acoustic signature of tidal currents, Label B shipping noise and Label C tonal noise 125
Figure 5.78 Density probability spectrograms for the entire recording period at UN1. The 5th, 50th, and 95th percentiles and RMS are plotted. Sample density is the spectral probability density 126
Figure 5.79 Underwater sound map for piling work with frequency range 100 Hz to 1250 Hz relevant to fishes. The red dots represent marine aquaculture farms in the region of interest. Black stripes box represents the fish farming zones 128
Figure 5.80 Placement of 0.25 m^2 quadrats within the irregular rocky intertidal area based on the VQP method. Red dots: Survey location marked by GPS; Squares: three (3) or six (6) quadrats randomly placed around the survey location. For this study, six quadrats per point were used 130
Figure 5.81 Images showing (left) an overview of the intertidal area at ULL and (right) a surveyor quantifying benthic coverage on the intertidal area 130
Figure 5.82 Map of the locations of the Visual Quadrat Points (VQP) carried out at the intertidal areas around ULL 131
Figure 5.83 Mean density (±SE) of different classes of fauna detected during VQP surveys. 132

Figure 5.84 Survey photographs depicting the overview of the intertidal area and various fauna found there 133
Figure 5.85 Map of the mangrove transects carried out and the locations of the conservation significant species found during surveys. Note that two *Ceriops* sp. were found within 50 m of the jetty footprint 134
Figure 5.86 DHI surveyor carrying out visual transect walk-through survey.... 135
Figure 5.87 Images of the mangrove species found during mangrove surveys 135
Figure 5.88 DHI surveyor operating the grab sampler (left) and DHI biologist counting and sorting specimens (right).... 136
Figure 5.89 Map showing the benthic composition (based on abundance) of each of the five classes of organisms at SQ1 137
Figure 5.90 Representative photos from the 5 classes of organisms recorded from the sampling stations 138
Figure 5.91 Map showing three (3) spot dive locations, SC01 to 03 139
Figure 5.92 Images of CS fauna species found during fish and coral spot dive surveys 140
Figure 5.93 Map showing the locations of the flora study area and the three (3) sampling 15 x 15 m plots, and one (1) 50 x 5 m flora transect. Locations of various conservation significant species are shown at points on the map, this includes one conservation significant species within the project footprint and development working area. ... 158
Figure 5.94 Locations of line transects and camera traps for terrestrial fauna surveys around ULL.... 161
Figure 5.95 Images of selected fauna species found around ULL. The Arrow Emperor and Malayan Crow are both locally "Critically Endangered", while the Oriental Magpie-Robin is locally "Vulnerable" 162
Figure 5.96 Example images of DHI Camera trap deployment and day and night footage captured by the Camera Trap 163
Figure 5.97 Singapore Port Limit and proximity to study area.... 185
Figure 6.1 Post-Construction Phase final profile for assessment of hydrodynamic impacts. The profile includes four (4) piling locations (i.e., Pile 1, Pile 2, Pile 3, and Pile 4) and two (2) trimming locations (i.e., TR1 in the seabed and TR2 in the shoreline) with a trimming volume of 200 m^3 each 189
Figure 6.2 Mean current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña 191
Figure 6.3 Mean current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon 192
Figure 6.4 95th percentile current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña.... 194
Figure 6.5 95th percentile current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon 195
Figure 6.6 Slackwater duration (Current speeds <0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-

Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña.. 197
Figure 6.7 Slackwater duration (currents <0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon 198
Figure 6.8 Percentage of time when current speeds exceeded 2.0 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña.. 199
Figure 6.9 Percentage of time when current speeds exceeded 2.0 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon.. 200
Figure 6.10 Percentage of time when current speeds exceeded 3.5 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña.. 201
Figure 6.11 Percentage of time when current speeds exceeded 3.5 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon.. 202
Figure 6.12 Mean BSS during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña................. 204
Figure 6.13 Mean BSS during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon 205
Figure 6.14 95th percentile BSS during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña 207
Figure 6.15 95th percentile BSS during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW

monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon 208
Figure 6.16 Proposed future vessel routes by MPA (Source: Client) 210
Figure 6.17 Ship wake assessment area for Pulau Ubin and Pulau Ketam shorelines........... 212
Figure 6.18 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ubin shoreline 215
Figure 6.19 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ketam shoreline 216
Figure 6.20 Location of BSS extraction points for impact assessment of ship wake impacts on the shoreline.. 217
Figure 6.21 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 1 for varying vessel speeds of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)... 219
Figure 6.22 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 220
Figure 6.23 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 221
Figure 6.24 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 222
Figure 6.25 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 223
Figure 6.26 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 224
Figure 6.27 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 226
Figure 6.28 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 227
Figure 6.29 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 228
Figure 6.30 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 229
Figure 6.31 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 230
Figure 6.32 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right).. 231
Figure 6.33 Time series of mean BSS generated by currents (derived from HD) for Pulau Ubin and Pulau Ketam shorelines. Potential erosion occurs when BSS is >0.14 N/m^2 233
Figure 6.34 Time series of BSS generated by current (HD) and ship wake at Area 1 mangrove for Pulau Ubin shoreline (UB-A01M). Each line represents the calculated BSS caused by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2.. 234
Figure 6.35 Time series of BSS generated by current (HD) and ship wake at Area 3 intertidal zone for Pulau Ubin shoreline (UB-A03N). Each line represents BSS at different vessel speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2........ 235

Figure 6.36 Time series of BSS generated by current (HD) and ship wake at Area 3 Pulau Ketam shoreline (KT-A03). Each line represents BSS at different vessel speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2 236
Figure 6.37 Vessel track for propeller wash-induced sediment modelling.............................. 238
Figure 6.38 Mean incremental SSC from the future vessel traffic activities during El Niño year, NE monsoon 239
Figure 6.39 95th percentile incremental SSC from the future vessel traffic activities during El Niño year, NE monsoon... 239
Figure 6.40 Percentage of time in exceedance of 5 mg/l for SSC from the future vessel traffic activities during El Niño year, NE monsoon.. 240
Figure 6.41 Total bed thickness change from the future vessel traffic activities during El Niño year, NE monsoon. Positive (yellow to red colour) and negative (blue colour) values indicate changes in sedimentation and erosion respectively 241
Figure 6.42 The black polygon indicating the area where the subset AIS data around the Project area was extracted for more detailed analyses....................................... 253
Figure 6.43 Distribution of vessel tracks based on mean Speed Over Ground (SOG) from the subset 2019 AIS data... 254
Figure 6.44 Distribution of vessel tracks (top) and percentage (bottom) based on Length Overall (LOA) from the subset 2019 AIS data 255
Figure 6.45 Distribution of vessel Length Overall (LOA) and Speed Over Ground (SOG) from the subset AIS data. The red box indicates typical vessel sizes, with LOA of <13 m, for SOG >12 knots 256
Figure 6.46 Distribution of vessel type and Speed Over Ground (SOG) from the subset AIS data 257
Figure 6.47 Distribution of the total number of vessels' tracks per month in 2019, obtained from the subset AIS data.. 258
Figure 7.1 EMMP Framework 277

TABLES

Table 3.1 Objectives of key EIA stages in Singapore... 8
Table 4.1 Identified environmental pressures arising from the construction and operation of Project 13
Table 4.2 Description of known environmental receptors within the defined study area........ 14
Table 4.3 Scoping Matrix for the Project. Pressures = changes in environmental parameters as a result of the project. Receptors = social, economic or ecological features that may be affected by the pressure. S = Short-term impacts, Construction Phase impacts. L = Long-term impacts, Post-Construction Phase impacts. Some pressures are related, either causatively or by co-occurrence. Linkages between pressures are indicated.. 16
Table 4.4 Field surveys conducted in this Study, in order of mention from Section 5 onwards 18
Table 4.5 Habitat types found within Singapore and general description of each habitat, modified from the Biodiversity Impact Assessment (BIA) Guidelines (National Parks Board 2020) and Yee *et al.* (2016) 19
Table 4.6 List and definitions of native status terms for flora and fauna used in this report... 21
Table 4.7 List and definitions of non-native status terms for flora used in this report 21
Table 4.8 List of global and local conservation statuses used to regard a species as 'conservation significant (CS)'.. 21
Table 4.9 Summary of potential impacts and corresponding assessment methods 23
Table 4.10 Broad definitions for each level of predicted impact significance. Impacts can be either negative or positive 27
Table 4.11 Evaluation criteria and the associated standard definitions and ordinal scores used in the calculation of Environmental Scores... 28

Table 4.12 Range bands of ES and the associated Impact Significance used in RIAM 30
Table 5.1 Current speed and direction statistical information 36
Table 5.2 Wave height, direction, and time period statistical information........ 36
Table 5.3 Modelling scenarios for current impact assessment during Construction Phase ... 50
Table 5.4 Terrestrial sediment sample results 61
Table 5.5 Terrestrial sediment particle size results 61
Table 5.6 Sediment plume assessment schedule 63
Table 5.7 Marine sediment particle size results 68
Table 5.8 Bulk density, total organic carbon, total nitrogen and total phosphorous test results of sediments at SQ1 69
Table 5.9 Heavy metals test results of sediments at SQ1 69
Table 5.10 Summary of in-situ water quality results of stations WQ01 to WQ03 during spring and neap tide, ebb tide, benchmarked against the ASEAN MWQC (if applicable). Exceedances of ASEAN MWQC are highlighted in orange (i.e. Dissolved Oxygen content below 4mg/l was highlighted as it is not within ASEAN MWQC). 72
Table 5.11 Summary of *ex-situ* water quality results of stations WQ01 to WQ03 during spring and neap tide, ebb tide, benchmarked against the ASEAN MWQC (if applicable). Cells highlighted in orange indicate exceedance of ASEAN MWQC for Aquatic Life Protection in Coastal areas 80
Table 5.12 Reference table of sediment quality guidelines for heavy metals, adapted from MPA's 'General guidelines on the requirements for application on dredging and dumping works' 92
Table 5.13 Adapted ASEAN Marine Water Quality Criteria (MWQC) for evaluation in this EIA 93
Table 5.14 Table showing the heavy metals found within SQ1 benchmarked against the MPA guidelines 94
Table 5.15 Ambient air quality measurement stations 95
Table 5.16 Ambient air quality monitoring parameters and respective instruments used for monitoring 97
Table 5.17 Measured 24-hr average concentrations of SO_2, $PM_{2.5}$ and PM_{10} at AQ1.............. 98
Table 5.18 Measured maximum concentrations of NO_2, CO, O_3 and VOC at AQ1 98
Table 5.19 Measured long-term concentrations of SO_2, $PM_{2.5}$, PM_{10}, NO_2, CO and O_3 from NEA's monitoring station at Pulau Ubin 104
Table 5.20 IAQM's definition of potential dust emission magnitude 106
Table 5.21 Evaluation framework for magnitude of change in air quality 107
Table 5.22 Airborne noise measurement stations 110
Table 5.23 Range of Leq 5 mins (dBA) during different periods........ 111
Table 5.24 L_{10} of Leq 5 mins (dBA) during different periods........ 111
Table 5.25 Range of Leq 12 hrs (dBA) during different periods 111
Table 5.26 L_{10} of Leq 12 hrs (dBA) during different periods 111
Table 5.27 Correction factor to be applied to adjust the maximum permissible noise level at NSRs........ 112
Table 5.28 Adjusted noise limits at socio-economic NSRs........ 114
Table 5.29 Maximum Permissible Noise Levels for Construction Site – Weekday (Monday to Saturday)........ 116
Table 5.30 Maximum Permissible Noise Levels for Construction Site – Sunday and Public Holidays 116
Table 5.31 Five (5) construction stages and activities considered in this noise assessment. 118
Table 5.32 Typical sound levels from construction equipment. Sound levels are at 10 m from the source. Reference: BS 5228-1:2009 Code of practice for noise and vibration control on construction and open sites 118
Table 5.33 Total noise levels from construction activities at 10 m distance 119
Table 5.34 Predicted cumulative noise levels at relevant sensitive receptors........ 120
Table 5.35 Summary of the statistical metrics of noise levels (dB) at the monitoring station UN1........ 126
Table 5.36 Modelling scenario for underwater noise impact assessment during Construction Phase 127

Table 5.37 Coordinates of the ten (10) VQP points carried out for the intertidal seagrass surveys 131
Table 5.38 Mean percentage cover (%) and standard error (SE) of the major benthic categories recorded during the VQP surveys 132
Table 5.39 List of species found during VQP surveys at the intertidal areas around ULL jetty. 133
Table 5.40 Species checklist of mangrove species observed at each mangrove transect 135
Table 5.41 Macrobenthic density distribution across sampling stations 137
Table 5.42 Macrobenthic density distribution across taxonomic classes recorded from the sampling station at SQ1 137
Table 5.43 Selected species detected during the visual qualitative spot dives 140
Table 5.44 Evaluation of the importance of ecological and biodiversity receptors in accordance with the RIAM methodology 141
Table 5.45 Criteria used for scoring Magnitude of Change on biodiversity and ecological receptors. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted 142
Table 5.46 Magnitude of condition matrix for impact on coral reefs in Singapore from excess (i.e., in addition to background) suspended sediment concentrations (SSC) 144
Table 5.47 Magnitude of condition matrix for impact on seagrass from excess (i.e., in addition to background) suspended sediment concentrations (SSC) 144
Table 5.48 Allowable level of total suspended solids for production systems in discharged effluent across the two standards 146
Table 5.49 Magnitude of condition matrix for suspended sediment impact on fish 146
Table 5.50 Calculated heavy metal content at the specific marine ecology and biodiversity receptor during the Construction Phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection 149
Table 5.51 Mitigation measures to minimise impacts to marine ecology and biodiversity receptors during the Construction Phase 151
Table 5.52 Mitigation measures to minimise impacts to marine ecology and biodiversity receptors during the Construction Phase 154
Table 5.53 RIAM results for Construction Phase (short-term) impacts from the Project on marine ecology and biodiversity receptors 156
Table 5.54 The different key vegetation types and their respective sizes found within the flora study area around the proposed jetty at ULL 159
Table 5.55 Flora species richness within the sample plots or transect, as well as the number of CS species detected within 159
Table 5.56 Terrestrial fauna taxa of interest and the corresponding survey methodology for line transect surveys 160
Table 5.57 Species richness of targeted terrestrial fauna taxa recorded within the fauna study area. The number of species with conservation status, as listed in the Singapore Red Data Book (SRDB) and International Union for Conservation of Nature (IUCN), is also shown 161
Table 5.58 Number of independent detections for each fauna species captured from camera trap surveys. The number of camera traps (out of two traps) that captured each species is also shown. Locally conservation-significant species are indicated in bold 164
Table 5.59 Mitigation measures to minimise impacts to terrestrial fauna receptors during the Construction Phase 166
Table 5.60 RIAM results for Construction Phase (short-term) impacts from the Project on terrestrial ecology and biodiversity receptors 168
Table 5.61 Environmental changes affecting navigation to inform the Magnitude of Change for RIAM assessment 170
Table 5.62 Changes in various hydrodynamic measurements relating to hydrodynamic change, which are anticipated to be arising from Construction Phase during the “worst case” scenario (i.e., El Niño 2015, Northeast Monsoon), for each maritime transport receptor for the Project 171

Table 5.63 RIAM results for Construction Phase (short-term) impacts from the Project on marine navigation receptors 172
Table 5.64 Tolerance limits of aquaculture fish to suspended sediment 174
Table 5.65 Tolerance limits for process water intakes to excess SSC 174
Table 5.66 Predicted mean incremental SSC (mg/l) (above background concentrations) at two aquaculture receptors of concern within and around the Ubin-Ketam Channel 175
Table 5.67 Calculated heavy metal content at the seawater intake for the land farm on Pulau Ketam, during the construction phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection 175
Table 5.68 RIAM results for Construction Phase (short-term) impacts from the Project on aquaculture receptors 177
Table 5.69 Evaluation framework for sensitivity and importance of socio-economic receptors. IAQM's definitions of receptor sensitivity are also included 178
Table 5.70 Evaluation Framework for Magnitude of Change in noise level for human and fauna receptors. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted in evaluating the Magnitude of Change 179
Table 5.71 Magnitude of condition matrix for visual impact from suspended sediments on recreational receptors during daylight hours 180
Table 5.72 Mitigation and management measures to minimise SSC impacts on socio-economic receptors during the Construction Phase 182
Table 5.73 RIAM results for Construction Phase (short-term) impacts from the Project on socio-economic receptors 184
Table 5.74 RIAM results for Construction Phase (short-term) impacts from the Project on transboundary receptors 187
Table 6.1 Modelling scenarios for current impact assessment during Post-Construction Phase 189
Table 6.2 Properties of the vessels applied for ship wake assessment 212
Table 6.3 Modelling scenarios for the ship wake assessment 213
Table 6.4 Coordinates of the nine (9) extract points 217
Table 6.5 Ship wakes simulated to be experienced by the nearest fish farms, at varying boat speeds 232
Table 6.6 Frequency, type, and speed of future vessel traffic assumption used as model input for the propeller wash assessment 237
Table 6.7 Calculated heavy metal content at the specific marine ecology and biodiversity receptor during the jetty Post-Construction Phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection 243
Table 6.8 Maximum ship wake height created by vessels for 5 and 7 knots at the respective shorelines around the proposed jetty at ULL 245
Table 6.9 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine biodiversity and shorelines' receptors 247
Table 6.10 LTA Guidelines for public street lighting. 251
Table 6.11 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine ecology and biodiversity receptors 251
Table 6.12 Tolerance limits for marine infrastructure to excess (i.e., in addition to background) sedimentation 259
Table 6.13 Changes in various hydrodynamic measurements relating to hydrodynamic change, which are anticipated to be arising from Post-Construction Phase during the "worst case" scenario (i.e., El Nino 2015, Northeast Monsoon), for each maritime transport receptor for the Project 259
Table 6.14 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine navigation receptors 260
Table 6.15 Predicted mean incremental SSC (mg/l) (above background concentrations) due to Propeller-wash, at the aquaculture seawater intake and around the Ubin-Ketam Channel. 262

Table 6.16 Calculated heavy metal content at the seawater intake for the land farm on Pulau Ketam, during the operation phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection 263
Table 6.17 RIAM results for Post-Construction Phase (long-term) impacts from the Project on aquaculture receptors 264
Table 6.18 RIAM results for Post-Construction Phase (long-term) impacts from the Project on socio-economic receptors 266
Table 6.19 RIAM results for Post-Construction Phase (long-term) impacts from the Project on transboundary receptors 268
Table 6.20 RIAM table for Construction (short-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures .. 269
Table 6.21 RIAM table for the Post-Construction (long-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures .. 273
Table 7.1 Recommended Environmental Monitoring 280
Table 7.2 Environmental Impact Register 283

APPENDICES

A **Hydrodynamics Model Setup and Results**

B **Sediment Plume Model Setup and Results**

C **Ship Wake Model Setup and Results**

D **Flora Baseline Report**

All maps/charts in this Report are purely illustrative and are to be used solely for the purpose of assessing the environmental impact of the proposed works, and not for any other purpose.

1 Introduction

With reference to the Letter of Acceptance (Ref. NPB000ECI20301770 / 1) dated 03 December 2020, DHI Water & Environment (S) Pte Ltd ("DHI") has been engaged by National Parks Board (henceforth termed "NParks" or "Client") for an Environmental Impact Assessment (EIA) (henceforth also referred to as "Study") for a proposed jetty at Ubin Living Lab (ULL) (henceforth termed "Project") (Figure 1.1).

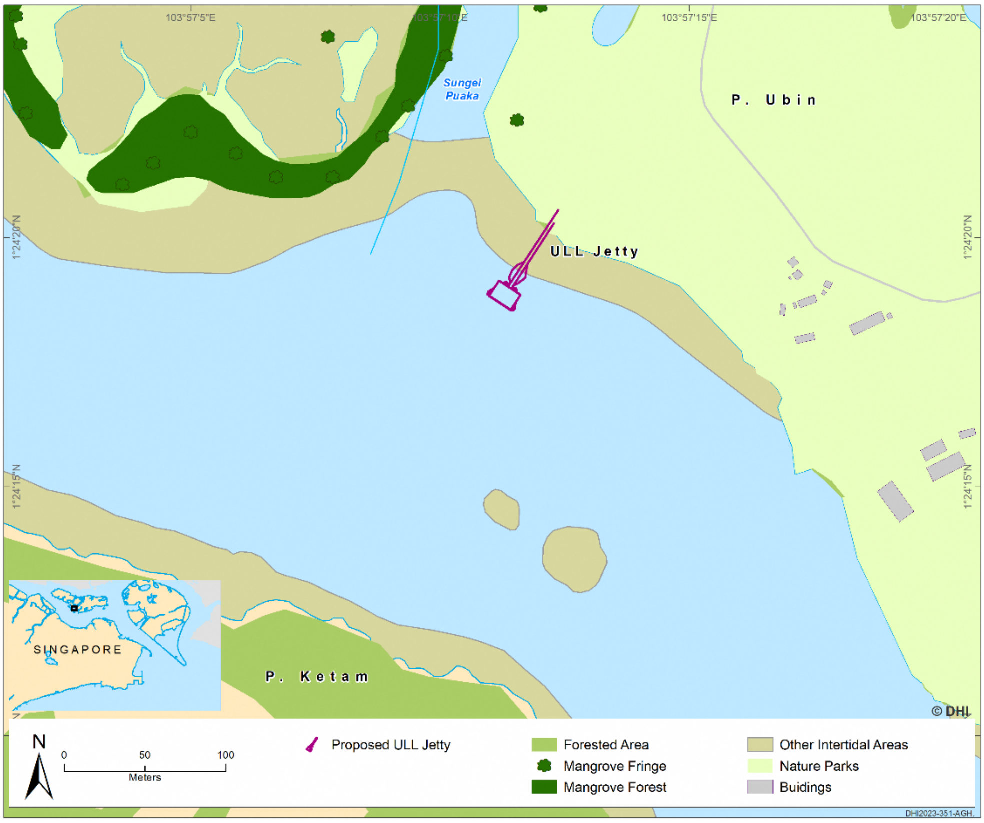


Figure 1.1 Location of the proposed development

1.1 Background

To address the limitations of the current jetty at the main village on Pulau Ubin, a new jetty in ULL area has been proposed to be erected at the headland area and would be partially floating on Ketam Channel. This new jetty was designed as a complementary secondary jetty with accessible features, allowing accessible bumboats to berth and to increase the accessibility of Pulau Ubin to handicapped members of society. It is also capable of berthing larger vessels with up to 60 passengers, as well as bumboats.

The new jetty would be located at the site of the former Ubin Celestial Beach Resort jetty, where three existing underwater structural pylons remain after the former jetty was demolished. It would be linked to an existing footpath along ULL and would serve as a secondary entrance gateway to Pulau Ubin for:

- Visitors going to Pulau Ubin;
- Prearranged school trips;
- Campers and other users accessing the site;

- Special-needs, mobility limited visitors; and
- SCDF and Police Coast Guard response personnel.

1.2 EIA Objectives

The initial consultation with relevant authorities, which took place between February and April 2021, concluded that an environmental study was required as part of planning permission for the proposed enhancement jetty works at ULL. This environmental study, i.e., the Study, reviews the existing environmental conditions in and around the Project area, analyses potential changes to the physical, chemical, and biological environment, and assesses the significance of the potential impacts on environmental and socio-economic receptors within the study area. DHI's scope of work comprises three (3) main components, the purposes of which are listed as follows:

- **Environmental Impact Assessment (EIA):** to assess and document the environmental impacts of the proposed development;
- **EMMP Tender Specifications and Evaluation:** to prepare EMMP-related specifications for the EMMP component of construction tender and provide evaluation and inputs for the award of tender; and
- **EMMP Supervision:** to supervise and evaluate EMMP implementation during Construction and Post-Construction Phases.

The adequacy and relevance of the recommended EMMP framework and its implementation hinge on the EIA study. The aim of the Study is, therefore, to provide information and assessment on the nature and extent of environmental impacts arising from the construction of the proposed development to (1) obtain environmental approval for the Project and (2) form a basis for a robust EMMP framework for Construction and Post-Construction Phases.

The detailed objectives are as follows:

- To identify and determine the baseline conditions of biodiversity and to formulate a biodiversity inventory and distribution map;
- To assess the extent of potential environmental impacts caused by the construction of the proposed Project based on the detailed development plan;
- To propose suitable mitigation measures in order to prepare a robust Environmental Monitoring and Management Plan (EMMP) for the Construction and Post-Construction Phases of the Project in preparation for future steps.

This report outlines the objectives and methodologies for the EIA, details the environmental baseline results, describes the development works and discusses the potential impacts predicted to arise from them. It also documents the recommended measures to mitigate the predicted impacts and outlines an Environmental Management and Monitoring Programme (EMMP) for the Project.

2 Project Description

2.1 Project Location

The Project is located on Pulau Ubin Island, northeast of the Singapore mainland (Figure 2.1). The island of approximately 1,020 hectares has a rich cultural and natural heritage and is home to Singapore's last villages (also known as kampongs). Pulau Ubin also hosts a thriving natural environment with biodiversity ranging from native mammals, birds, reptiles, amphibians and odonates. On the island's eastern shore is the Chek Jawa Wetlands, one of Singapore's richest marine ecosystems. In a major push towards discovering the diversity of species found on this unique offshore island, the Comprehensive Ubin Biodiversity Survey published on 25 September 2020 found 20 new species records, including *Piranthus sp.*, a spider species new to science (Tan, 2020a). This highlights the sensitive nature of the environmental setting where the proposed works will occur.

As a popular recreational destination, Pulau Ubin is frequented by many visitors to the island engaging in activities such as cycling, fishing and camping. To support this popularity, NParks has installed various basic amenities such as campsites, tracks, and shelters (Figure 2.1). The proposed Project is part of these efforts to upkeep and renew facilities for people to continue enjoying the island's various activities.

Figure 2.1 Pulau Ubin visitor information map (Source: NParks, 2020)

2.2 Project Design

The works will involve the construction of a floating pontoon jetty with an arrival pavilion (Figure 2.2). The jetty is approximately 65 m by 11 m. The proposed work area around the jetty is around 96 m by 35 m (including the jetty within).

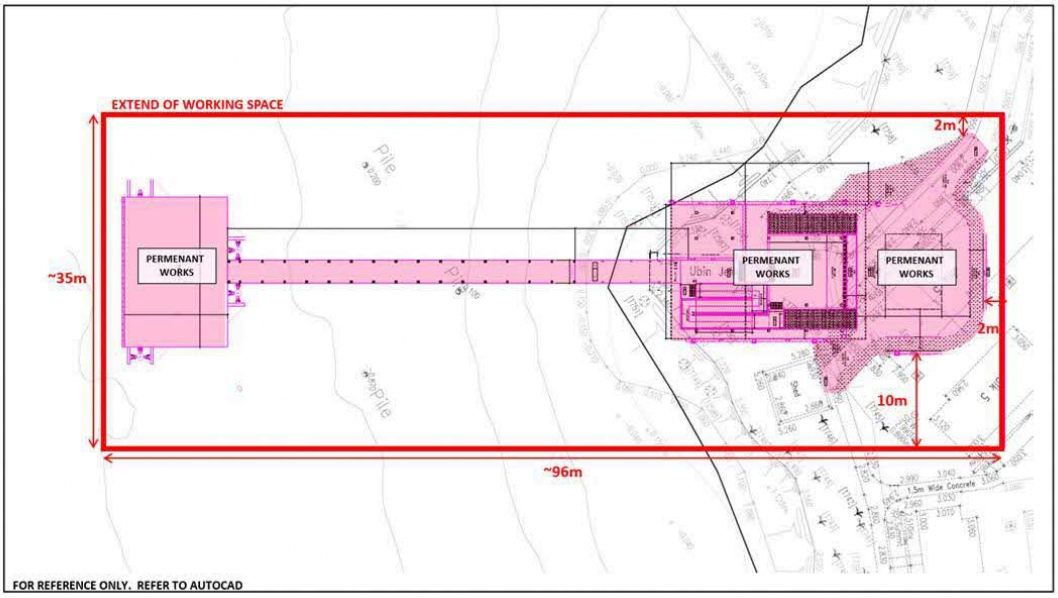


Figure 2.2 Plan view of the proposed jetty and arrival pavilion, including the proposed working space around the jetty (Source: PAL Consultancy)

Key construction works anticipated for the proposed jetty at ULL include the following:

- Removal of three existing underwater structural pylons – left over from the former jetty;
- Trimming of the seabed and shoreline to the desired bed level via excavator (Figure 2.3) (estimated total trimming volume: 400 m^3);
- Demolition of existing concrete landing;
- Micro piles at gangway landing site via drilling rigs (Figure 2.3);
- Construction of new sloping stone revetment;
- Piling of marine steel pipe piles infilled with concrete via a piling rig (Figure 2.3);
- Installation of pre-fabricated pontoons and gangway; and,
- Erection of arrival pavilion.

There were also lighting requirements for the jetty, requested by the Police Coast Guard (PCG) for security reasons. At the timing of writing of the EIA, the measures were yet to be confirmed, however, there was potential need to light up the jetty, as well as the Ubin-Ketam Channel, even during night hours (i.e., 7pm to 7am). Do note that the subsequent assessment was conducted based on the worst case scenario for potential lighting impacts.

Figure 2.3 Construction equipment types to be used for the development (Top: for trimming of seabed; Middle: for micro piling; Bottom: for marine piling)

2.3 Project Timeline (2024 onwards)

Task Description	Jan	Feb	Mar	Apr	May	Jun	Q3 2024 to Q3 2026		
URA clearance									
Public Disclosure									
Address comments and final clearance of EIA report									
Publication and award of construction Tender									
Construction Period									

3 Environmental Laws, Standards and Guidelines

In addition to the EIA Process employed across various EIAs in Singapore (Section 3.1), there is a selection of laws, regulations, guidelines, conventions, and protocols identified and considered in the process of conducting the Study. These are presented in the sub-sections as follows:

Section 3.2 Relevant Singaporean Acts

Section 3.3 Relevant Singapore Regulations and Guidelines

Section 3.4 Applicable International Guidelines

Section 3.5 Conventions, Treaties and Protocols

3.1 EIA Process in Singapore

At present, under the Planning Act (1998), statutory permissions and conditions can be imposed for the conduct of environmental studies and investigations into biodiversity. These studies are called Environmental Impact Assessments (EIAs), where potential environmental impacts of development proposals are assessed internally or collectively by relevant government agencies as part of the planning approval process.

The aim of an EIA is to protect the environment by ensuring that a local planning authority, when deciding whether to grant planning permission for a project, does so in full knowledge of the likely significant environmental effects and takes this into account in the decision-making process. The EIA Framework in Singapore comprises 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 summarised in Table 3.1.

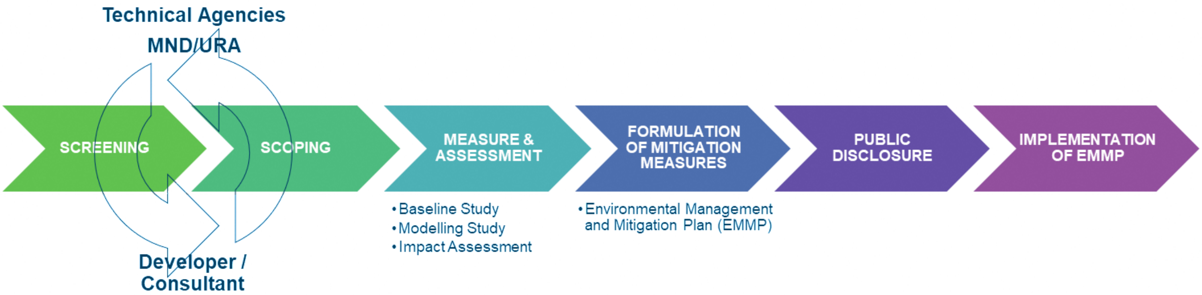


Figure 3.1 An illustration of the EIA Process in Singapore. The relevance and requirement of stakeholder engagement are project-dependent and can take place at various stages of the study

Table 3.1 Objectives of key EIA stages in Singapore

EIA Stage	Objectives
Screen	To identify and recommend whether or not an Environmental Impact Assessment 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.
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 which are required to mitigate the impacts to an as-low-as-reasonably-practicable level (ALARP) and monitoring regime for the Construction Phase to ensure that impacts are managed accordingly.
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.
Public Disclosure	After incorporation of relevant agencies' views, EIA reports should be made available for public feedback. Public feedback received should be incorporated into the final EIA report.
Implementation of the EMMP	Relevant agencies to implement and monitor the approved EMMP.

3.2 Relevant Singaporean Acts

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

- 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.
- 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.
- 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.
- Sewerage and Drainage Act 1999 (revised 2001). An Act to provide for and regulate the construction, maintenance, improvement, operation and use of sewerage and land drainage systems, and to regulate the discharge of sewage and trade effluent. Implemented by PUB.

3.3 Relevant Singapore Regulations and Guidelines

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

- MPA General Guidelines on Requirements for Application on Dredging and Dumping Works (2014);
- JTC Guideline on Environmental Baseline Study (EBS) (2019);
- SLA Guideline on Environmental Site Assessment (ESA);
- NEA Hazardous Waste (Control of Export, Import and Transit) Regulations 1998 (revised 2000). Covers transport of hazardous waste (BASEL permits);
- NEA Environmental Public Health (Toxic Industrial Waste) Regulations 1988 (revised 2000);
- NEA Environmental Protection and Management (Hazardous Substances) Regulations 1999 (revised 2008);
- NEA Code of Practice on Pollution Control (2013);
- NEA Guidebook on Waste Minimisation for Industries (2002);
- NEA Code of Practice on Environmental Health (2017);
- PUB Code of Practice on Surface Water Drainage (2011);
- PUB Sewerage and Drainage (Trade Effluent) Regulations 1999 (revised 2007);
- PUB Requirements for Discharge of Trade Effluent into the Public Sewers 2016;
- NEA Environmental Protection and Management (Control of Noise at Construction Sites) Regulations 1999 (revised 2008) that include Maximum Permissible Noise Levels for Construction Work Commenced on or after 1st October 2007;
- NEA Singapore Ambient Air Quality Targets (2011)

3.4 Applicable 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.

3.4.1 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
- Performance Standard 8: Cultural Heritage.

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:

- Air emissions and ambient air quality;
- Wastewater and ambient water quality;
- Hazardous materials management; and
- Waste management.

3.4.2 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;
- Hong Kong Sediment Quality Criteria for Management of Dredged/Excavated Sediment (ETWB 2002);
- International Panel on Climate Change (IPCC), 2013: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5 WG1 2013);
- 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;
- The Netherlands Ministry of Housing, Spatial Planning and Environment Target Values and Intervention Values for Soil Remediation (VROM 2000) for assessing soil toxicity; and
- USEPA Guidelines for Assessing Air Quality.

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.

3.5 Conventions, Treaties and Protocols

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

- ASEAN Agreement on Transboundary Haze Pollution 2002;
- BASEL Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal 1989;
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, the "London Convention" in short;
- International Convention on Civil Liability for Oil Pollution Damage, 1969, renewed in 1992 and often referred to as the CLC Convention;
- International Regulations for Preventing Collisions at Sea 1972 (Colregs) are published by the International Maritime Organization (IMO);
- International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) 1990;
- 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.);
- Montreal Protocol on Substances that Deplete the Ozone Layer 1987 and its Amendments;
- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade 1998;
- Stockholm Convention on Persistent Organic Pollutants 2001;
- UN Convention on Biological Diversity 1992;
- UN Framework Convention on Climate Change (UNFCCC) 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
- Vienna Convention for the Protection of the Ozone Layer 1988.

4 EIA Scope and Approach

4.1 Study scope

DHI identified potential impacts from the Project using a Scoping Matrix. This process requires a clear understanding of impact processes, including ecosystem processes and linkages. An impact process describes how a specific receptor is affected by a specific type of impact, i.e., from Pressure via Pathway to Receptor. All three elements are required for there to be an impact. For example, if there is no pathway from the source of a pressure to the receptor, then no impact will eventuate; and if there is a pressure source but no receptor, there will also be no impact.

Environmental pressure is defined as a change in environmental conditions (such as currents, waves, water quality, etc.) resulting from a development project. A sensitive receptor is a social, economic or ecological feature that may be affected by a pressure or a group of pressures. The following subsections discuss in detail the pressures and receptors relevant to the Project.

It should be noted that from Form A's findings, TAs' feedback and the Inception Report, the scope identified only covers impacts from construction works planned to take place in the foreshore and marine areas for the construction of the jetty. Therefore, no impact assessment would be carried out for land works (road construction and electrical works etc.) in this EIA.

4.1.1 Spatial and Temporal Scope

The Project was anticipated to result in several changes (determined as "pressures") on the physical, biological, and socio-economic environments, both marine and terrestrial. Hence, the Project has the potential to exert several impacts on sensitive environmental receptors within the vicinity of the proposed jetty. The spatial scope for analysis was defined based on the spatial scale of change that could result from the proposed construction and operation of the Project.

The Project was expected to induce changes in hydrodynamics (e.g., due to the jetty structures to be constructed) and water quality (e.g., due to increased suspended sediments during construction). Despite that, the anticipated impacts to the environment are minimal due to the relatively small scale of the demolition, trimming, piling, and final constructed footprint. These impacts were also expected to be highly localised due to the low current speeds in the Project area. The spatial extents for assessment of potential impacts due to potential changes to (i) noise and physical disturbances, (ii) terrestrial flora and fauna, and (iii) air quality, considered impact zones of 150 m radius, 250 m radius, and 350 m radius respectively from the works area (Figure 4.1).

The temporal scale at which the potential impacts were assessed was determined based on the period at which the Project was expected to take place as well as the nature of the post-construction/ operational phase. This Study considered that construction works would commence in 2024 and take 24 months (up to 2026) for completion, and the jetty was assumed to have a design life of 25 years. Given the near future and small scale of the Project, potential impacts from construction and operation activities were assessed against a Baseline situation based on the present-day development status and land profile of the study area.

4.1.2 Assessment Scope

Expert scoping for the Project was carried out between April and July 2020, including consultation with URA and Technical Agencies. The exercise identified relevant environmental pressures as listed in Table 4.1, sensitive receptors in Table 4.2, and the Scoping Matrix in Table 4.3.

4.1.2.1 Environmental Pressures

Table 4.1 Identified environmental pressures arising from the construction and operation of Project

Construction Phase	Post-construction (Operation) Phase
• Physical disturbances on land and in the marine environment • Hydrodynamic changes due to intermediate stages of development • Sediment plume due to piling and trimming works • Atmospheric admissions from demolition works and construction works • Noise emissions from land (airborne) and marine piling works (underwater) • Water quality changes due to sediment plumes, silty runoffs, or spills/leaks	• Project footprint • Hydrodynamic changes (minimal) due to shoreline and seabed alteration • Ship wakes (including erosion/sedimentation of shoreline) • Propeller wash-induced sediment plume • Future additional vessel traffic and visitors

No long-term morphological changes due to the presence of the jetty and slipways were expected to result from such small-scale modifications of the existing shoreline. Specific environmental pressures are elaborated upon in Table 4.3 below against the sensitive receptors in the vicinity.

4.1.2.2 Sensitive Receptors

Based on DHI's extensive in-house receptor database and a desktop review of public information, the known environmental receptors within the vicinity of the Project area were identified, as shown in Figure 4.1. Descriptions for the various types of sensitive receptor groups are provided in Table 4.2. The potential impacts on these sensitive receptors are shown in the scoping matrix in Table 4.3.

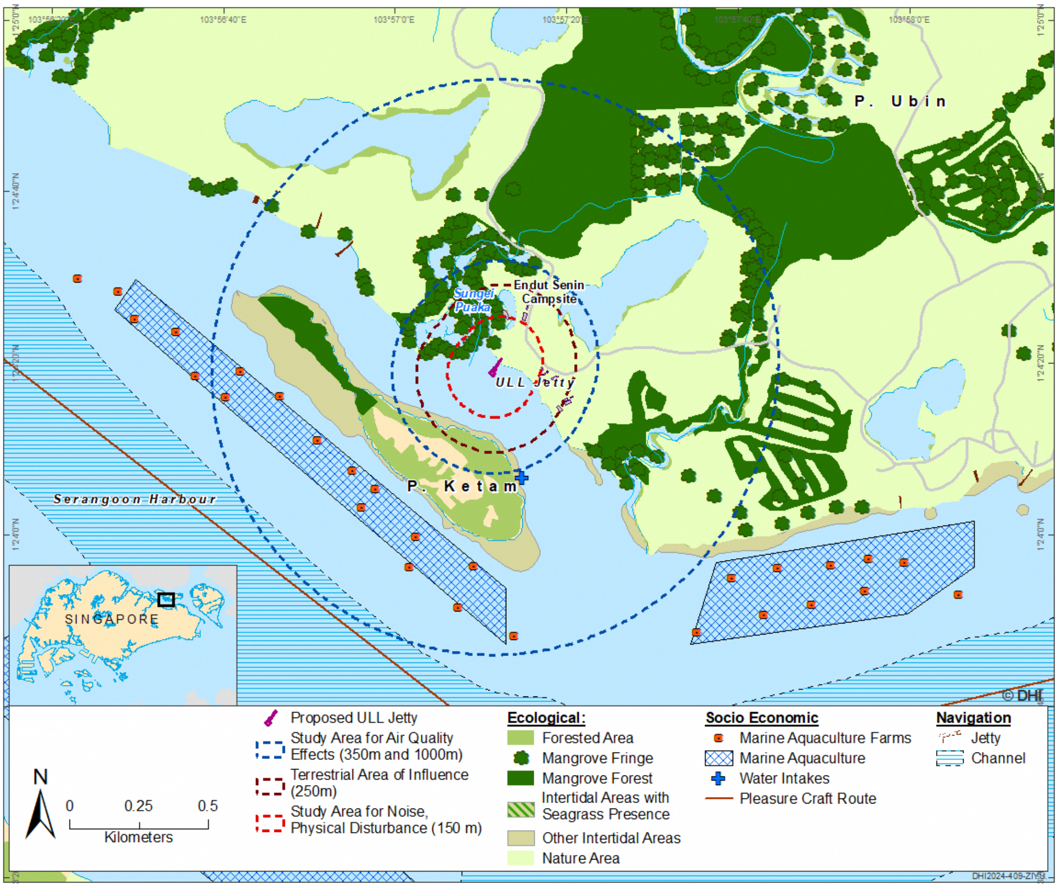


Figure 4.1 Overview of known environmental receptors in the study area

Table 4.2 Description of known environmental receptors within the defined study area

Receptor Groups	Sensitive Environmental Receptors
Ecology and biodiversity	• Terrestrial flora and fauna within and near the project footprint • Avifauna (resident and migratory birds) of the general study area • Intertidal habitats • Mangroves at Sungei Puaka • Marine fauna of the general study area • Soft-bottom seafloor macrobenthos within the project footprint and surrounding seabed
Socio-economic receptors (human health and visual impacts)	• Villagers of Pulau Ubin • Staff on Pulau Ubin • Recreational users (e.g., campers at Endut Senin Campsite, sea sports participants, intertidal and mangrove visitors)
Marine navigation	• Serangoon Harbour navigation channel, a major shipping lane used by ships and boats to enter ports in Malaysia • Boating channel between Pulau Ubin and Pulau Ketam
Aquaculture facilities	• Marine aquaculture facilities south of Pulau Ubin and south of Pulau Ketam • Land-based Aquaculture farm on Pulau Ketam, including its water intake point to the southwest of the island

4.1.2.3 Potential Impacts

One of the tasks during the EIA was to describe the pressures and receptors, including their spatial and temporal characteristics and sensitivities. Based on this understanding, an impact pathway between the two can be confirmed, and the significance of this impact have been assessed. An impact can occur due to a direct interaction between the pressure and the receptor, which could consequently impact receptors lower down the food web or on ecosystem services that economic activities are dependent on, such as fish provision.

Table 4.3 illustrates the environmental receptors that may be impacted by environmental pressures from the Project. This jetty development comprises several marine piles, floating gangway and pontoon and an arrival pavilion on land. The only flow-obstruction component is the marine piles. These piles are few in numbers and small in size hence were not expected alter hydrodynamic conditions in the area. No alteration in flushing was therefore anticipated that warrants the need for water quality modelling. Water quality modelling was scoped out of this EIA at the scoping stage in consultation with Technical Agencies. It was subsequently evident from the HD model results that the jetty causes no change to current patterns in the study area.

All interactions in Table 4.3 were explored in the Study. However, several key environmental issues were identified that helped to focus the efforts of the Study. Additional details of how the anticipated short-term (Construction Phase) and long-term (post-construction/operational phase) impacts on specific receptors were measured are found in Section 4.2.1 below.

Table 4.3 Scoping Matrix for the Project. Pressures = changes in environmental parameters as a result of the project. Receptors = social, economic or ecological features that may be affected by the pressure. S = Short-term impacts, Construction Phase impacts. L = Long-term impacts, Post-Construction Phase impacts. Some pressures are related, either causatively or by co-occurrence. Linkages between pressures are indicated[1].

S/N	Pressures:	Link To Other Pressures	Receptors									
			Terrestrial Flora	Terrestrial Fauna	Avifauna	Intertidal Habitats	Mangroves at Sungei Puaka	Marine Fauna	Macrobenthos	Marine Navigation	Aquaculture Facilities	Socio-Economic
1	**Physical Disturbances (Presence of Construction Site/Equipment/Activities)[2]**			SL	S	S	S	SL	S	S		
2	**Project Footprint**		L			L			L			
3	**Hydrodynamic Changes**	**2**								SL		
4	**Sediment Plume**	**1, 11**				SL	SL	SL			SL	SL
5	**Ship Wakes**	**11**				L	L				L	
6	**Erosion/Sedimentation**	**3, 5, 11**				L	L			L		
7	**Accidental Spills/Leaks[1]**	**1**	S	S	S	S	S	S	S		S	S
8	**Atmospheric Emissions**	**1**		S	S						S	S
9	**Airborne Noise**	**1**		S	S							S
10	**Underwater Noise**	**1**						S			S	
11	**Future Additional Vessel Traffic and Visitors**									L	L	L

[1] For example: Hydrodynamic Changes (S/N 3) assessed in this study are caused by Project Footprint (S/N 2), hence the two pressures are interlinked in the table.

[2] Including the resulting water quality changes

4.2 Study Approach

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

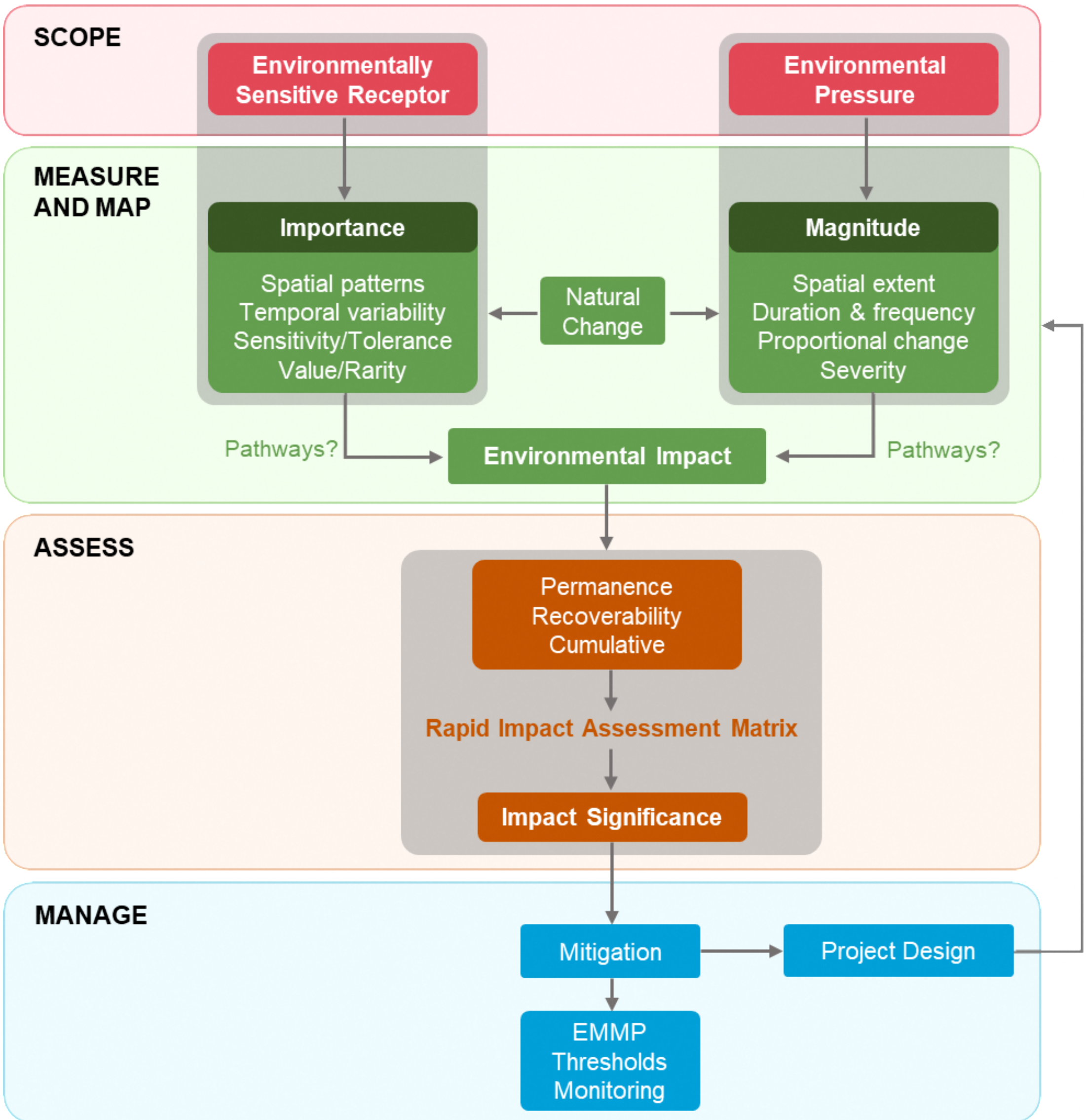


Figure 4.2 DHI's approach to environmental scoping, impact assessments and environmental management

4.2.1 Measurement

4.2.1.1 Baseline Conditions

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., AIS data) or from other projects or agencies associated with other environmental studies (e.g., the previous shoreline study for Pulau Ubin and Pulau Ketam (SJ, 2016)).

DHI will also undertake an extensive review of available satellite imagery, which in combination with the collated secondary data, will allow DHI to update our GIS database with the latest details of:

- Aquaculture farms;
- Ecological receptors (protected and key species, mangroves, seagrass, etc.);
- Marine infrastructure (ports/jetties, navigation areas, anchorages, etc.);
- Coastal features (breakwaters, revetments, sandy shorelines, mudflats, etc.); and
- Land use (cleared land, residential land, industrial areas, natural vegetation, etc.).

Table 4.4 Field surveys conducted in this Study, in order of mention from Section 5 onwards

Environmental Aspects	No. of Stations/ Transects	Survey Dates
Bathymetry	Within the study extent	15 – 16 February 2021
Current and Waves	1 ADCP station 3 current transects	23 November – 06 December 2022 (ADCP) 22 November 2022 (current transect)
Shoreline Survey	4	16 November 2022
Terrestrial Sediment Quality	1	16 November 2022
Seabed Sediment Quality	1	15 November 2022
Marine Water Quality	3	15 November 2022 (neap-tide) 22 November 2022 (spring-tide)
Intertidal surveys	10 points	24 November 2022
Mangrove Habitats	3	24 November 2022
Macrobenthos and Cyst	1	16 November 2022
Fish and Corals	3	11 January 2023
Terrestrial Flora	1 transect 3 plots	22 November 2022 (transect) 22 November 2022 (plot)
Terrestrial Fauna Transect	1	16 – 17 November 2022 13 – 14 December 2022
Camera Trap	2	11 – 18 November 2022
Air Quality	1	16 – 22 November 2022
Noise Quality	1 continuous 2 spots	23 – 30 November 2022 (continuous measurement) 22 November 2022 (spot measurements)
Underwater Noise	1	22 November – 06 December 2022

Findings from the above surveys and secondary data research are discussed in Sections 5 and 6 of this report and integrated into the relevant impact assessments for Construction Phase. Flora and fauna surveys were conducted in compliance with the local Biodiversity Impact Assessment (BIA) Guidelines (NParks, 2020).

Biological Classifications: Flora and Fauna

Habitat Type Classifications

Table 4.5 Habitat types found within Singapore and general description of each habitat, modified from the Biodiversity Impact Assessment (BIA) Guidelines (National Parks Board 2020) and Yee *et al.* (2016)

Habitat	Description	Source(s)
Primary forest	Contains an emergent layer that has dipterocarp trees such as *Shorea* and *Dipterocarpus*. Has a continuous layer of tall native trees, a sub-canopy consisting of smaller trees, and an understorey dominated by saplings of big tree species interspersed with other shrubs and treelets.	Tan *et al.* (2007)
Native-dominated young secondary forest	Naturally-regenerated vegetation on land cleared not long before the 1960s, or on degraded soils and not near other native-dominated forests. Dominated by native pioneer trees such as *Adinandra*, *Macaranga*, *Mallotus* and *Trema*.	Yee *et al.* (2016)
Native-dominated old secondary forest	Naturally-regenerated vegetation on land cleared much earlier than the 1950s, often on less degraded soil and with higher species richness than early successional native dominated secondary forest. Common species found in the canopy layer include *Alstonia* spp., *Calophyllum* spp., *Campnosperma* spp., *Elaeocarpus* spp., *Garcinia* spp., *Litsea* spp., *Rhodamnia* spp. and *Syzygium* spp. Common understorey plants include *Anisophyllea disticha* and *Agrostistachys borneensis.*	Yee *et al.* (2016)
Exotic-dominated secondary forest	Regrown on land that was recently cleared, usually after the 1960s. Typically dominated by *Acacia auriculiformis* and *Falcataria moluccana*, and in recent years, *Cecropia pachystachya* and *Leucaena leucocephala*, depending on the seed sources available from the surroundings during the time of clearance and succession.	National Parks Board (2020)
Abandoned kampong	Naturally-regenerated vegetation on an abandoned kampong or orchard, usually dominated by fruit trees such as Durian (*Durio zibethinus*) or Rambutan (*Nephelium lappaceum*), or ornamental plants such as *Spathodea campanulata*, *Aglaonema commutatum*, *Dieffenbachia seguine* and *Heliconia* spp..	Yee *et al.* (2016)
Abandoned plantation	Naturally-regenerated vegetation on an abandoned plantation, usually dominated by Para Rubber (*Hevea brasiliensis*).	Yee *et al.* (2016)

Habitat	Description	Source(s)
Scrubland / grassland	Exposed areas with very little tree cover, typically dominated by grasses, shrubs and herbs.	Yee *et al.* (2011); Lee Kong Chian Natural History Museum (2017a)
Freshwater swamp forest	Formed where slow-flowing streams drain into shallow valleys. The swamp is flooded periodically or semi-permanently, resulting in waterlogged soils that are anaerobic and unstable. Dominated by plants with special adaptations such as stilt roots, plank-like buttresses and pneumatophores. Examples include *Xylopia fusca* and *Paloquium xanthochymum*.	Tan *et al.* (2007)
Freshwater marsh or pond	A wetland which is covered by water and typically dominated by grasses, sedges and other herbaceous plants or hydrophytes that are able to tolerate flooding.	Lee Kong Chian Natural History Museum (2017b)
Natural stream	A well-shaded stream which is shallow, cool, and typically has mildly acidic waters (pH 6-7). Typically flows along natural topographical gradients over sand, clay or mud substrate with accumulations of leaf litter and woody debris.	Yeo *et al.* (2010)
Naturalised stream	A stream which is warm and typically has less acidic water than natural streams (slightly less than pH 7). Typically modified from pre-existing natural streams and is often linear. Flows through natural earth or open grassy banks, lacking leaf litter and woody debris.	Yeo *et al.* (2010)
Mangrove forest	A tidal habitat consisting of flora that normally grows above mean sea level in the intertidal zone of marine environments and estuarine margins. Common species include Rhizophore, *Bruguiera* spp., *Avicennia* spp., and *Sonneratia* spp. trees which have roots that provide structural and respiratory support in the soft anaerobic sediments of the habitat.	Ng *et al.* (2011)
Coastal vegetation	Found along un-reclaimed coasts where the forest is on sandy or rocky substrate. Dominated by hardy plants which can withstand higher temperatures, strong winds and salt sprays. Common species include *Casuarina equisetifolia*, *Cerbera* spp., and *Barringtonia* spp..	Tan *et al.* (2007)
Reclaimed land vegetation	Developed on reclaimed land. Can be similar to exotic-dominated secondary forests (waste-woodlands) or dominated by *Casuarina equisetifolia*.	Yee *et al.* (2016)

Habitat	Description	Source(s)
Urban vegetation	Consists of turf, shrubs or trees (often mostly non-native) which are planted by humans. This type of vegetation is typically managed for aesthetic purposes.	National Parks Board (2020)

Species Status

The species status for flora and fauna is categorised as native, non-native or cryptogenic (Table 4.6). In addition, non-native flora species are further classified into casual, naturalised, and cultivated species (Table 4.7).

Table 4.6 List and definitions of native status terms for flora and fauna used in this report

Native Status	Definition (adapted from Lindsay et al., 2022)
Native	Originated or arrived in Singapore without intentional or unintentional involvement of human activities
Non-native	Presence in Singapore is because of intentional or unintentional involvement of human activities
Cryptogenic	Uncertain whether presence in Singapore is from natural dispersal or as a result of human activities

Table 4.7 List and definitions of non-native status terms for flora used in this report

Non-native Species Categories for Flora (adapted from Chong *et al.*, 2009 and Lindsay *et al.*, 2022)	
Casual	Non-native species that do not maintain self-sustaining populations
Naturalised	Non-native species that maintain self-sustaining populations
Cultivated-Only	Species not naturally found in the wild that is produced and maintained by horticultural techniques

Species of Conservation Significance

The classification of species of conservation significance is presented in Table 4.8, based on the Singapore Red Data Book version 2 and version 3 (Davison *et al.*, 2008).

Table 4.8 List of global and local conservation statuses used to regard a species as 'conservation significant (CS)'

Conservation Status	Definition
Local - Singapore Red Data Book 3	
Vulnerable (VU)	Species with <1,000 mature individuals and >250 total individuals
Endangered (EN)	Species with <250 mature individuals
Critically Endangered (CR)	Species with <50 mature individuals or <250 total individuals

Conservation Status	Definition
Presumed Nationally Extinct (NEx)	Flora and fauna not recorded within the last 30 and 50 years, respectively
Globally Extinct (EX)	Globally extinct, including in captivity or through cultivation
Local (Flora) – Lindsay *et al.*, 2022	
Vulnerable (VU)	Between 250 to 1000 mature individuals estimated in Singapore
Endangered (EN)	Between 50 and 250 mature individuals estimated to be in Singapore, with no evidence of decline or fragmentation of populations
Critically Endangered (CR)	Fewer than 50 mature individuals estimated to be in Singapore; or if more than 50 but fewer than 250 mature individuals, with evidence of rapid decline or decline and fragmentation of populations
Presumed Nationally Extinct (NEx)	Not recorded in Singapore within the last 30 years. Endemic species that are presumed nationally extinct will consequently also be presumed to be globally extinct
Globally Extinct (EX)	Globally extinct
Data Deficient (DD)	Not enough information available to assess the risk of extinction
Global - IUCN Red List	
Vulnerable (VU)	Species facing a high risk of extinction in the wild
Endangered (EN)	Species facing a very high risk of extinction in the wild
Critically Endangered (CR)	Species facing an extremely high risk of extinction in the wild
Extinct in the Wild (NW)	Species that only survives through cultivation, captivity or as a naturalised population(s) outside its natural range
Extinct (EX)	Globally extinct, including in captivity or through cultivation

4.2.1.2 Impact Prediction

Prioritisation of key impacts and applicable assessment methodologies have been agreed upon at the scoping stage and presented in the Inception Report (ref. 61802820-RPT-Inception-2.3). In this Study, DHI adopts a selection of qualitative (e.g., review of existing survey data/ consultation data), semi-quantitative and modelling analyses to predict changes arising from the Project, as presented in Table 4.9.

Table 4.9 Summary of potential impacts and corresponding assessment methods

Receptor	Potential Short-term Impacts	Potential Long-term Impacts
Terrestrial Flora	N/A	Loss of vegetation due to clearance and excavation to make way for project footprint. **Tool:** GIS-supported assessment of the extent of direct vegetation loss
	Potential contamination due to spills/leaks from the construction site if wastes and inventories are not properly managed. **Tool:** Qualitative assessment on spills/leaks impacts	N/A
Terrestrial Fauna	Physical disturbance, including airborne noise and vibration, and dust emission within the project site cause avoidance behaviour of terrestrial fauna. **Tool:** Qualitative assessment of physical disturbances on site	N/A
	Potential contamination due to spills/leaks from construction site if wastes and inventories are not properly managed. **Tool:** Qualitative assessment on spills/leaks impacts	N/A
Avifauna	Physical disturbance, including airborne noise and vibration, dust emission, loss of access, etc. within the project site causing avoidance behaviour of fauna in the shoreline/intertidal habitats. **Tool:** Qualitative assessment of physical disturbances on site	N/A
	Potential contamination due to spills/leaks from the construction site if wastes and inventories are not properly managed. **Tool:** Qualitative assessment on spills/leaks impacts	N/A

Receptor	Potential Short-term Impacts	Potential Long-term Impacts
Intertidal Habitats	Physical disturbances in the intertidal area for both benthic and mobile fauna (causing site avoidance, loss of access etc.). **Tool:** Qualitative assessment of physical disturbances on site	N/A
	N/A	Direct loss of intertidal habitats in the project footprint. **Tool**: Qualitative assessment & GIS-supported assessment of the extent of lost intertidal habitat.
	N/A	Long-term morphological changes at the intertidal areas due to ship wakes from future additional vessels. **Tool**: DHI's MIKE 21 Spectral Wave (SW) model and ship wake calculation
	Contamination of the intertidal area due to silty runoffs, sediment plume, spills and leaks from construction site. **Tool:** Qualitative assessment & DHI's MIKE 21 Mud Transport (MT) model	Increased Suspended Sediment Concentration (SSC) at intertidal areas due to propeller wash-induced suspended sediment by future additional vessels. **Tool:** DHI's MIKE 21 MT model
Mangroves at Sungei Puaka	Physical disturbances onto mangrove area, for both benthic and mobile fauna (causing site avoidance, loss of access etc.). **Tool:** Qualitative assessment on physical disturbances on site	N/A
	N/A	Long-term morphological changes at the mangrove areas due to ship wakes from future additional vessels. **Tool**: DHI's MIKE 21 SW model and ship wake calculation
	Contamination of the mangrove area due to silty runoffs, sediment plume, spills and leaks from construction site. **Tool:** Qualitative assessment & DHI's MIKE 21 MT model	Increased SSC at intertidal areas due to propeller wash-induced suspended sediment by future additional vessels. **Tool:** DHI's MIKE 21 MT model
Marine fauna (including fish)	Physical disturbance, including underwater noise and vibration within the project site causing avoidance behaviour of fauna in the area. **Tool:** Qualitative assessment on physical disturbances on site	N/A

Receptor	Potential Short-term Impacts	Potential Long-term Impacts
	Increased SSC and resultant altered water quality block gills and adversely affect fish nearby the construction site. **Tool:** DHI's MIKE 21 MT model	Increased SSC block gills and/or adversely affect fish from potential long-term propeller wash-induced SSC from future additional vessels. **Tool:** DHI's MIKE 21 MT model
	Altered water quality (spills/leaks) affecting the fish community. **Tool:** Qualitative assessment on spills/leaks impacts	N/A
	Impact from underwater noise generated from marine piling works potentially affecting fish nearby the construction site. **Tool:** Underwater noise calculation	N/A
Macrobenthos	Physical disturbances in subtidal area, for benthic fauna (causing site avoidance, loss of access etc.). **Tool:** Qualitative assessment of physical disturbances on site	N/A
	N/A	Direct loss of macrobenthic community in the project footprint. **Tool:** GIS-supported assessment of the extent of smothered or lost macrobenthos
	N/A	Propeller wash-induced sediment plume may cause smothering of macrobenthos, altering sediment quality and reducing dissolved oxygen levels, potentially affecting the macrobenthos community. **Tool**: DHI's MIKE 21 MT model
	Spills or leaks during construction might smother or intoxicate subtidal benthic communities around the Project site. **Tool:** Qualitative assessment	N/A
Marine Navigation	Changes in hydrodynamic conditions (current speed and direction) due to construction of jetty affecting navigation activities in the area. **Tool:** DHI's MIKE 21 Hydrodynamic (HD) model	Changes in hydrodynamic conditions (current speed and direction) due to the operating jetty affecting navigation activities in the area. **Tool:** DHI's MIKE 21 HD model

Receptor	Potential Short-term Impacts	Potential Long-term Impacts
	N/A	Potential shoreline morphological impact on navigation of vessels, from ship wakes of future additional vessel traffic. **Tool:** DHI's MIKE 21 MT model
	N/A	Potential navigational risk due to increase in future additional vessel traffic at marine navigation channel. **Tool:** Qualitative assessment
Aquaculture	N/A	Disruption of fish farming operations due to ship wakes from future additional vessels. **Tool:** DHI's MIKE 21 SW model
	Sediment plumes from construction works increasing SSC, causing a wide range of physiological effects on the caged fishes. **Tool:** DHI's MIKE 21 MT model	Sediment plumes from vessels' propeller movement increasing SSC, causing a wide range of physiological effects on the caged fishes. **Tool:** DHI's MIKE 21 MT model
	Altered water quality (spills/leaks) affects the aquaculture fishes. **Tool:** Qualitative assessment	N/A
	Impact of underwater noise generated from marine piling works could affect the caged fishes. **Tool:** Underwater noise calculation	N/A
	N/A	Potential for collision risk of future additional vessel traffic with fish farmers. **Tool:** Qualitative assessment
Socio-economic	Physical disturbances, including spills/leak impacts, airborne noise and dust emission during construction, could potentially affect villagers, office workers, or recreational users utilising nearby areas. **Tool:** Qualitative assessment of physical disturbances on site	N/A
	Visual impact of the construction equipment and activities, sediment plumes, silty runoffs, and spills/leaks. **Tool:** DHI's MIKE 21 MT model	Visual impact due to potential increase in propeller wash-induced SSC from future additional vessels. **Tool:** DHI's MIKE 21 MT model
	N/A	Potential impact on accessibility, and businesses on the island. **Tool:** Qualitative assessment

4.2.2 Assessment

4.2.2.1 Methodology

The well-recognised Rapid Impact Assessment Matrix (RIAM) developed by Pastakia & Jensen (1998) is applied in this EIA. RIAM allows for a holistic and rapid comparable presentation and summary of the overall project impacts. The method provides for a transparent presentation and summary of overall Project impacts within a common framework and ultimately aids in pinpointing which impacts are most significant. RIAM also accounts for the presence of impacts that may be cumulative in nature. The RIAM method is also consistent with the Biodiversity Impact Assessment (BIA) Guidelines of Singapore (National Parks Board, 2020) recommendation as being one of three approved methods for assessing and summarising the overall significance of impacts. The definitions applied in the ranking of impacts are provided in Table 4.10 below.

Table 4.10 Broad definitions for each level of predicted impact significance. 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 unlikely to be 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 the Environmental Score (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:

(I) Importance – This defines the importance of the sensitive receptor identified, 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 physical-chemical, biological, or socio-economic deviation from baseline conditions and the relevant environmental standards, benchmarks, guidelines, or tolerance limits. Notably, 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 temporal overlap between the environmental change and receptor. Positive or negative impacts are represented through 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. For example, slope stabilisation with gabion walls will be a permanent impact, while slope stabilisation with sheet piles will be a temporary impact, given their eventual removal.

(R) Reversibility – The score expresses whether the receptor can recover from the impact, either unassisted or via mitigation measures. Reversibility is also a measure of control over the effect of the condition. It is not equated with permanence. For example, the loss of streetscape trees is recoverable with replacement plantings, while the loss of an endemic species is irrecoverable.

(C) Cumulative Impact – This is a measure of whether the effect will have a single direct impact, a cumulative effect over time or a synergistic effect with other conditions. For example, the loss of flora and fauna species is cumulative, as it is also associated with other impacts, such as the loss of ecosystem functioning and ecological connectivity.

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, Reversibility, and Cumulative potential.

The multiplication of Magnitude and Importance in the formula ensures that each evaluation criterion's weight is expressed and can 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 criterion and the associated ordinal scores used to calculate ES are shown in Table 4.11. 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 4.11 will be customised and made specific for sensitive receptors and predicted environmental impacts, respectively, with justifications elaborated in each assessment in Sections 5 and 6.

Table 4.11 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

Evaluation Criteria	Standard Definitions	Ordinal Score
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
	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 Sections 5 and 6

For each identified environmental impact affecting a sensitive receptor, an ES will be calculated. The ES is then banded together and ranked in range bands as presented in Table 4.12, which are then translated to Impact Significance – the reported output of the impact assessment process.

Table 4.12 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, also found within the evaluation framework sections within this report. This EIA adopts various assessment criteria from the above-mentioned laws, standards, and guidelines.

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 receptor.

The criteria adopted in this Study are described in each impact assessment section of Sections 5 and 6.

4.2.3 Management and Mitigation

A core aspect of the EIA is providing appropriate mitigation measures to address any significant predicted impacts, particularly those classified as 'Moderate' or 'Major' negative. Mitigation measures are recommended and designed to reduce the impact to an as-low-as-practicable level. Slight or Minor impacts may also require mitigation actions, but these are often in the form of best environmental management procedures and operational controls.

Mitigation measures are often established through industry standards and may include:

- Changes to the design of the Project during the design process;
- Engineering controls and other physical measures applied (e.g., noise barrier);
- Operational plans and procedures (e.g., noise pollution control management plan);
- Provision of like-for-like replacement, restoration, or compensation;
- Pollution control measures during the preparation and construction stages for the contractor to implement accordingly.

The mitigation hierarchy concept is presented in Figure 4.3. In developing mitigation measures, the primary focus is to avoid or minimise impacts through design modification or optimisation and/or project management, e.g., by applying appropriate abatement measures. Where impacts cannot be avoided, offsets and compensation could be considered.

It is important to note that not all impacts are necessarily negative. Some actions can be recommended to create net positive gains. Avoidance, minimisation and restoration alone are generally not enough to achieve a net gain, and some form of offset is also necessary.

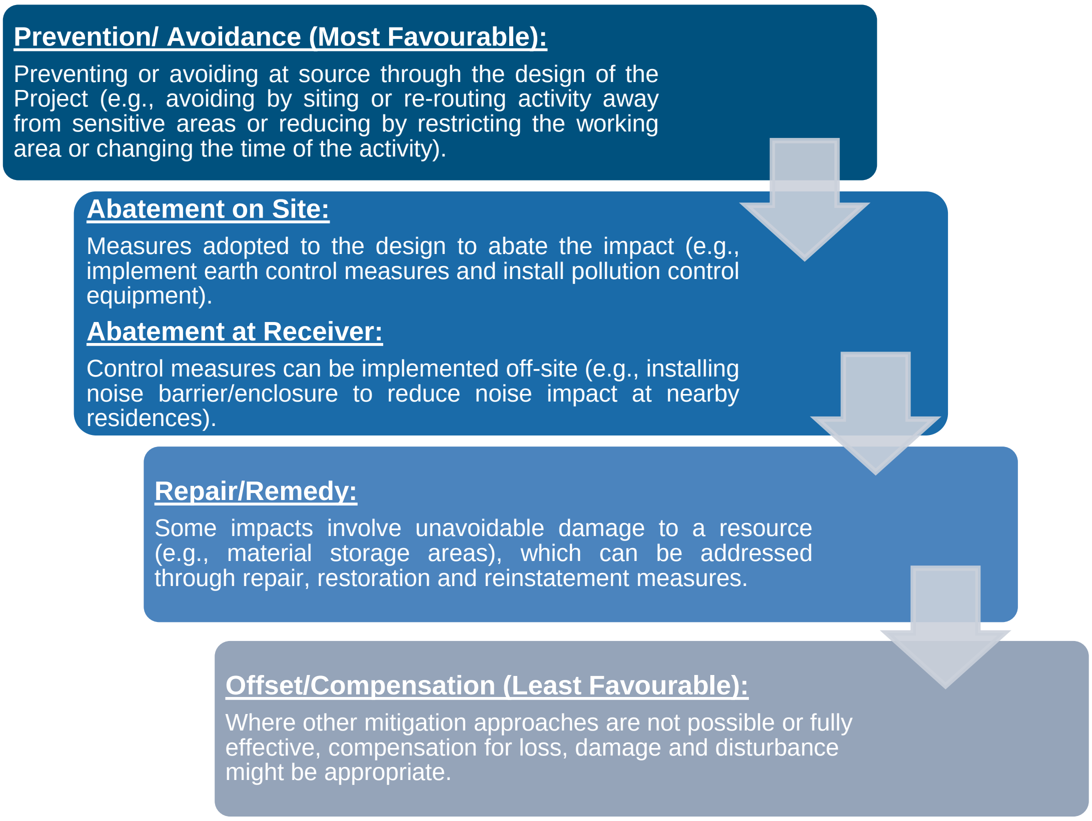


Figure 4.3 Hierarchy of mitigation strategy adopted in this EIA

DHI will also identify, predict and evaluate potential residual impacts associated with the Project construction. A residual impact is an impact that is predicted to remain after mitigation measures have been designed into the intended activity.

4.3 Reporting Flow

The impact assessment sections for Construction Phase (Section 5) and Post-Construction Phase (Section 6) are carefully structured to describe the key components involved in analysing environmental impacts, namely:

- Identification of relevant baseline features;
- Identification of relevant sensitive receptors;
- Description of an evaluation framework for measuring, defining and scoring the Magnitude of environmental change. This would include modelling methodologies and scenarios, and reference standards, guidelines or tolerance limits, if any;
- Prediction of Impact Significance for specific receptor groups;
- Proposed mitigation measures; and
- Evaluation of Residual Impact Significance (if necessary)

After mitigation measures are recommended, the Impact Significance is re-evaluated to derive the Residual Impact Significance. Mitigation measures are expected only to affect the RIAM variable of Magnitude; hence only the change in Magnitude is shown for the evaluation of Residual Impact Significance.

5 Construction Phase (Short-Term) Impacts

The assessment of impacts for the Construction Phase is aimed at predicting and analysing the level of environmental changes in the surrounding marine and terrestrial areas due to the construction activities and highlighting if any of these changes can be expected to have secondary consequences, for example, to ecology and biodiversity or marine navigation. The assessment comprises the quantification of relevant deviations from baseline conditions, including changes in currents, suspended sediments, water quality, air quality, and airborne and underwater noise quality associated with the Construction Phase of the Project. The impacts that could result from these changes are expected to be short-term and assessed for ecology and biodiversity, and other sensitive receptors previously identified in Section 4.1.2.2.

5.1 Coastal Dynamics

This section describes baseline coastal hydrodynamics in the Study area, including bathymetry, baseline current and wave conditions, and shoreline profile, as well as presents results of the hydrodynamic modelling, which was carried out to predict changes in currents during the Construction Phase.

5.1.1 Relevant Key Receptors

The key receptor considered sensitive to coastal dynamics during the Construction Phase is maritime navigation along the navigation channel between Pulau Ubin and Pulau Ketam, i.e., Ketam Channel. This section only discusses the Pressure or Stressor, i.e., the Change in hydrodynamic conditions; the resultant effects or impact on maritime navigation are assessed and discussed in the Receptor chapter (Section 5.9).

5.1.2 Baseline Conditions

Bathymetry

A bathymetric survey was carried out on 15 and 16 February 2021, following IHO Standards for Hydrographic Surveys S44 and in accordance with MPA Standards. The bathymetry survey extent covered the Study area as well as a portion of the Johor Strait. There has been no major development in the area in the last two (2) years; as a result, the bathymetry data are considered representative of baseline conditions prior to the proposed jetty construction.

Water depth is an important factor during modelling, as it can shape local hydrodynamics and bed shear stress (BSS). Measured bathymetry along Ketam Channel ranged from above 0 mCD (near the shoreline) to approximately -20 mCD in the deepest locations (Figure 5.1). Within the area in the immediate vicinity of the proposed jetty (indicated by the inset black box in Figure 5.1), the bathymetry is above 0 mCD along the shoreline, as deep as approximately -20 mCD in the middle of Ketam Channel to the west of the proposed jetty, and also approximately -20 mCD nearer the Pulau Ubin shoreline to the east of the proposed jetty. To the south of the proposed jetty location, closer to Pulau Ketam, is a shallow area with bathymetry above 0 mCD.

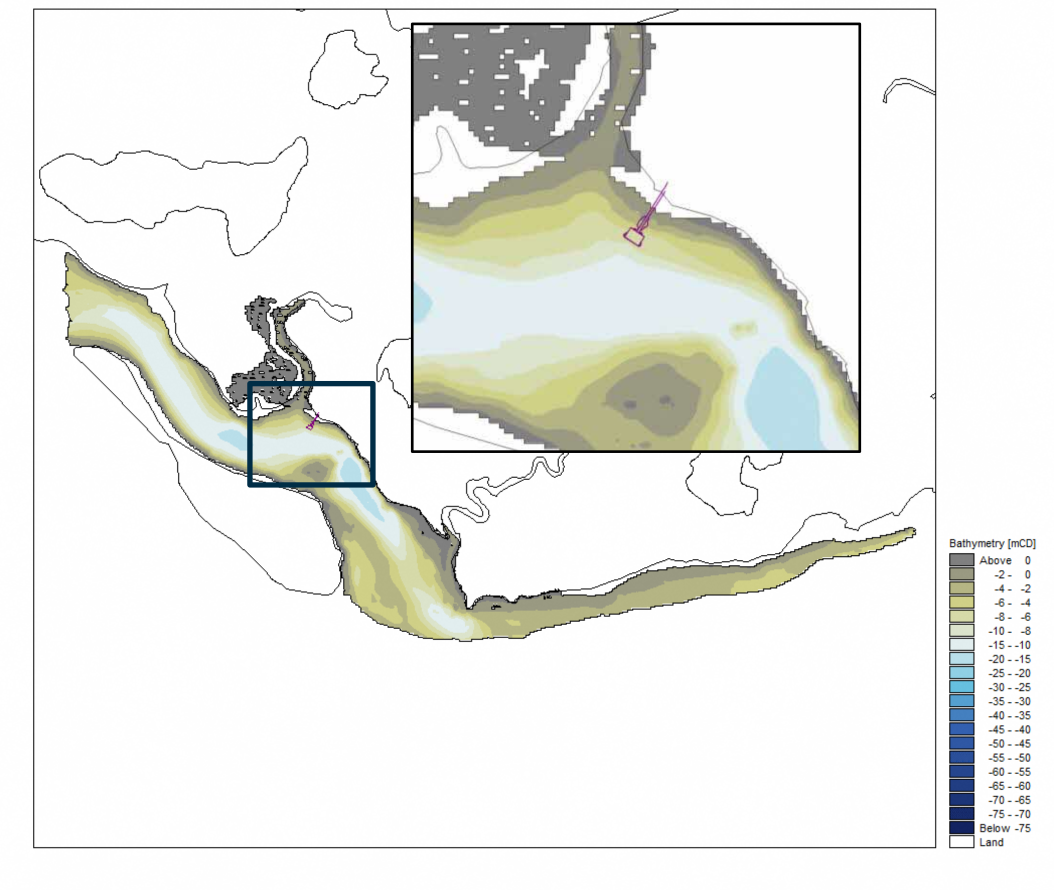


Figure 5.1 Bathymetric map of the Johor Strait, including the area of interest (black box)

Hydrodynamics

Pulau Ubin is a natural offshore island of roughly 1,020 ha, located north-east of Singapore mainland (Surbana Jurong Consultants Pte Ltd (SJ), 2015), along East Johor Strait, with Nenas Channel in the north, and Serangoon Harbour in the south, and influenced by discharge from Johor River. The annual hydrodynamics of this site is primarily characterised by the two monsoon seasons, including the Southwest (SW) monsoon season (i.e., June to September) and the Northeast (NE) monsoon season (i.e., November to March) (SJ, 2016). Calmer wind conditions are common during April, May and October, although direction varies. Pulau Ubin is also heavily influenced by the neighbouring rivers (e.g., due to its location at the mouth of the Johor River) and dynamics within the East Johor Straits. Singapore experiences low wave energy and is dominated by a strong tidal environment. Pulau Ubin has a spring tidal range of 2.2 m and a neap tidal range of 1.0 m (SJ, 2016).

Current and Wave

Baseline current speed, current direction and waves measurements were carried out at ADCP1 (Figure 5.2) for approximately two (2) weeks from 23 November 2022 to 06 December 2022, with measurements taken at 5-minute intervals (Figure 5.5).

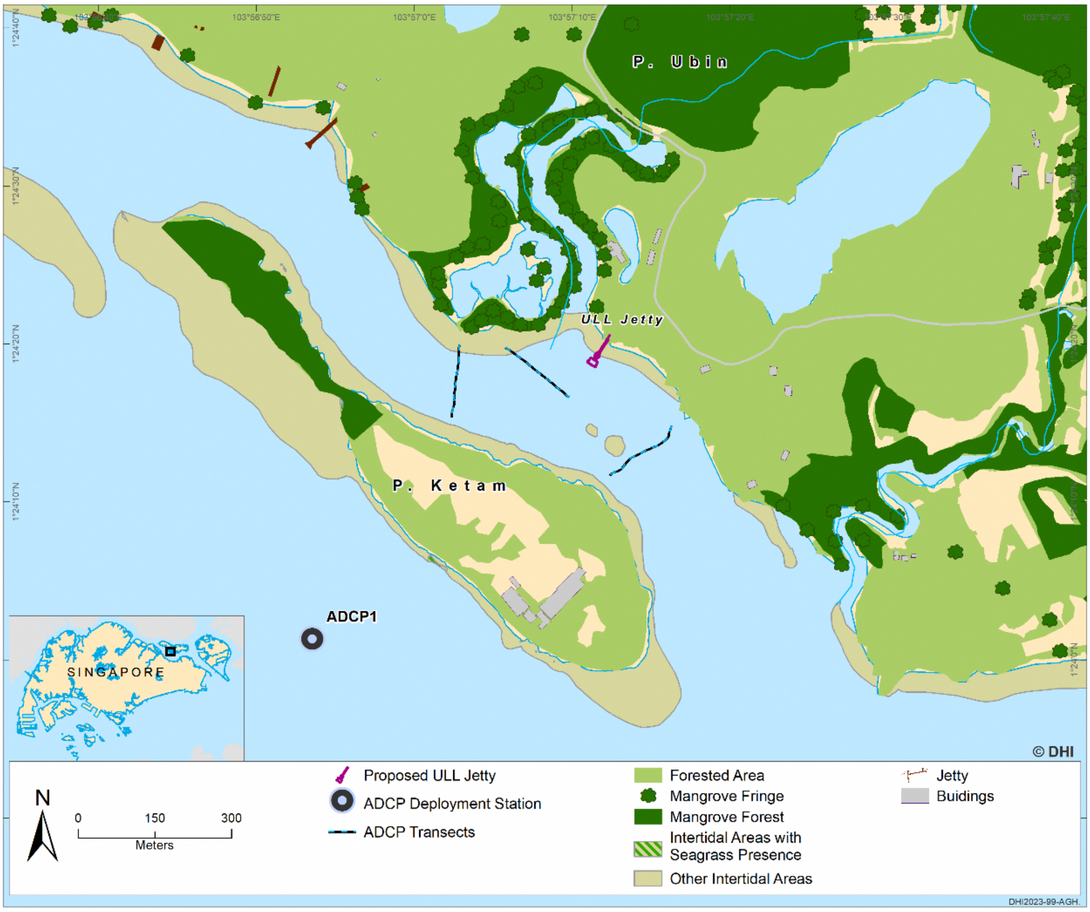


Figure 5.2 Location of the ADCP deployment (ADCP1) as well as the current transects

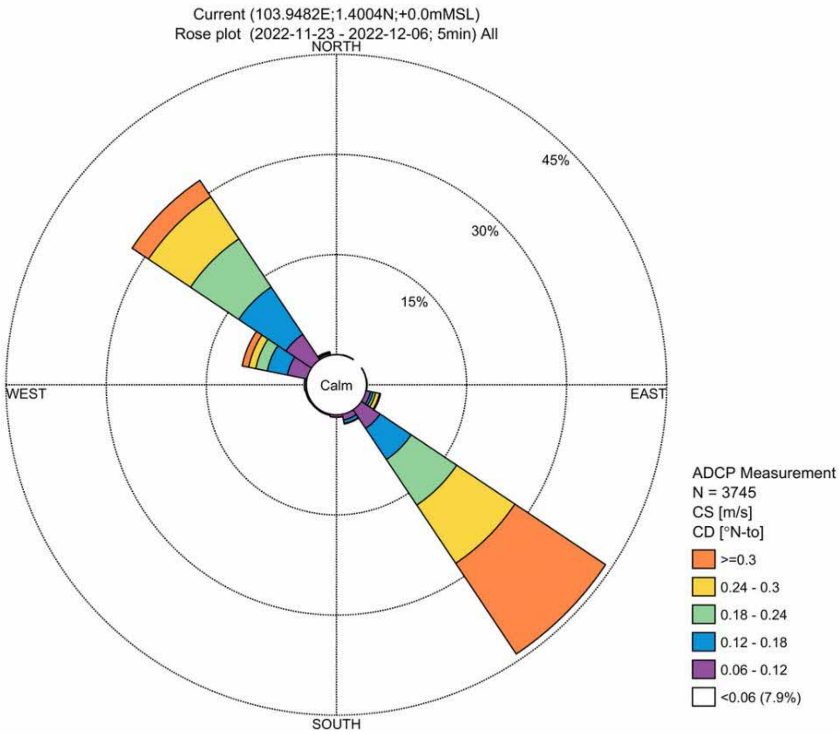


Figure 5.3 Rose plot of current speed and direction

The baseline measurements show that currents along the East Johor Straits flow predominantly in the southeast and northwest directions. There were currents greater than 0.3 m/s in both directions (Table 5.1), and current speed can reach up to 0.55 m/s (Table 5.1), with a minimum and maximum of 0.0 m/s and 0.55 m/s, respectively, in the southeast direction. The overall depth averaged current speed was 0.21 m/s (Table 5.1).

Table 5.1 Current speed and direction statistical information

Parameter	N	Mean	Minimum	Maximum	STD
Current Speed (m/s)	3745	0.21	0.0	0.55	0.11
Current Direction (˚N-to)	3745	-	0.49	359.44	-

For waves, Table 5.2 highlights wave data obtained from the time series plots in Figure 5.6. Significant wave height, mean wave direction, and peak wave period measurements were taken at hourly intervals. The average significant wave height was 0.08 m, and the average peak wave period was 2.47 s. The minimum significant wave height was 0.01 m, and the maximum was 0.19 m. Wave direction predominantly came from the southeast to northwest, similar to currents (Table 5.2). The area of interest is dominated by the local prevailing wind, with no swells observed. The minimum and maximum peak wave periods measured were 0.82 s and 5.05 s, respectively.

Table 5.2 Wave height, direction, and time period statistical information

Parameter	N	Mean	Minimum	Maximum	STD
Significant Wave Height (H_{m0})	321	0.08	0.01	0.19	0.04
Mean Wave Direction (˚N-from)	324	-	8.65	356.61	-
Peak Wave Period (s)	307	2.47	0.82	5.05	0.76

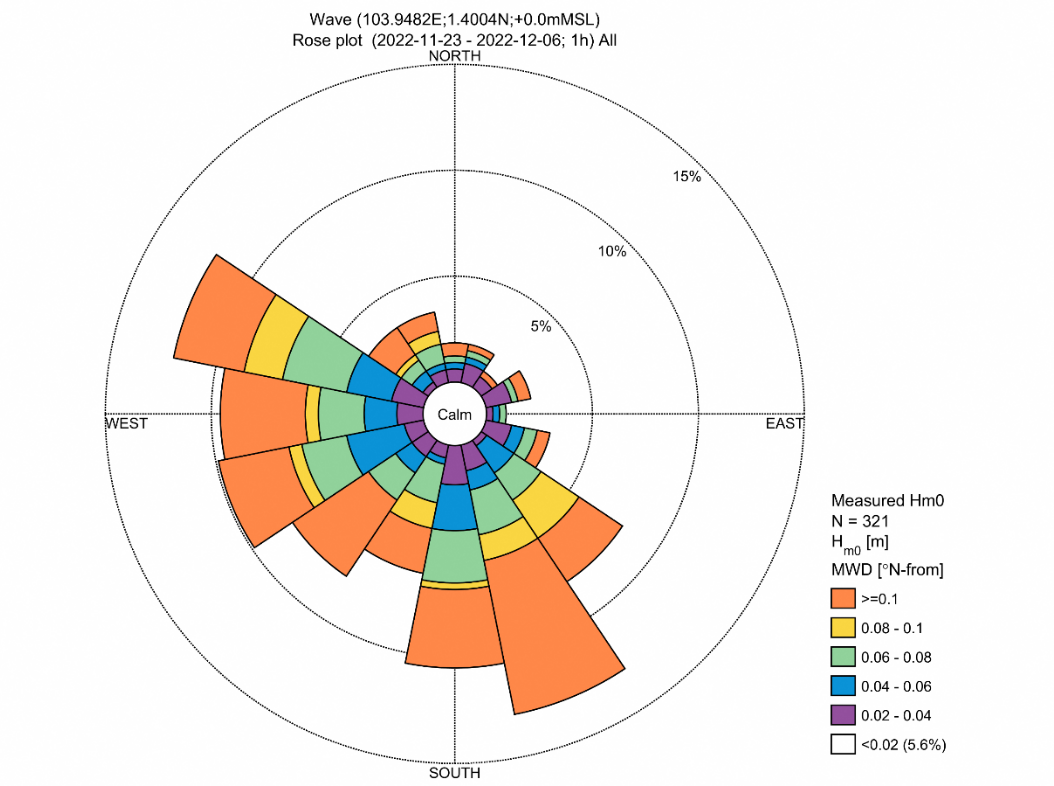


Figure 5.4 Rose plot of wave speed and direction

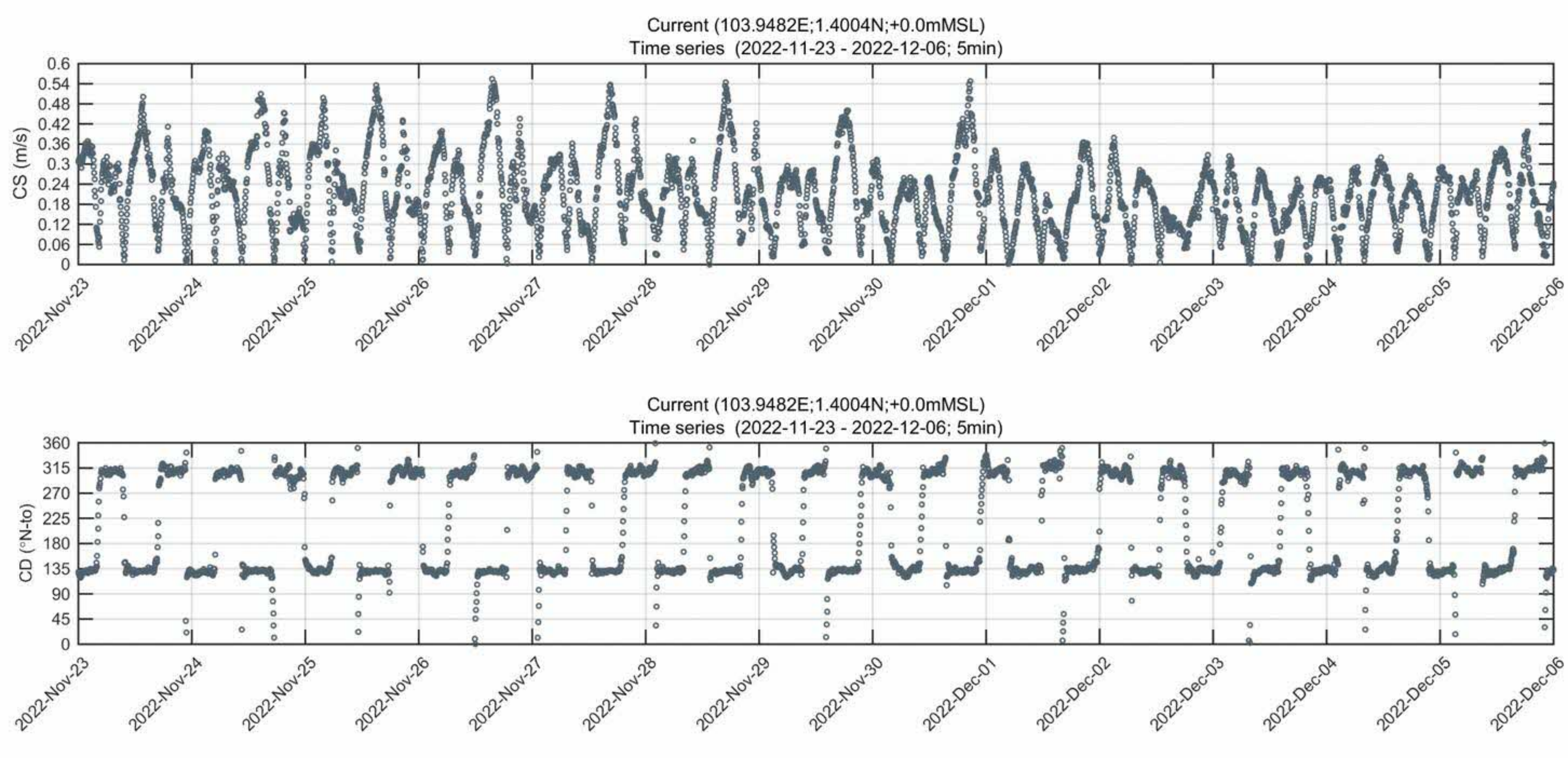


Figure 5.5 Time series of current speed (top) and current direction (bottom) measurements at ADCP1

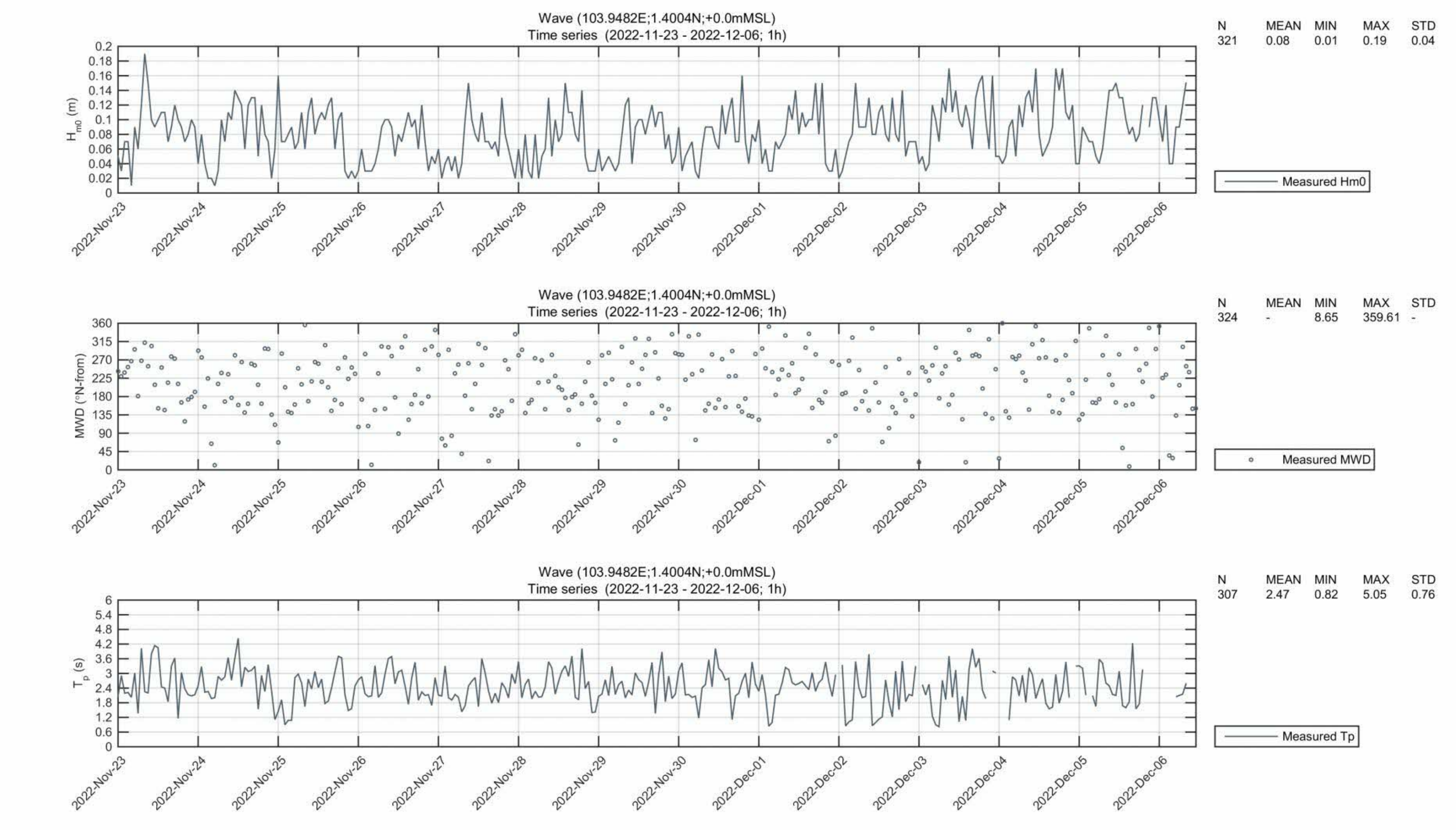


Figure 5.6 Time series of significant wave height (top), wave direction (middle) and wave time period (bottom) measurements at ADCP1

General Terrestrial Sediment

Sediment along the shoreline ranges from rocks, pebbles, sand, and mud. Sand has been reported as the dominant sediment type within the foreshore, mainly along beaches. Mud has been reported as the more dominant sediment type along the nearshore (SJ, 2015). The study area experiences cohesive (mixed sand and silts) and non-cohesive (sand) sediment transport. The total sediment volume transported along Pulau Ubin is low at rates typically less than 1000 m^3. Sediment transport is generally to the west of Pulau Ubin (SJ, 2016).

Shoreline Profile and Conditions

The shoreline of Pulau Ubin is roughly 23 km long and is home to diverse and rich ecological habitats. The shoreline change over the last decade was assessed visually; the shoreline in June 2012 was digitised using Google Earth imagery (red lines in Figure 5.8), and the digitised shoreline was overlaid on Google Earth imagery for June 2015, May 2018, and June 2022 for comparison of the shorelines. While sea level rise could be a potential contributor shaping this assessment, it is likely, not detectable within the study period (~7 years) for this shoreline assessment; several decades are usually required to observe sea level rise changes to a shoreline.

Four areas of focus were identified from the assessment (indicated by grey boxes in Figure 5.7 and further described below).

Figure 5.7. Overview of area of interest in June 2022 imagery with digitised shoreline from June 2012 (red line) overlaid. Areas of focus A., B., C., and D. indicated by grey boxes. The proposed jetty is indicated by white lines

Figure 5.8. Area of focus A. Images show shoreline position change around the proposed jetty location from 2012 to 2022. The shoreline position from 2012 was digitised and then overlaid on the subsequent shoreline images. The 2012 shoreline position is indicated in red for all images. The proposed jetty is indicated by white lines

Near the proposed jetty area (i.e., area of focus A.), some variation in the shoreline can be seen, mainly accretion to the north and east of the proposed jetty location in 2015, 2018, and 2022 (Figure 5.8). When assessed visually, there was no major shoreline change besides the accretion around the jetty site.

There is evidence of erosion within areas of focus B. and C., both located on Pulau Ketam (Figure 5.7). Area of focus B., located toward the northwest point of Pulau Ketam, shows a change in shoreline position from June 2012 to June 2022, clearly identified by the deviation from the red line (Figure 5.9). The deviation was approximately 20 m to 25 m, indicated by the yellow dashed line.

Figure 5.9. Area of focus B. Northwest point of Pulau Ketam with signs of erosion from June 2012 to June 2022. The largest deviation from the 2012 shoreline is approximately 24 m, indicated by the yellow dashed line

Area of focus C. is where a narrowing of Pulau Ketam occurred (Figure 5.10). In June 2012, this area appeared to be populated with established vegetation. In June 2022, this area was devoid of vegetation and seemed to be a wash over location impacted by tidal and wave energy, causing sediment erosion and preventing vegetation from re-establishing. The area seems to be still connected by sediment, though with the lack of vegetation to stabilise said sediment, the area is at higher risk of further erosional impacts.

Figure 5.10. Area of focus C. Narrow area of Pulau Ketam from June 2012 to June 2022

Signs of erosion were also found near Sungai Jelutong in the area of focus D., indicated by the grey box in Figure 5.11. This narrow extension off Pulau Ubin is southeast of the proposed jetty site. A close-up view of the eroded area in Figure 5.12 shows the large woody debris within the area from fallen vegetation and what appears to be a small channel separating the extension from the island (indicated by a yellow dashed line). Signs of erosion or deviation from the June 2012 shoreline could be seen forming in May 2018, with larger discrepancies in June 2022.

Figure 5.11. Area of focus D. southeast of the proposed jetty site. Signs of erosion can be seen from June 2012 to June 2022 within the grey box

Figure 5.12. Close-up view of the eroded area in area D. Red path indicates the 2012 shoreline. Yellow dashed line highlighting a channel formed detaching the extension from the island

In previous studies, erosion along the Pulau Ubin shoreline had been observed mainly impacting the island's northern side (Zaccheus, 2014; SJ, 2016). Figure 5.13 shows the overall shoreline condition of Pulau Ubin based on information from a previous modelling and shoreline study (SJ, 2016). All severe erosional shoreline states were found to be located along the northern coast., but the proposed jetty would be situated within an accreting shoreline state with a stable shoreline to the west and moderate erosion to the east near Sungai Jelutong (Figure 5.13). This study's visual assessment of historical shoreline change corroborates with the previous study of the Pulau Ubin shoreline.

Figure 5.13. Overall shoreline erosion of Pulau Ubin based on satellite image analysis (Source: Surbana Jurong (SJ), 2015)

To further complement desktop studies and historical shoreline analyses, a series of photographs were taken on-site on 16 November 2022 along four segments of shoreline defined based on the different statuses observed in the desktop assessment. The first shoreline segment consisted of sixteen (16) locations, the second and third shoreline segments had eight (8) locations each, and the fourth shoreline segment had six (6) locations, collectively covering approximately 3 km of shoreline (Figure 5.14). At each location, two (2) to three (3) images were taken at varying angles to capture the shoreline conditions of the site better. A frontal photo was taken at each location, and photo(s) at a 45 ˚ angle to the left and right from the frontal photo was taken. Segment 1’s images were taken facing Pulau Ketam, and the three remaining segment’s photos were taken facing Pulau Ubin. The various shoreline sections and their image locations are shown below in Figure 5.14.

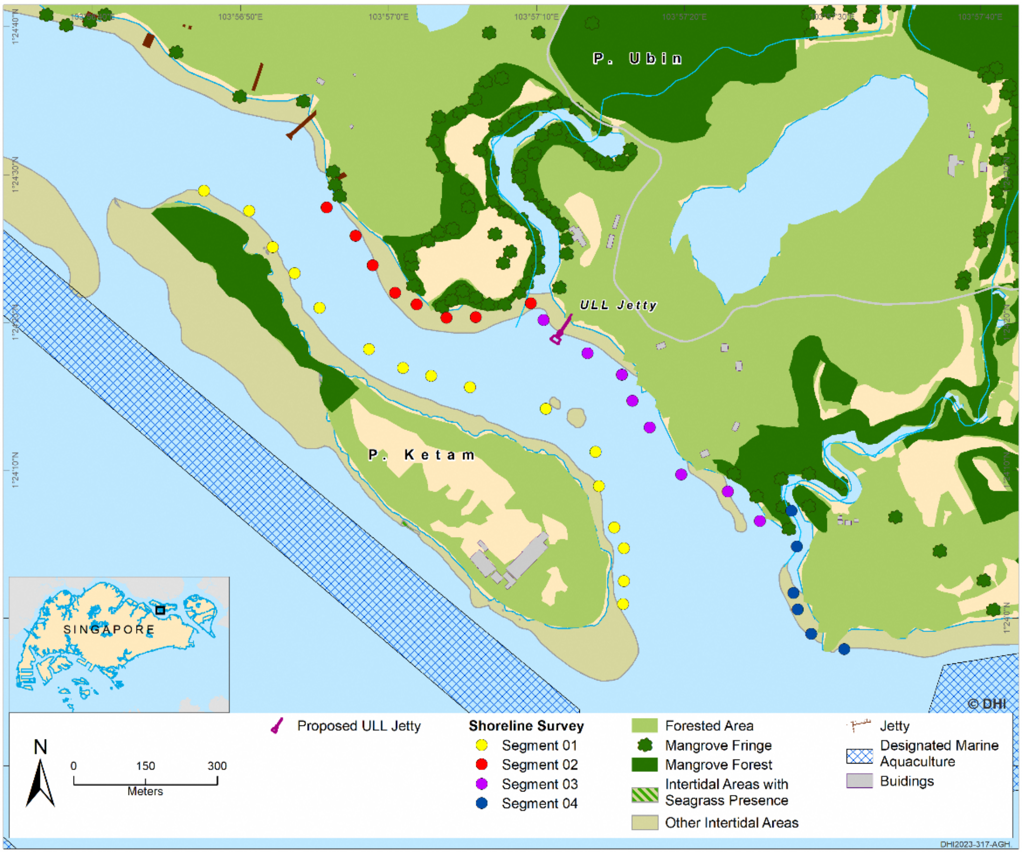


Figure 5.14 Shoreline survey segments along Pulau Ketam and Pulau Ubin

Segment 1 faces Pulau Ketam and is characterised by mature and dense mangrove species with sections of exposed shoreline sediment populated by terrestrial species (Figure 5.15). The exposed sediment appears to range from rocky pebbles to fine sand and mud. Vegetation appears dense, diverse, and healthy along the majority of the shoreline. Some infrastructure present along the shoreline may have some degree of negative impact on vegetation and shoreline processes (Figure 5.15).

Figure 5.15 Dense and mature mangrove species along the shoreline of Pulau Ketam (top left and right); exposed sandy sediment along the shoreline of Pulau Ketam (bottom left); and infrastructure extending to the shoreline (bottom right)

Segment 2 is west of the proposed jetty location and faces Pulau Ubin. The area farthest west of this segment captures Ketam Beach, a short, narrow sandy beach surrounded by rocks and dense, mature vegetation. Moving east along this segment, dense mangroves and terrestrial vegetation populate the shoreline. The east end of this segment is characterised by a bay (i.e., the mouth of Sungei Puaka) which is surrounded by patches of vegetated shoreline (Figure 5.16).

Figure 5.16 Sandy shoreline of Ketam Beach surrounded by rocks and dense vegetation (top); mature and dense mangrove species (bottom)

Segment 3 faces Pulau Ubin and captures the location of the proposed jetty. The shoreline towards the west end of this segment (closest to the proposed jetty location) is characterised by dense and mature mangroves and terrestrial vegetation with patches of exposed sediment. In addition to dense mangroves and terrestrial vegetation, much of this segment is a rocky shoreline with man-made access points, including The Living Fisher Village, an area common for recreation (Figure 5.17).

Figure 5.17 Area near the proposed jetty location (top); shoreline of the Living Fisher Village with the rocky vegetated shoreline and man-made access point (bottom)

Segment 4 is the farthest east segment of the shoreline captured (Figure 5.14). Similar to the other segments, this area has dense mangroves and terrestrial vegetation populating much of the shoreline. Sediment varied from large rocks to pebbles to fine sand and mud. However, this segment is unique and appears to have unregulated structures and garbage scattered along the shoreline (Figure 5.18). In addition, this location has evidence of erosion with sections of steep, scarped shoreline (Figure 5.18).

Figure 5.18 Dense and mature mangrove and terrestrial vegetation (top left); variation in sediment type along the shoreline (top right); unregulated man-made structure with garbage along the shore (bottom left); evidence of scarped shoreline erosion (bottom right)

5.1.3 Evaluation Framework

Model Extent

The levels of change to hydrodynamic conditions (currents) due to the Construction Phase were predicted and quantified using DHI's MIKE 21 Hydrodynamics (HD) Flexible Mesh (FM) model. The calibrated and validated hydrodynamic model of the Singapore Strait (the full extent shown in Figure 5.19) was used. The finest resolution of 25 m was applied to define features within the immediate construction area and the nearby areas of interest (Figure 5.19). The model was calibrated and validated with the observation HD data, i.e., current and sea level, at the area south of Pulau Ketam for the period of 23 November 2022 to 05 December 2022. Details on the model setups, calibrations, and assumptions can be referred to in Appendix A.

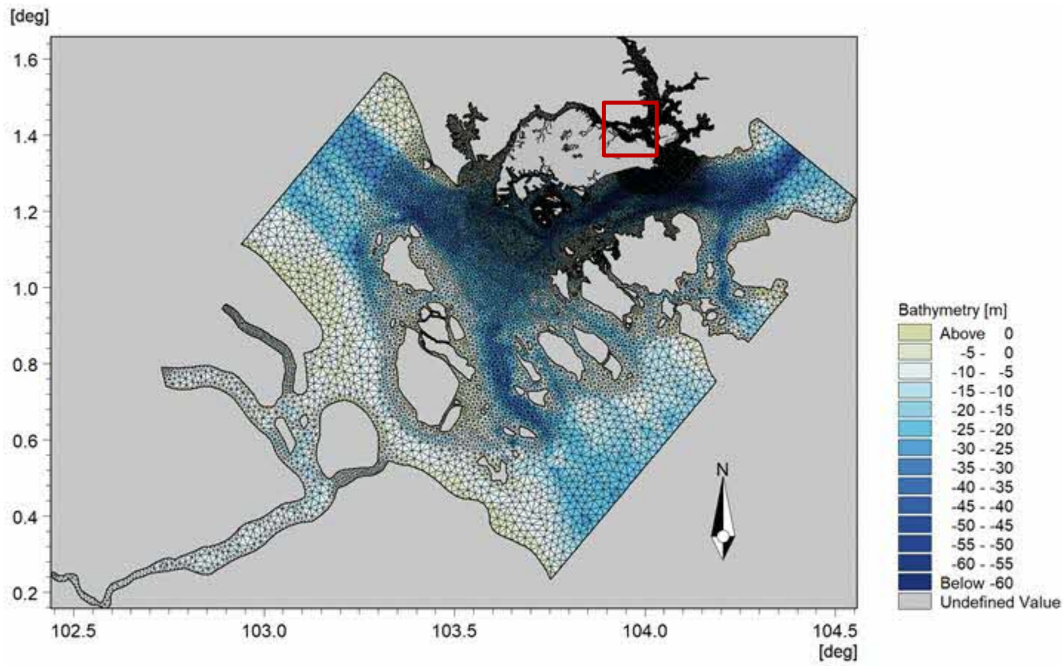


Figure 5.19 DHI's calibrated and validated Singapore Straits' model domain and bathymetry. The location of the study area with 25 m resolution in the model is indicated by the red box

Modelling Scenarios

Due to concerns over the impact of El Niño/La Niña events from the Client, the neutral ENSO conditions as well as El Niño/La Niña conditions are considered in this project. The Baseline and Construction Phase scenarios (Figure 5.20) were defined and simulated for fourteen (14) days, covering one spring-neap tidal cycle, during NE monsoon in El Niño and La Niña (ENSO) years and both NE monsoon and SW monsoon in a Neutral year (Table 5.3). This covered the range of seasonal variations in currents that might affect the model results. Only the NE monsoon was simulated for the El Niño and La Niña years, as these were the worst-case scenarios based on the intensity of an ENSO-related index. Similarly, the neutral year was also determined from the ENSO-related index.

With reference to Section 2.2, the key construction activities during the Construction Phase that could potentially result in changes to the hydrodynamic conditions are the piling of four (4) marine steel pipe piles and the trimming of the seabed and shoreline to the desired bed level. Hence, the scenario with two (2) pipe piles (Pile 1 and Pile 2 in Figure 5.20) and two trimming areas with a volume of 200 m^3 each (TR1 and TR2 in Figure 5.20) was simulated as an Intermediate scenario for the Construction Phase.

Table 5.3 Modelling scenarios for current impact assessment during Construction Phase

Scenario	Phase	ENSO Conditions	Year	Monsoon
1	Baseline	El Niño	2015	NE
2		La Niña	2010	NE
3		Neutral	2013	NE
4		Neutral	2013	SW
5	Construction	El Niño	2015	NE
6		La Niña	2010	NE
7		Neutral	2013	NE
8		Neutral	2013	SW

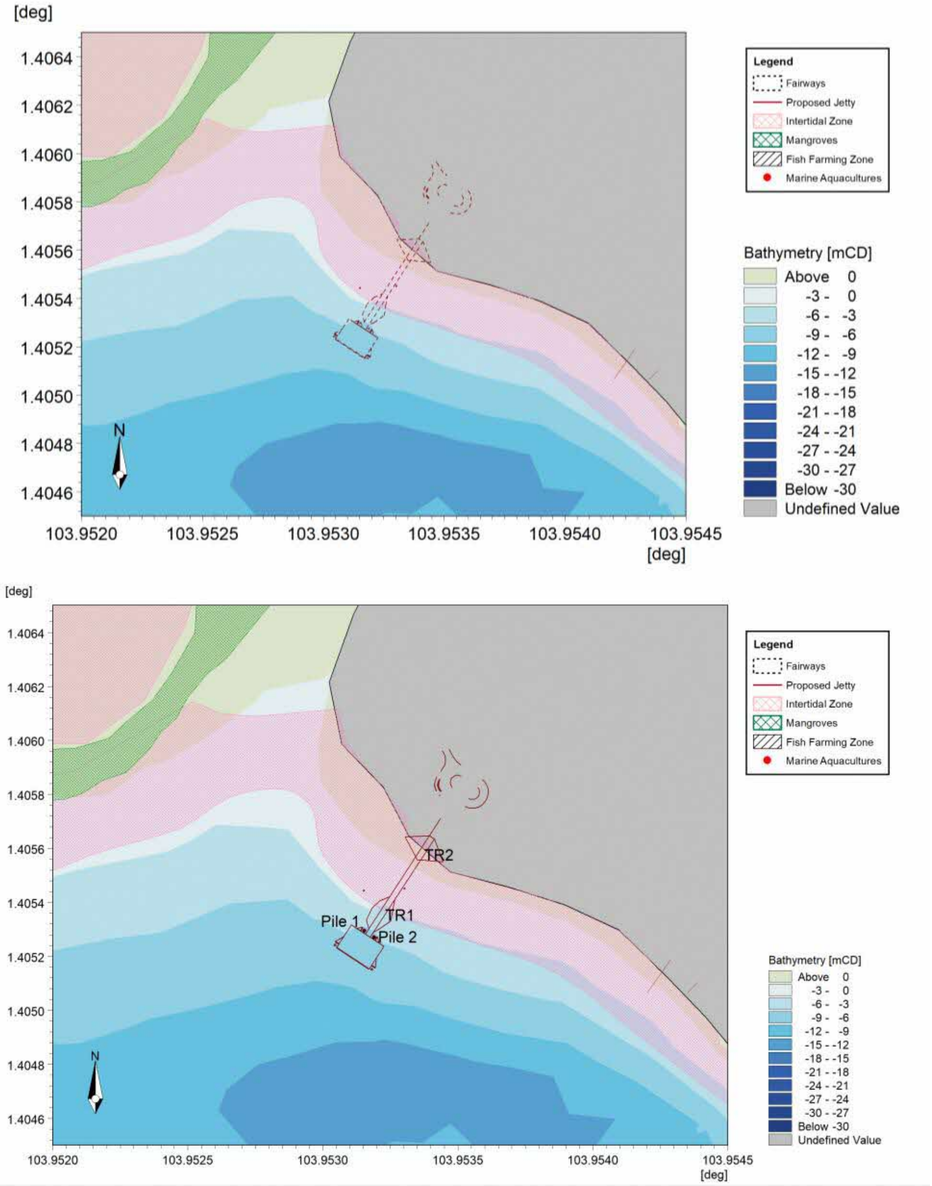


Figure 5.20 Baseline (top) and Construction Phase (bottom) profile for assessment of hydrodynamic impacts. The Construction Phase profile includes two (2) piling locations

(i.e., Pile 1 and Pile 2) and two (2) trimming locations (i.e., TR1 in the seabed and TR2 in the shoreline) with a trimming volume of 200 m^3 each

Model Results Analysis

Several current statistical parameters were evaluated to examine and assess hydrodynamic changes that could arise during the Construction Phase of the Project. The specific parameters were used to provide an overview of where changes are expected to occur in the Study area and assess the potential impact on the identified receptors (Section 5.1.1) according to tolerance limits defined for these receptors. These parameters include:

- Mean current speeds;
- Maximum (95th percentile) current speeds; and,
- Representative current speeds (<0.5 knots, >2.0 knots and >3.5 knots).

It is important to note that in numerical models, there may be infrequent short-term spikes (~1 model time step), which are not representative of the expected maximum results. These artefacts in the model results are caused by numerical transients, and not maximums arising from physical processes which span longer temporal scale in the model. When analysing the continuous data generated by a model, it is therefore more conservative to assess the 95th percentile, rather than the absolute maximum value.

5.1.4 Result and Discussion

The assessment of current speeds for the Baseline and Construction Phase scenarios shows that overall:

- Baseline current speeds were generally mild in the construction area, due to its sheltered location, with maximum current speeds of up to 0.60 m/s near Pulau Ketam south of the proposed jetty, which was well below the representative current speeds of interest for safe berthing and navigation, i.e., 2.0 knots and 3.5 knots respectively.
- The Project was predicted to cause negligible change to hydrodynamics in the study area. This observation holds for both ENSO and the Neutral year.

The detailed results and predicted changes due to the Construction are presented and described in the following subsections.

Change in Mean Current Speeds

Figure 5.21 illustrates the mean current speeds for the Baseline and Construction Phase scenarios during the NE Monsoon in El Niño and La Niña years. Figure 5.23 presents the results for NE and SW Monsoons during the Neutral year. The average current speed before any construction works (i.e., Baseline) is up to 0.10 m/s where the jetty is proposed to be constructed, generally up to 0.15 m/s along Ketam Channel, and up to 0.30 m/s where the shallow area was observed in the bathymetry south of the proposed jetty. The overall range and spatial trend of current speeds in the Study area are similar for the El Niño year, La Niña year, and Neutral year.

The Project is predicted to result in less than 0.05 m/s change in mean current speed in the local Project area and the entire Study area for all ENSO conditions and monsoon seasons simulated (Figure 5.22 and Figure 5.24).

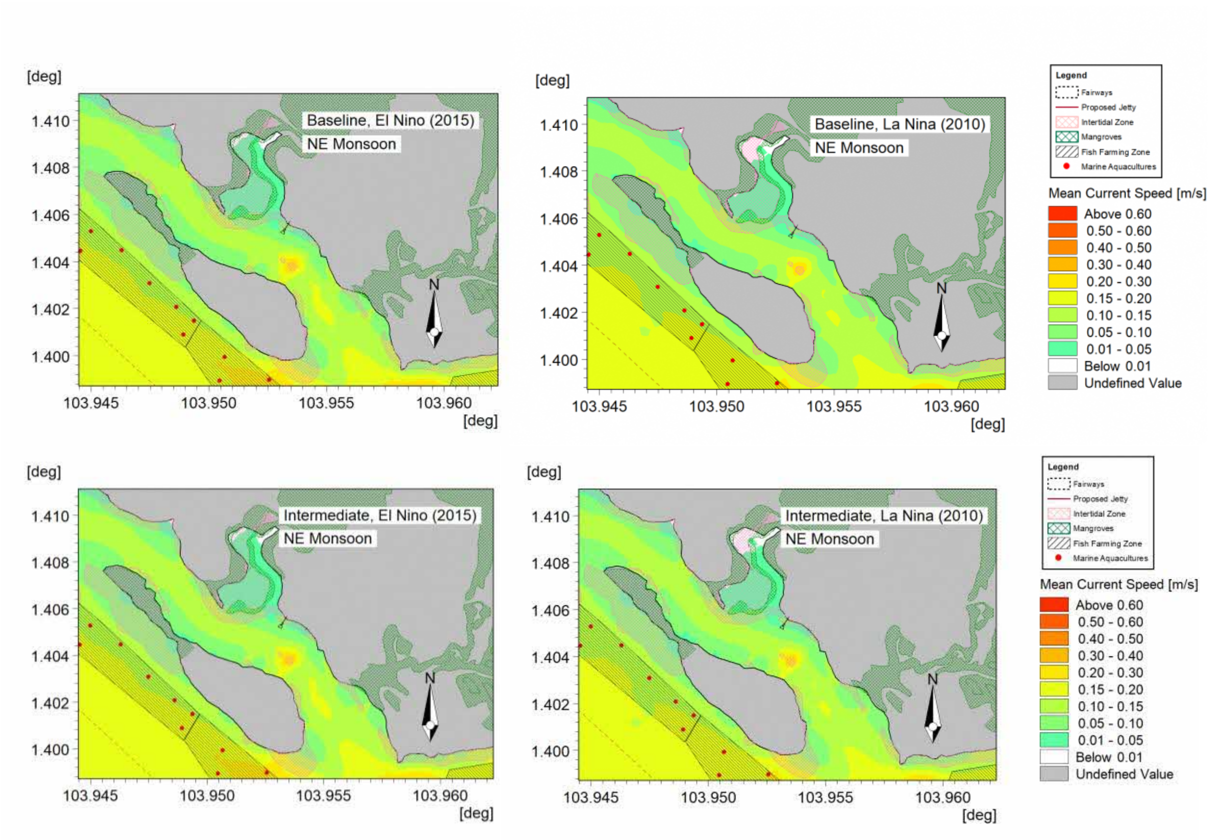


Figure 5.21 Mean current speed during NE monsoon in El Niño (left column) and La Niña (right column) years, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios

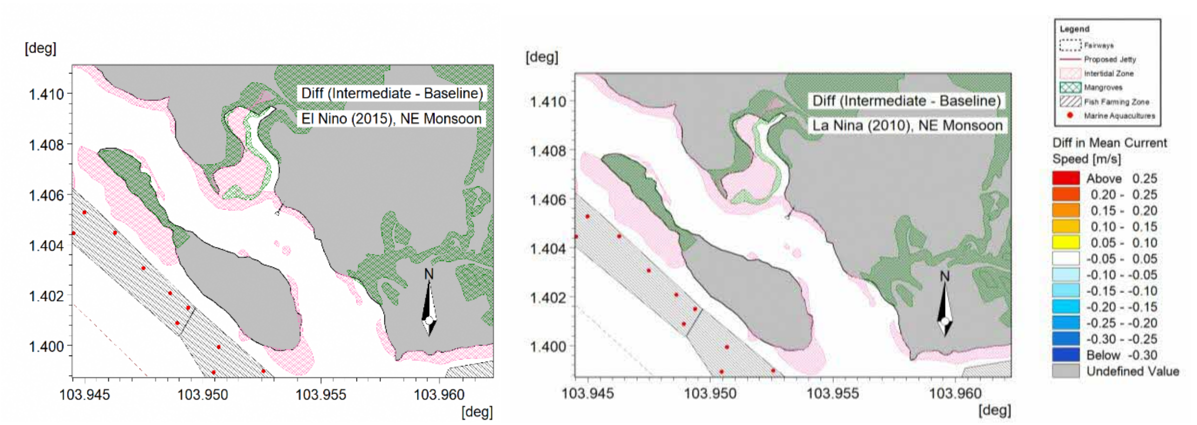


Figure 5.22 Difference in mean current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon in El Niño (left column) and La Niña (right column) years

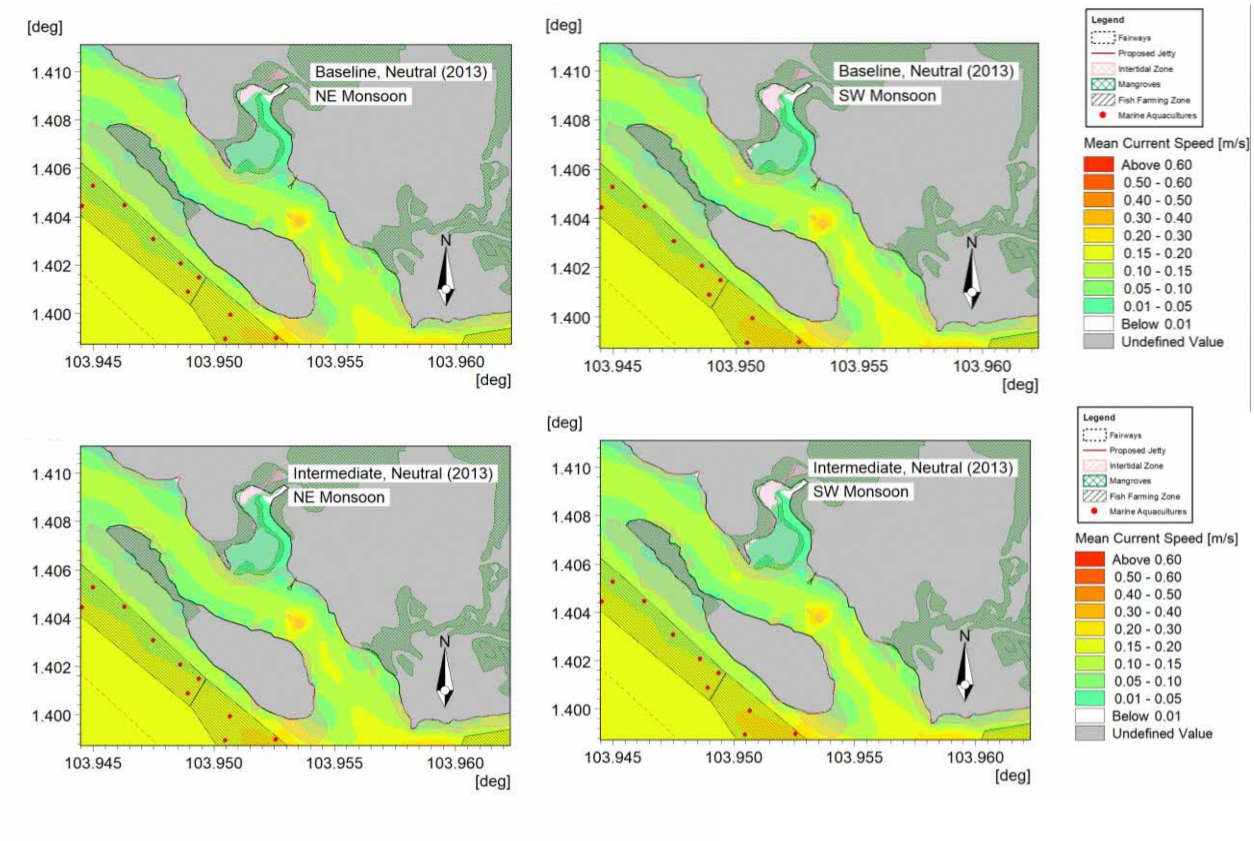


Figure 5.23 Mean current speed during NE monsoon (left) and SW monsoon (right) in the Neutral year, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios

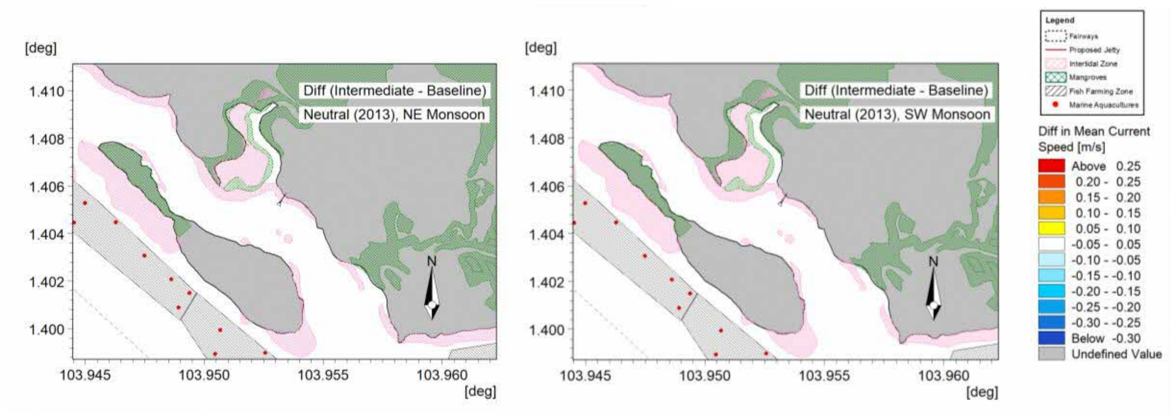


Figure 5.24 Difference in mean current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon (left) and SW monsoon (right) in the Neutral year

Change in 95th Percentile Current Speeds

Figure 5.25 illustrates the maximum (95th percentile) current speeds for the Baseline and Construction Phase scenarios during the NE Monsoon in El Niño and La Niña years. Figure 5.27 presents the results for NE and SW Monsoons during the Neutral year. The predicted maximum current speeds in both the Baseline and Construction Phases are generally slack along the shore of Pulau Ubin, increasing up to 0.60 m/s south of the proposed jetty in the middle of the channel between Pulau Ubin and Pulau Ketam.

The predicted difference in maximum current speed between the Baseline and Construction Phase (i.e., with the trimming and pile driving) is less than 0.10 m/s for all ENSO conditions and monsoon seasons simulated (Figure 5.26 and Figure 5.28).

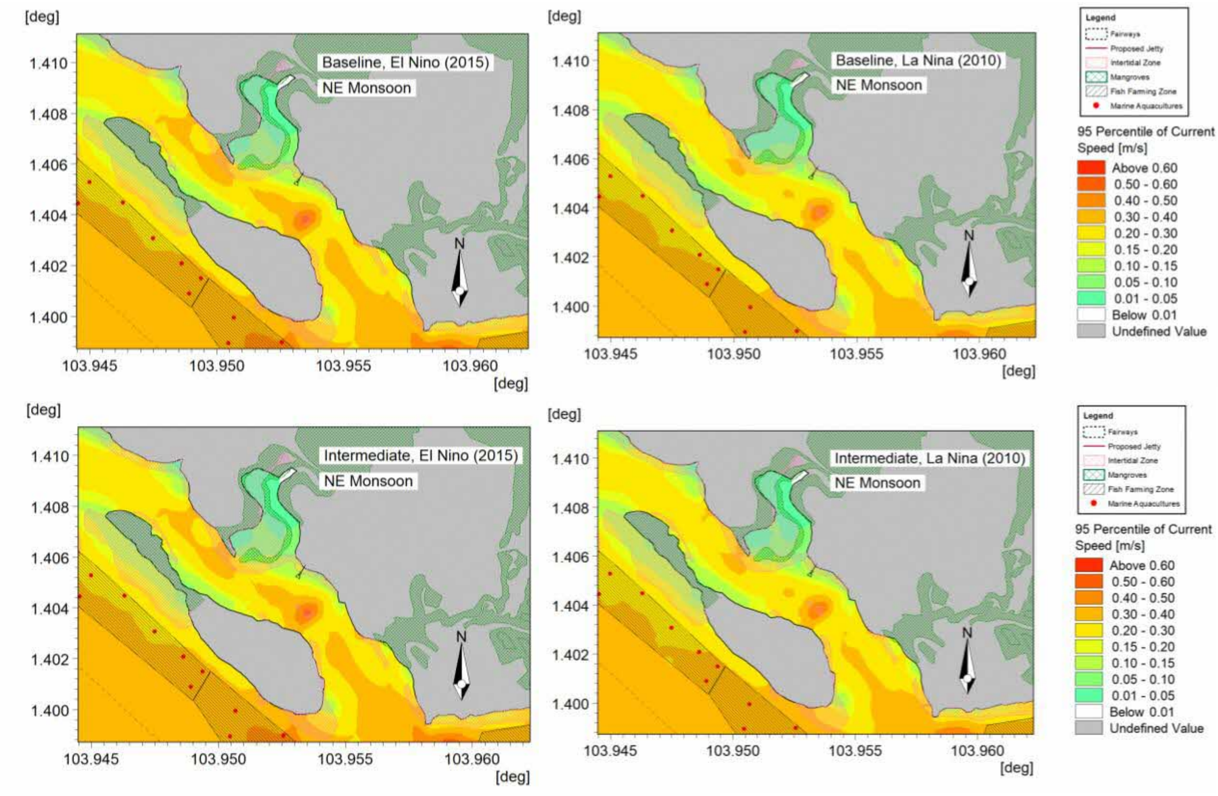


Figure 5.25 95th percentile current speed during NE monsoon in El Niño (left column) and La Niña (right column) years, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios

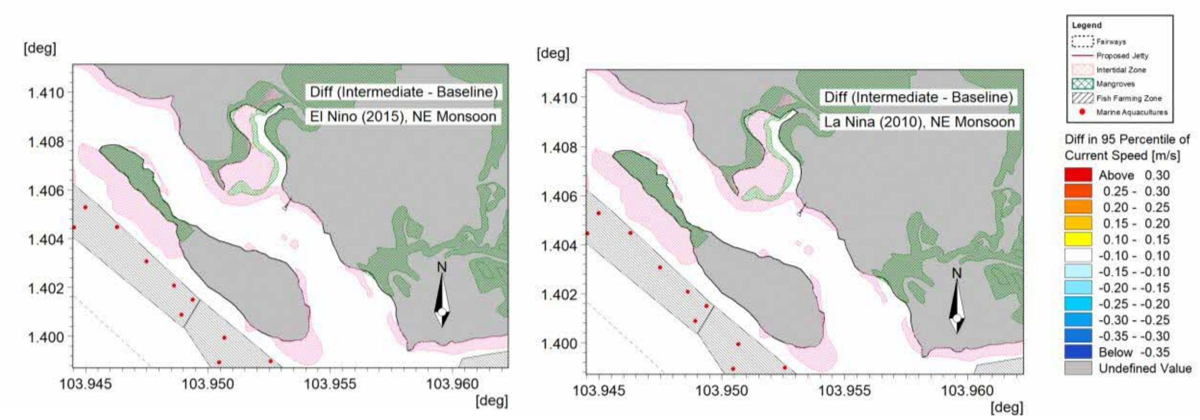


Figure 5.26 Difference in 95th percentile current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon in El Niño (left column) and La Niña (right column) years

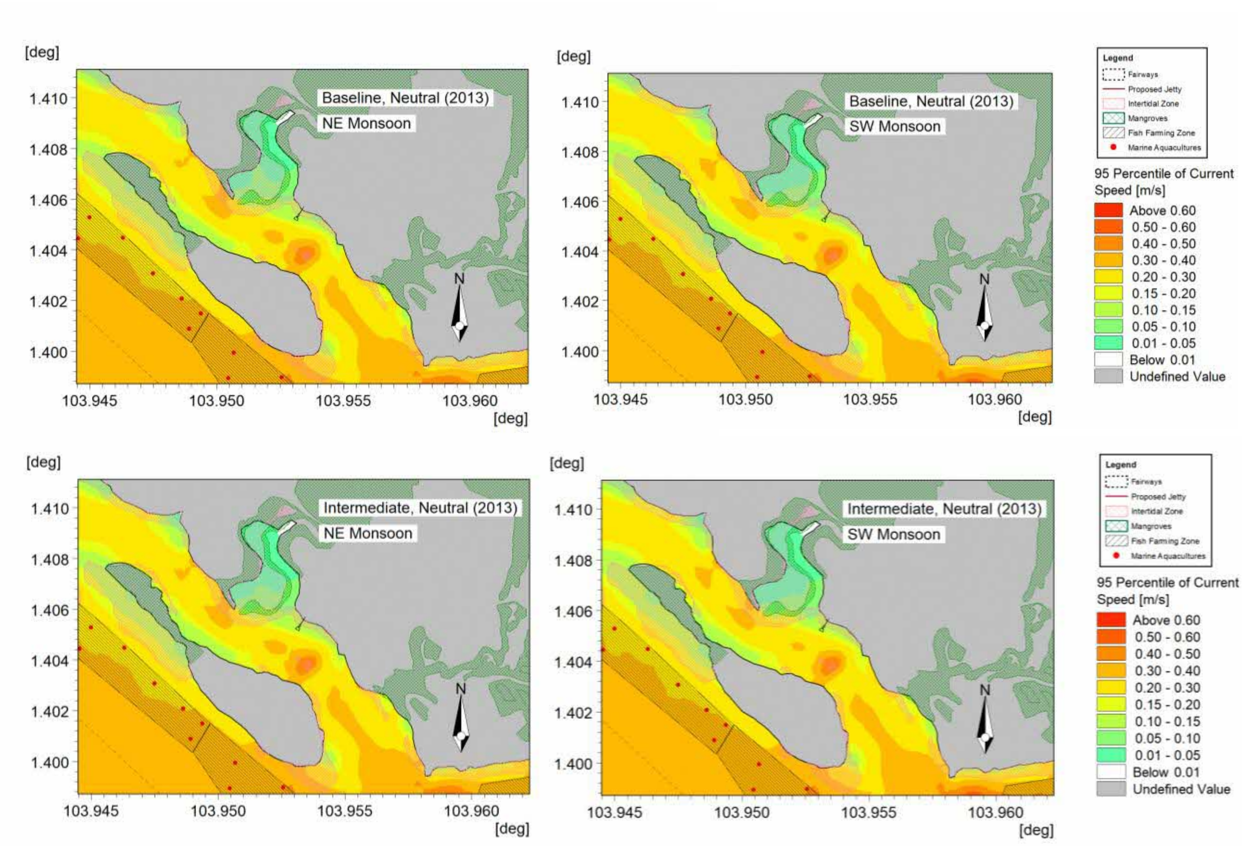


Figure 5.27 95th percentile current speed during NE monsoon (left) and SW monsoon (right) in the Neutral year, for Baseline/Pre-construction Phase (top) and Intermediate/Construction Phase (bottom) scenarios

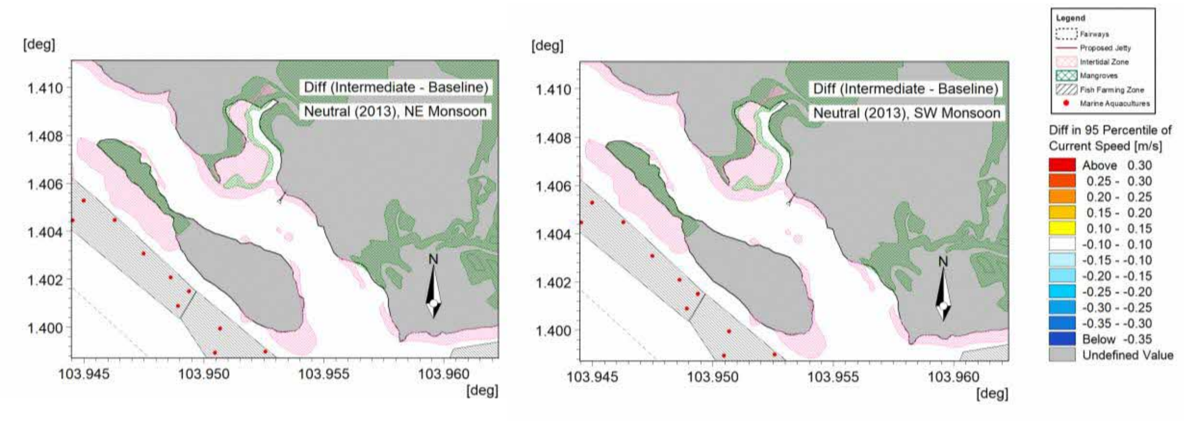


Figure 5.28 Difference in 95th percentile current speed between the Construction Phase and Baseline Phase for the scenarios during NE monsoon (left) and SW monsoon (right) in the Neutral year

Representative Current Speeds: Slackwater (<0.5 knots), exceedances of 2.0 knots and 3.5 knots

This section presents exceedances of selected representative current speeds as an alternative to the analysis of mean and 95th percentile current speeds. This alternative is meant to provide additional understanding of the scale of change in current speeds, and for this purpose, the speeds of 3.5 knots (1.8 m/s), 2.0 knots (1 m/s) and below 0.5 knots (0.25 m/s) were used. A current speed lower than 0.5 knots is generally referred to as slackwater.

Figure 5.29 and Figure 5.30 present slackwater duration in the study area during ENSO and the Neutral year, respectively. It is evident that the baseline currents at the jetty construction area are in slack condition for more than 98 % of the time, and that does not change during the Construction Phase. The presence of the proposed jetty at ULL is predicted to cause less than a 0.5 % change in slackwater duration in the entire study area.

Regarding the exceedance of 2.0 knots and 3.5 knots, model results show that the construction of the proposed jetty at ULL will result in no change (0 %) to the duration of current speeds exceeding 2.0 knots and 3.5 knots in the study area. The empty plots are, therefore, not shown here in this report.

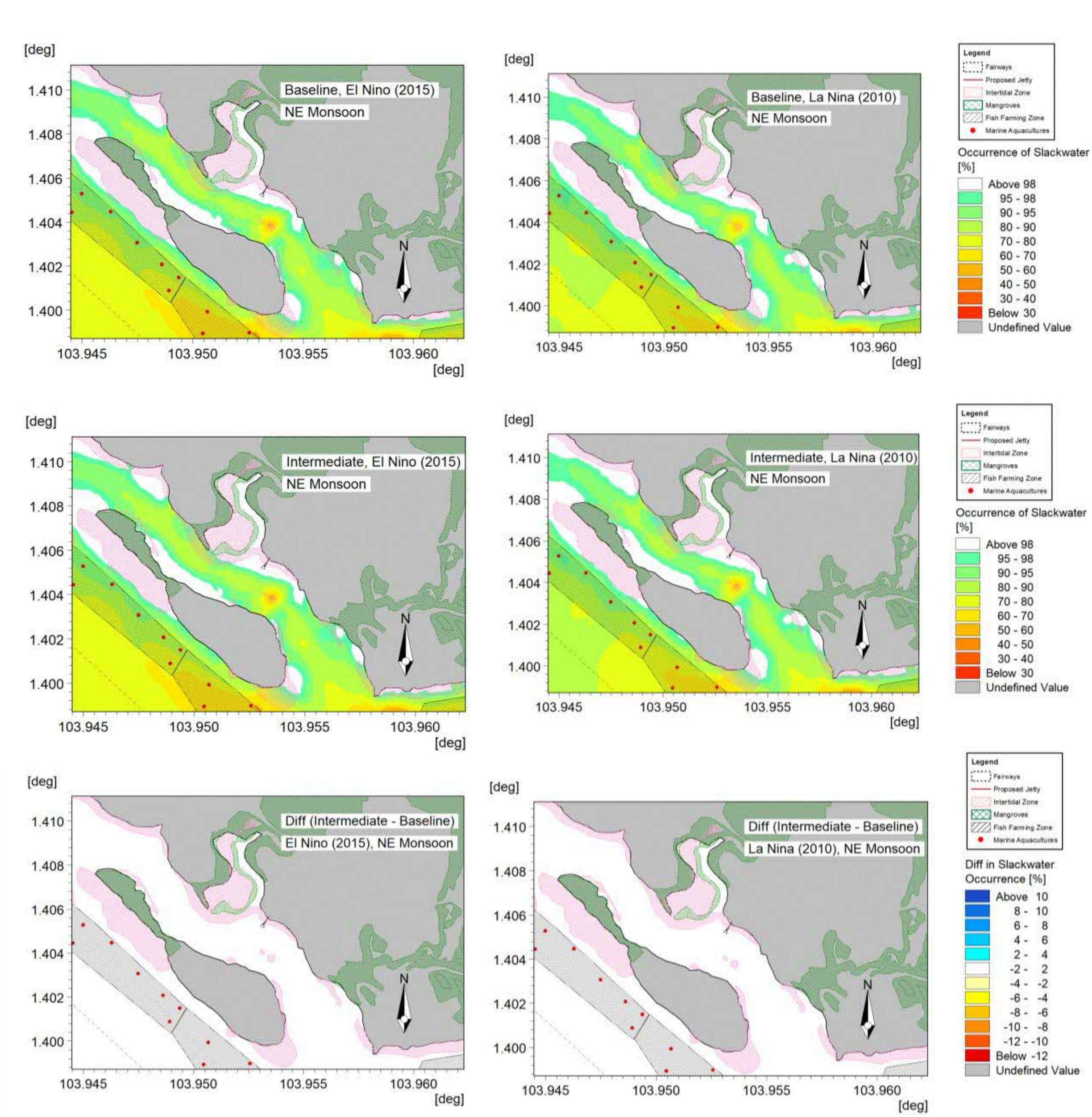


Figure 5.29 Slackwater duration (Current speeds <0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña

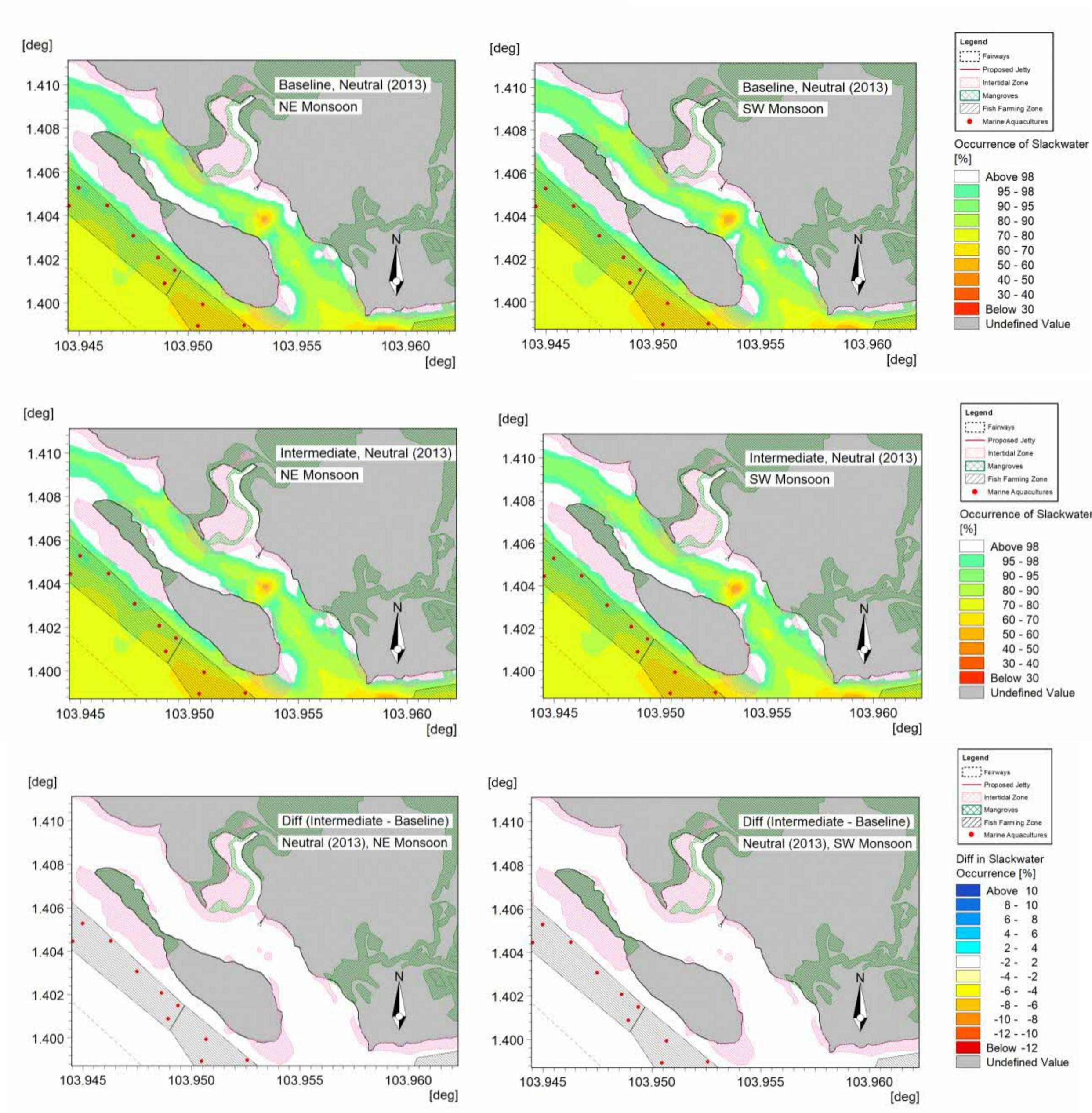


Figure 5.30 Slackwater duration (currents <0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon

5.1.5 Coastal Dynamics Summary

Overall, the Project is located in a sheltered area and characterised by low current speeds. The hydrodynamic simulations predicted that the Construction Phase would result in negligible changes to the mean, 95th percentile, and exceedance of representative current speeds within the study area—the relevant receptor sections present an assessment of impact related to changes in currents (Section 5.9).

5.2 Sediment Plume

Marine works (e.g., piling and trimming works) during the Construction Phase of the Project are likely to result in disturbance and suspension of shoreline and seabed sediments. These sediments will form a plume and, if not managed properly, may be transported to nearby sensitive receptors.

5.2.1 Relevant Key Receptors

The key receptors that could potentially be impacted by changes in suspended sediment concentrations (SSC) due to the construction include:

- Intertidal habitats;
- Mangroves;
- Marine fauna (e.g., coral and fish) ;
- Aquaculture facilities; and
- Socio-economic receptors

This section only discusses the Pressure or Stressor, i.e., the Change in SSC; the resultant effects or impact on the receptors are assessed and discussed in the respective Receptor chapters (Sections 5.7, 5.10, and 5.11).

5.2.2 Baseline Conditions

General Terrestrial Sediment

A hand auger collected a terrestrial sediment sample on 16 November 2022. The hand auger core sample was performed to the maximum depth capable by hand based on site-specific conditions. A sediment core of 32 cm was extracted (Figure 5.31). A digital photo and GPS coordinates were collected at the core site (Figure 5.32). Sediment was noted as coarse, as evidenced by the sediment grading results in Table 5.5. The terrestrial sediment sample is primarily composed of sand (65 %), followed by gravel (32 %), silt (2 %), and clay (1 %). Table 5.4 and Table 5.5 describes the sediment sample results for bulk density and heavy metals, and particle size, respectively.

Figure 5.31. Hand auger sediment core location (top left), an example of the extraction process (top right), and final sample (bottom)

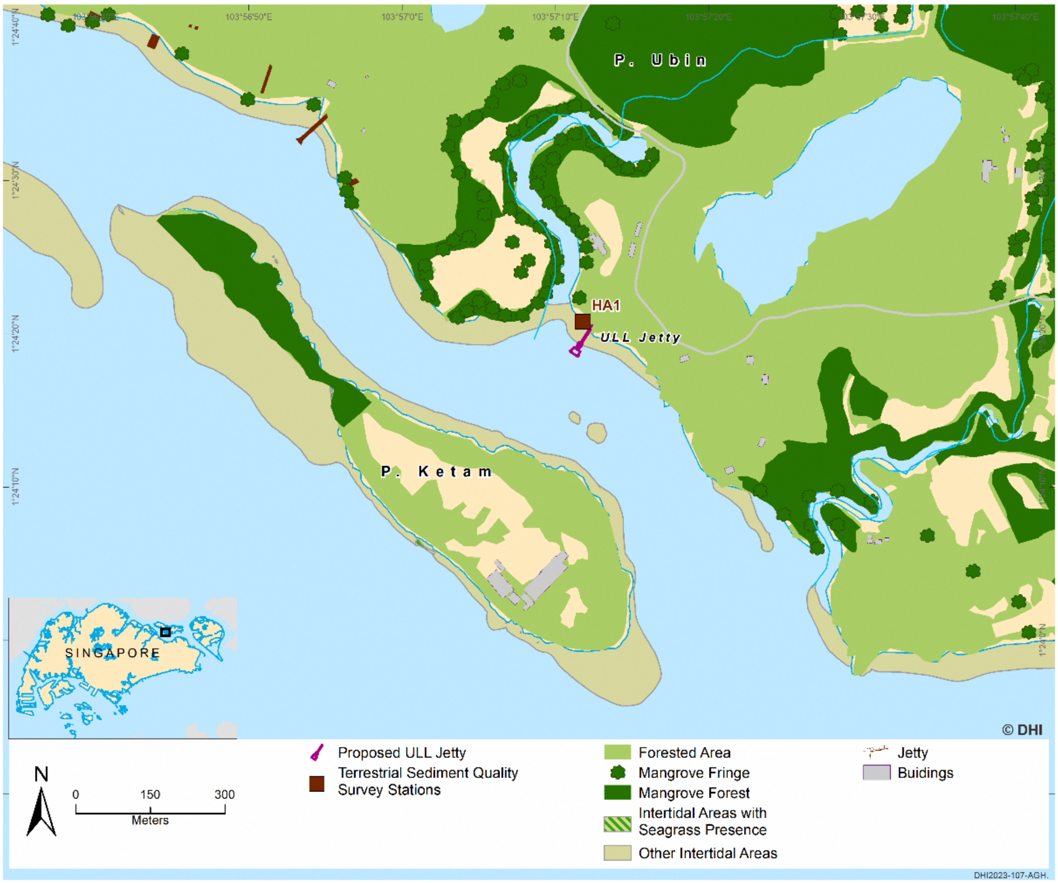


Figure 5.32 Location for terrestrial sediment (HA1) sample

Table 5.4 Terrestrial sediment sample results

Test Parameter	Unit	HA1
Bulk Density	mg/m^3	1.71
Nickel (Ni)	mg/kg	ND
Zinc (Zn)	mg/kg	32.9
Arsenic (As)	mg/kg	3.14
Cadmium (Cd)	mg/kg	ND
Chromium (Cr)	mg/kg	2.72
Copper (Cu)	mg/kg	37.7
Lead (Pb)	mg/kg	13.7
Mercury (Hg)	mg/kg	ND

Table 5.5 Terrestrial sediment particle size results

Material	Clay	Silt	Sand	Gravel
Percentage (%)	1	2	65	32

5.2.3 Evaluation Framework

Based on the project design in Section 2.2, the seabed of the project site will be trimmed, and four (4) marine steel pipe piles will be used for piling during the construction of the proposed jetty at ULL. This section presents the methodology to assess the sediment plume impact from the construction activities (i.e., trimming and piling). It describes the evaluation framework related to sediment plume impacts using DHI's MIKE 21 Mud Transport (MT) Model.

DHI's MIKE 21 Mud Transport (MT) Model primarily simulates the spatial and temporal variation in SSC subject to hydrodynamic transport and settling, deposition and re-suspension processes. In the present model, the sediment spill is represented by three fractions of sediment, representing the ranges from silt to clay characterised by their settling velocities, critical shear stress of deposition and erosion. The sediment plume model only simulates the incremental effects arising from the development project and does not simulate background sediment concentrations. The model outputs are incremental sediment concentrations. Details of the sediment plume model setup are described in Appendix B.

Modelling Scenarios

One (1) representative scenario was simulated for the Construction Phase, and the northeast (NE) monsoon was selected for that purpose. There is no significant difference in current speed between El Niño and La Niña year, hence the scenario was simulated during the El Niño year only. The production period for the sediment plume modelling was fourteen days to cover one full spring-neap tidal cycle.

Information as presented in Section 2.2 (Project Design) was used to determine the exact scenario to be input into the MIKE 21 MT model. It is noted that the project construction comprises trimming works and piling works which will happen in parallel. Total marine construction duration relevant to sediment plume modelling is estimated to be twelve (12) days as there are four (4) piles and each pile takes approximately three (3) days, one pile at a time. Trimming works involve excavating seabed materials at two locations, 200 m^3 each, and is assumed to be completed in a day within the 12-day period. The detailed sediment plume assessment scenario is presented in Table 5.6, while the location of piling and trimming works for simulation is displayed in Figure 5.33.

Table 5.6 Sediment plume assessment schedule

Construction Phase/ Model Period (Day)	1	2	3	4	5	6	7	8	9	10	11	12
Piling	■	■	■	■	■	■	■	■	■	■	■	■
Trimming						■						

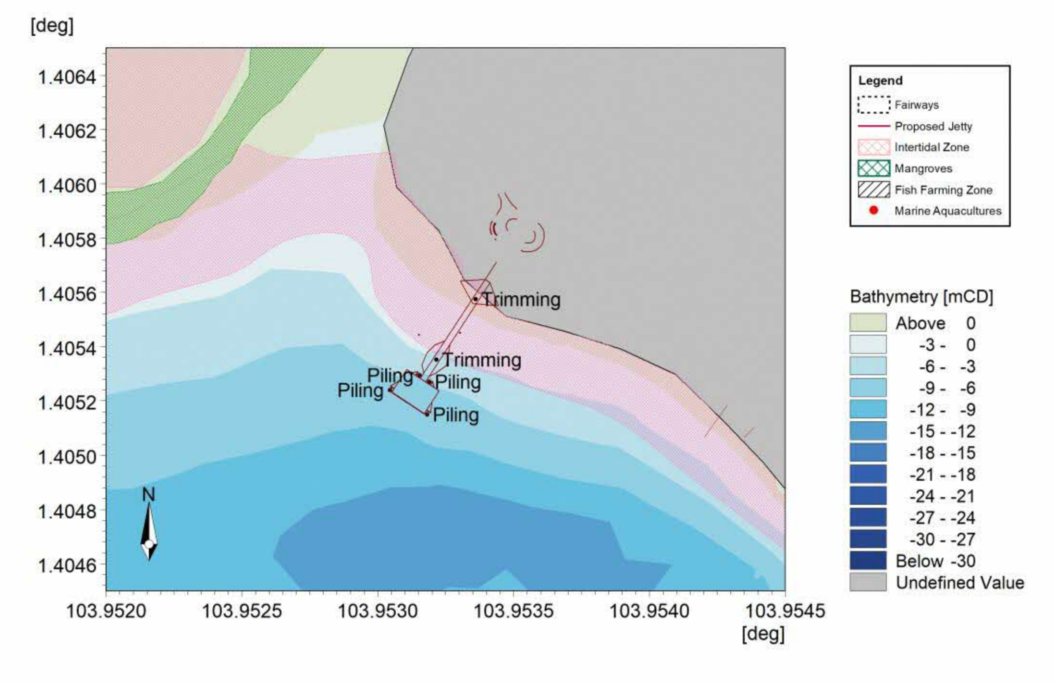


Figure 5.33 Scenario for the sediment plume modelling, involving two (2) trimming areas and four (4) piling locations. Black points indicate the location of sediment release from the works

Model Outputs

The following statistical analysis was carried out on the model results for an overview of where changes in suspended sediment concentrations (SSC) are expected to occur in the Study area due to the construction of the proposed jetty and for the assessment of sediment plume impacts on the identified receptors (Section 5.2.1) according to tolerance limits defined for these receptors:

- Mean and 95th percentile incremental SSC (mg/l) over 14 days; and,
- Percentage of time incremental SSC exceed 5 mg/l, 10 mg/l and 25 mg/l.

5.2.4 Results and Discussion

Overall, the mean incremental SSC due to the trimming and piling activities for the proposed jetty was predicted to be below 5 mg/l within the construction area and in the overall Study area (Figure 5.34). The 95th percentile incremental SSC was modelled to be less than 10 mg/l around the piling locations at the proposed jetty.

Within the construction area, incremental SSC was predicted to exceed 5 mg/l for less than 10% of the time (Figure 5.36), exceed 10 mg/l for less than 5% of the time (Figure 5.37), and exceed 25 mg/l for less than 2.5% of the time (Figure 5.38). Beyond the construction area, incremental SSC was predicted to exceed 5 mg/l for less than 5% of the time in Sungai Puaka, where the bathymetry is shallow (Figure 5.1) and currents are slack (Figure 5.25). In other parts of the Study area outside the construction area, incremental SSC is expected to exceed 5 mg/l for less than 2.5% of the time.

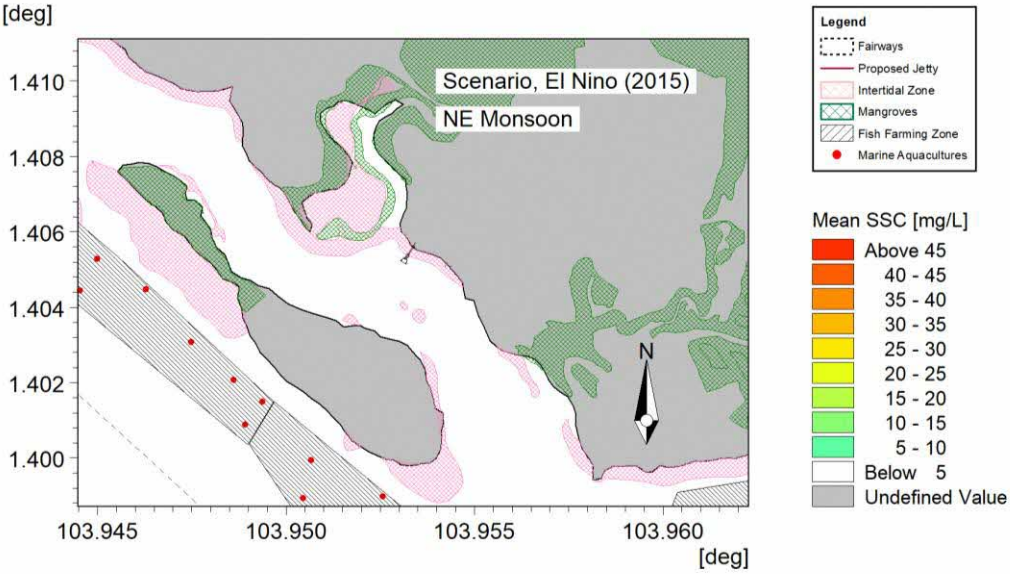


Figure 5.34 Mean incremental SSC from piling and trimming works during El Niño year, NE monsoon

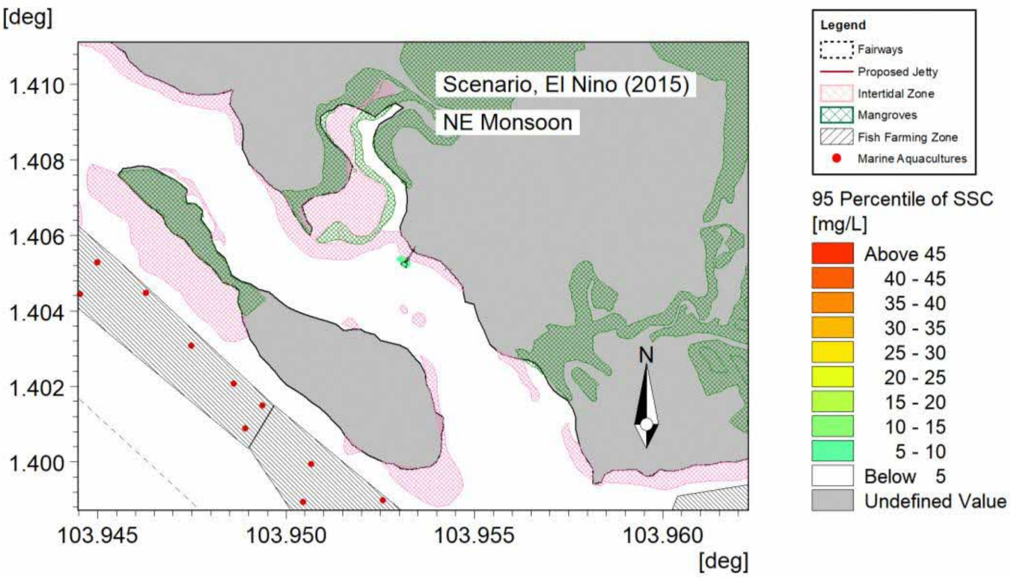


Figure 5.35 95th percentile incremental SSC from piling and trimming works during El Niño year, NE monsoon

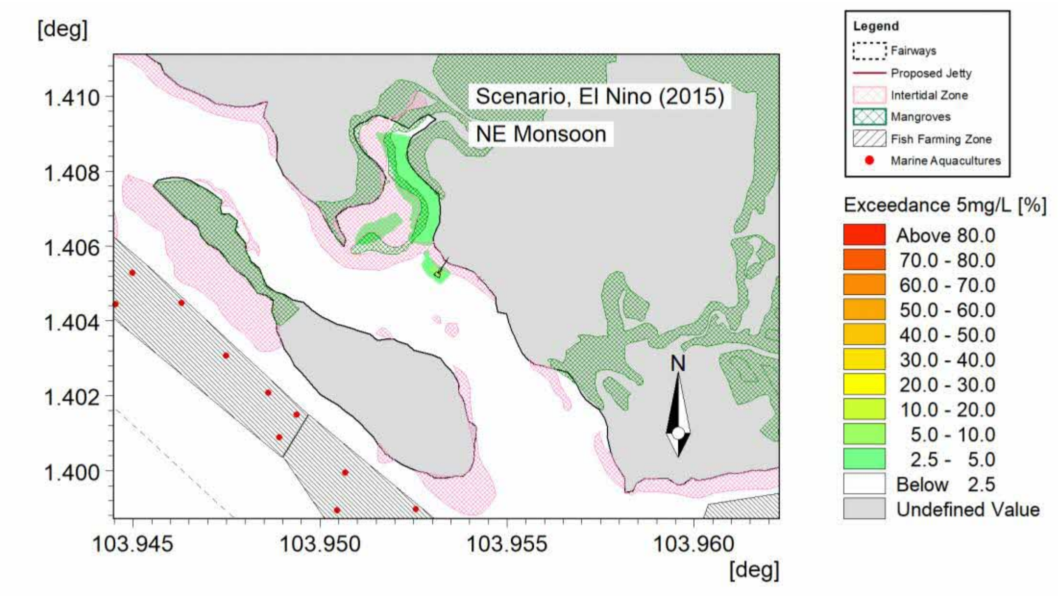


Figure 5.36 Percentage of time in exceedance of 5 mg/l for SSC in the study area, during El Niño year, NE monsoon

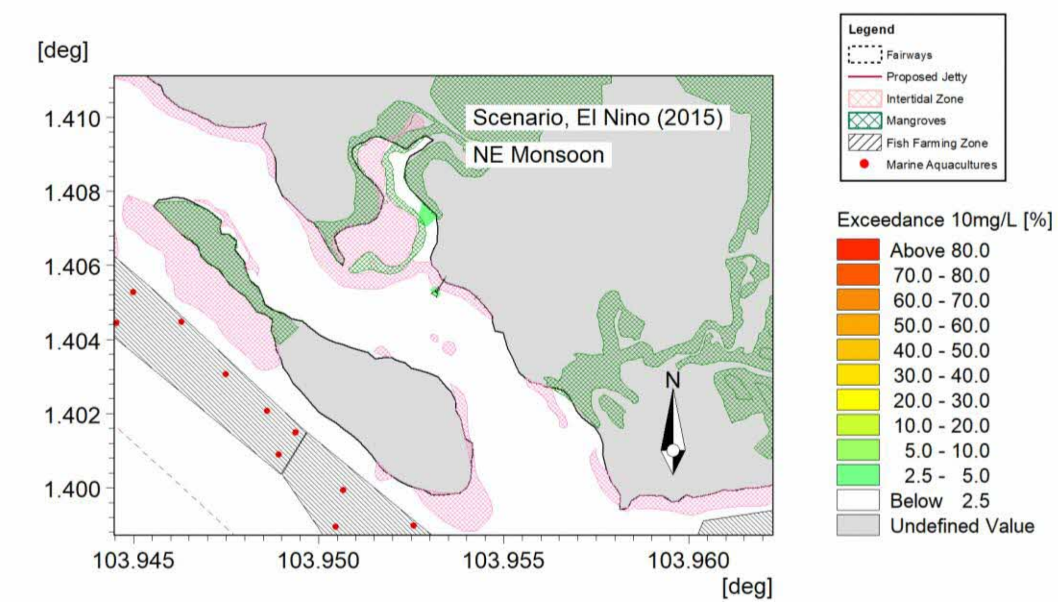


Figure 5.37 Percentage of time in exceedance of 10 mg/l for SSC in the study area, during El Niño year, NE monsoon

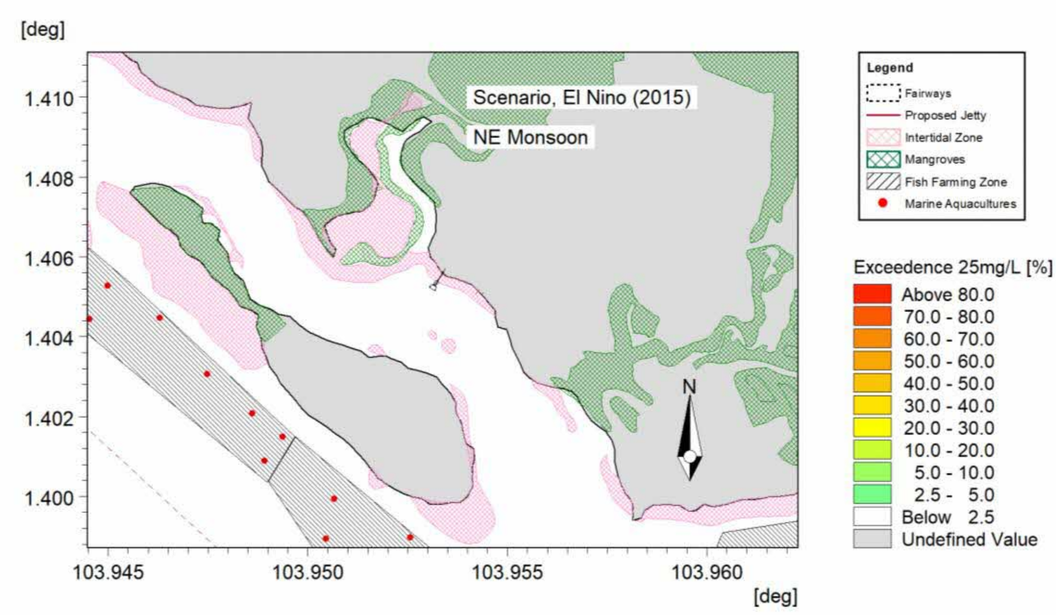


Figure 5.38 Percentage of time in exceedance of 25 mg/l for SSC in the study area, during El Niño year, NE monsoon

5.2.5 Sediment Plume Summary

During the Construction Phase, marine steel pipe piles and revetment will be constructed for the proposed jetty, resulting in sediment plumes generated during the piling and trimming activities. Sediment plume simulation results show that the trimming and piling works will result in localised and minimal plumes. An increase in SSC (mean, maximum, exceedance of 5 mg/l, 10 mg/l and 25 mg/l) is predicted within localised areas in the immediate vicinity of the proposed jetty at ULL.

5.3 Pollutant Release

5.3.1 Relevant Key Receptors

Sediments along the seabed or shoreline, which would be disturbed and potentially suspended and transported during the trimming and piling works, may carry elevated levels of pollutants. If not properly managed, this could affect water quality which could potentially impact nearby receptors such as:

- Marine ecology; and
- Aquaculture farms

This section only discusses the Pressure or Stressor, i.e., the potential change in water quality; the resultant effects or impact on the receptors are assessed and discussed in the respective Receptor chapters (Sections 5.7 and 5.10).

5.3.2 Baseline Conditions

5.3.2.1 Seabed Sediment Quality

Marine seabed sediment sampling was carried out at SQ1 near the construction area (Figure 5.39) on 15 November 2022 using a Van Veen grab sampler (Figure 5.40).

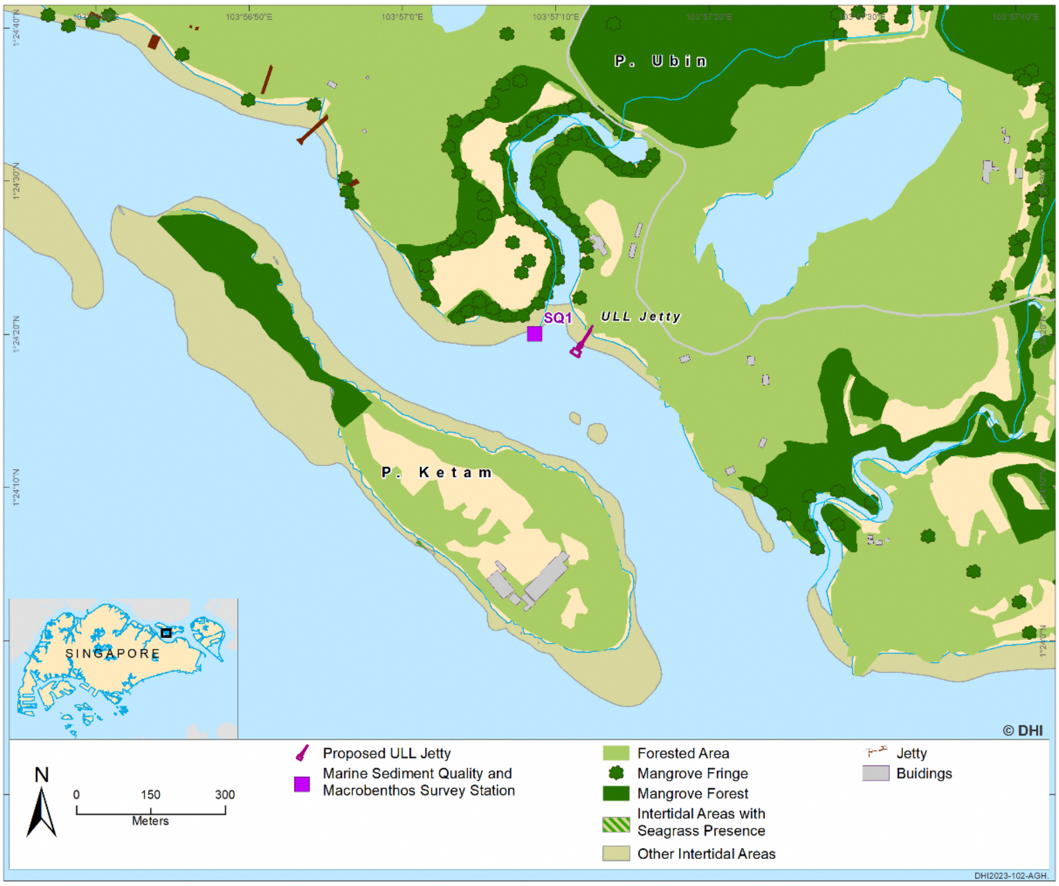


Figure 5.39 Location of the marine sediment quality survey point (SQ1)

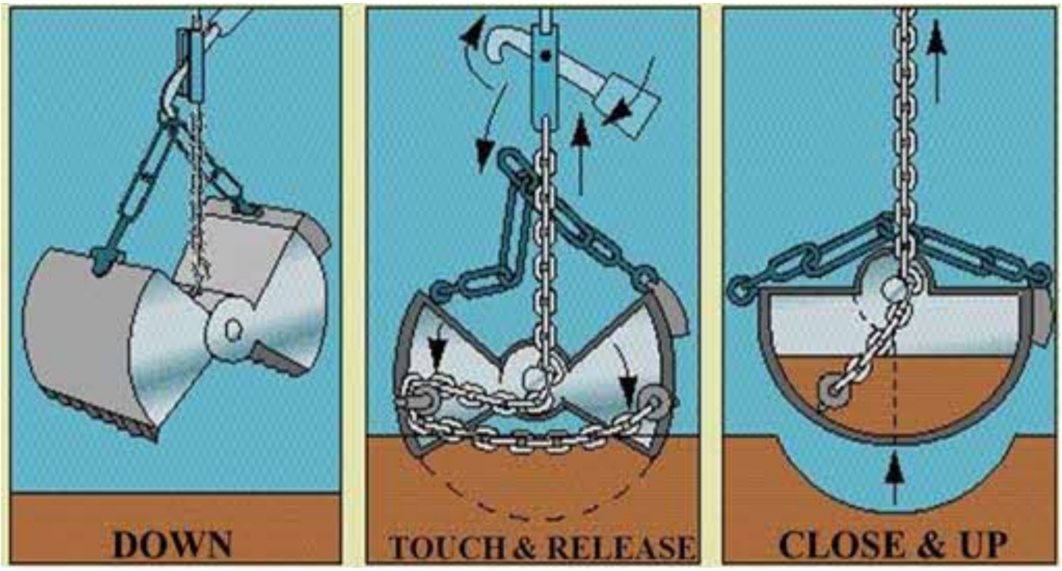


Figure 5.40 Operation of Van Veen grab sampler

Marine sediment at SQ1 is classified as predominantly silty, composed of silt (52 %), clay (38 %), and sand (10 %) (Table 5.7 and Figure 5.41). No gravel was detected in the marine sediment sample. Table 5.8 describes the sediment sample results for bulk density, Total Organic Carbon, Total Nitrogen, and Total Phosphorus found within the sediments.

Table 5.7 Marine sediment particle size results

Material	Clay	Silt	Sand	Gravel
Percentage (%)	38	52	10	0

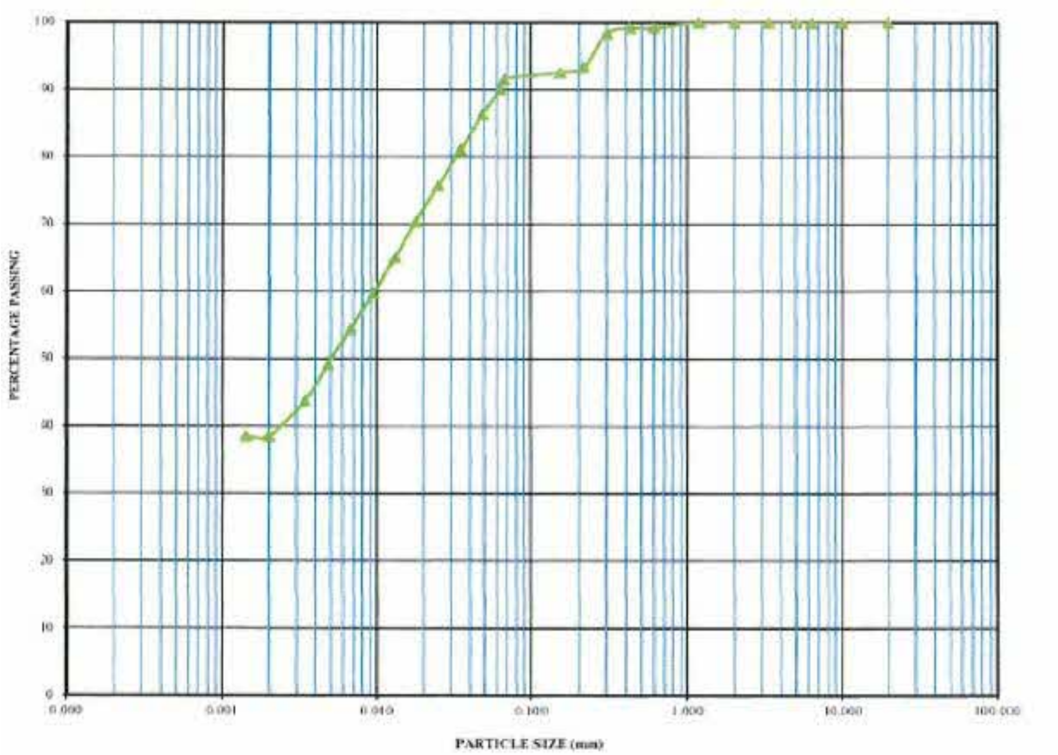


Figure 5.41 Sediment profiles at SQ1 showing the particle size distribution of sediments found

Table 5.8 Bulk density, total organic carbon, total nitrogen and total phosphorous test results of sediments at SQ1

Test Parameter	Unit	SQ1	Limits of Reporting (LOR)
Bulk Density	mg/m^3	1.14	0.01
Total Organic Carbon (TOC)	%	11.7	0.3
Total Nitrogen (TN)	mg/kg	2,570	25
Total Phosphorus (TP)	mg/kg	4.33	1

5.3.2.2 Heavy Metals in Sediment

The heavy metal content of SQ1 was also tested to document the sediment toxicity data. The sediment quality results are indicated in Table 5.9 for heavy metals analysis. These results will be reviewed against the MPA Guidelines.

Table 5.9 Heavy metals test results of sediments at SQ1

Test Parameter	Unit	SQ1
Arsenic as As	mg/kg	46.6
Cadmium as Cd	mg/kg	0.84
Chromium as Cr	mg/kg	27.0
Copper as Cu	mg/kg	29.9
Lead as Pb	mg/kg	32.3
Mercury as Hg	mg/kg	0.22
Nickel as Ni	mg/kg	31.3
Zinc as Zn	mg/kg	148

5.3.2.3 Cyst

Cyst content in the sediment samples was analysed using DHI in-house cyst analysis methods. Cysts are the natural product of some plankton species' sexual production, which are highly resistant to decay (Matsuoka & Fukuyo, 2000). Empty cysts, therefore, indicate that the live organism inside has already exited the cyst into the waters. For baseline assessment, the total number of cysts gives an indication of cyst abundance at the sampled location at that point in time, while the density of live cysts indicates the potential contribution of phytoplankton blooms.

The average cyst density found at SQ1 was 679 org/g (of dry sediment), of which 274 org/g were live cysts and 405 org/g were empty. These levels are moderate compared to other studies in the eastern Johor Straits, with values ranging from 121 to 1,591 org/g.

In terms of species detected, seven (7) genera of plankton cysts were detected, out of which the most abundant species with live cysts was *Gonyaulax* sp. This species has previously been detected in Singapore's waters (Trottet *et al.*, 2018) and is known to have produced toxins that contaminated shellfish (Rhodes *et al.*, 2006). The next most abundant genera are *Protoperidinium sp*. Species of this genera have been previously found to be highly abundant in Singapore waters from previous studies (Trottet *et al.*, 2018) and have been known to cause algal blooms here (Trottet *et al.*, 2022). From numerous previous studies, cyst concentrations are known to be patchy and can vary greatly within a single estuary or strait (e.g., Trottet *et al.*, 2018; Liu *et al.*, 2020). The baseline results show cyst density consistent with literature findings of concentrations in the Singapore marine environment.

5.3.2.4 Marine Water Quality

Marine water sampling was carried out on 15 and 22 November 2022 to investigate the pre-construction water quality in the study area. Sampling was carried out at three (3) locations (Figure 5.42), covering only spring and neap tides during ebb tide. Ebb tide, rather than flood tide, was chosen so that the discharge from Sg Puaka is captured through the water quality surveys.

Six (6) water quality parameters were measured *in-situ* (on-site), and twenty-one (21) parameters were measured *ex-situ* (in the laboratory) over the three (3) locations (WQ01-03), covering a range of chemical and biochemical parameters. The *in-situ* measurements and laboratory results are presented in this section and benchmarked against the ASEAN Marine Water Quality Criteria (MWQC).

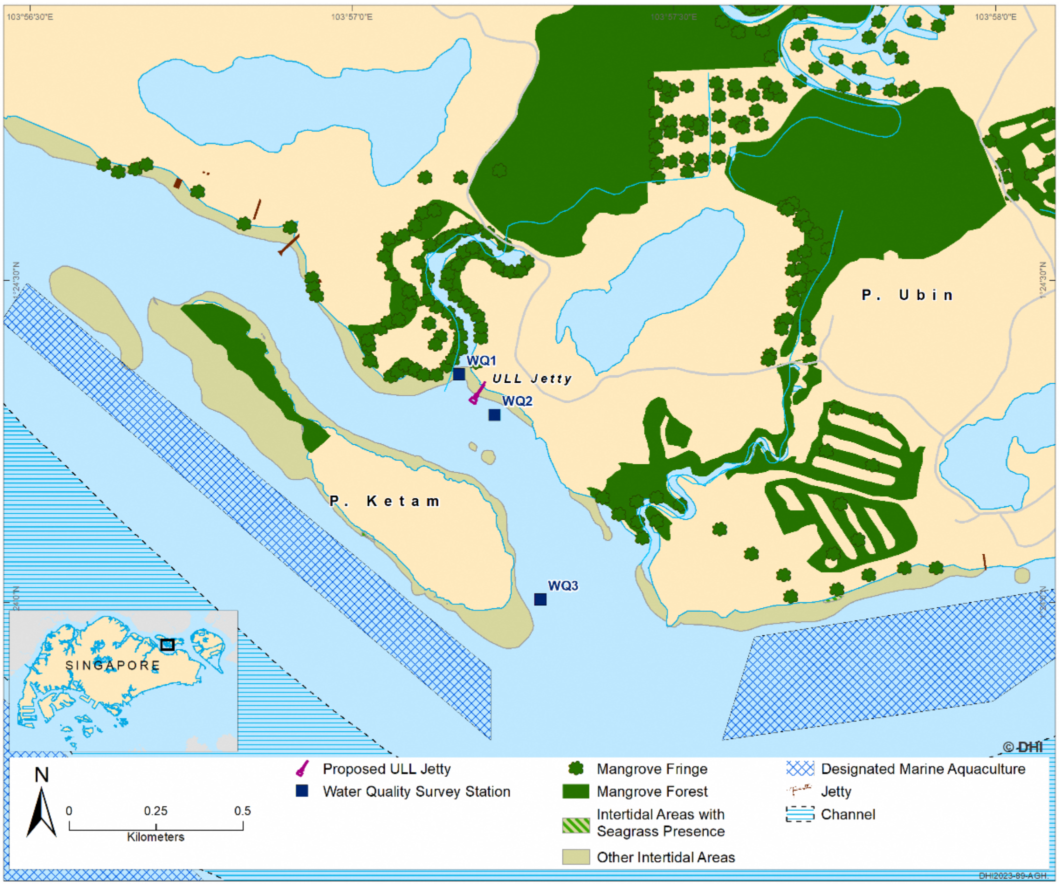


Figure 5.42 Locations of marine water quality survey (WQ01-03)

In-situ Water Quality Parameters

In-situ physical-chemical water quality parameters in this section include water temperature, salinity, dissolved oxygen, pH, turbidity and Secchi depth. These parameters were measured using an EXO multi-parameter probe programmed to collect discrete physical-chemical measurements throughout the water column. The bar graphs present the depth-averaged values, with standard error bars presented as whiskers of each parameter. The graphs are discussed in the subsequent section, and a summary of *in-situ* readings is provided in Table 5.10.

Table 5.10 Summary of in-situ water quality results of stations WQ01 to WQ03 during spring and neap tide, ebb tide, benchmarked against the ASEAN MWQC (if applicable). Exceedances of ASEAN MWQC are highlighted in orange (i.e. Dissolved Oxygen content below 4mg/l was highlighted as it is not within ASEAN MWQC).

Reading	Spring Tide			Neap Tide			ASEAN MWQC
	WQ01	WQ02	WQ03	WQ01	WQ02	WQ03	
Depth (m)							
Maximum	3.7	13.6	7.0	3.7	15.4	6.8	-
Minimum	1.2	0.8	1.1	1.0	1.1	1.0	
Temperature (°C)							
Median	29.69	29.50	29.56	29.79	29.40	29.54	Increase not more than 2 °C above the maximum ambient temperature
Standard Deviation	0.03	0.02	0.08	0.03	0.17	0.11	
5th percentile	29.66	29.49	29.47	29.76	29.35	29.38	
95th percentile	29.72	29.53	29.67	29.84	29.89	29.67	
Salinity (ppt)							
Median	27.96	28.03	28.27	23.05	27.64	24.65	-
Standard Deviation	0.01	0.10	0.15	0.18	2.23	1.76	
5th percentile	27.95	27.90	28.17	22.72	22.19	22.92	
95th percentile	27.97	28.18	28.53	23.24	28.29	27.41	
Dissolved Oxygen (mg/l)							
Median	7.14	6.18	5.81	11.00	3.97	6.11	> 4 mg/l
Standard Deviation	0.05	0.44	0.27	0.36	2.49	2.34	
5th percentile	7.06	5.83	5.41	10.77	3.77	4.29	
95th percentile	7.18	7.22	6.09	11.76	10.38	9.98	
pH							
Median	8.10	8.07	8.07	8.34	7.85	8.00	-

Reading	Spring Tide			Neap Tide			ASEAN MWQC
	WQ01	WQ02	WQ03	WQ01	WQ02	WQ03	
5th percentile	8.10	8.05	8.05	8.31	7.84	7.88	
95th percentile	8.10	8.12	8.09	8.53	8.22	8.25	
Turbidity (NTU)							
Median	5.39	5.45	6.93	1.67	3.92	2.42	-
Standard Deviation	0.35	1.16	1.08	0.10	1.88	2.13	
5th percentile	4.87	4.79	5.88	1.56	1.33	1.63	
95th percentile	5.75	8.31	8.93	1.87	6.54	7.03	

Temperature

Temperature is a key driver of water quality, directly influencing dissolved oxygen concentrations, salinity, and to a lesser extent, pH. Temperature is also coupled to diurnal cycles and associated photosynthetic activity. Ambient water temperature in Singapore's near-shore coastal waters varies demonstrably, although these changes are slight over temporal and spatial scales.

The results of temperature (°C) in Figure 5.42 showed a very low variation of <1.00 °C, with similarly low variability between dates (<1.00 °C). Median temperatures across each location ranged from 29.40 °C to 29.79 °C (Table 5.10). These results indicate no temperature-driven water column stratification and that the temperature had little variability throughout the sampling period.

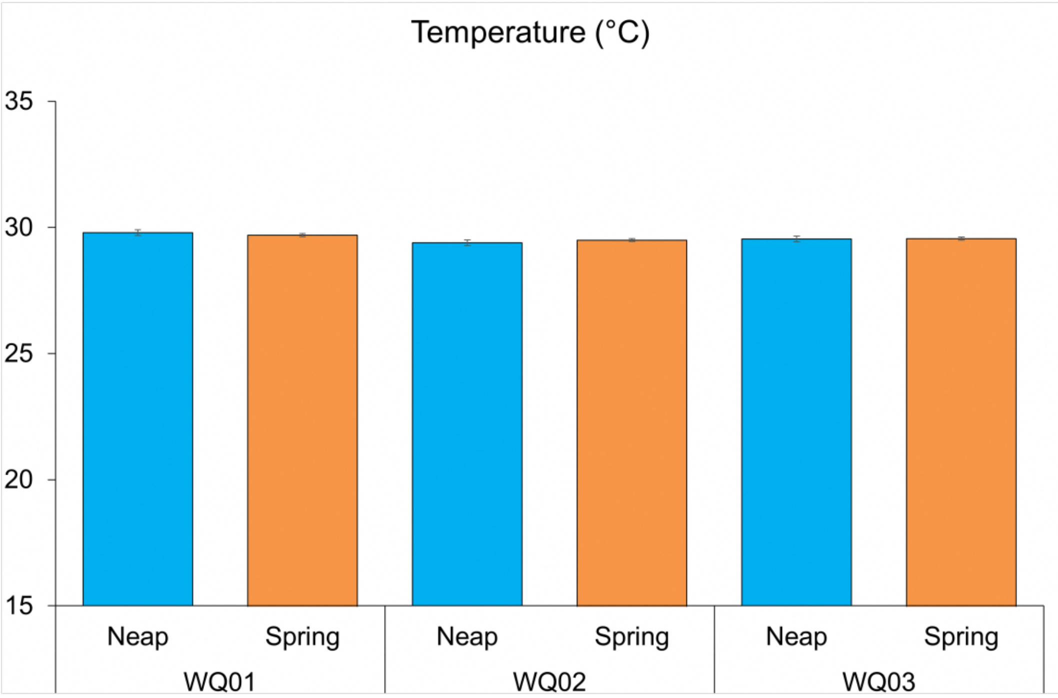


Figure 5.43 Median temperature results across all three (3) locations with error bars

pH

pH is a key parameter which affects the fundamental chemistry of the environment (for example, the proportion of total ammoniacal nitrogen present as toxic ammonia) and may shape the local ecology due to species-specific pH tolerances (such as reductions in the competitiveness and growth of calcifying organisms at low pH) amongst other impacts. Environmental pH generally exists between 4.5 in acidic peatland-fed rivers and up to 10 at locations where intense photosynthetic activity occurs.

Median pH levels across sampling sites varied between 7.85 to 8.10. The 5th percentile of pH levels varies from 7.84 to 8.31, and the 95th percentile values vary from 8.09 to 8.53 (Table 5.10). Figure 5.44 shows little pH variability over the sampling period and values typical of the estuarine Johor Strait. Surface and bottom pH values were generally similar and showed no indication of stratification during the survey period.

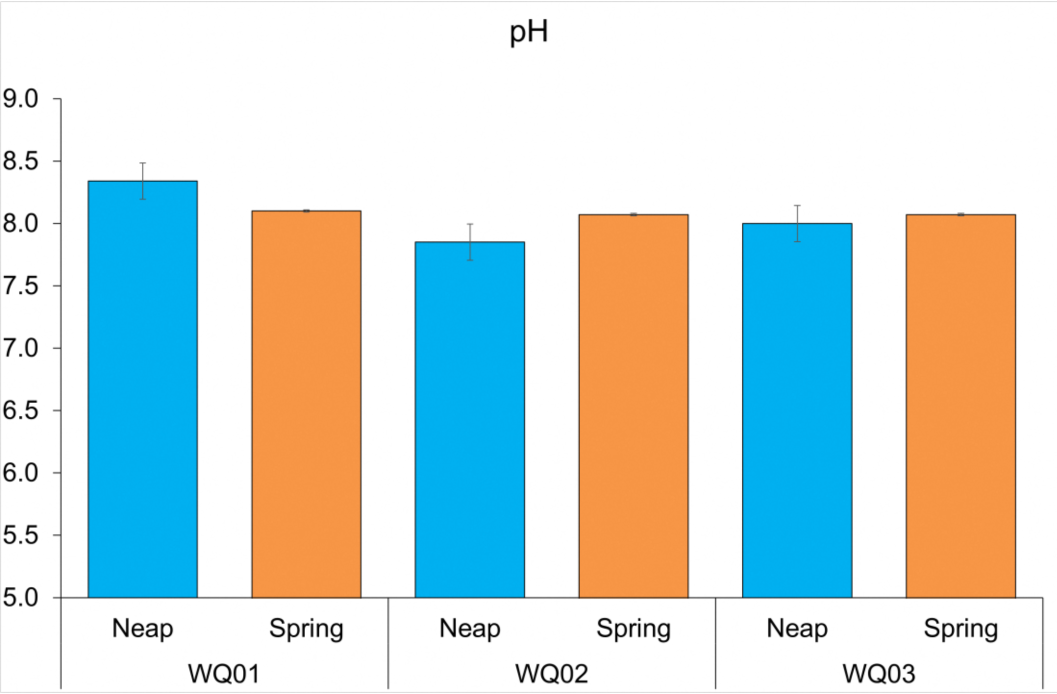


Figure 5.44 Median pH results across all three (3) locations with error bars

Salinity

Salinity varies according to season and is particularly influenced by freshwater runoff during the pronounced monsoon events experienced in Singapore's territorial waters. The water's salinity indicates the extent of mixing and the presence of salinity stratification, which may occur when there is significant freshwater runoff.

The median salinity levels ranged between 23.05 ppt and 28.03 ppt. The 5th percentile of salinity levels varies from 22.19 to 27.95 ppt, and the 95th percentile values vary from 23.24 to 28.53 ppt (Table 5.10). The results in Figure 5.45 showed that salinity levels were consistently below 29 ppt during both spring and neap tides, and this could be due to low flushing within the Project area.

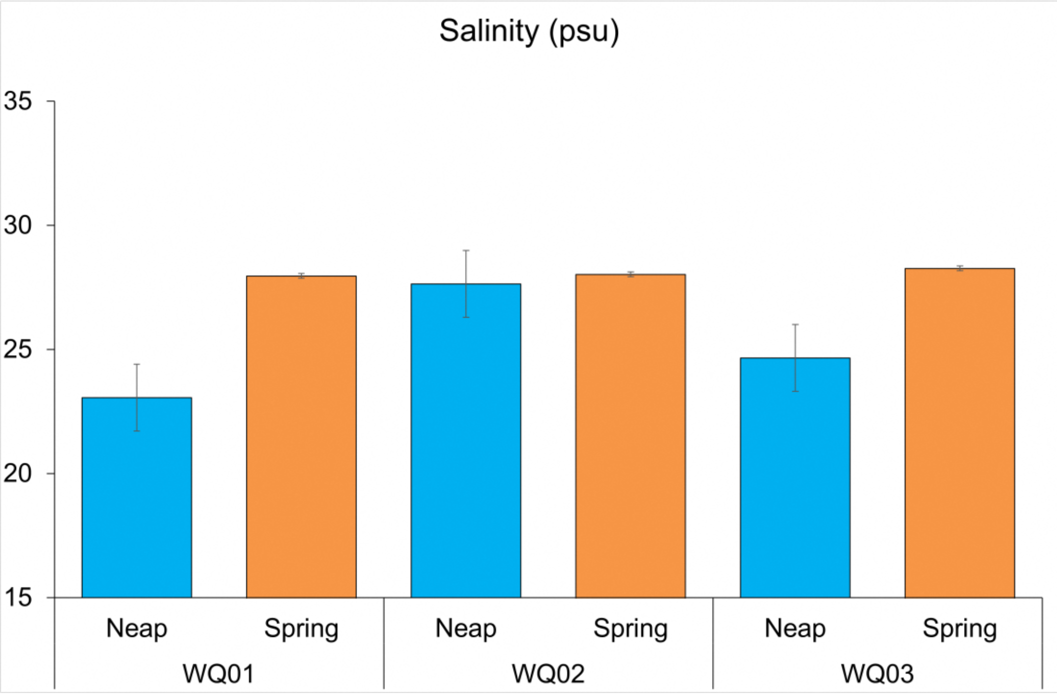


Figure 5.45 Median salinity results across all three (3) locations with error bars

Turbidity

Turbidity is an indicator of water clarity. It measures the degree to which the water loses its transparency due to suspended particulates and dissolved organic matter in water.

Generally, the turbidity readings across all stations were below 10 Nephelometric Turbidity Unit (NTU) across spring and neap tides (Table 5.10 and Figure 5.46). Median turbidity values ranged from 1.67 to 6.93 NTU. Additionally, turbidity increased with increasing water depth at WQ02 and WQ03 (Figure 5.47), which was similarly observed in TSS results where higher TSS readings were obtained at the water depth bottom.

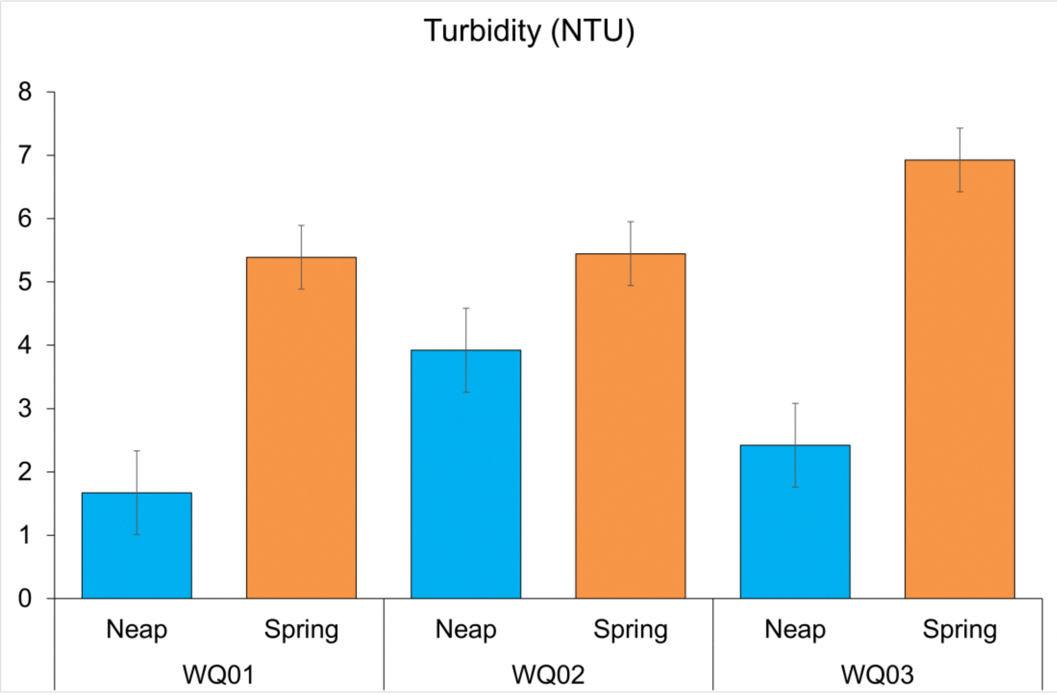


Figure 5.46 Median turbidity results across all three (3) locations with error bars

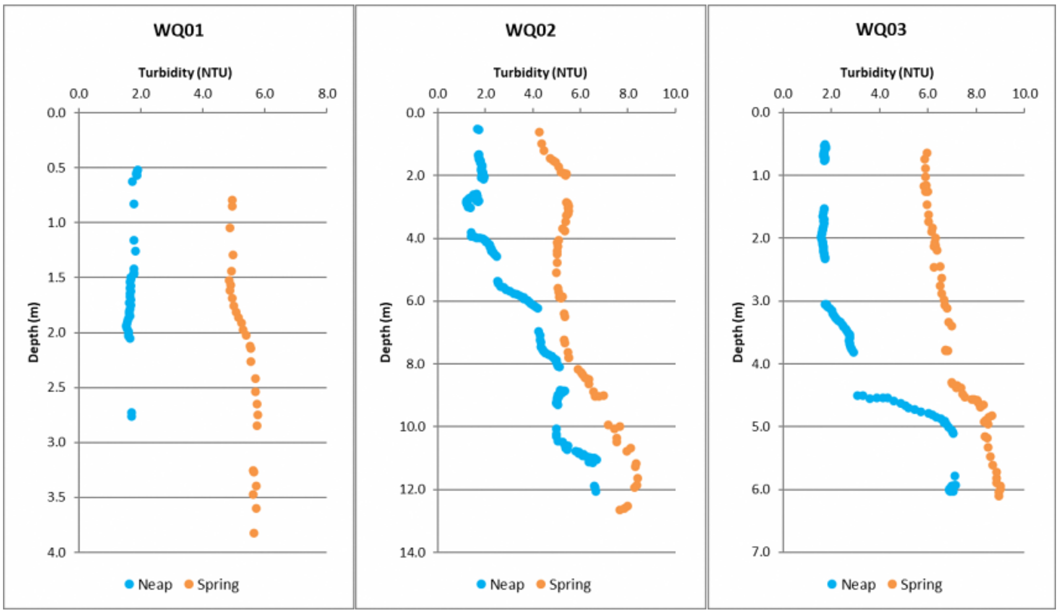


Figure 5.47 Turbidity profiles for each water quality station (note that the x- and y- axes ranges vary for each plot)

Dissolved Oxygen (DO)

The concentration of dissolved oxygen is used as an indicator to determine the ecological condition of the waters. It is primarily maintained through bio-physical processes such as wind-driven agitation of surface waters, tidal exchange and biological processes such as photosynthesis from aquatic flora (algae, seagrass and phytoplankton). The median dissolved oxygen concentrations were consistently higher than the ASEAN MWQC of 4.0 mg/l except for WQ02 at neap tide, near the borderline limit of 4 mg/l. Hence, the waters around the project site are generally well-oxygenated.

Low values of dissolved oxygen (< 4mg/l) were captured at deeper depths, causing the exceedances see in Table 5.10. This can be which can be attributed to low flushing at depths at the project site. Moreover, high amounts of algae found at the project site can change dissolved oxygen levels due to the photosynthetic or respiratory rates of algae, and the degradation of organic matter by heterotrophic microbes. Dramatic fluctuations in dissolved oxygen can also be due to algal blooms.

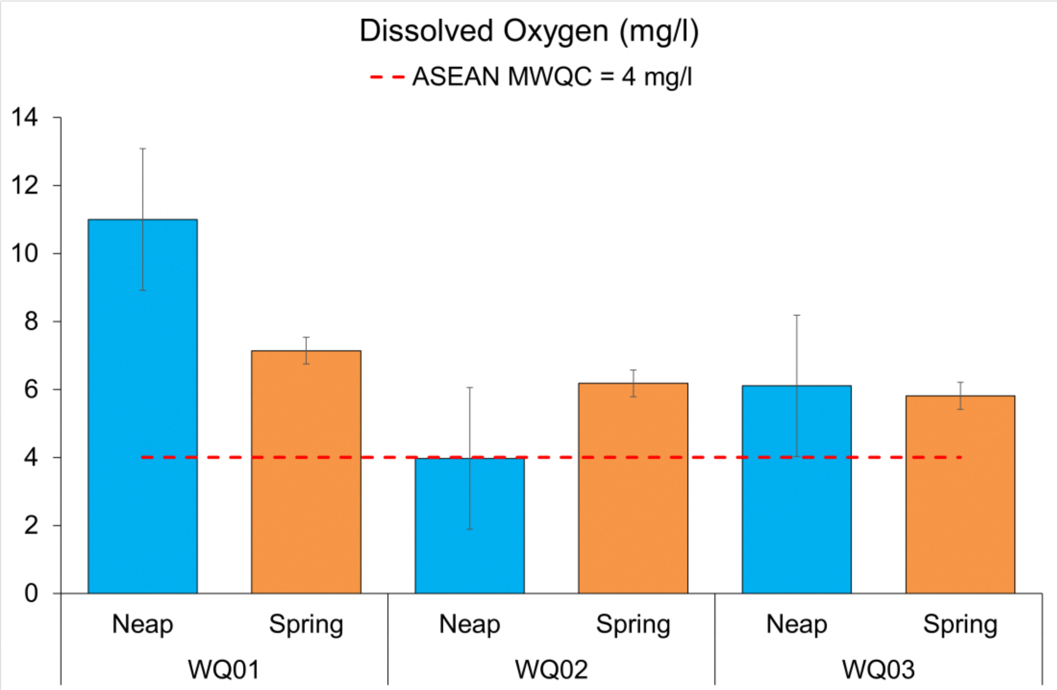


Figure 5.48 Median dissolved oxygen results across all three (3) locations with error bars

Secchi Disc Depth

Secchi depth indicates the water clarity, which is influenced by various factors that will affect the visibility of the disc underwater, e.g., plankton, suspended sediment and cloud cover. Secchi disc depth measurements across the locations indicated moderately high turbidity levels (Figure 5.49). This could be due to the high Chlorophyll-*a* levels observed at the water surface, suggesting high levels of floating algae in the water column. Secchi disc depth measurements were less than the 1.2 m target depth for all stations and all tides.

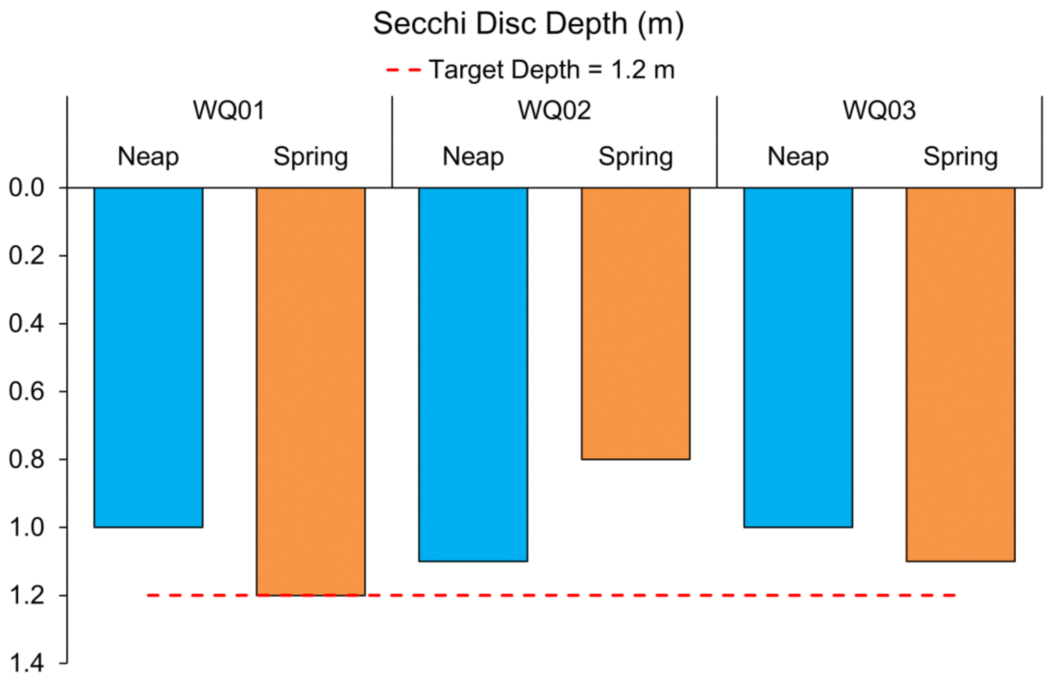


Figure 5.49 Maximum Secchi disc depth results across all three (3) locations

Ex-situ Water Quality Results

This section summarises the *ex-situ* analytical water quality parameters. The parameters include TSS, TN, TP, TAN, PO_4-P, NO_3-N, NO_2-N, BOD_5, Cl_2, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn, oil and grease, faecal coliform, enterococci and Chlorophyll-a. Laboratory analyses of water quality samples were undertaken by a Singapore Laboratory Accreditation Scheme (SINGLAS) accredited laboratory in accordance with the Singapore Accreditation Council requirements for standard procedures.

The analytical results are summarised in Table 5.11. Reported concentrations of Cl_2, oil and grease, Pb and Hg are below the detection limits and will not be discussed in this section. Generally, the water quality in the area was characterised by high concentrations of nutrients and bacteria. Most of the stations indicated compliance with the ASEAN MWQC, where applicable. Nitrate, nitrite, and phosphate were above ASEAN MWQC. Elevated levels of faecal coliforms were also observed, exceeding ASEAN MWQC for recreational waters. This is consistent with conditions in the East Johor Strait (Gin *et al.,* 2000), which are similarly eutrophic in other studies conducted by DHI.

Table 5.11 Summary of *ex-situ* water quality results of stations WQ01 to WQ03 during spring and neap tide, ebb tide, benchmarked against the ASEAN MWQC (if applicable). Cells highlighted in orange indicate exceedance of ASEAN MWQC for Aquatic Life Protection in Coastal areas

Parameter	Unit	Depth	Spring Tide			Neap Tide			ASEAN MWQC	Compliance
			WQ01	WQ02	WQ03	WQ01	WQ02	WQ03		
Total Suspended Solids (TSS)	mg/l	Surface	8.90	7.60	9.60	8.60	9.57	8.57	≤ 10% increase over seasonal average concentration[3]	N/A
		Bottom	14.00	14.10	22.80	8.00	9.88	10.60		
Total Nitrogen (TN)	mg/l	Surface	0.48	0.46	0.49	0.87	1.02	0.91	-	N/A
		Bottom	0.47	0.38	0.51	0.70	0.61	0.60		
Nitrate as NO_3-N	mg/l	Surface	0.033	0.053	0.067	0.084	0.065	0.093	0.060	×
		Bottom	0.047	0.073	0.074	0.110	0.150	0.160		×
Nitrite as NO_2-N	mg/l	Surface	0.019	0.011	0.036	0.060	0.055	0.064	0.055	×
		Bottom	0.024	0.038	0.038	0.068	0.100	0.088		×
Total Ammoniacal Nitrogen (NH_3-N + NH_4-N)	mg/l	Surface	0.044	0.042	0.034	0.012	0.010	0.012	-	N/A
		Bottom	0.016	0.043	0.037	0.013	0.054	0.054		
Total Phosphorus (TP)	mg/l	Surface	0.014	0.017	0.023	0.024	0.021	0.023	-	N/A
		Bottom	0.022	0.026	0.024	0.021	0.068	0.063		
Phosphate as PO_4-P	mg/l	Surface	0.012	0.011	0.017	0.014	0.014	0.014	0.015	×
		Bottom	0.014	0.024	0.022	0.014	0.057	0.049		×
Biological Oxygen Demand (BOD_5)	mg/l	Surface	1.45	1.98	1.02	<1	<1	<1	-	N/A
		Bottom	1.28	1.03	1.02	<1	<1	<1		
Chlorine as Cl_2	mg/l	Surface	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	N/A
		Bottom	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		
Chlorophyll-a	µg/l	Surface	15.10	21.50	11.70	65.60	70.60	63.70	-	N/A

[3] TSS criterion refers to change from the baseline levels and does not apply to baseline results

Parameter	Unit	Depth	Spring Tide			Neap Tide			ASEAN MWQC	Compliance
			WQ01	WQ02	WQ03	WQ01	WQ02	WQ03		
		Bottom	13.20	9.98	8.46	64.60	3.78	20.10		
Arsenic	µg/l	Surface	2.48	2.42	2.32	1.97	1.92	1.91	-	N/A
		Bottom	2.07	2.38	2.01	1.80	2.19	2.13		
Cadmium	µg/l	Surface	<0.15	<0.15	<0.15	0.19	<0.15	<0.15	10	✓
		Bottom	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15		✓
Chromium	µg/l	Surface	2.20	2.07	2.21	2.35	2.17	2.22	50	✓
		Bottom	2.06	2.29	2.26	2.14	3.30	2.62		✓
Copper	µg/l	Surface	1.19	1.09	0.94	1.05	1.11	0.80	8	✓
		Bottom	0.96	1.35	1.20	0.71	0.74	0.69		✓
Lead	µg/l	Surface	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	8.5	✓
		Bottom	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15		✓
Mercury	µg/l	Surface	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.16	✓
		Bottom	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		✓
Nickel	µg/l	Surface	3.72	<3	<3	<3	<3	<3	-	N/A
		Bottom	<3	3.89	<3	<3	<3	<3		
Zinc	µg/l	Surface	3.49	<1.5	<1.5	8.75	<1.5	<1.5	-	N/A
		Bottom	1.80	4.76	3.53	<1.5	<1.5	<1.5		
Oil and grease	mg/l	Surface	<10	<10	<10	<10	<10	<10	0.14	✓
		Bottom	<10	<10	<10	<10	<10	<10		✓
Faecal Coliform	MPN/ 100 ml	Surface	7.8	49	46	46	540	540	100*	×
		Bottom	17	6.8	31	350	130	170		×
Enterococci	CFU/ 100 ml	Surface	6	18	21	20	16	25	35*	✓
		Bottom	5	12	8	16	13	10		✓

* Value for recreational waters

Total Suspended Solids (TSS)

TSS are particulate solid materials, including organic and inorganic solids suspended in the water column. Although similar to the measure of turbidity, TSS is a separate measurement that provides the actual weight of particulate material present in the sample. Natural sources of TSS include runoff, erosion and transportation of sediments through riverine and estuarine processes, and organic material decomposition. Elevations in TSS values through anthropogenic-related activities include point source discharges of pollutants from effluent, sewage, runoffs from site clearances and marine construction projects. High concentrations of TSS can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life. TSS can also smother benthic environments, clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development.

TSS readings at WQ01 to WQ03 (Table 5.49) during the baseline surveys ranged between 7.6 mg/l to 22.8 mg/l during spring tide. It fluctuated within a smaller window of 8.0 mg/l and 10.6 mg/l during neap tide.

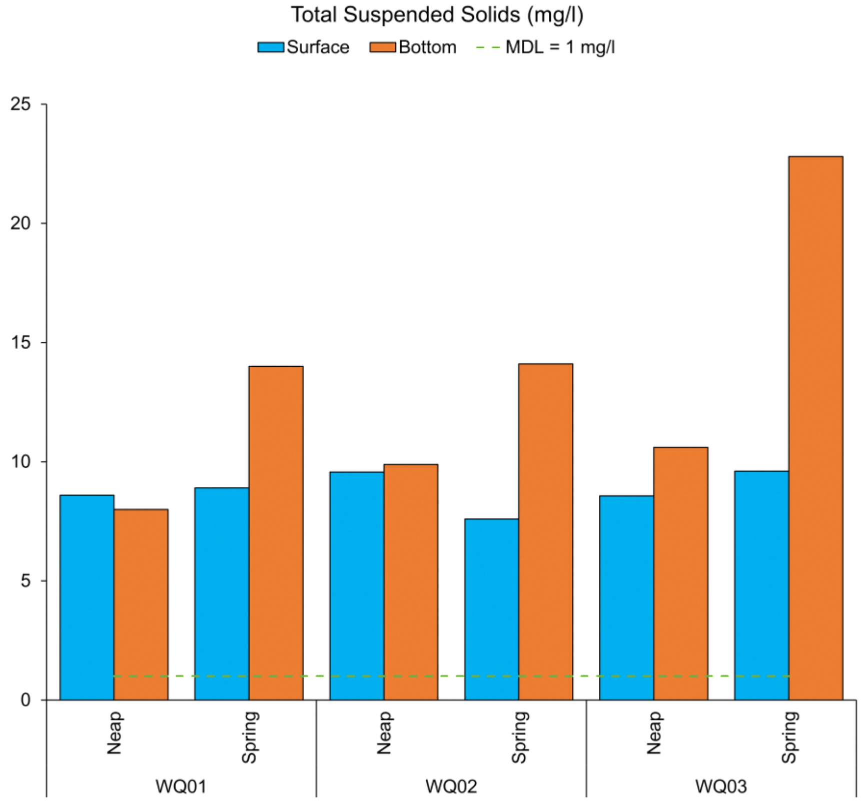


Figure 5.50 TSS concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

Nitrogen

Nitrogen compounds are necessary for plant and algal growth. It is often a limiting factor in the growth of phytoplankton in marine waters. Excess quantities of nitrogen can lead to undesirable algal blooms resulting in incidents of oxygen depletion (hypoxia). Nitrogen parameters include Total Nitrogen (TN), Total Ammoniacal Nitrogen (TAN) nitrate, and nitrite. Both nitrate and nitrite were above the ASEAN MWQC of 0.060 mg/l and 0.055 mg/l, respectively, whereas there are no available ASEAN MWQC values for TN and TAN.

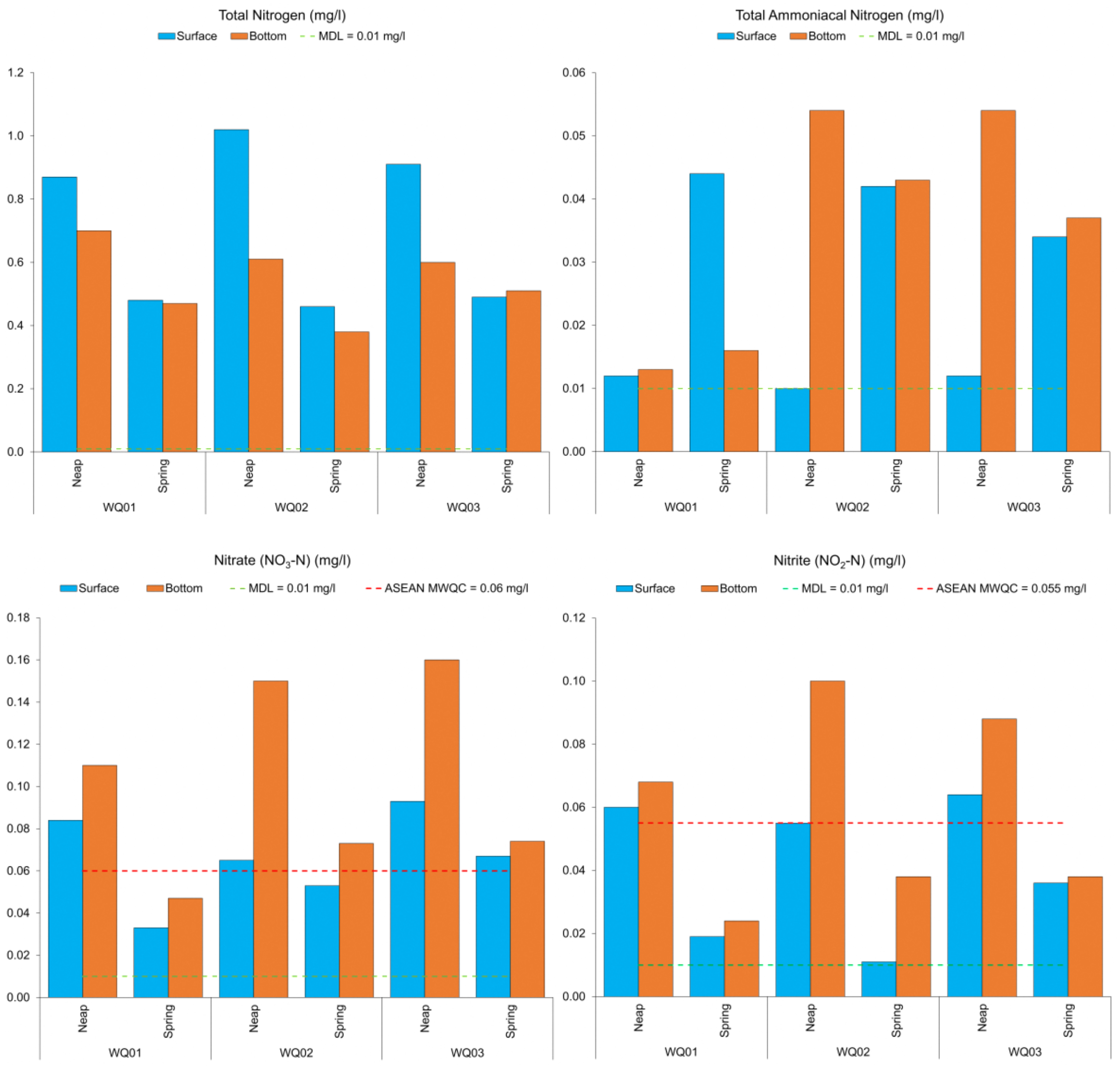


Figure 5.51 Total nitrogen (TN), Total Ammoniacal Nitrogen (TAN), Nitrate and Nitrite concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

Phosphorus

Phosphorous, like nitrogen, is also necessary for plant and animal growth. As such, an abundance of phosphorous-based nutrients (such as phosphate) can lead to excessive growth of aquatic plants such as phytoplankton and other algal species in warm tropical waters. Two measures of phosphorous content were measured: Total Phosphate (TP) and phosphate concentration.

The concentrations of phosphate found during the survey ranged between 0.011 mg/l and 0.057 mg/l. A few of the stations during both spring and neap tides were slightly in excess of the ASEAN MWQC (0.015 mg/l for coastal habitats).

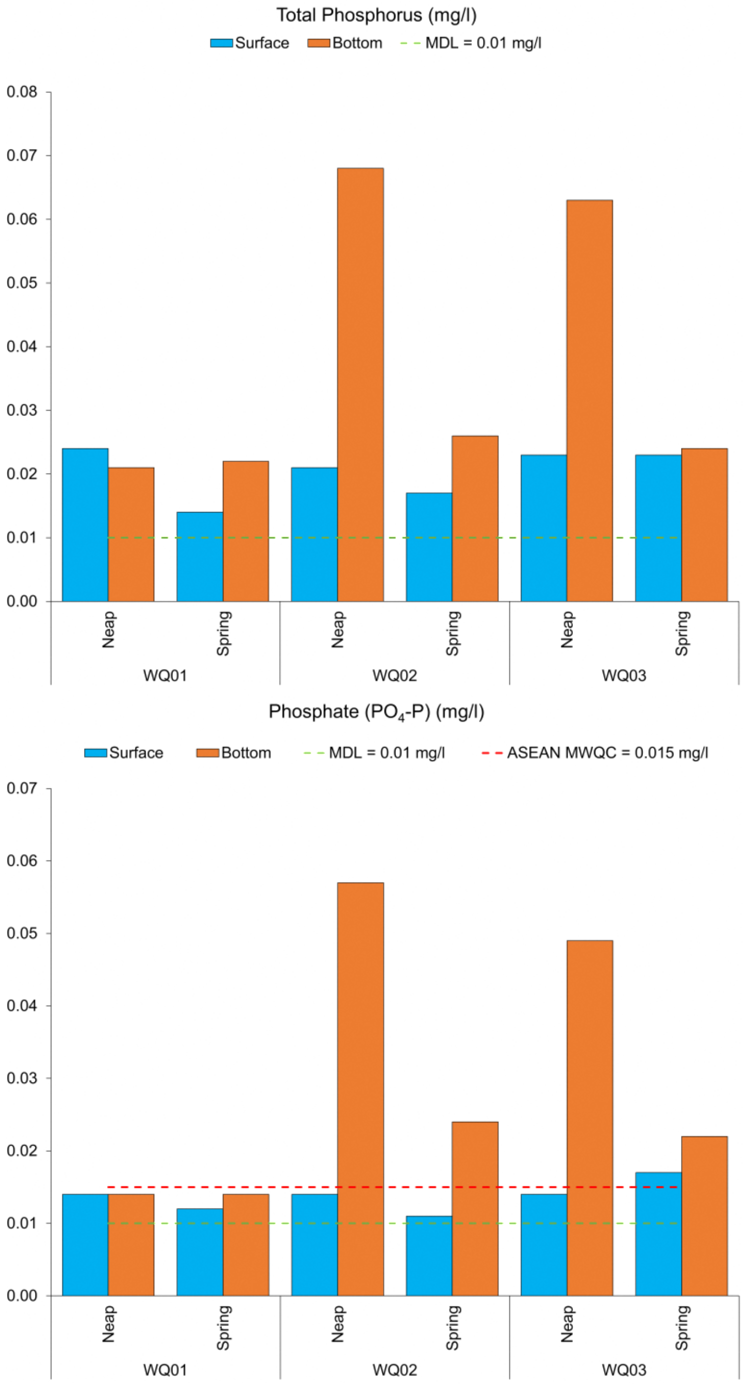


Figure 5.52 Total Phosphorous (TP) (top) and phosphate (bottom) concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

BOD_5

BOD_5 is the amount of oxygen needed for aerobic bacteria in a water body to break down organic material within a five (5) day period at a constant temperature of 20 ± 1 °C. BOD_5 can also be applied to understanding the effectiveness of wastewater treatments, with higher readings of BOD_5 indicating lower effectiveness. No ASEAN MWQC for BOD_5 exists; however, less than 1.0 mg/l is generally accepted as indicative of pristine waters (Wilhelm, 2009). Detected BOD_5 (>1 mg/l) indicates the presence of microbiological decomposition (oxidation) of organic material in water.

With respect to the baseline water quality survey, BOD_5 concentrations were not detected for neap tides at all stations. During spring tide, however, all stations at all depths showed slightly higher than 1.0 mg/l readings, with an overall average concentration of approximately 1.3 mg/l. Results for the BOD_5 concentrations from the baseline water quality surveys are presented in Figure 5.53.

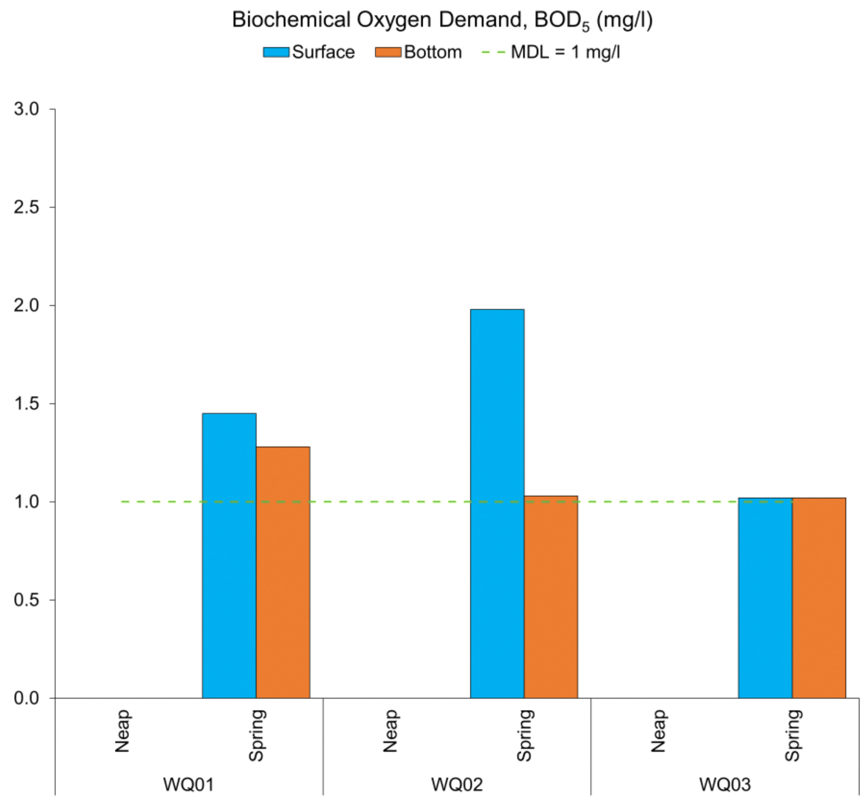


Figure 5.53 BOD_5 concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

Chlorophyll-a

Chlorophyll-*a*, in various forms, is bound within the living cells of phytoplankton (microalgae) in surface water. Chlorophyll-*a* levels, together with other parameters (e.g., TP), can indicate possible eutrophic conditions and project-induced changes, so this parameter should be closely examined despite the lack of ASEAN or other standards in Singapore.

During the baseline surveys, chlorophyll-*a* concentrations ranged from 3.78 µg/l to 70.60 µg/l, indicating elevated levels of algae (phytoplankton) in the water column, especially at the water surface (Figure 5.54).

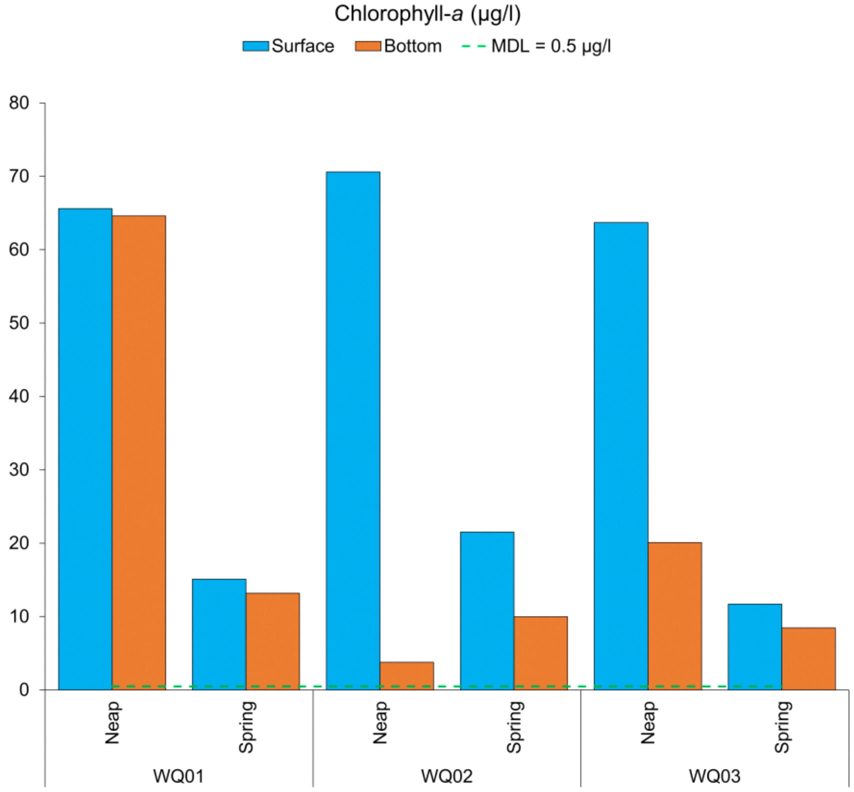


Figure 5.54 Chlorophyll-a concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

Faecal Coliform and Enterococci

Bacterial counts of faecal coliform and enterococci are commonly used in water quality monitoring as indicators of water hygiene and faecal contamination, as these concentrations determine potential risks to human health. Enterococci results are considered more relevant for marine environments since they survive better in saline environments. ASEAN MWQC states that concentrations of 100 MPN/ml and 35 CFU/100 ml for faecal coliforms and enterococci should apply, respectively.

Faecal coliform concentrations as high as 540 MPN/100 ml were observed at WQ02, and several exceedances above the ASEAN MWQC of 100 MPN/100 ml for faecal coliform were observed across some stations at the surface, and bottom depths (Table 5.11) Enterococci concentrations were compliant and below the ASEAN MWQC of 35 CFU/100 ml (Figure 5.55). Some sources of faecal indicator bacteria include stormwater runoff, leaking septic systems, sewage discharged or dumped from recreational boats, domestic animal and wildlife waste, and runoff from manure storage areas, etc. The eastern Johor Straits have also been previously documented for high levels of Enterococci (Tan, 2020b; NEA, 2023). Despite this, it is important to note that there are limitations to spot sampling in water quality assessments due to localised factors that can affect readings and that analysis of longer-term trends is required for a more conclusive assessment of water quality (WHO, 2003).

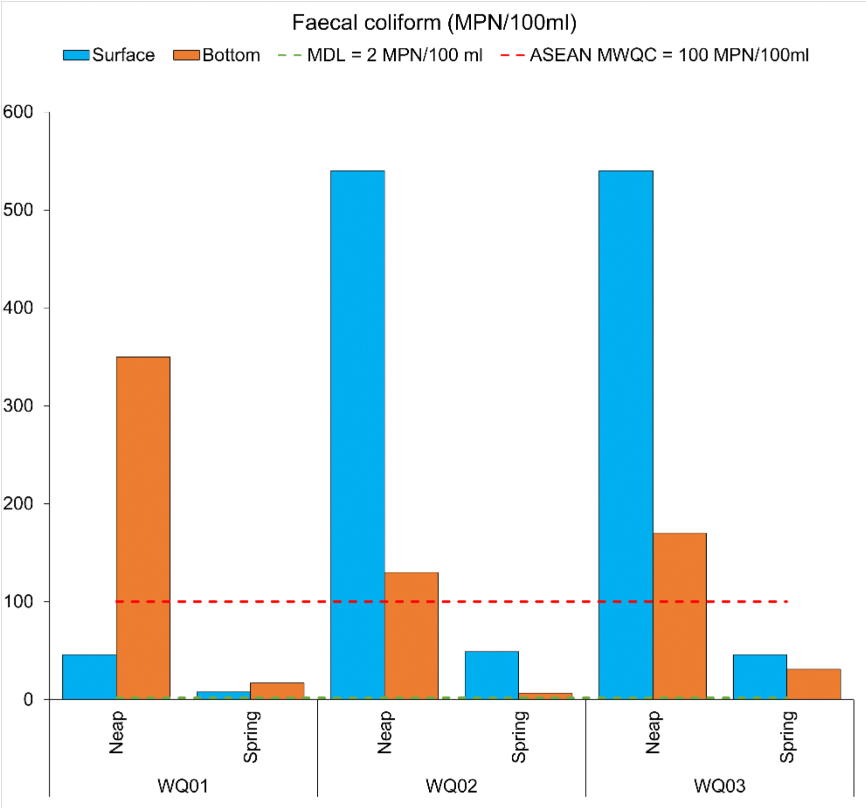


Figure 5.55 Faecal coliform concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

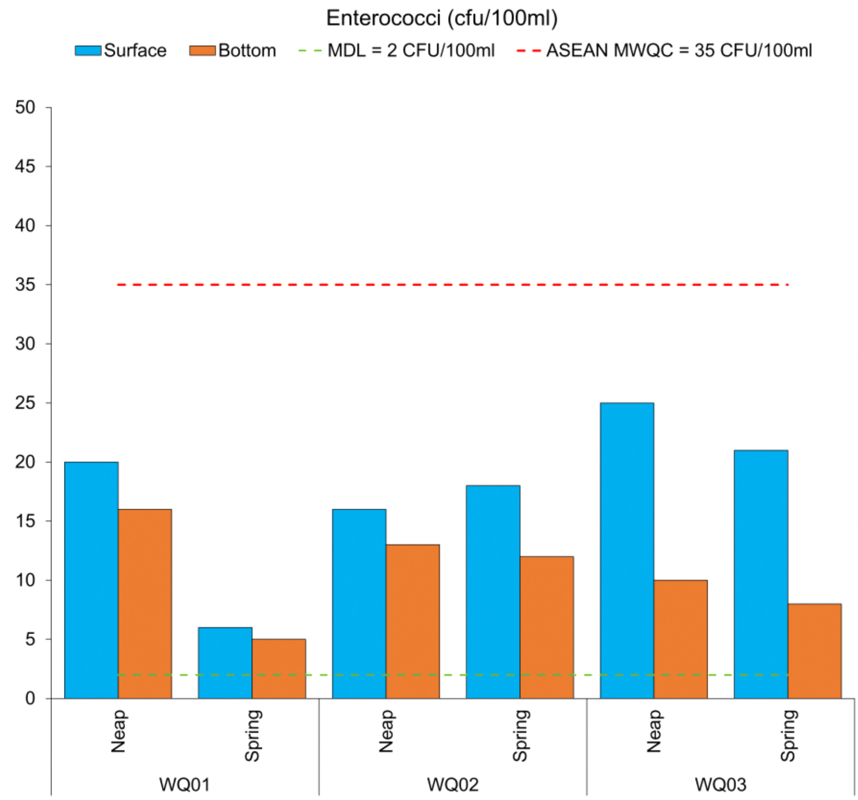


Figure 5.56 Enterococci concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

Heavy Metals in Water Samples

The ecological health of a marine community is dependent on environmental quality to a large degree. High concentrations of heavy metals in marine ecosystems could cause toxicity in various groups of marine organisms. Additionally, primary producers can take up toxic heavy metals, enter the food web and be potentially transferred to higher trophic levels and threaten human beings (Wang, 2002).

All heavy metal parameters were well below the stated ASEAN MWQC, as indicated in the results in Table 5.11. There is no ASEAN MWQC for Arsenic, Nickel, and Zinc. Overall, all detected heavy metal concentrations were below 9 µg/l. Results for Arsenic (Figure 5.57), Cadmium (Figure 5.58), Chromium (Figure 5.59), Copper (Figure 5.60), and Nickel (Figure 5.61) showed low concentrations (i.e., below 4 µg/l). Zinc had the highest average concentration across all stations, with a range of <1.5 µg/l to 8.75 µg/l, likely from the cathodic protections from nearby jetties.

Sources of these metals can be diverse and include, for example, stormwater runoff carrying catchment-based contaminants, vessels' waste and wastewater releases, or re-suspension as a legacy of historical activities.

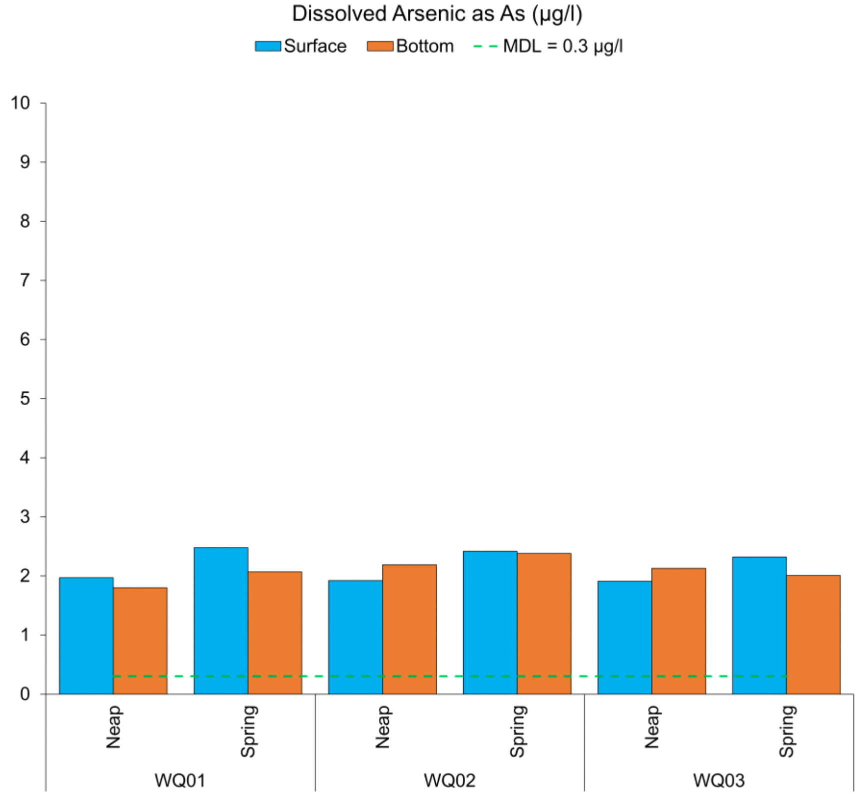


Figure 5.57 Arsenic concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

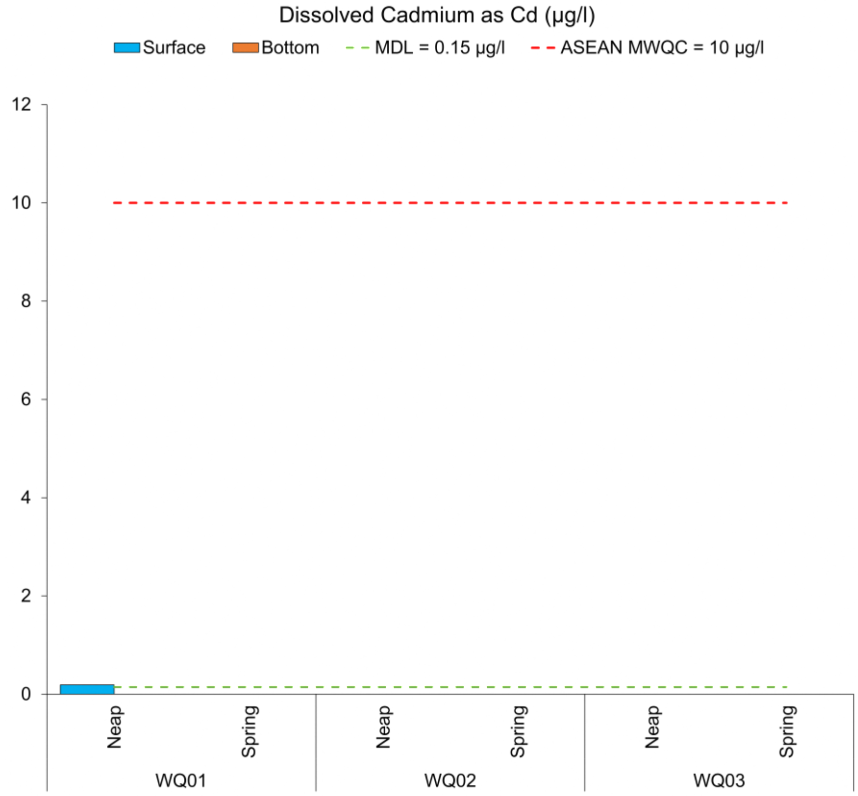


Figure 5.58 Cadmium concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

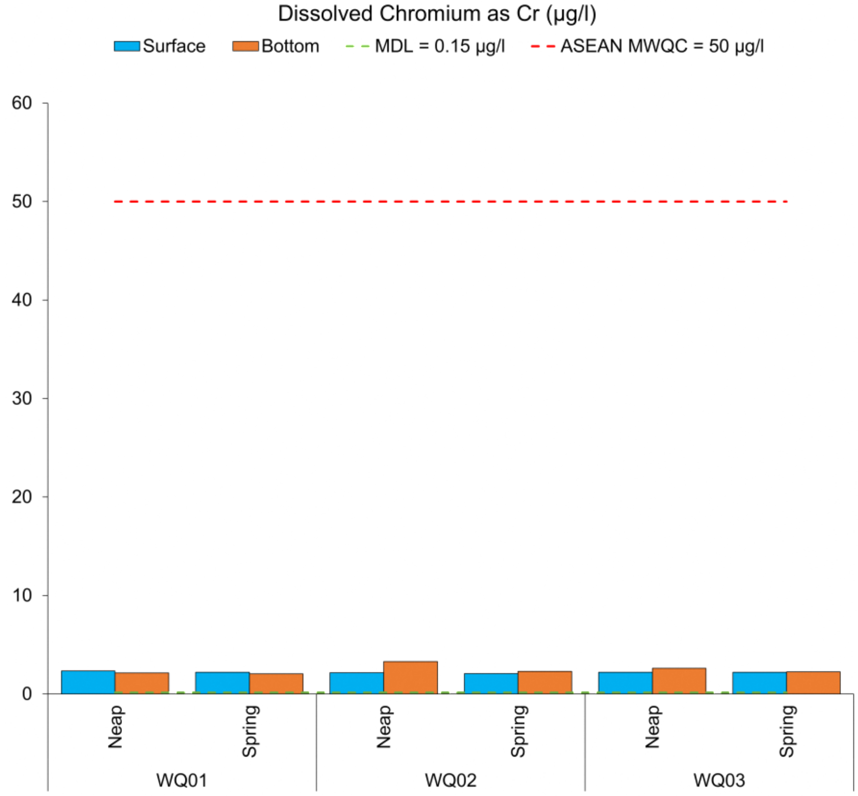


Figure 5.59 Chromium concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

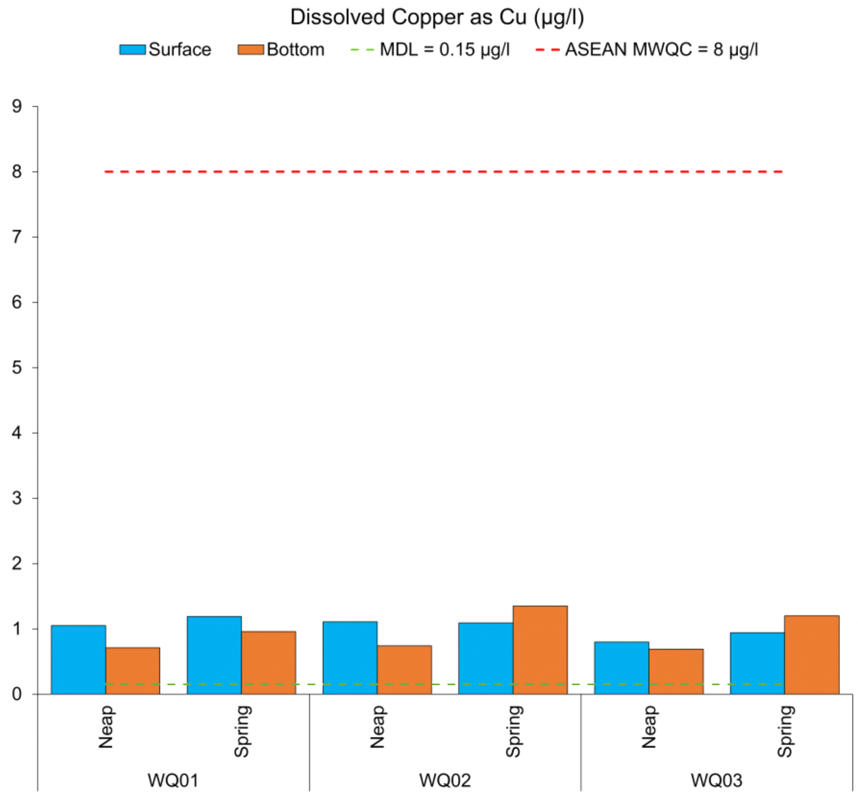


Figure 5.60 Copper concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

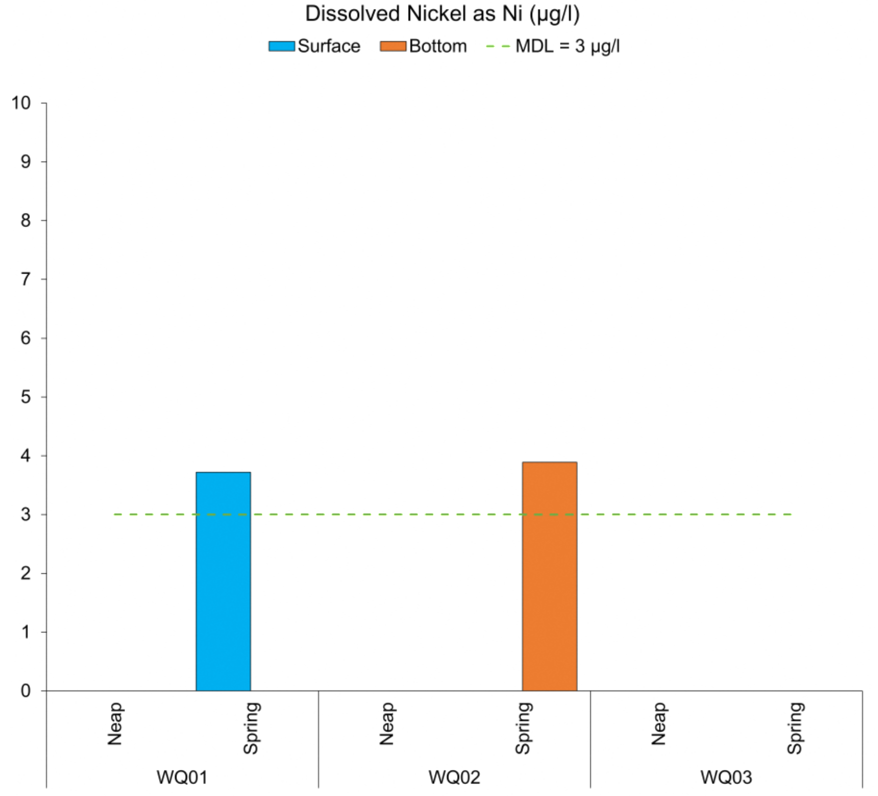


Figure 5.61 Nickel concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

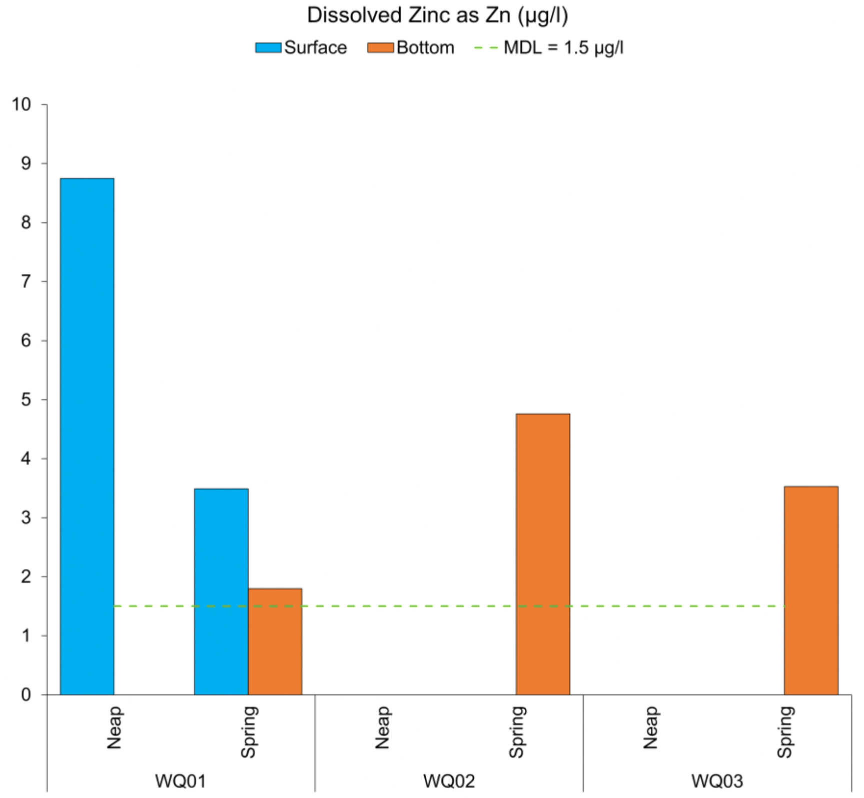


Figure 5.62 Zinc concentrations for stations WQ01 to WQ03 for all depths during both spring and neap tides

5.3.3 Evaluation Framework

Sediment Quality

The Marine Port Authority of Singapore (MPA) has guidelines for assessing marine dredged material in Singapore referred to as 'General guidelines on the requirements for application on dredging and dumping works' (Table 5.12). The aim of these guidelines is to support management decisions on marine sediments, for example, whether they are safe enough to be dredged and re-used on land or disposed of in a contained dumping ground. With reference to baseline survey data on marine sediments, the guidelines, therefore, give a helpful indication of whether the sediments are considered contaminated from a management point of view.

The source strength for the pollutant release will be based on the results of the seabed sediment quality surveys described in Section 5.3.2.1. These will be scaled against the results of the sediment plume model described in Section 5.2, considering the likely distribution between the bound and dissolved phase of the sediment-attached pollutants, before adding to baseline water quality in the study area (Section 5.3.2.4). The final pollution amount received by respective receptors is benchmarked against the water quality guidelines, elaborated in Section 5.7.3. This method is considered standard for marine EIAs in Singapore.

Table 5.12 Reference table of sediment quality guidelines for heavy metals, adapted from MPA's 'General guidelines on the requirements for application on dredging and dumping works'

Test Parameter	Limit (mg/kg)
Arsenic	30
Cadmium	1
Chromium	50
Copper	55
Lead	65
Mercury	0.8
Nickel	35
Zinc	150

There are no known tolerance limits for pollution release for the respective receptors listed in Section 5.3.1 above, and the impact will be assessed qualitatively. This will be carried out using a simple calculation: Using the simulated sediment plume values at each sensitive receptor, the amount of heavy metal released from sediment will be calculated, then added to the water heavy metal concentration. This final amount is compared against the ASEAN Marine Water Quality Criteria (MWQC).

Cyst content in the sediment will be compared to other papers in the region to understand whether their concentration is high or low. A qualitative assessment will be carried out to assess any potential risks during construction.

Marine Water Quality

As a member of the Association of Southeast Asian Nations (ASEAN), the ASEAN marine water quality criteria (MWQC) for the ASEAN region applies to Singapore waters. These criteria state acceptable ambient marine water quality limits for both aquatic life protection and human health protection and are used in the assessment of water quality in this Study (Table 5.13).

Table 5.13 Adapted ASEAN Marine Water Quality Criteria (MWQC) for evaluation in this EIA

Parameter	Units	Aquatic Life Protection	Human Health Protection
Bacteria - Faecal Coliforms	counts/100mL	-	100
Bacteria – Enterococci	counts/100mL	-	35
Copper	µg/l	8	-
Cadmium	µg/l	10	-
Chromium (VI)	µg/l	50	-
Lead	µg/l	8.5	-
Mercury	µg/l	0.16	-
Zinc	µg/l	50*	-
Ammonia	µg/l	70	-
Nitrite	µg/l	55	-
Nitrate	µg/l	60	-
Phosphate	µg/l	45 (estuaries)	-
Phosphate	µg/l	15 (coastal)	-
Arsenic	µg/l	120*	-
Cyanide	µg/l	7	-
Oil and grease	mg/l	0.14	-
Total Phenol	mg/l	0.12	-
Tributyltin	mg/l	10	-
Dissolved Oxygen	mg/l	4	-
TSS	-	≤ 10% increase over seasonal average	-
Temperature	˚C	≤ 2˚C increase over maximum ambient	-

*Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

5.3.4 Results and Discussion

Sediment Quality

Total Nitrogen (TN) in the sediment was high, while Total Phosphorus (TP) was low. This is in comparison to other studies in the Johor Straits (e.g., Trottet *et al.* (2018) found sediment TN and TP values to range between 95.4 – 539 mg/kg and 133 – 355 mg/kg, respectively), and nearby EIA studies, which found TN ranges between 807 mg/kg to 1849 mg/kg.

Arsenic content in the sediment exceeded the MPA Guidelines for heavy metals (Table 5.14). As such, there will be subsequent impact assessments (in Section 5.7 onwards) on the potential impact of heavy metal pollution on sensitive receptors.

Table 5.14 Table showing the heavy metals found within SQ1 benchmarked against the MPA guidelines

Test Parameter	Unit	SQ1	MPA Guidelines
Arsenic as As	mg/kg	46.6	30
Cadmium as Cd	mg/kg	0.84	1
Chromium as Cr	mg/kg	27.0	50
Copper as Cu	mg/kg	29.9	55
Lead as Pb	mg/kg	32.3	65
Mercury as Hg	mg/kg	0.22	0.8
Nickel as Ni	mg/kg	31.3	35
Zinc as Zn	mg/kg	148	150

In comparison with the literature, the cyst values found in this study's baseline are considered relatively high. Other studies in the region found cyst density at much lower values, ranging from 0.8 to 2.1 cysts/cm^3 (Kotani et al., 2006) to a maximum of 80 cysts/cm^3 (Liu et al., 2020). Similarly, a recent study in Singapore by Trottet et al. (2018) also found much lower cyst values, with a maximum detected density of 5.34 cysts/g of sediment in the West Johor Straits. However, cyst densities have been found to be highly variable temporally and spatially, and this study only conducted a single measurement at a single location.

5.3.5 Pollution Release Summary

Seabed sediment found at the site was primarily silty-clayey soil, with only Arsenic content exceeding the MPA guidelines for dumping marine sediment. TN and Cyst content of the soils was considered high compared to other studies on the region. However, cyst densities have been known to be highly variable in time and space.

5.4 Air Quality

Air quality in Singapore is influenced by both local and transboundary conditions. Domestic sources of air pollutants include industries and motor vehicles. In contrast, the region's transboundary pollutants from land and forest fires in the region contribute to air pollution in Singapore, particularly during the monsoon seasons. The local air quality along the southern shoreline of Pulau Ubin is expected to be relatively good compared to areas affected by emissions from major traffic and industries on mainland Singapore. The existing key contributors of air pollutants near the proposed construction of the jetty are likely due to shipping emissions and local traffic, and there is expected to be some variation in local air quality due to these local sources, against the background regional air quality which is also expected to vary with the monsoon seasons. The use of construction machinery and equipment during the proposed jetty construction is expected to result in emissions which may contribute to local air pollution.

This section presents the baseline air quality monitoring results, the framework for semi-quantitatively analysing the predicted change in particulate matter concentrations in the vicinity of the proposed jetty construction, and the analysis results.

5.4.1 Relevant Key Receptors

Socio-economic and terrestrial ecological receptors near the construction of the Project have been identified as air sensitive receptors (ASRs) that could be impacted by dust from the construction works. Human exposure to high concentrations of dust (i.e., PM_{10} and $PM_{2.5}$) above recommended levels could potentially result in adverse health impacts. A defined 350 m study area was set for the air quality assessment (Figure 5.63). The identified relevant ASRs to air quality pressures include:

- Terrestrial ecology and biodiversity; and
- Socio-economic receptors (villagers of Pulau Ubin, staff at ULL, recreational users at Endut Senin Campsite, sea sports participants).

5.4.2 Baseline Conditions

The baseline air quality was assessed using field monitoring data (at a selected baseline monitoring location for the Project) and secondary data (NEA data). The findings from the baseline assessment are presented in the subsections to follow in order to assess potential air pollution impacts on the ASRs.

5.4.2.1 Local Monitoring Data

Ambient air quality monitoring was carried out at one (1) station (Figure 5.63) for one (1) week (Table 5.15) for an understanding of baseline local air quality to which the villagers and terrestrial fauna near the jetty construction site were already exposed to prior to the construction works.

Table 5.15 Ambient air quality measurement stations

Station	Air Sensitive Receptors of Interest	Monitoring Period
AQ1	• Residential houses • Terrestrial fauna	16 Nov 2022 – 22 Nov 2022

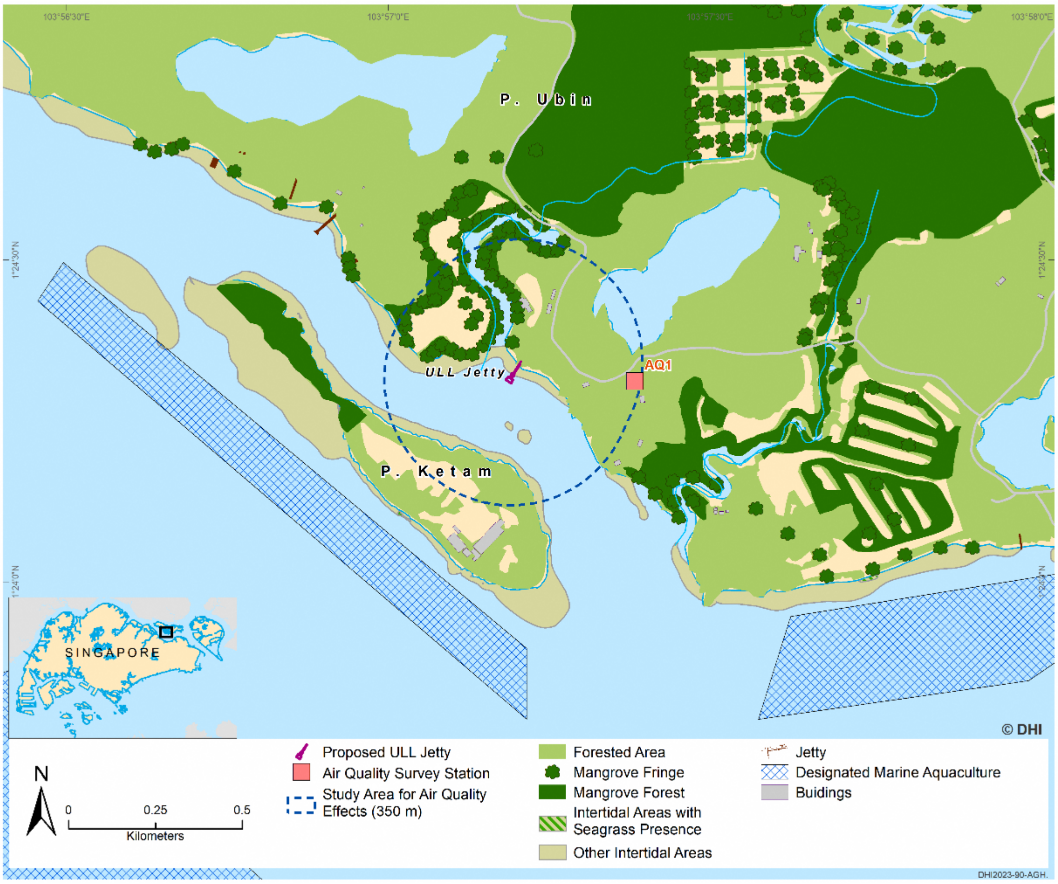


Figure 5.63 Location of baseline ambient air quality monitoring station (AQ1)

An accredited laboratory carried out the field measurements for seven (7) consecutive days (Figure 5.64). The air pollutants monitored during the baseline consisted of Volatile Organic Compounds (VOCs) and NEA's six criteria air pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$, with diameters of less than 10 µm and 2.5 µm respectively). VOCs were monitored as they could be emitted from building materials, paints and lacquers and contains various chemicals which may have short- and long-term adverse health effects (Environmental Protection Agency, 2022). The list of air pollutants measured, and the instrument used is shown in Table 5.16.

Figure 5.64 Air monitoring set-up on-site

Table 5.16 Ambient air quality monitoring parameters and respective instruments used for monitoring

Air Pollutants	Instrument
Carbon monoxide (CO) Nitrogen dioxide (NO_2) Sulphur dioxide (SO_2) Ozone (O_3)	AQMesh Pod with Electrochemical sensors
Particulate matter smaller than 2.5 µm ($PM_{2.5}$) Particulate matter smaller than 10 µm (PM_{10})	TSI Dusttrak 8543M
Volatile Organic Compounds (VOCs)	MiniRAE Lite

A summary of the survey results is presented in Table 5.17 and Table 5.18. Results were compared against the Singapore Ambient Air Quality Targets (SG AQTs), with reference to WHO's Air Quality Guidelines, and where available, more stringent long-term targets, i.e., for SO_2 and $PM_{2.5}$, were also applied. When measured levels exceeded the SG AQT, these levels are indicated in orange.

Notably, the WHO has recently issued an update to the WHO global air quality guidelines (2021), including new air quality guidelines pertaining to $PM_{2.5}$ and PM_{10}, O_3, NO_2, SO_2 and CO and interim targets. These guidelines are included in the summary tables, where applicable, for reference.

Table 5.17 Measured 24-hr average concentrations of SO_2, $PM_{2.5}$ and PM_{10} at AQ1

Date	SO_2 (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)
16-Nov-22	< 5	20.8	26.7
17-Nov-22	< 5	23.5	30.6
18-Nov-22	< 5	29.7	37.5
19-Nov-22	< 5	18.2	24.3
20-Nov-22	< 5	16.7	22.7
21-Nov-22	< 5	18.8	24.7
22-Nov-22	< 5	18.0	23.9
SG AQT 2020	**50**	**37.5**	**50**
SG AQT Long Term	**20**	**25**	**-**
WHO AQG 2021	40	15	-

Table 5.18 Measured maximum concentrations of NO_2, CO, O_3 and VOC at AQ1

Date	NO2 (µg/m³)	CO (mg/m³)		O3 (µg/m³)	VOC (ppm)
	Daily Maximum of 1-hr Mean	Daily Maximum of 1-hr Mean	Daily Maximum of 8-hr Mean	Daily Maximum of 8-hr Mean	24-hour Mean
16-Nov-22	70.54	0.36	0.25	23.69	< 1
17-Nov-22	72.10	0.35	0.25	15.57	< 1
18-Nov-22	64.57	0.63	0.48	23.73	< 1
19-Nov-22	64.28	0.34	0.32	11.15	< 1
20-Nov-22	64.08	0.35	0.30	25.57	< 1
21-Nov-22	87.02	0.32	0.27	25.32	< 1
22-Nov-22	77.68	0.28	0.24	25.61	< 1
SG AQT 2020	**200**	**30**	**10**	**100**	**-**
SG AQT Long-Term	**-**	**-**	**-**	**-**	**-**
WHO AQG 2021	200	35	10	100	-

SO_2

The 24-hour average SO_2 concentration recorded at AQ1 during the monitoring period was not detected (<5 µg/m³) and was below the SG AQTs (Table 5.17). It is noted that SO_2 concentrations in the area were generally low.

PM_{10} and $PM_{2.5}$

The measured 24-hour average of $PM_{2.5}$ and PM_{10} concentrations are plotted in Figure 5.65 and Figure 5.66, respectively. There were no exceedances of the SG AQTs except for $PM_{2.5}$ on 18 November 2022 for the SG AQT long-term target. The hourly $PM_{2.5}$ and PM_{10} concentrations are plotted in Figure 5.67 and Figure 5.68, respectively. Elevated concentrations of $PM_{2.5}$ and PM_{10} were observed on weekday nights around 22:00 to 23:00.

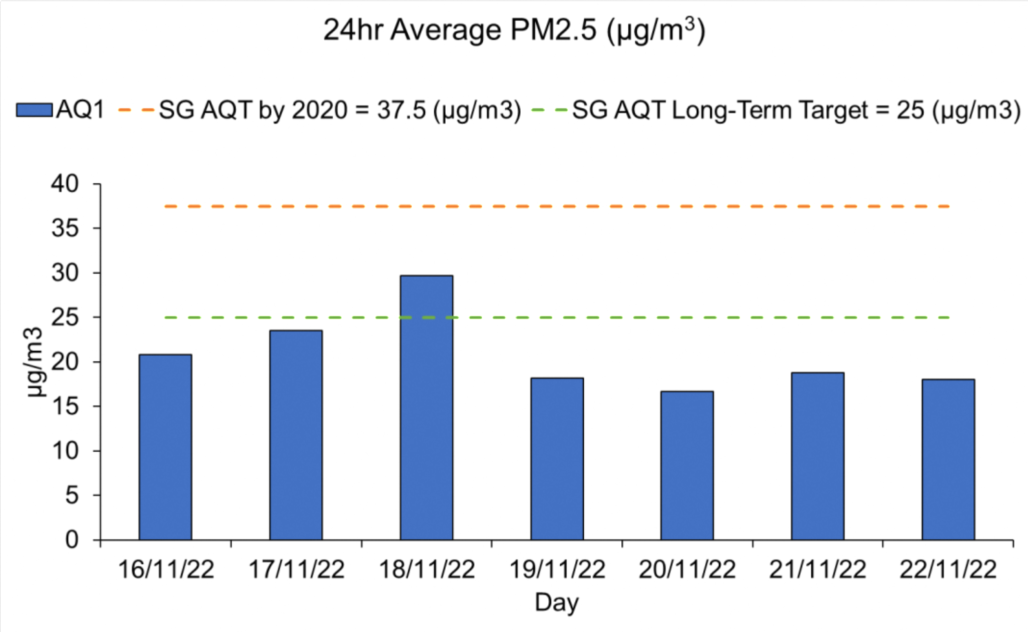


Figure 5.65 Measured 24-hour average concentrations of $PM_{2.5}$ at AQ1

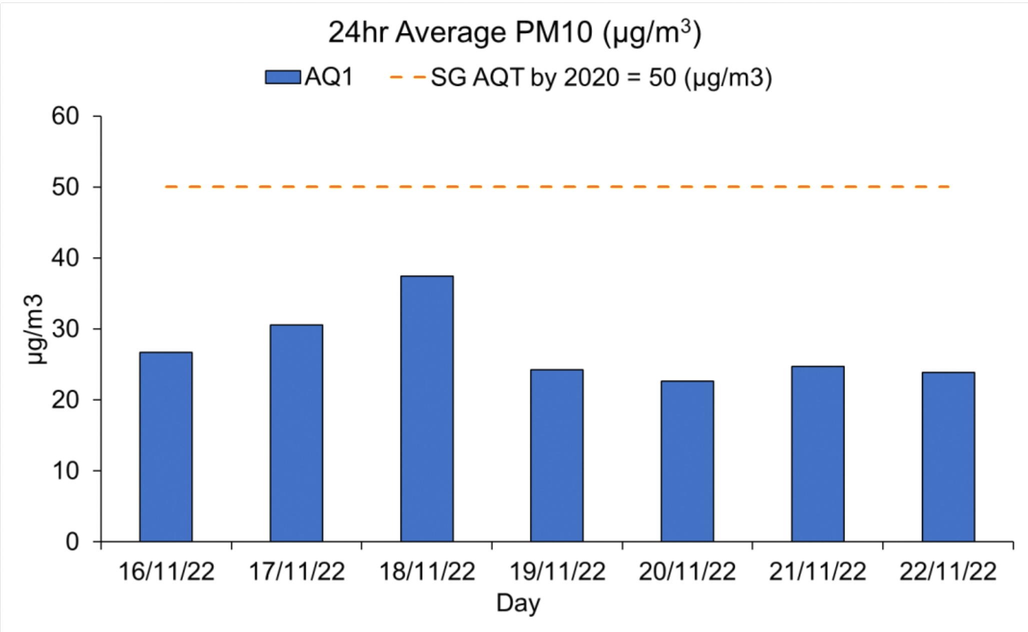


Figure 5.66 Measured 24-hour average concentrations of PM_{10} at AQ1

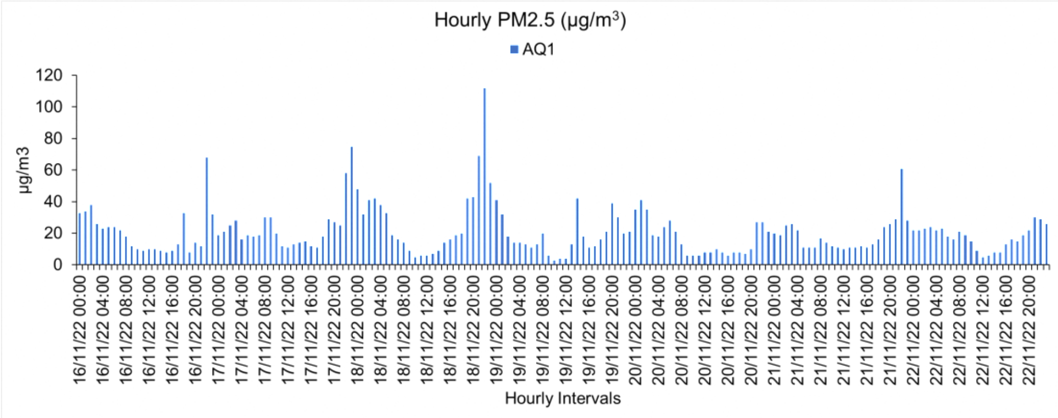


Figure 5.67 Measured hourly concentrations of $PM_{2.5}$ at AQ1

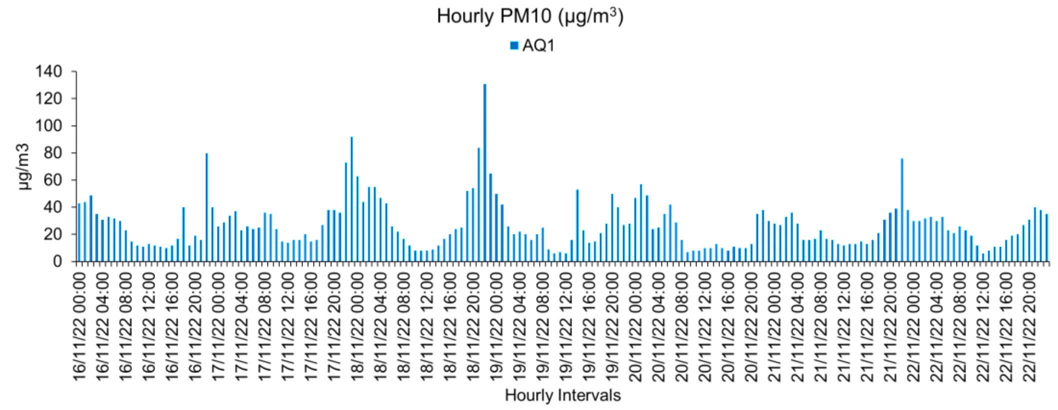


Figure 5.68 Measured hourly concentrations of PM_{10} at AQ1

NO_2

The measured hourly NO_2 concentrations are plotted in Figure 5.69. There were no exceedances of the SG AQTs.

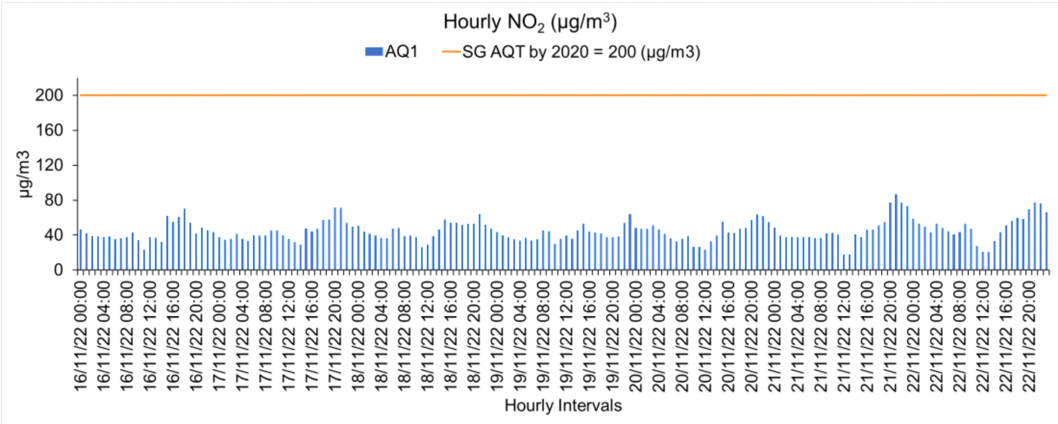


Figure 5.69 Measured hourly concentrations of NO_2 at AQ1

CO

The measured hourly and 8-hour average CO concentrations are plotted in Figure 5.70 and Figure 5.71, respectively. CO concentrations were below the SG AQTs. With no other known CO emission sources in the area, the main CO contributor is likely from road and vessel traffic.

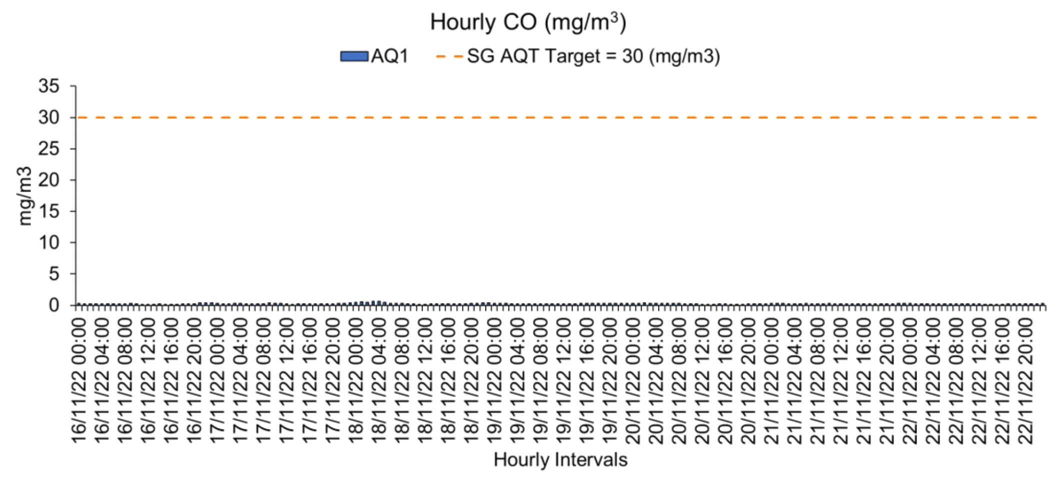


Figure 5.70 Measured hourly concentrations of CO at AQ1

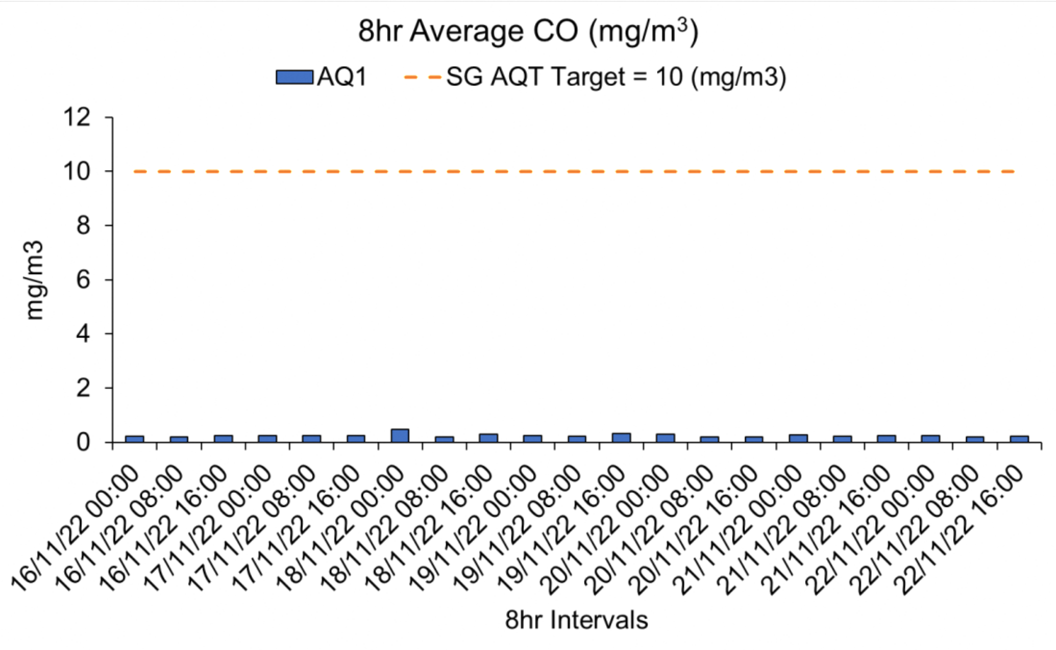


Figure 5.71 Measured 8-hour average concentrations of CO at AQ1

O_3

The measured 8-hour average CO concentrations are plotted in Figure 5.72. O_3 concentrations were below the SG AQTs. Note that ozone in ambient air is not from a direct emission but a secondary pollutant formed from a chemical reaction between nitrogen oxides and volatile organic compounds driven by sunlight. This can be observed from the recorded measurements, which exhibited regular O_3 peaks during the daytime and generally coincided with a drop in NO_2 concentrations.

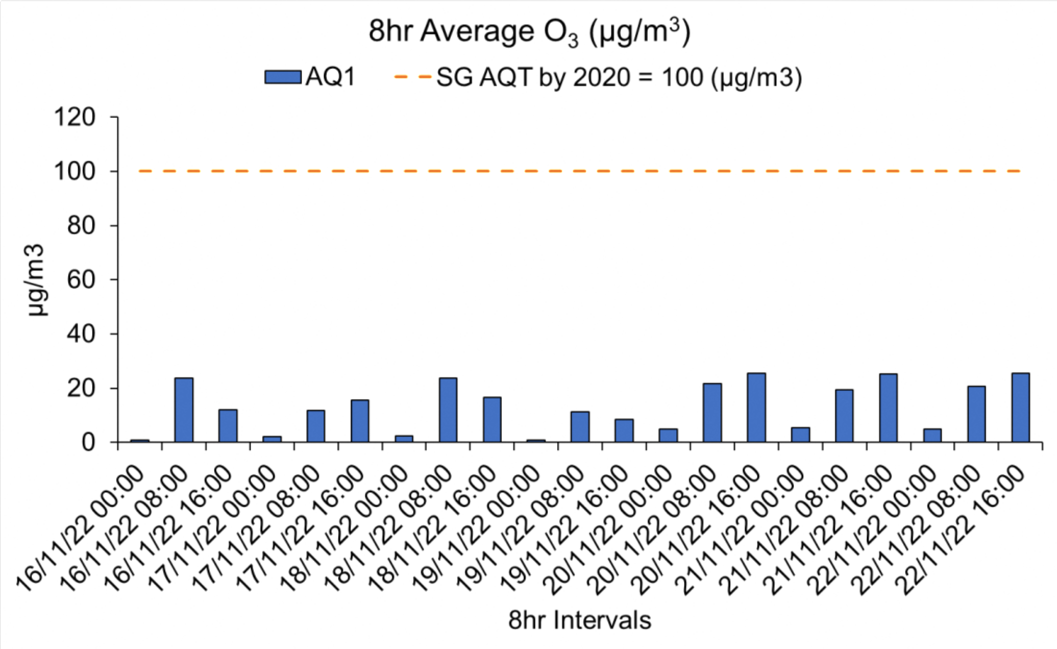


Figure 5.72 Measured 8-hour average concentrations of O_3 at AQ1

VOC

The 24-hour maximum VOC concentration recorded at AQ1 during the monitoring period was not detected (<1 ppm). There are no guidelines/limits for VOC.

5.4.2.2 Secondary Data

Supplementing the measured baseline monitoring data is the long-term air quality data requested from NEA's monitoring station at Pulau Ubin from 2016 to 2021 to represent air quality conditions during the pre-COVID (before and including 2019) and COVID periods (2020 to 2021). The data is summarised in Table 5.19, with pollutant levels exceeding the SG AQTs indicated in orange.

SO_2

The maximum 24-hour mean SO_2 concentration in 2016 was above the long-term SG AQTs.

PM_{10} and $PM_{2.5}$

The annual and 24-hour mean of $PM_{2.5}$ and PM_{10} concentrations were above the SG AQTs during both pre-COVID and COVID periods, except for the 24-hour mean of $PM_{2.5}$ and PM_{10} in 2021 and 2020, respectively. It is likely that the lower PM concentrations in 2020 and 2021 could be a result of the movement control and activity restrictions implemented during the COVID pandemic.

NO_2

The annual mean and maximum 1-hour mean NO_2 concentration were below the SG AQTs during both pre-COVID and COVID, with a general decrease in concentrations observed during COVID in 2020, most likely due to the movement control and activity restrictions implemented during the pandemic.

CO

The maximum 8-hour and 1-hour mean CO concentrations were below the SG AQTs during both pre-COVID and COVID periods, with a general decrease in concentrations observed during COVID in 2020, most likely due to the movement control and activity restrictions implemented during the COVID pandemic.

O_3

The maximum 8-hour mean O_3 concentrations were above the SG AQTs during both pre-COVID and COVID periods, with a spike in concentrations observed during 2018 and a general increase from 2019 to 2021.

Table 5.19 Measured long-term concentrations of SO_2, $PM_{2.5}$, PM_{10}, NO_2, CO and O_3 from NEA's monitoring station at Pulau Ubin

Year	SO_2 (µg/m³)	$PM_{2.5}$ (µg/m³)		PM_{10} (µg/m³)		NO_2 (µg/m³)		CO (mg/m³)		O_3 (µg/m³)
	Maximum 24-hour Mean	99th Percentile 24-hr Mean	Annual Mean	99th Percentile 24-hr Mean	Annual Mean	Maximum 1-hr Mean	Annual Mean	Maximum 1-hr Mean	Maximum 8-hr Mean	Maximum 8-hr Mean
2016	22	33	16	52	28	73	15	N/A#	N/A#	105
2017	N/A#	N/A#	N/A#	N/A#	N/A#	N/A#	N/A#	N/A#	N/A#	N/A#
2018	12	N/A#	N/A#	55	32	85	15	2.2	1.8	162
2019	20	45	17	66	30	82	14	1.6	1.4	118
2020	15	N/A#	N/A#	42	25	63	12	1.4	1.2	124
2021	15	24	13	52	33	71	16	1.6	1.2	149
SG AQT 2020	**50**	**37.5**	**12**	**50**	**20**	**200**	**40**	**30**	**10**	**100**
SG AQT Long-Term	**20**	**25**	**10**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
WHO AQG 2021	40	15	5	45	15	200	10	35	10	100

Not available due to <75% data availability

5.4.3 Evaluation Framework

Air quality impact could potentially result due to dust emissions from demolition, general construction works and vehicle movements (trackout). Potential impacts due to emissions of CO, NO_2, and SO_2 from heavy vehicles and powered machinery were expected to be low due to the size and timespan of the construction works. In particular, with effect from 01 July 2012, all off-road diesel engines (including construction machinery) imported into Singapore must comply with the EU Stage II, US Tier II or Japan Tier I off-road diesel engine emission standards, according to Environmental Protection and Management (Off-Road Diesel Engine Emissions) Regulations 2012.

For the assessment of potential dust (i.e., PM_{10} and $PM_{2.5}$) impacts (which informs the Magnitude of Change in RIAM), DHI referred to the Institute of Air Quality Management (IAQM)'s Guidance on the Assessment of Dust from Demolition and Construction (the Guidance). Due to the small nature of the Project, air quality modelling was not conducted.

The process suggested in the Guidance includes the following steps:

Step 1: Screening the requirement for a more detailed assessment. This was carried out by setting a study boundary of 350 m followed by the identification of relevant receptors, both social-economic and ecological, within the established study area.

Step 2: Assessing the risk of dust impacts from each of the anticipated emission sources during Project construction by determining the potential dust emission sources and magnitude, i.e., small, medium, large, based on an estimated scale of the work and nature of receptors. In the context of this Project, earthworks are not within the EIA assessment scope to be assessed, but demolition, construction and trackout are considered.

Step 3: Prescribing site-specific mitigation measures to abate anticipated air quality impacts.

Step 4: Determining the significance of the residual impacts to each air quality sensitive receptor.

Step 1 was completed in the expert scoping exercise for this Study, as presented in Section 4.1.1. Step 2 is highlighted below in Table 5.20 and Table 5.21. According to IAQM's Guidance on the Assessment of Dust from Demolition and Construction, activities on construction sites that will potentially result in dust impact include demolition, earthworks, construction and trackout. The Guidance provides quantitative definitions of the magnitude of emissions, as summarised in Table 5.20. The magnitude classifications include 'Small', 'Medium' and 'Large' and were adapted for use in the RIAM framework adopted by DHI (that includes five [5] ratings of magnitude) (Table 5.21). Steps 3 and 4 are discussed if the impact significance exceeds the acceptable level (see Section 7.1 for more details).

Table 5.20 IAQM's definition of potential dust emission magnitude

Type of Activity	Dust Emission Magnitude Classification Reference		
	Large	Medium	Small
Demolition	• Total building volume >50,000 m^3 • Potentially dusty construction material (e.g., concrete) • On-site crushing and screening [a] • Demolition activities >20 m above ground level	• Total building volume 20,000 m^3 - 50,000 m^3 • Potentially dusty construction material • Demolition activities 10 - 20 m above ground level	• Total building volume <20,000 m^3 • Construction material with low potential for dust release (e.g., metal cladding or timber) • Demolition activities <10 m above ground • Demolition during wetter months
Construction	• Total building volume >100,000 m^3 • On site concrete batching [a] • Sandblasting	• Total building volume 25,000 m^3 - 100,000 m^3 • Potentially dusty construction material (e.g., concrete) • On site concrete batching [a]	• Total building volume <25,000 m^3 • Construction material with low potential for dust release (e.g., metal cladding or timber)
Trackout	• >50 heavy duty vehicle (HDV) (>3.5 tonnes) outward movements [b] in any one day [c] • Potentially dusty surface material (e.g., high clay content) • Unpaved road length >100 m	• 10-50 HDV outward movements [b] in any one day [c] • Moderately dusty surface material (e.g., high clay content) • Unpaved road length 50 m - 100 m	• <10 HDV outward movements [b] in any one day [c] • Surface material with low potential for dust release • Unpaved road length <50 m

[a] Mobile crushing equipment and concrete batching plants can be significant sources of dust. Professional judgement will be required to determine how the use of crushing and screening equipment, or on-site concrete batching will affect the dust emission magnitude.

[b] A vehicle movement is a one-way journey, i.e., from A to B, and excludes the return journey.

[c] HDV movements during a construction project vary over its lifetime, and the number of movements is the maximum not the average.

Table 5.21 Evaluation framework for magnitude of change in air quality

Score	IAQM Risk of Impacts Classification	Generic Definition	Specific Definition
-4	Large	Major negative disadvantage or change	• Severe effects on air quality, which are likely to be long lasting, typically widespread in nature and requiring significant intervention to return to baseline • Air quality is likely to routinely exceed baseline criteria levels or allowable criteria
-3		Moderate negative disadvantage or change	• Potential effects on air quality, which are likely to be long last, typically widespread in nature and requiring moderate intervention to return to baseline • Air quality is likely to occasionally exceed baseline criteria levels or allowable criteria
-2	Medium	Minor negative disadvantage or change	• Short-term localised effects on air quality but which are likely to return to equilibrium conditions within a short timeframe (hours or days at most) • Air quality is likely to be within baseline criteria levels or allowable criteria
-1	Small	Slight negative disadvantage or change	• Short-term localised effects on air quality but likely to be highly transitory (lasting hours) and well within natural fluctuations • Air quality is likely to be well within baseline criteria levels or allowable criteria
0	Negligible	No change	• Status quo

5.4.4 Results and Discussion

Key dust emitting activities identified for this construction project include:

- Demolition of the existing concrete landing;
- Erection of the arrival pavilion;
- General construction works; and
- Vehicle movement.

The predicted magnitude of change in air quality due to potential dust emission from each source is discussed in detail in the following sub-sections.

Demolition

The existing concrete landing will be demolished before the pavilion of the new jetty is constructed. The demolition works will likely take several days. Dust emissions are expected during the concrete breaking and handling of debris above water. The current concrete landing is approximately 20 m x 5 m (L x B); the removal of the concrete surface of about 1 m makes the total demolition volume much lower than 20,000 m^3 which is the referenced volume for 'Small' emission according to the IAQM guideline, or Slight Change in RIAM for receptors within 350 m.

Construction

The construction of new structures is known to generate dust. The key issues when determining the potential dust emission magnitude during the Construction Phase include the size of the building or infrastructure, method of construction, construction materials, and duration of the build. The construction of the arrival pavilion is expected to generate varying dust levels in the ambient environment. The dimensions of the arrival pavilion are approximately 30 m x 20 m x 8 m (L x B x H), equating to a building volume of < 25,000 m^3. Thus, for this assessment, a classification of ‘Small’ (or Slight Change in RIAM) dust emission magnitude is assigned for receptors within 350 m.

Trackout

It is expected that dust and dirt from the construction/demolition site, if unmanaged, may accumulate and then be re-suspended into the air by vehicles using the road network. The number of dump trips per day was not available at the time of writing. However, given that the demolition works are relatively small in scale and that the debris will likely be rehandled within the site, it is assumed that there will be less than 10 Heavy Duty Vehicle (HDV) outward movements a day. Since paved road networks exist in Pulau Ubin, it is reasonable to assume that the trucks will take these routes and that movement on unpaved roads is limited. These assumptions lead to a classification of ‘Small’ dust emission magnitude or Slight Change in RIAM for receptors within 350 m.

5.4.5 Air Quality Impact Summary

The construction works are expected to have minimal, transient impacts on air quality, which should be maintained through the application of the management and mitigation measures as recommended in Sections 5.8 (for Terrestrial Ecology and Biodiversity receptors) and Section 5.11 (for Socio-economic receptors).

5.5 Airborne Noise

Noise is defined as unwanted sound that disrupts normal activities or that diminishes the quality of the environment. It is usually caused by human activity and detracts from the natural acoustic setting of an area, sometimes known as the soundscape. Noise sources contributing to regional ambient noise levels are moving transportation-related sources, including vehicular traffic, ship traffic and aircraft flyovers. In contrast, noise sources contributing to local ambient noise levels are generally from fixed point sources, including construction sites, industrial sites, or other places where heavy equipment or noise-generating machinery is used. For this Project, the main concern for the impact assessment is ambient noise levels.

5.5.1 Relevant Key Receptors

The Environmental Protection and Management (Control of Noise at Construction Sites) Regulations (2011) stipulates noise limits for various land use types, including (a) hospitals, schools, institutions of higher learning, and homes for the aged sick; (b) residential buildings; and (c) buildings other than (a) and (b). Such facilities within the defined 150 m study area for noise impact assessment are identified as Noise Sensitive Receptors (NSRs) for this Study. This regulation does not regulate noise levels in parks. It should be noted that this Study has identified fauna within the forest around the Project as an NSR. The closest residential house to the Project site and ULL office have also been identified as NSRs, although they are outside the study area as they are likely to be affected by the works. The identified noise sensitive receptors are, therefore, as follows:

- Terrestrial ecology and biodiversity (terrestrial fauna and avifauna); and
- Socio-economic receptors (villagers of Pulau Ubin, staff at ULL, recreational users at Endut Senin Campsite, sea sports participants)

5.5.2 Baseline Conditions

A habitat's background ambient noise level varies according to the local ecology. Tropical rainforests are among the most diverse habitat where multiple species of fauna signallers are likely to be active simultaneously. Ambient noise levels in the tropical rainforest are heavily proportioned to the signalling activity of insects (Ellinger & Hödl, 2002).

To establish the baseline airborne noise at the NSRs within the study area, DHI carried out a baseline airborne noise monitoring program from 22 December to 30 December 2022 at three (3) locations, as presented in Figure 5.73. Continuous noise measurement was conducted over seven (7) consecutive days at N1, and spot measurements were carried out at SN1 and SN2 to provide supplementary data for baseline establishment. Triplicate 1-second interval measurements for 5 minutes (mins) were sampled at each spot measurement station. Measurements were taken using a calibrated NEA approved Type 1 sound level meter mounted on a fixed pole at 1.2 m from ground level. The description of the monitoring locations and the respective monitoring period for each station are provided in Table 5.22.

Table 5.22 Airborne noise measurement stations

Station	NSR Description	Monitoring Period
N1	Residential House	23 Dec 2022 – 30 Dec 2022
SN1	ULL Office Senin Endut Campsite	22 Dec 2022 • AM: 0854 – 0914 • PM: 1215 – 1233
SN2	Terrestrial Fauna	22 Dec 2022 • AM: 0919 – 0940 • PM: 1238 – 1257

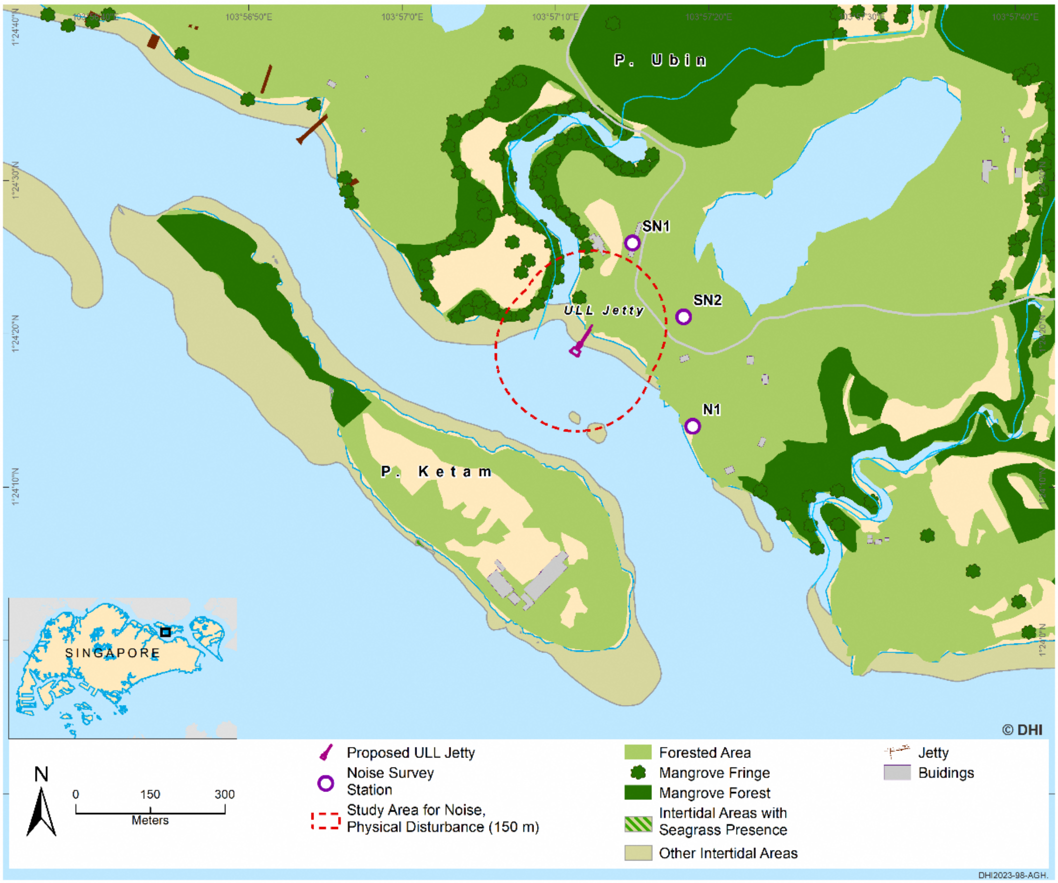


Figure 5.73 Locations of baseline airborne noise monitoring stations (SN1, SN2 and N1)

A summary of the ranges and L_{10} of Leq 5 mins and Leq 12 hrs values measured at the three (3) locations are presented in Table 5.23 to Table 5.26. L_{10} represents the noise level exceeded 10 % of the recorded time, which means that during the remaining 90 % of the recording time, the observed noise level falls below this value. The L_{10} values filter out the higher 10 % of recorded noise levels, possibly due to sporadic or intermittent events. While the maximum Leq 5 mins was higher than the NEA's criteria on Sunday night at N1, the L_{10} of Leq 5 mins was below the corresponding limits.

Table 5.23 Range of Leq 5 mins (dBA) during different periods

Station	Measured Noise Level, Weekdays (dBA)		Measured Noise Level, Sunday (dBA)	
	7am – 7pm	7pm – 7am	7am – 7pm	7pm – 7am
N1	45 – 84 (90)	47 – 69 (70)	46 – 66 (90)	49 – 83 (70)
SN1	52 – 53 (90)	-	-	-
SN2	49 – 54 (90)	-	-	-

Notes:
1. Values in bracket indicate the NEA's criteria for the type of NSR at corresponding time period.
2. Exceedance values are indicated in red.

Table 5.24 L_{10} of Leq 5 mins (dBA) during different periods

Station	Measured Noise Level, Weekdays (dBA)		Measured Noise Level, Sunday (dBA)	
	7am – 7pm	7pm – 7am	7am – 7pm	7pm – 7am
N1	59 (90)	58 (70)	58 (90)	63 (70)
SN1	53 (90)	-	-	-
SN2	54 (90)	-	-	-

Notes:
1. Values in bracket indicate the NEA's criteria for the type of NSR at corresponding time period.
2. Exceedance values are indicated in red.

Table 5.25 Range of Leq 12 hrs (dBA) during different periods

Station	Measured Noise Level, Weekdays (dBA)		Measured Noise Level, Sunday (dBA)	
	7am – 7pm	7pm – 7am	7am – 7pm	7pm – 7am
N1	53 – 65 (75)	50 – 60 (65)	55 (75)	64 (65)

Notes:
1. Values in bracket indicate the NEA's criteria for the type of NSR at corresponding time period.
2. Exceedance values are indicated in red.

Table 5.26 L_{10} of Leq 12 hrs (dBA) during different periods

Station	Measured Noise Level, Weekdays (dBA)		Measured Noise Level, Sunday (dBA)	
	7am – 7pm	7pm – 7am	7am – 7pm	7pm – 7am
N1	65 (75)	58 (65)	55 (75)	64 (65)

Notes:
1. Values in bracket indicate the NEA's criteria for the type of NSR at corresponding time period.
2. Exceedance values are indicated in red.

N1

Airborne noise monitoring station N1 was located at Living Fisher Village. The continuous measurement of Leq 5 mins at N1 is plotted in Figure 5.74. It is compared against NEA's permissible construction noise limits for premises other than residential and school/health care centre premises. The measured Leq 5 mins data during daytime were consistently below the permissible construction noise limit. Records of noise limit exceedances that occurred on 25 December 2022 from 7 pm to midnight were likely due to villagers of Pulau Ubin celebrating the Christmas festivity.

SN1

Airborne noise monitoring station SN1 was located near the ULL office and Senin Endut Campsite. The measurement of Leq 5 mins generally ranged from 52 dBA to 53 dBA.

SN2

Airborne noise monitoring station SN2 was located within a forested area. Due to the relatively secluded location, the baseline noise level recorded at SN2 was lower than the other two (2) monitoring stations. The measurement of Leq 5 mins generally ranged from 49 dBA to 54 dBA.

Correction Factor

According to the regulation, a correction factor is to be applied to the maximum permissible noise levels or the baseline noise level at respective NSRs, whichever is higher. The stipulated correction factors correspond to the difference between the applicable permissible level and the background noise level, as shown in Table 5.27. The adjusted noise limits at the NSRs are tabulated in Table 5.28.

Table 5.27 Correction factor to be applied to adjust the maximum permissible noise level at NSRs

Difference Between 2 Noise Levels dBA	Correction Factor
Below 2	3
2 to less than 4	2
4 to less than 10	1
10 and above	Nil

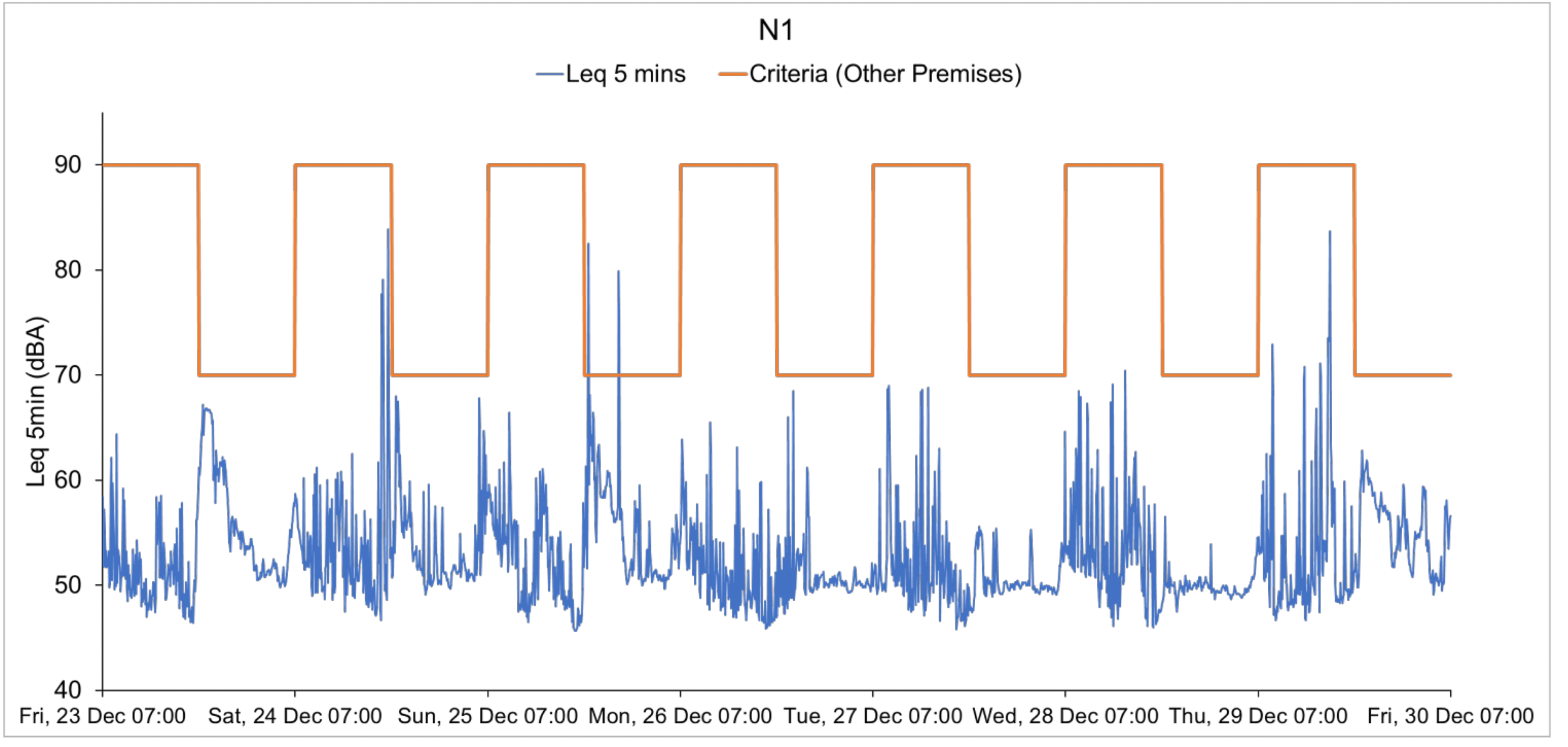


Figure 5.74 Continuous noise monitoring data recorded at N1, noise criteria for type c) other premises

Table 5.28 Adjusted noise limits at socio-economic NSRs

NSRs	Station	Time Period	Baseline Noise Level (Leq 5 mins)	Maximum Permissible Noise Level (Leq 5 mins)	Adjusted Noise Limit (Leq 5 mins)	Baseline Noise Level (Leq 12 hr)	Maximum Permissible Noise Level (Leq 12 hr)	Adjusted Noise Limit (Leq 12hr)
• Residential House • ULL Office • Endut Senin Campsite	N1	Weekday 7am – 7pm	59	90	90	65	75	75
		Weekday 7pm – 7am	58	70	70	58	65	66
		Sunday/PH 7am – 7pm	58	90	90	55	75	75
		Sunday/PH 7pm – 7am	63	70	71	64	65	68

Notes:

L_{10} is presented for baseline noise levels, i.e., level exceeded for 10% of time

5.5.3 Evaluation Framework

Local Construction Noise Guidelines

Construction noise in Singapore is regulated through the Environmental Protection and Management (Control of Noise at Construction Sites) Regulations (NEA, 2011). NEA established this set of maximum permissible noise levels at premises within 150 m of construction sites in 2011, primarily concerned with quantifying the impacts of construction noise on human receptors.

The limits are in the form of equivalent sound levels over 5-min, 1-hour and/or 12-hour durations (Leq 5 mins, Leq 1 hr and Leq 12 hr respectively) for different time periods of a day, 7 am to 7 pm, 7 pm to 10 pm and/or 10 pm to 7 am. Leq represents the sound energy equivalent over a defined period of time. The permissible noise limits for construction, which are in the form of Leq 5 mins, Leq 1 hr and Leq 12 hr, therefore represent the limit of noise level equivalent over 5 minutes, 1 hour and 12 hours, respectively. While Leq 5 mins is affected more by impulsive / spike noise emission, Leq 1hr and 12hr are more representative of the background noise level generalised over a longer time period. Do note that there is a differentiation in the maximum permissible limits for different types of premises, i.e., residential buildings, versus highly sensitive noise receivers, i.e., hospitals, schools and homes for the aged, and other premises.

Based on DHI's site survey in the area, no commercial, industrial, or residential premises were identified within a 150 m radius of the Project footprint. There are also no known hospitals, schools, institutions of higher learning or homes for the aged sick in the close vicinity. Recreational campsites and offices in the study area, i.e., Endut Senin Campsite and ULL office, were considered under the 'Other Premises' category. The criteria stated in NEA's Environmental Protection and Management (Control of Noise at Construction Sites) Regulations will be adopted to assess construction noise (Table 5.29 and Table 5.30).

Airborne noise measurements taken during the baseline were analysed to produce Leq 5 mins and Leq 12 hr for each time period. These equivalent sound levels are then compared against the corresponding limits from NEA. In the event of exceedances, mitigation measures would be proposed.

Table 5.29 Maximum Permissible Noise Levels for Construction Site – Weekday (Monday to Saturday)

Types of Affected Buildings	Maximum Permissible Noise Levels dBA		
	7 am – 7 pm	7 pm – 10 pm	10 pm – 7 am
(a) Hospitals, schools, institutions of higher learning, homes for the aged sick.	60 (Leq 12 hrs)	50 (Leq 12 hrs)	50 (Leq 12 hrs)
	75 (Leq 5 mins)	55 (Leq 5 mins)	55 (Leq 5 mins)
(b) Residential buildings located less than 150m from the construction site.	75 (Leq 12 hrs)	65 (Leq 1 hr)	55 (Leq 1 hr)
	90 (Leq 5 mins)	70 (Leq 5 mins)	55 (Leq 5 mins)
(c) Buildings other than those in (a) and (b) above.	75 (Leq 12 hrs)	65 (Leq 12 hrs)	65 (Leq 12 hrs)
	90 (Leq 5 mins)	70 (Leq 5 mins)	70 (Leq 5 mins)

Table 5.30 Maximum Permissible Noise Levels for Construction Site – Sunday and Public Holidays

Types of Affected Buildings	Maximum Permissible Noise Levels dBA		
	7 am – 7 pm	7 pm – 10 pm	10 pm – 7 am
(a) Hospitals, schools, institutions of higher learning, homes for the aged sick	60 (Leq 12 hrs)	50 (Leq 12 hrs)	50 (Leq 12 hrs)
	75 (Leq 5 mins)	55 (Leq 5 mins)	55 (Leq 5 mins)
(b) Residential buildings located less than 150m from the construction site	75 (Leq 12 hrs)	65 (Leq 1 hr)	55 (Leq 1 hr)
	75 (Leq 5 mins)	55 (Leq 5 mins)	55 (Leq 5 mins)
(c) Buildings other than those in (a) and (b) above	75 (Leq 12 hrs)	65 (Leq 12 hrs)	65 (Leq 12 hrs)
	90 (Leq 5 mins)	70 (Leq 5 mins)	70 (Leq 5 mins)

Note:

1. No work is allowed from 10pm on Saturdays or eves of public holidays to 7am on the following Mondays or days after public holidays.
2. Since 1 January 2017, construction sites at the architectural/project completion stage are allowed to carry out quieter forms of work on specific Sundays and public holidays upon approval by NEA.

Calculation of Noise Levels at Relevant Receptors

Environmental pressures, i.e., noise emissions from construction activities, will be quantified by adopting conservative empirical equations publicly available in relevant international standards and guidelines.

The general approach for assessing noise impacts related to construction activities consists of the following sequential steps:

1. Identification of relevant noise sources and establishing a representative scenario of their usage;
2. Calculation of nearfield noise level of the identified sources;
3. Calculation of the propagation of the above-mentioned noise levels in relation to the selected representative receptor; and
4. The resulting noise level results will be compared with tolerance limits of the relevant receptors, or in the absence of which, benchmarked against available environmental quality guidelines, either local or international (see previous section).

In the noise assessment, a common statistical descriptor is LAeq, which is the A-weighted (adjusted for frequencies sensitive to human hearing) constant average noise level, which would result in the same total sound energy produced over a period of time. The total equivalent sound level for a given period of time during a particular Construction Phase is computed as follows:

Equation 1: LAeq (dB) = $10 \times log_{10} \sum [10^{\frac{LAeq(i)}{10}}]$

Where,

$LA_{eq,\ total}$ = the total equivalent noise level during a given period;
$LA_{eq,\ i}$ = the equivalent noise level for equipment type, i.

The equation for noise level propagation over a distance is:

Equation 2: $Lp_2 = Lp_1 - 20 log_{10} \frac{r_2}{r_1}$

Where,

Lp_1 = the measured sound pressure level at distance r_1 from the source.

Lp_2 = the calculated sound pressure level at distance r_2 from the source.

r_1, r_2 = distance from source to measurement Lp_1 and Lp_2, respectively

The following sequence of noise prediction was performed:

- Using Equation 1, the total equivalent sound level/noise emission level for multiple equipment sources was computed. In this case, sound level source refers to powered construction equipment.

- Using Equation 2, the total equivalent sound level for equipment, Lp_1 (result from Equation 1), was further propagated over a distance to obtain noise level at receptors due to the equipment (Lp_2).

- Using Equation 1, the resultant noise level at receptors due to the equipment (result from Equation 2) was added with background/baseline noise level to obtain cumulative noise level at the receptors.

This Study conservatively calculated equivalent sound pressure levels from various construction activities. Hence, we assume that at any one time, all the equipment involved in an activity will be active and operate throughout the construction hours. With that, the results presented below are Leq 5 mins and at the same time Leq 12 hrs. In the subsequent impact assessment on human health, the calculated noise levels at the relevant receptors will be benchmarked against Leq 12 hrs (limits with lowest numerical values).

5.5.4 Results and Discussion

Key activities anticipated to be carried out during the Construction Phase are:

- Demolition of the existing concrete slab;
- Trimming of the seabed and shoreline to the desired bed level;
- Placing of rocks for rock revetment;
- Piling of marine steel pipe piles infilled with concrete; and
- Erection of arrival pavilion.

Detailed construction equipment and activities were not available at the time of writing. Five (5) main construction activities are defined in this noise study, each with an assumed list of equipment as outlined in Table 5.31 below. Typical noise levels from this equipment (at 10 m away) are as per Table 5.32.

Table 5.31 Five (5) construction stages and activities considered in this noise assessment

Activity	Description	Assumed Construction Equipment
1	Demolition of existing concrete slab	1 Breaker 1 Excavator 1 Dump Truck
2	Trimming of seabed & along shoreline	1 Excavator 2 Barges 1 Dump Truck
3	Placing of rocks for rock revetment	1 Crane 1 Dump Truck
4	Piling of marine steel pipe piles	1 Piling Rig 1 Barge
5	Erection of arrival pavilion	1 Concrete Mixer Truck + Pump 1 Crane

Table 5.32 Typical sound levels from construction equipment. Sound levels are at 10 m from the source. Reference: BS 5228-1:2009 Code of practice for noise and vibration control on construction and open sites

Equipment	Sound Level (dBA)
Barge	85*
Breaker	90
Concrete Mixer Truck + Pump	75
Crane	82
Dump Truck	81
Excavator	78
Piling Rig	83

* Maximum acceptable sound pressure levels (in dBA) on board ships in workspaces

With the typical noise emission data in Table 5.32, each activity's total equivalent noise level is computed using Equation 1. The calculated total noise emission level from each activity at a 10 m distance is presented in Table 5.33 below.

Table 5.33 Total noise levels from construction activities at 10 m distance

Activity	Description	Total Noise Level (dBA) at 10 m Distance
1	Demolition of existing concrete slab	91
2	Trimming of seabed & along shoreline	89
3	Placing of rocks for rock revetment	84
4	Marine Piling	87
5	Erection of arrival pavilion	75

Equation 2 was then used to compute the resulting noise levels at the relevant noise receptors, including the nearest terrestrial fauna receptors, staff at the ULL office, and residential houses. Equation 1 is used again to obtain cumulative noise level at the relevant noise receptors by adding the resultant noise level at noise receptors due to the equipment (result from Equation 2) with the respective baseline noise levels (i.e., SN2 and Terrestrial Fauna, SN1 and ULL Office/Endut Senin Campsite, N1 and Residential Houses). The predicted noise levels at the receptors are tabulated in Table 5.34 below. It should be noted that the predicted values are based on a worst-case situation where attenuation or obstacles are not considered. The assessment of noise impacts on these receptors will be discussed in relevant receptor sections.

Table 5.34 Predicted cumulative noise levels at relevant sensitive receptors

Activity	Predicted Cumulative Noise Level (dBA) at Receptor				
	Fauna Adjacent to Work Area (10 m away)	Fauna at Coastal Vegetation Along Sungei Puaka (245 m away)	Secondary Forest (135 m away)	ULL Office/Endut Senin Campsite (190 m away)	Residential Houses (280 m away)
Demolition of existing concrete slab	91	67	70	68	67
Trimming of seabed & along shoreline	89	67	69	67	66
Placing of rocks for rock revetment	84	66	67	66	65
Piling of marine steel pipe piles	87	66	68	67	66
Erection of arrival pavilion	75	65	65	65	65
Relevant Noise Limit	60	60	60	75	75

5.5.5 Airborne Noise Summary

Noise emissions from the construction of the jetty may disrupt terrestrial fauna in the vicinity, be a nuisance to the staff at the ULL office, and disturb villagers in their homes. The resulting noise levels at these receptors have been calculated, ranging from 75 to 91 dBA at the fauna receptors adjacent to the work area, 65 to 67 dBA at the fauna receptors at the coastal vegetation along Sungei Puaka, 65 to 70 dBA at the Secondary Forest, 65 to 68 dBA at the ULL office/Endut Senin Campsite, and 65 to 67 dBA at the residential houses.

The assessment of noise impacts is discussed in detail in Sections 5.6 (for Terrestrial Ecology and Biodiversity receptors) and Section 5.11 (for Socio-economic receptors). This assessment framework references NEA's Environmental Protection and Management (Control of Noise at Construction Sites) Regulations stipulating construction noise limits in Leq or equivalent sound pressure level (Table 5.29 and Table 5.30).

5.6 Underwater Noise

This section presents the results of baseline underwater noise monitoring and the results of underwater noise modelling to assess the effect of the proposed construction activities, mainly pile driving, on the levels of underwater noise in the vicinity of the construction area.

5.6.1 Relevant Key Receptors

Underwater noise receptors near the project sites are:

- Aquacultures facilities; and
- Marine fauna (primarily fish).

Hence, underwater noise modelling was performed using frequency ranges 100 Hz to 1250 Hz, values which are relevant for marine fauna and fish receptors. This section only discusses the Pressure or Stressor, i.e., the Change in underwater noise levels; the respective Receptor chapters assess and discuss the resultant effects or impact on the receptors (Sections 5.7 and 5.10).

5.6.2 Baseline Conditions

Baseline underwater noise monitoring was carried out using a SoundTrap ST600 hydrophone at one (1) location (UN1) near the study site along Ketam Channel (Figure 5.75) for fifteen (15) continuous days (i.e., 23 November to 06 December 2022).

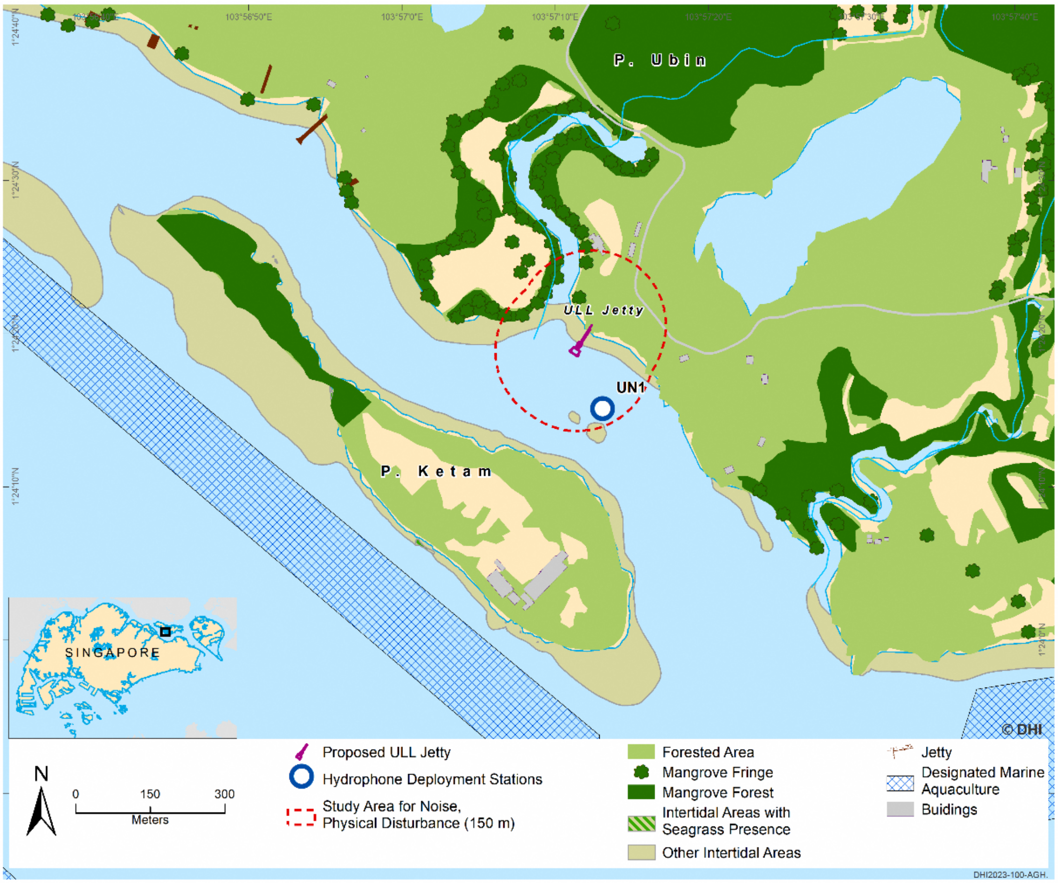


Figure 5.75 Location of underwater noise monitoring station (UN1)

The 1/3 octave band-analysis Sound Pressure Level (SPL) is the most common underwater acoustic metric to assess noise levels in frequency bands. The recorded acoustic data was calibrated using hydrophone SoundTrap ST600 (6890 series) factory value of 176 dB. The calibrated acoustic data was processed using dBWav tools with an unweighted window, Butterworth filter order 2, and a sampling rate of 1 second. The final output is a spectrogram in 1/3 octave band levels using the frequency band between 2 Hz and 48 kHz. Noise level statistics were also calculated for specific frequency bands (e.g., low, medium and high ranges), which sheds light on three different noise sources detected within Ketam Channel.

Noise Level Variability

Spectrograms of the 1/3 octave band analysis at the UN1 monitoring site are shown in Figure 5.77. The first underwater noise category is natural sources. The tidal current (typically in the range of 10 to 80 dB) can be identified in the entire period by its low-frequency content (usually below 100 Hz) and its repetitive occurrence (here lasting over several hours at 12-hour intervals) (Figure 5.77, Label A). The sound levels observed below ~100 Hz (Figure 5.77, Label A) were likely caused by water flow and tidal periodicity. This type of noise is usually termed ‘pseudo-noise’, caused by turbulence around the hydrophone and contributes little to the ambient sound level.

The second category of underwater noise is anthropogenic ambient noise. This category of noise contribution was detected at UN1 throughout the period of 23 November to 06 December 2022, shown by fourteen (14) occurrences of peaks up to ~120 dB in frequency bands between 200 Hz and 8 kHz (Figure 5.77, Label B, red boxes). The ambient noise trend recorded during the monitoring period varies. For example, from 23 to 24 November 2022, there were peaks up to 120 dB to 125 dB at frequency bands between 1 kHz and 8 kHz; from 25 to 27 November 2022, there were with peaks up to 120 dB at frequency bands between 200 Hz and 1 kHz, and from 05 to 06 December 2022, higher peaks up to 125 dB were detected at frequency bands between 2 kHz and 8 kHz. Examples of sources that could cause anthropogenic ambient noise are vessel traffic and industrial activities. According to extracted AIS data during the monitoring period, passing vessels in the area was dominated by pleasure crafts (Figure 5.76). Anthropogenic sources (smaller and medium-sized vessels and industrial noise) represent the low-medium frequencies ranging from 10 Hz to 8 kHz (Figure 5.77, Label B).

The final category of noise is tonal noise, which is continuous and concentrated in a narrow part of the spectrum at a consistent frequency. It was recorded at levels up to 118 dB and was observed during the entire monitoring period at a high band above 10 kHz frequency (Figure 5.77, Label C). This tonal noise was likely generated by rotating equipment. Examples of sources that could generate tonal noise include compressors, motors, waterjet pumps and transformers.

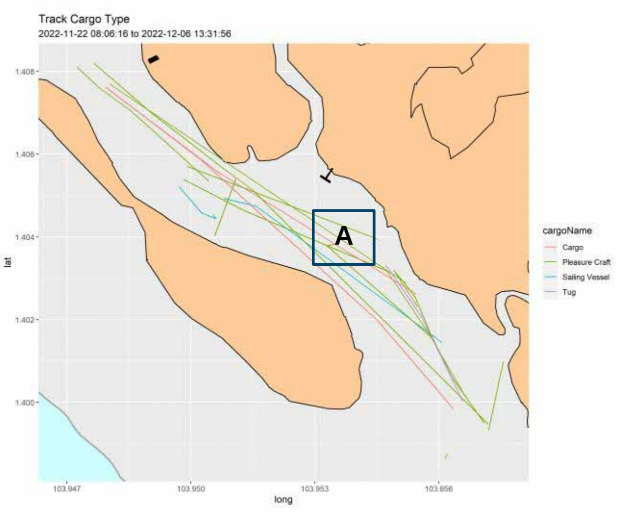


Figure 5.76 Passing vessel recorded by AIS data between 22 November and 06 December 2022. Label A represents the underwater noise monitoring area UN1

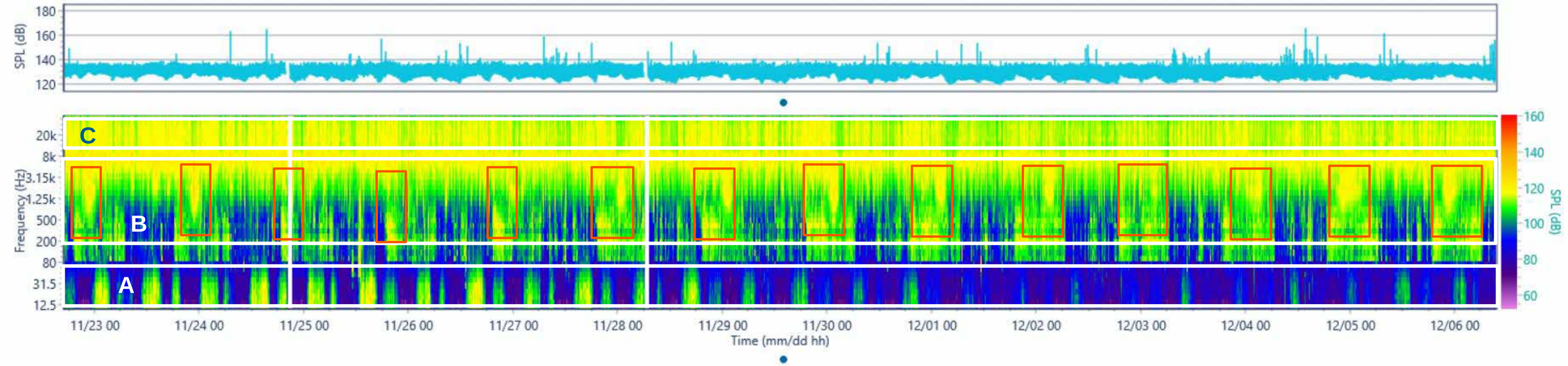


Figure 5.77 Sound pressure level distribution over time (top) and spectrograms of the 1/3 octave band-analysis (bottom) for UN1. The colour legend presented on the right side of the spectrogram indicates the sound pressure level (SPL) in decibels (dB); the vertical axis on the left side of the spectrogram indicates the frequency band in hertz (Hz). Label A indicates the acoustic signature of tidal currents, Label B shipping noise and Label C tonal noise

Noise Level Statistics

Noise level statistics for specific frequency bands were plotted as density probability spectrograms for the entire recording (Figure 5.78). For the entire monitoring period, four (4) summary metrics of sound level were computed: 5th percentile (minimum), 50th percentile (median), 95th percentile (maximum), and Root Mean Square (RMS) level, as summarised in Table 5.35. RMS is the square root of the mean square pressure, which conventionally represents the mean for variables of a continuous nature in time.

Background sound levels recorded below 100 Hz (dominated by natural sources, e.g., tidal flow) had median values ranging from 85 to 101 dB. At frequencies from 100 Hz to 1 kHz (sounds dominated by vessel passages and industrial activities), the median values ranged from 103 to 104 dB, and the 95th percentile ranged from 114 to 116 dB. Sound pressure levels recorded in frequency of up to 10 kHz (tonal noise) had median values ranging up to 116 dB and the 95th percentile spanning up to 120 dB.

The RMS exceeded the 95th percentile for several frequencies (i.e., between frequency bands of 70 and 90 Hz), which means the 95th percentile metric is more appropriate to represent the ambient noise level at UN1. RMS was found to overlap with typical open ocean ambient noise levels (74 to 100 dB) and vessel presence (up to 120 dB) measured in the band 20 to 1 kHz (Urick, 1983).

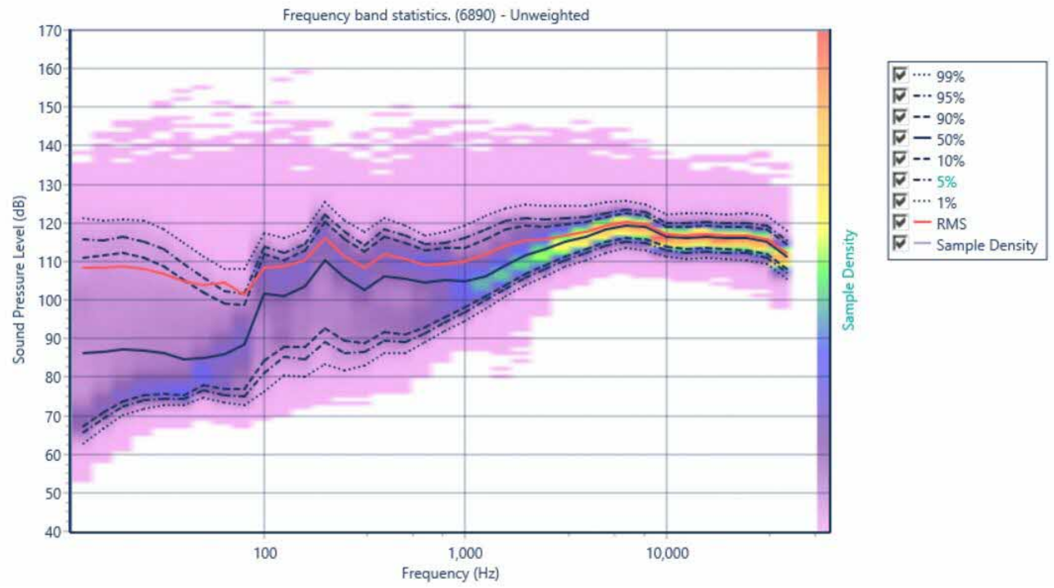


Figure 5.78 Density probability spectrograms for the entire recording period at UN1. The 5th, 50th, and 95th percentiles and RMS are plotted. Sample density is the spectral probability density

Table 5.35 Summary of the statistical metrics of noise levels (dB) at the monitoring station UN1

Station	Statistical Metric	63 Hz	100 Hz	160 Hz	250 Hz	500 Hz	1 kHz	12.5 kHz
UN1	5th percentile	75	80	84	86	89	96	112
	Median	85	101	103	105	105	104	116
	95th percentile	102	113	114	117	116	116	120
	RMS	104	108	110	111	110	109	116

5.6.3 Evaluation Framework

The underwater sound propagation modelling was performed by DHI's UAS (Underwater Acoustic Simulation), part of DHI's MIKE Powered by DHI software package. The UAS model is a transect model simulating the sound propagation in a 2D vertical transect (slice) of the sea (the range-depth or r-z plane). It is based on solving the Parabolic Equation (PE), assuming that outgoing energy dominates over backscattered energy. Hence, it computes the solution for the outgoing wave equation only.

Modelling Scenario

In the assessment of underwater noise and its impacts, there was one (1) scenario of underwater noise modelling during the Construction Phase. As described in Section 2.2, the Construction Phase requires marine pile driving works known to be very noise intensive. Hence, the modelling tasks in this study will simulate underwater noise for the worst-case scenarios for piling during the Construction Phase. A summary of the modelling scenario for underwater noise impact assessment is shown in Table 5.36.

Table 5.36 Modelling scenario for underwater noise impact assessment during Construction Phase

Scenario	Station	Longitude (°)	Latitude (°)	Noise Source
01	P1	1.405235	103.953046	Piling work

The noise source used in the UAS model is a typical sound spectrum resolved in third-octave frequency bands. The pile driving diameter size was 700 mm at the time of this study. Hence, the source level for piling work is scaled to a Sound Exposure Level (SEL) of 201.13 dB re$1 \mu Pa^2 s$ based on the estimation of the sound pressure level derived from the pile diameter presented by Bellman *et al.* (2020).

Sound speed in seawater and its attenuation were calculated using salinity, temperature and pH distributions in seawater from MIKE 3 HD and MIKE ECO Lab water quality simulations results. After UAS runs, 2D sound maps for frequency ranges of interest are generated using UAS transect results. A conservative approach is employed so that the maximum SEL value of the whole water depth is taken as representative of a point in the line transect. It is important to note that due to the time-independent nature of the simulation, only one water depth is considered, i.e., the mean sea level.

A sound map which shows SEL distribution over space in the vicinity of the sound source is used to assess the sound level received by the receptors in various locations (Figure 5.79). Noise levels in 100 Hz to 1250 Hz were extracted at relevant receptor sites, and depending on the receptor, different criteria will be applied to deduce the impact of the underwater noise.

5.6.4 Results and Discussion

The underwater sound map for piling work in the Project is shown in Figure 5.79. Sound propagation in the water is very dependent on the water depth, as sound attenuation at the seabed is much greater than in the water column. As seen in Figure 5.79, the intertidal areas have much lower water depths than the rest of the project site. Hence, these areas consistently show SEL lower than 150 dB re $1 \mu Pa^2 s$. It is also apparent that SEL generated from piling work stays relatively localised around the modelled source locations with a maximum value of up to 190 dB re $1 \mu Pa^2 s$. SEL received by the fish farming zone at the southeast of the project site is less than 130 dB re $1 \mu Pa^2 s$ (at the boundary of the fish farming zone, Figure 5.79). Sound attenuates or reduces as it travels through water. Thus, the SEL level received by fish farm receptors located farther away is lower than that within

Ketam Channel. For the mobile marine fauna around the study site, it was estimated that they would receive SEL of up to 180 dB re $1\mu Pa^2 s$.

Since each receptor or group of receptors is represented as an area, they will receive varying SEL values. Hence, the maximum modelled values are extracted to obtain the worst-case scenario for the receptor for the impact assessment in the later sections.

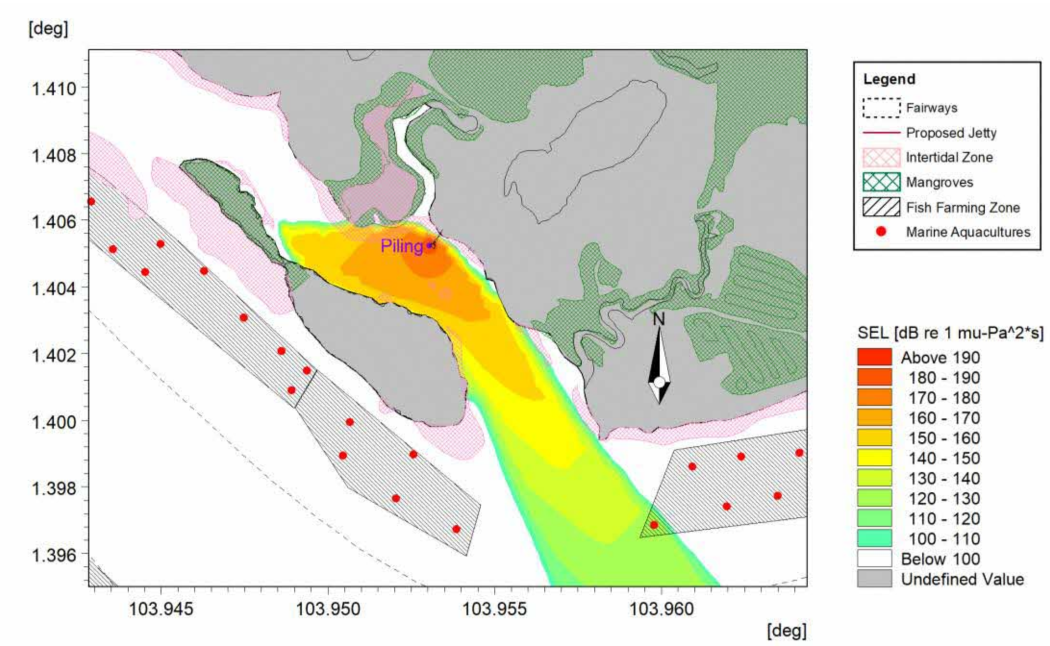


Figure 5.79 Underwater sound map for piling work with frequency range 100 Hz to 1250 Hz relevant to fishes. The red dots represent marine aquaculture farms in the region of interest. Black stripes box represents the fish farming zones

5.6.5 Underwater Noise Summary

The typical noise recorded in the Project area for the baseline conditions generally can be characterised as common noise conditions for the marine water bodies in Singapore. Underwater noise from the impact of pile driving activity in the channel between Pulau Ubin and Pulau Ketam region was modelled using DHI's UAS (part of DHI's MIKE Powered by DHI software package). Model results were presented in Section 5.6.4, showing that the effect of the modelled underwater noise generated from piling works is localised around the modelled source, shaped by water depth and location from the piling sources. A relatively low magnitude of underwater noise is experienced at the furthest sensitive receptors. Sound exposure levels at receptor sites include aquaculture farms and marine fauna, with the detailed impact assessment to be conducted in the relevant receptor sections (Section 5.7 and onwards).

5.7 Marine Ecology and Biodiversity

Pulau Ubin is home to a large diversity of coastal environments and a large number of associated faunae. It is home to the largest area of mangroves in Singapore, at 149 ha, including 35 'true' mangrove species (Yang *et al.*, 2013). Specific to this Project's study area, the Sungei Puaka mangroves stretch approximately 1.06 km^2 across the channel and are home to a rich biodiversity of organisms such as the fiddler crab, mudskipper and mud lobsters (Yee *et al.*, 2010).

In light of numerous marine ecologically sensitive receptors in the area, baseline studies on intertidal areas, mangroves and subtidal habitats were carried out to assess potential impacts on these coastal communities adequately. This is because construction activities associated with marine works can result in changes in hydrodynamics, suspended sediment concentrations, and pollution concentration loads in the surrounding water. Sediment spills from piling works may temporarily increase the concentration of suspended sediments, resulting in increased turbidity.

Direct impacts of the project footprint, i.e., direct removal or change to the study area within the marine footprint of the proposed jetty, are addressed in Section 6 as long-term post-construction (operational) impacts.

5.7.1 Environmental Baseline, Relevant Key Receptors and Pressures

Key receptor groups within marine ecology and biodiversity include:

- Intertidal areas (including the current shoreline);
- Mangrove habitat;
- Macrobenthos; and
- Marine fauna (particularly fish).

From the nature of the proposed construction, the following sources of "pressure" and potential impact on sensitive receptors in the marine ecosystem have been assessed:

- Physical disturbances to the environment as a result of the coastal construction works;
- Increased suspended sediments (with reference to sediment plume modelling);
- Potential cyst or water quality changes arising from pollutant release due to suspended sediments;
- Secondary impacts due to changes to marine environmental quality as a result of accidental spills and leaks; and
- Underwater noise impacts from the piling and other associated coastal works.

5.7.1.1 Intertidal Surveys

Visual Quadrat Point Surveys

Methods

Intertidal habitats are coastal areas that get exposed when the tides recede, including mangroves, seagrasses and other shores such as sandy shores.

The Visual Quadrat Point (VQP) method (Figure 5.80) was used to survey this location (Figure 5.82) due to the narrow nature of the intertidal area in the vicinity of the ULL jetty. Surveys were conducted during periods of spring low tide. Six (6) replicate 0.25 m^2 (0.5 m by 0.5 m) quadrats were placed randomly at ten (10) predetermined points distributed across the site (Table 5.37) to ensure adequate representation of the study area.

The VQP surveys documented and characterised the intertidal communities (and seagrass, if any), including:

- Benthic percentage cover of a predetermined list of flora and fauna, including seagrass, macroalgae, and abiotic substrate;
- Counts of individual motile organisms from major fauna classes; and
- Biodiversity of major intertidal flora and fauna identified at the taxonomic species level

Where possible, all major flora and macro-invertebrate fauna encountered were identified to the taxonomic level of species. Species of conservation significance were identified in accordance with published lists (e.g., IUCN Red List and the Singapore Red Data Book by Davison *et al.* 2008). Where possible, in-situ photographs of the taxa encountered were recorded.

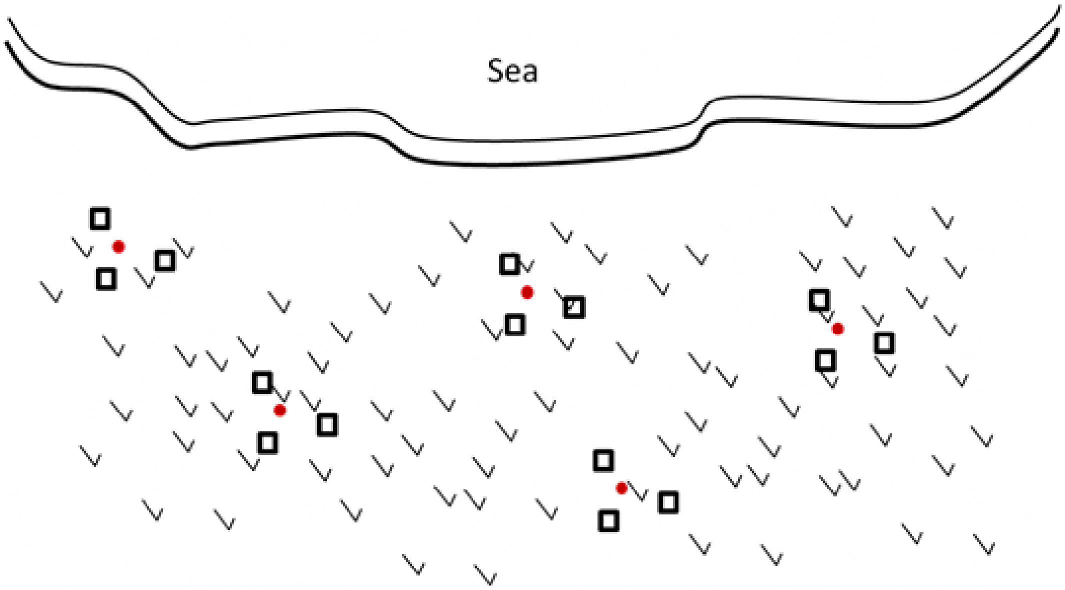


Figure 5.80 Placement of 0.25 m^2 quadrats within the irregular rocky intertidal area based on the VQP method. Red dots: Survey location marked by GPS; Squares: three (3) or six (6) quadrats randomly placed around the survey location. For this study, six quadrats per point were used

Figure 5.81 Images showing (left) an overview of the intertidal area at ULL and (right) a surveyor quantifying benthic coverage on the intertidal area

Figure 5.82 Map of the locations of the Visual Quadrat Points (VQP) carried out at the intertidal areas around ULL

Table 5.37 Coordinates of the ten (10) VQP points carried out for the intertidal seagrass surveys

Stations	Coordinates	
	Longitude (°)	Latitude (°)
ULL01	103.953110	1.406374
ULL02	103.953075	1.406111
ULL03	103.953047	1.405909
ULL04	103.953166	1.405866
ULL05	103.953232	1.405728
ULL06	103.953314	1.405636
ULL07	103.953457	1.405548
ULL08	103.953785	1.405436
ULL09	103.954084	1.405291
ULL10	103.954356	1.405013

Results

Benthic coverage on the site was mostly abiotic (98.5 ± 1.17 %), comprising Sandy-rocky substrate (Table 5.38). The remaining 1.5 % of the biotic cover was dominated by sponges

(Table 5.38). For fauna found within the quadrats, Gastropoda (e.g., snails) were detected at the highest density of 57.3 individuals/m^2, followed by Hexanauplia (e.g., barnacles) at a density of 48.7 individuals/m^2.

A total of 20 species of fauna were recorded during surveys, none of which are Conservation Significant (CS) species (Table 5.39). Some examples of fauna that were recorded include Banded Fanworm (*Sabellastarte spectabilis*), the Green Mussel (*Perna viridis*) and the Black Sea Urchin (*Temnopleurus toreumaticus*), species that are frequently documented in Singapore's northern shores (Figure 5.84).

Table 5.38 Mean percentage cover (%) and standard error (SE) of the major benthic categories recorded during the VQP surveys

Major Benthic Category	Mean (%)	SE (%)
Seagrass	0.00	0.00
Macroalgae	0.23	0.55
Ascidian	0.02	0.05
Anemone	0.20	0.32
Hard coral	0.32	0.57
Soft coral	0.00	0.00
Sponge	0.44	0.57
Zoanthid	0.00	0.00
Other fauna	0.32	0.28
Abiotic	98.49	1.17

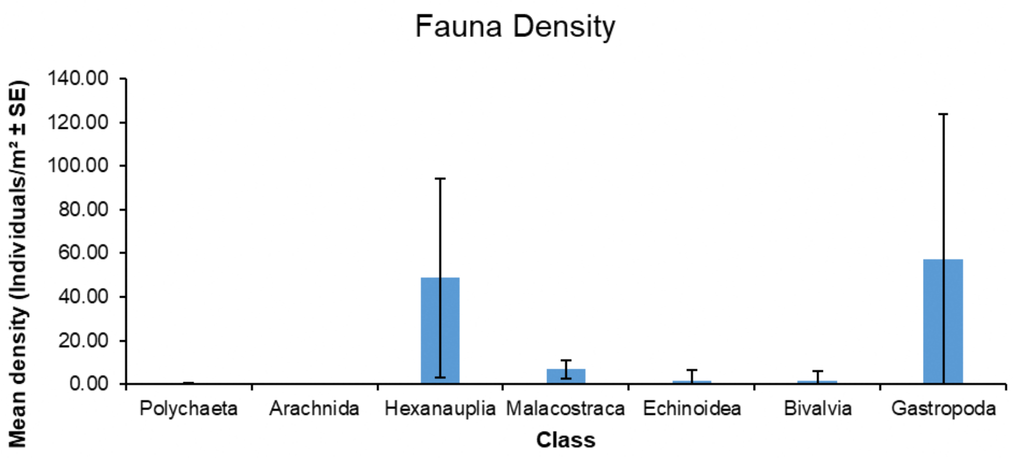


Figure 5.83 Mean density (±SE) of different classes of fauna detected during VQP surveys.

Table 5.39 List of species found during VQP surveys at the intertidal areas around ULL jetty.

No.	Scientific Name	Common Name
1	*Alpheus* sp.	Snapping shrimp
2	*Arcuatula senhousia*	Nest mussel
3	*Balanus amphitrite*	Acorn barnacle
4	*Carpilius maculatus*	Spotted reef crab
5	*Circe scripta*	Script venus clam
6	*Clibanarius* sp.	Striped hermit crab
7	*Dardanus megistos*	Orange-spotted hermit crab
8	*Diogenes* sp.	Tidal hermit crab
9	Family Veneridae	Venus clams
10	*Goniodiscaster scaber*	Biscuit sea star
11	*Haliclona* sp.	Elegant branching sponge
12	*Laevistrombus turturella*	Gong-gong/Pearl conch
13	*Neopetrosia* sp.	Blue jorunna sponge
14	*Palaemon* sp.	Glass shrimp
15	*Perna viridis*	Green mussel
16	*Polychaeta* sp.	Gregarious tubeworm
17	*Portunus pelagicus*	Flower crab
18	*Sabellastarte spectabilis*	Banded fan worm
19	*Salmacis* sp.	White sea urchin
20	*Temnopleurus toreumaticus*	Black sea urchin


Overview of intertidal area at ULL


Banded Fanworm (*Sabellastarte spectabilis*)


Black sea urchin (*Temnopleurus toreumaticus*)


Example fauna from class Hexanauplia (barnacles)


Green Mussel (*Perna viridis*)


Biscuit Sea Star (*Goniodiscaster scaber*)

Figure 5.84 Survey photographs depicting the overview of the intertidal area and various fauna found there

Mangrove Surveys

Methods

Mangrove surveys were carried out during suitable available low tides near the mouth of Sungei Puaka, which opens out into the Ketam Channel and the shoreline in front of ULL (Figure 5.85). DHI carried out a visual transect survey of the mangrove fringes in this area.

At low tide, a visual transect walk-through of the mangroves with indistinct community structures was carried out (Figure 5.86). During the survey, binoculars were used to aid in the identification of plants located in areas which are not immediately accessible or if the trees are too tall. Plants will be recorded and documented according to their type and conservation status (i.e., IUCN Red List or the Singapore Red Data Book by Davison *et al.*, 2008). A handheld GPS was used to mark plants of interest and to track the survey route/transects. Further information on the mangrove fringe was also obtained from secondary information from published data.

Figure 5.85 Map of the mangrove transects carried out and the locations of the conservation significant species found during surveys. Note that two *Ceriops* sp. were found within 50 m of the jetty footprint

Figure 5.86 DHI surveyor carrying out visual transect walk-through survey

Results

A total of 10 species of mangroves were found within the study extent, with MN1 having three (3) species and MN2 and MN3 each with nine (9) species detected (Table 5.40). A total of 3 CS species were found, including the locally "Vulnerable" *Ceriops tagal* and *Rhizophora stylosa* and the locally "Endangered" *Ceriops zippeliana*. Selected photographs showing an overview of the mangrove area and key flora are presented in Figure 5.87.

As seen in Figure 5.85 above, two *Ceriops* sp. were found within 50 m of the proposed jetty footprint.

Figure 5.87 Images of the mangrove species found during mangrove surveys

Table 5.40 Species checklist of mangrove species observed at each mangrove transect

Genus/Species	Common Name	Singapore RDB Status	MN1	MN2	MN3
Avicennia alba	Api-api bulu	N.A.		√	
Avicennia rumphiana	Api-api putih	N.A.		√	√

Genus/Species	Common Name	Singapore RDB Status	MN1	MN2	MN3
Bruguiera cylindrica	Bakau putih	N.A.	√	√	√
Bruguiera gymnorhiza	Tumu	N.A.	√	√	√
Ceriops sp.	Tengar	Vulnerable			√
Ceriops tagal	Tengar putih	Vulnerable		√	√
Ceriops zippeliana	Tengar merah	Endangered		√	
Rhizophora apiculata	Bakau minyak	N.A.	√	√	√
Rhizophora mucronata	Bakau kurap	N.A.		√	√
Rhizophora stylosa	Bakau pasir	Vulnerable			√
Sonneratia alba	Perepat	N.A.		√	√

5.7.1.2 Subtidal Surveys

Macrobenthos Surveys

Methods

Grab sampling is a commonly employed method used to quantitatively assess the macrobenthic fauna inhabiting the soft-bottom seafloor communities. For this baseline survey, a Van Veen grab was used to capture the slow moving and sessile epifauna and infauna in the sampling area.

Three replicate samples measuring approximately 0.063 m^2 were collected at various depths at each sampling site. Each successful sample retrieved by the grab was sieved through 1 mm mesh-size test sieves. Macrobenthos specimens retained in the sieve were counted, sorted and placed into labelled preservation containers containing 70 % ethanol (Tagliapietra & Sigovini, 2010). The collected specimens were analysed in DHI's laboratory and identified to the taxonomic rank of class, and subsequently photographed using a stereo zoom microscope with a maximum magnification of up to 126x.

Figure 5.88 DHI surveyor operating the grab sampler (left) and DHI biologist counting and sorting specimens (right)

Results

The average macrobenthos density at SQ1 (Table 5.41) was 68.78 ± 40.71 individuals/m^2. The benthic diversity originated from 5 classes (Table 5.42 and Figure 5.90). It was dominated by Holothuroidea (the average density of 45.5 ± 40.7 individuals/m^2, brittle stars and sea cucumbers etc.), followed by Bivalvia (7.4 ± 6.6 individuals/m^2, bivalves) (Figure 5.89). Representative images of each class of macrobenthos are found in Figure 5.90.

Table 5.41 Macrobenthic density distribution across sampling stations

Station	Average Density per station (individuals/m²)	SE
SQ1	68.78	40.71

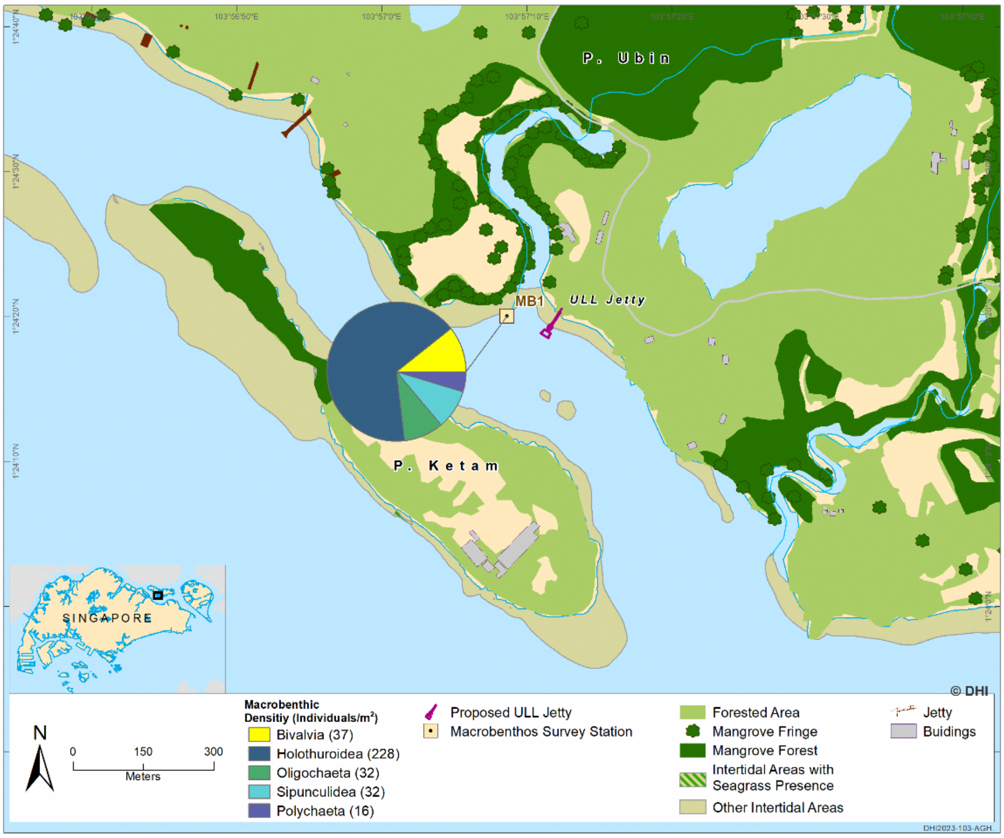


Figure 5.89 Map showing the benthic composition (based on abundance) of each of the five classes of organisms at SQ1

Table 5.42 Macrobenthic density distribution across taxonomic classes recorded from the sampling station at SQ1

Class	Average Density per Class (individuals/m²)	SE
Bivalvia	7.41	6.63
Holothuroidea	45.50	40.70
Oligochaeta	6.35	5.68
Sipunculidea	6.35	5.68
Polychaeta	3.17	2.84

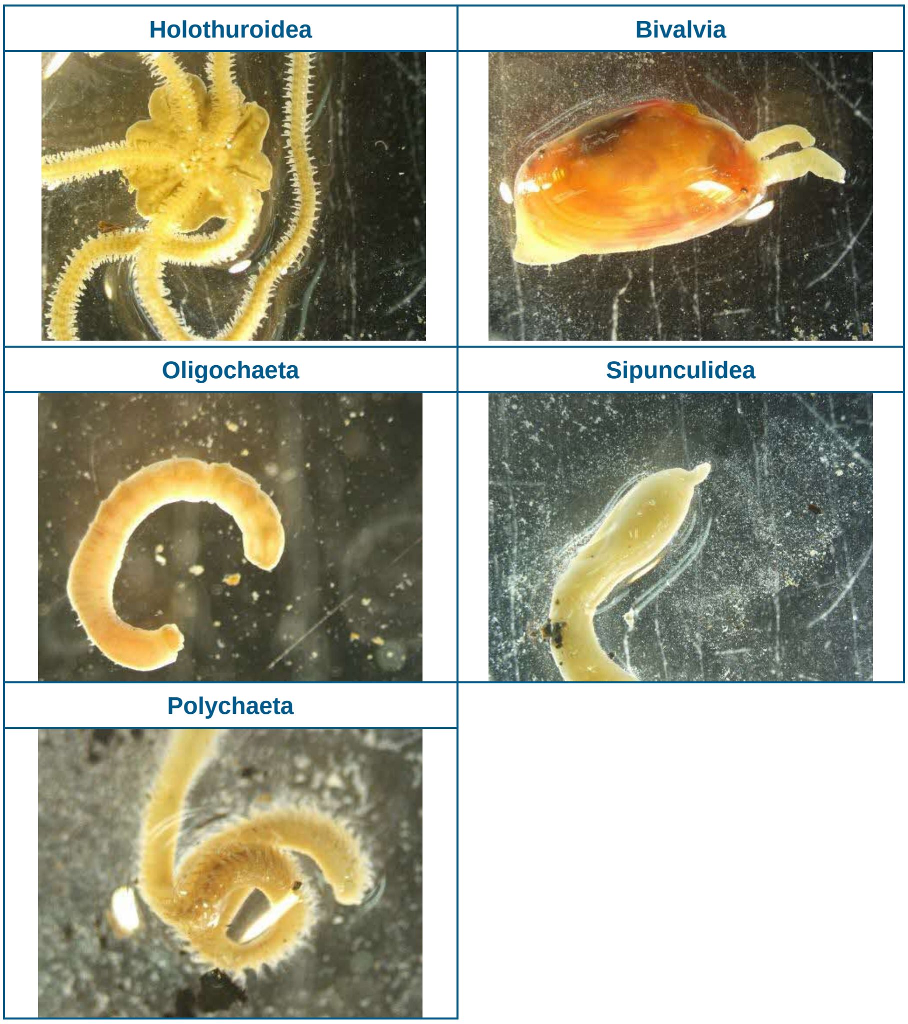


Figure 5.90 Representative photos from the 5 classes of organisms recorded from the sampling stations

Spot Dive Surveys

Methods

Visual qualitative spot dives were conducted along the reef areas to examine the presence of any significant coral and fish communities within the Project site, during which some macrobenthos were also documented. Three (3) points were selected for coral and fish surveys (Figure 5.91), including one point directly under the footprint of the proposed jetty at ULL and two points to its east and west.

Photos of various marine flora and fauna were captured and subsequently identified to the lowest taxonomic level possible. The conservation status of flora and fauna was then determined based on the Singapore Red Data Book by Davison *et al.* (2008), complemented by the Singapore Red Databook List (NParks, 2022) and the IUCN Red List.

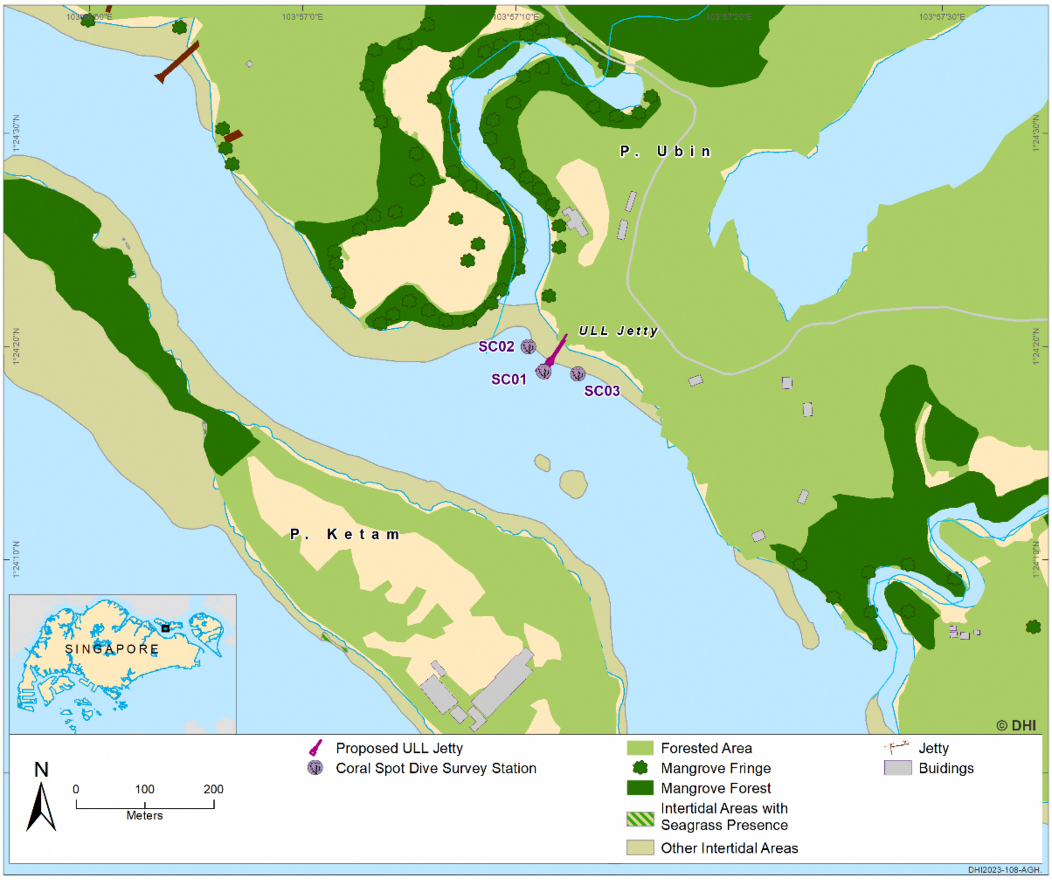


Figure 5.91 Map showing three (3) spot dive locations, SC01 to 03

Results

A total of thirty-eight (38) species from eight (8) genera were detected during the visual qualitative spot dive (Table 5.43).

The dominant fauna groups found were Cnidaria (nine [9] species, mostly sea fan and gorgonians), Echinodermata (eight [8] species of sea stars and sea cucumbers) and Chordata (eight [8] species, mainly comprising of fishes and ascidians). Out of the above fauna species, two (2) CS species were found during the spot dives, namely the Garlic Bread Sea Cucumber (*Holothuria scabra*) and the Velcro crab (*Camposcia retusa*) (Figure 5.92), internationally "Endangered" and locally "Vulnerable" respectively. While some hard corals were detected during the dives (Table 5.43; Figure 5.92), they have isolated individuals rather than a reef community, and none were found within the direct footprint of the proposed jetty.

One marine flora species, the Spoon Seagrass (*Halophila ovalis*), was also detected (Figure 5.92). This species is locally "Vulnerable", and the patch detected was small (<10 cm across in size) (Figure 5.92). For the seagrass, the patch was found at SC03, which is potentially a transitory patch at that size. This is due to the life history of *H. ovalis* and the fact that this location is highly turbid estuarine waters, known to be at the edge of seagrass physiological limits (Kilminster *et al.*, 2015). Therefore, the spot dive surveys revealed no significant coral or seagrass communities in the vicinity of the jetty.

Table 5.43 Selected species detected during the visual qualitative spot dives

Scientific Name	Common Name	RDB3 Status	IUCN
Camposcia retusa	Velcro crab	Vulnerable	-
Family: Oulastreidae	Encrusting hard coral	-	-
Oulastrea crispata	Zebra coral	-	-
Holothuria scabra	Garlic bread sea cucumber	-	Endangered
Halophila ovalis	Spoon seagrass	Vulnerable	-

Velcro Crab (*Camposcia retusa*)

Zebra Coral (*Oulastrea crispata*)


Spoon Seagrass (*Halophila ovalis*)

Garlic Bread Sea Cucumber (*Holothuria scabra*)

Figure 5.92 Images of CS fauna species found during fish and coral spot dive surveys

5.7.2 Evaluation Framework

In scoring receptor Importance and Magnitude of Change due to the pressures assessed, the same evaluation and scoring framework is used for marine (this section) and terrestrial (Section 5.8) ecological sensitive receptors, as presented in the following sub-sections. Tolerance limits specific to certain receptors' responses to the identified pressures are also presented where applicable. The scorings eventually feed into the RIAM assessment described in Section 4.2.2.

Evaluation of Receptor Importance

The generic evaluation of the Importance of ecological and biodiversity receptors, partly derived from the BIA Guidelines (NParks, 2020) and partly from DHI's standard RIAM definitions (Section 4.2.2), has been customised for terrestrial projects (Table 5.44). It considers the context-specificity of Singapore's ecological landscape and its constituent biodiversity, habitat types, and conservation values.

Table 5.44 Evaluation of the importance of ecological and biodiversity receptors in accordance with the RIAM methodology

Score	Generic Criteria	Customised Criteria Specific to Singapore's Ecological Context
5	Important to national/international interests	• Nationally or internationally designated sites, habitats of biological and ecological importance, e.g., designated Nature Reserves, Nature Areas, ASEAN Heritage Park. • Natural freshwater streams, freshwater swamp forests, and mangrove forests with distinct intertidal zonation. • Limited potential for substitution, harbours many species with a highly restricted spatial distribution. • Contains a high proportion of conservation-significant taxa/species, e.g., listed Critically Endangered in the Singapore Red Data Book; for flora – conservation-significant species refer to threatened species that are not relics of past cultivations, i.e., of native stock or wild populations.
4	Important to regional/national interests	• Large, forested sites (≥20 ha) with closed canopy cover, outside of designated nature reserves and nature areas, or native-dominated old secondary forest habitats. • Key habitats for several highly conservation-significant taxa/species, i.e., listed Critically Endangered in the Singapore Red Data Book. • Important for the functioning, connectivity, and integrity of adjacent habitats.
3	Important to areas immediately outside the local condition	• Forested sites ≥5 ha, or native-dominated young secondary forest habitats. • Naturalised streams with riparian vegetation and canopy cover. • Considered to be Endangered or Vulnerable in the Singapore Red Data Book. • Medium importance and rarity on a national level. • Limited potential for substitution. • Important for the functioning, connectivity, and integrity of adjacent habitats.
2	Important only to the local condition (within a large direct impact area)	• Forested sites ≥1 ha. • Habitats with some local biodiversity and potential for substitution. • Human-modified streams with soft landscaping feature, e.g., Active-Beautiful-Clean waterway projects. • Unmanaged habitats with limited biodiversity and ecological value, e.g., grasslands and shrubland . • Managed habitats that are adjacent to forested sites and serve as ecological buffers or corridors. • Species that are considered least concern in the Singapore Red Data Book.
1	Important only to the local condition (within a small direct impact area)	• Species of no national importance. • High proportion of weedy/invasive species. • Limited ecological importance. • Highly modified or fragmented habitats of little to no biodiversity value, e.g., managed turf.

Evaluation of Magnitude of Change

The evaluation of the Magnitude of Change on ecological and biodiversity receptors, as derived from the BIA Guidelines (NParks, 2020), has also been customised as outlined in Table 5.45. This customised evaluation of the Magnitude of Change is based on available and applicable legal standards, international guidelines, and applicable ecological tolerance limits as described in this section. However, it should be noted that such standards, guidelines and limits do not encompass all ecological considerations. So expert judgment of the local ecological context and relevant scientific literature supports the ecological impact assessment where necessary.

Table 5.45 also includes assessment limits related to airborne noise. For terrestrial and freshwater fauna receptors, there are no specific guidelines or thresholds stipulated globally or in Singapore, partly because the effects of noise on most fauna species are poorly understood (Larkin *et al.,* 1996; Brown, 2001); hence guidance is taken from relevant organisations, literature, and expert judgement. For example, The Nature Conservancy (2015) recommends that noise levels be ideally as low as 55 dB within 100 m from the source to protect sensitive animal species. Other studies have suggested that higher noise levels of around 68 dB may reduce birds' foraging ability and eventually lead them to avoid and abandon the habitat (Ortega, 2012). For acoustic noise pollution impacts specific to aquatic fauna and habitats, a noise level above 60 dB is accepted to induce behavioural changes in freshwater fauna and temporary changes in population patterns (Kunc *et al.*, 2016). Given that different species have varied tolerance to anthropogenic noise and noise levels (Parris & Schneider, 2008), a noise level of 60 dB was taken as the threshold for terrestrial fauna receptors in this Study, above which detectable changes are predicted. Exceedance of 60 dB will therefore result in a Magnitude of Change in the RIAM methodology to be 'slight' or higher.

There are no tolerance limits for assessing impacts from accidental spills or leaks – the general definitions of Magnitudes of Change as per the RIAM framework apply.

Table 5.45 Criteria used for scoring Magnitude of Change on biodiversity and ecological receptors. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted

Score	Generic Criteria	Specific Criteria
-4	Major negative disadvantage or change	• Affects the entire habitat or a significant proportion (>70%) of it and the long-term viability or function of the habitat is threatened. • Affects entire population or a significant part of it causing a substantial decline in abundance or change in and recovery of the population (or another dependent on it) is not possible either at all or within several generations due to natural recruitment. • Predicted airborne noise level exceeded 85 dBA, likely resulting in death or injury of fauna receptors.
-3	Moderate negative disadvantage or change	• Affects part of the habitat (40-70%) but does not threaten the long-term viability or function of the habitat. • Effect causes a substantial change in abundance or reduction in distribution of a population over one or more generations but does not threaten the long-term viability or function of that population, or any population dependent on it. • Predicted airborne noise level cause an increase of greater than 10 dBA as compared to baseline level. • Or predicted airborne noise level of 75-85 dBA, resulting in evident physiological and anatomical changes, and low survivability and biological fitness of fauna populations

Score	Generic Criteria	Specific Criteria
-2	Minor negative disadvantage or change	• Affects only a small area of habitat (10-40%) such that there is no loss of viability or function of the habitat. • Effect does not cause a substantial change in the population of the species, or other species dependent on it. • Predicted noise level cause an increase of up to 10 dBA as compared to baseline level. • Or predicted airborne noise level of 65-75 dBA, resulting in significant behavioural changes in fauna (change in feeding patterns, predator-prey interactions, reduced ability to maintain territories and increased aggression between individuals).
-1	Slight negative disadvantage or change	• Very limited loss of habitat (<10%). • Effect is within the normal range of natural variation accustomed to by the population of the species. • Predicted airborne noise level cause an increase of up to 5 dBA as compared to baseline level. • Or predicted airborne noise level of 60-65 dBA, resulting in temporary/recoverable shifts in fauna behaviour (e.g., change in vocalisation pattern or avoidance of areas with acoustic pollution), which are not expected cause a substantial change in species population.
0	No change	• Status quo or no loss of habitat. • Predicted airborne noise level cause an increase of up to 3 dBA as compared to baseline level. • Or predicted airborne noise level below 60 dBA, with no changes in fauna behaviour or populations expected.

Intertidal Habitat Tolerance to Suspended Sediments

The tolerance limits for corals (Table 5.46) and seagrass (Table 5.47) to suspended sediments are presented herein, even though no coral or seagrass habitats were found at the baseline intertidal or subtidal surveys (Section 5.7.1). As a conservative estimate, these are for reference in the assessment of the potential impact on intertidal habitats in the vicinity of the Construction area.

There is insufficient data on filter-feeder (e.g., octocoral and sponges) tolerance to suspended sediments available from the literature to develop the same comprehensive tolerance limits tables proposed for corals or seagrass. However, based on evidence from DHI's monitoring experience in Southeast Asia, it has been assumed that filter-feeder tolerance to suspended sediments is similar to (or not less than) hard corals. As octocorals often occur at the same depth or deeper than hard corals, such as *Turbinaria* that are considered to have a high tolerance for suspended sediments, it seems a reasonable assumption to consider it unlikely that octocorals and sponges would be more sensitive than the hard coral species that the coral tolerance limits are based on. Therefore, the tolerance limits for corals are assumed to apply to filter feeders.

Table 5.46 Magnitude of condition matrix for impact on coral reefs in Singapore from excess (i.e., in addition to background) suspended sediment concentrations (SSC)

Magnitude	Definitions
No Change	Excess SSC > 5 mg/l for less than 5% of the time, or Excess SSC < 5 mg/l
Slight Negative Change	Excess SSC > 10 mg/l for less than 5% of the time, or Excess SSC > 5 mg/l for 5 - 20% of the time
Minor Negative Change	Excess SSC > 25 mg/l for less than 5% of the time, or Excess SSC > 10 mg/l for 5 - 20% of the time, or Excess SSC > 5 mg/l for more than 20% of the time
Moderate Negative Change	Excess SSC > 100 mg/l for less than 1% of the time, or Excess SSC > 25 mg/l for 5 - 20% of the time, or Excess SSC > 10 mg/l for more than 20% of the time
Major Negative Change	Excess SSC > 100 mg/l for more than 1% of the time, or Excess SSC > 25 mg/l for more than 20% of the time

Table 5.47 Magnitude of condition matrix for impact on seagrass from excess (i.e., in addition to background) suspended sediment concentrations (SSC)

Magnitude	Definitions
No Change	Excess SSC > 5 mg/l for less than 20% of the time, or Excess SSC < 5 mg/l
Slight Negative Change	Excess SSC > 10 mg/l for less than 20% of the time, or Excess SSC > 5 mg/l for more than 20% of the time
Minor Negative Change	Excess SSC > 25 mg/l for less than 5% of the time, or Excess SSC > 10 mg/l for more than 20% of the time
Moderate Negative Change	Excess SSC > 75 mg/l for less than 1% of the time, or Excess SSC > 25 mg/l for 5 - 20% of the time
Major Negative Change	Excess SSC > 75 mg/l for more than 1, or Excess SSC > 25 mg/l for more than 20% of the time

Mangrove Tolerance to Suspended Sediments

A study in Cairns, Australia, demonstrated that 80% of suspended sediments brought into the mangroves from coastal waters at spring flood tide were trapped in the mangroves (Furukawa *et al.*, 1997). Sediment particles are carried in suspension into mangrove forests during high tide, where they are maintained in suspension due to the turbulence caused by mangrove structures. The particles settle in the mangroves only around low tide, when water turbulence is reduced, and the water velocity is not large enough to carry the particles back to the estuary (Kathiresan, 2003; Wolanski, 1995). However, the vertical accretion of suspended particles also depends on concentration and rare events such as tropical cyclones or floods in nearby rivers (Furukawa *et al.,* 1997).

Further observations at Cocoa Creek, a mangrove creek system near Townsville, Australia, suggest a complex but strong relationship between tidal hydrodynamics, sediment transport and geomorphology (Bryce *et al.,* 2003). Given this complexity, no clear estimates of thresholds for sediment fluxes in mangroves. However, mangroves can be considered fully tolerant to the range of suspended sediment loads that may be generated and transported from the trimming and piling activities.

Mangrove Tolerance to Sedimentation

Mangroves can withstand gradual sediment accumulation, which is part of their natural, dynamic state. However, acute increases in sedimentation due to natural or anthropogenic dumping of material can result in the burial of pneumatophores, reducing their ability to supply oxygen to the root system (Wolanski, 1995). Seedlings and pneumatophores are the most sensitive components of the mangrove ecosystem to sedimentation impacts. Both have a relatively small vertical extent and may therefore be partially or fully buried by high sedimentation rates within a short period of time.

In simple terms, there are two main types of mangrove root structures: those with stilt roots (e.g., *Rhizophora*) and those with pneumatophores (e.g., *Avicennia*). Mangrove root structures with pneumatophores are normally located on the outer fringe of the mangrove forest with a higher tidal range and are thus at higher risk of sediment ingress.

Some field data regarding mangroves' tolerance levels to levels of sedimentation are available. A study by Terrados *et al.* (1997) showed that sediment burial of 8 cm and above retarded growth and increased mortality of *Rhizophora apiculata* seedlings due to altered oxygen supply to the hypocotyl root system. Experimental fieldwork in Thailand carried out by Thampanya *et al.* (2002) on seedlings of *Avicennia officinalis*, *Rhizophora mucronate,* and *Sonneratia caseolaris* showed that *Avicennia officinalis* was five times more sensitive to burial than *Sonneratia caseolaris*, whilst *Rhizophora mucronata* showed no significant difference between the control and burial treatments (0, 4, 8, 16, 24 and 32cm). There was 100% mortality in *Avicennia officinalis* after 225 days at 32 cm burial and almost 90% mortality at 24 cm.

These figures are consistent with the fact that the pneumatophores of *Avicennia* typically extend 10 cm but can reach 30 cm or more above ground level, such that it requires extensive and prolonged sedimentation to have any effect on respiration.

Fish Tolerance to Suspended Sediments

The tolerance of fish to suspended sediments varies widely from species to species. Fish in open-water environments will generally move away from areas of high suspended sediment concentration (so-called turbidity barriers) to seek new habitats. If there has been no permanent damage to a fish's natural habitat in a given area (e.g., coral reef), the fish will eventually return after the suspended sediment loading has been removed.

The situation is different for cage culture, as the fish cannot move out of the affected area. Elevated concentrations will predominantly affect fish respiration, which will affect growth rates under sub-lethal loading. Other issues related to the clogging of the nets surrounding the cages with resultant depression in water quality within the cage due to reduced flushing. This clogging will increase in areas with high Suspended Sediment Concentrations (SSCs).

A detailed literature review of suspended sediments in a wide range of fish species was conducted in order to establish tolerance thresholds for fish against suspended sediments. It is noted that data for tropical fish are scarce. Most available data are for temperate fish, the thresholds derived from which must be applied with caution. The limits that are proposed for this impact evaluation (Table 5.49) take guidance primarily from Aquaculture

Stewardship Council (ASC) Tropical Marine Finfish Standard Version 1.0 and Best Aquaculture Practices (BAP) Farm Standard 3.1 (Table 5.48). The lower value of < 25 mg/l TSS allowable in recirculating aquaculture system discharge suggests that the fish can tolerate SSC levels of < 25 mg/l and anything above is deemed to potentially cause stress onset in the fish. Analysing available data for temperate fish's non-acute exposure to SSC shows that Moderate Change happens at around 50 mg/l and Major Change onsets at more than 100 mg/l.

It is noted that these conservative tolerance limits have not been used or validated by DHI in Singapore. They are used as conservative estimates in this Study to assess the Magnitude of Change to fish and aquaculture facilities (Section 5.10.3).

Table 5.48 Allowable level of total suspended solids for production systems in discharged effluent across the two standards

Standard	Ponds	Recirculating Aquaculture System
ASC Tropical Marine Finfish Standard Version 1.0	≤ 30 mg/l average and no higher than 50 mg/l	N/A
BAP Farm Standard 3.1	< 50 mg/l	< 25 mg/l

Table 5.49 Magnitude of condition matrix for suspended sediment impact on fish

Magnitude	Definitions
No Change	Excess SSC ≤ 5 mg/l
Slight Negative Change	Excess SSC > 5 mg/l to 25 mg/l
Minor Negative Change	Excess SSC > 25 mg/l to 50 mg/l
Moderate Negative Change	Excess SSC > 50 mg/l to 100mg/l
Major Negative Change	Excess SSC > 100 mg/l

Fish Tolerance to Underwater Noise

One of the most important factors when considering the impact of sound exposure in fish is the presence or absence of a gas bladder in the body. The presence of a gas bladder, and its anatomical location within the body, make fish more susceptible to pressure-mediated injury to the ears and general body tissues than species that lack gas bladders (Carlson, 2012). Fish species with gas bladders are also likely to be able to detect sounds over a broader frequency range and at a greater distance from the source than fish without such structures, thereby increasing the range from the source over which man-made sound sources have the potential to exert influence (Popper *et al.*, 2014).

Based on previous data collected on noise impact on fish, Popper *et al.* (2014) developed guidelines for noise levels arising from various activities such as underwater explosions, seismic airguns, naval sonar, and pile driving. For this EIA, the guidelines for pile driving were used as the other activities assessed were not related to construction noise. Aquaculture farms in the East Johor Straits (EJS) rear tropical foodfish species such as seabass and snapper species, which possess swim bladders, making them sensitive to changes in underwater noise. Under Popper *et al.*'s (2014) guidelines, mortality and potential mortal injury are expected at 207 dB re $1\mu Pa^2 s$ while temporary threshold shifts (TTS) in hearing can be expected at 186 dB re $1\mu Pa^2 s$.

In a more recent reference, i.e., an acoustic calculation tool that was set up for National Oceanic and Atmospheric Administration (NOAA) Marine Fisheries Service (NMFS) Southeast Regional Office (SERO) (2021), similar thresholds of physical injury onset are reported for fish. The tool additionally indicates 150 dB re $1\mu Pa^2 s$ RMS as the threshold for fish behaviour change.

Therefore, the behaviour change threshold of 150 dB re $1\mu Pa^2 s$ is set as the upper limit of No Change. The physiological threshold of 186 dB re $1\mu Pa^2 s$ is the lower limit for Minor Change, i.e., stresses induced by this sound level could potentially lead to measurable fish mortality.

5.7.3 Results and Discussion

Generally, the Importance scores for marine ecology and biodiversity receptors ranged from ‘1’ to ‘5’.

For the intertidal areas around the proposed jetty at ULL, there was generally low species diversity (20 species) with low biotic cover, and no CS species were found (Section 5.7.1.1) as such intertidal areas are scored ‘1’ on the Importance category in RIAM.

For mangrove habitats, there was quite a significant community around the proposed jetty at ULL, harbouring a high diversity (10 species) of mangroves despite their small size, out of which three (3) are CS species. Another consideration contributing to scoring the Importance of the mangrove sensitive receptor is the two CS *Ceriops* sp. individuals within 50 m of the jetty footprint. The entire Pulau Ubin is also considered a Nature Area. As such, the mangrove community within the Study area scored a ‘5’ on the RIAM Importance score.

For marine fauna (including fish), 37 species of fauna were found; however, most were common subtidal species. The only exceptions were the two (2) CS species that were detected (Section 5.7.1.2), one locally “Vulnerable” and one internationally “Endangered”. However, the Velcro crab (*Camposcia retusa*) is a mobile scavenger and a commonly encountered species, and the garlic bread sea cucumber (*Holothuria scabra*) is low in population primarily due to overfishing (Hamel *et al.*, 2013). Hence, marine fauna was given an Importance score of ‘2’.

Suspended Sediment Impacts on Intertidal Areas

Intertidal areas with no seagrass community presence have no known tolerance limits for determining the impact of suspended sediment concentrations (SSC) in waters. This is because intertidal area communities are varied and often of lower biodiversity than other key areas such as seagrass communities or coral reefs. While the sediment plumes are expected to be transported to the mouth and upstream of Sungei Puaka (Section 5.2.4), the percentage of time when SSC exceeds 5 mg/l was predicted to be less than 5%, which is classified as No Change, hence **No Impact**, on coral and seagrass habitats.

The sediment plume models also predicted some changes to mean and 95th percentile excess SSC at the internal area during the jetty construction, by 1.57 mg/l and 2.46 mg/l respectively. The background median and 95th percentile TSS in the study area were found in another EIA (for a nearby marine development) to range between 5.00 mg/l and 6.10 mg/l and between 8.30 mg/l and 10.50 mg/l accordingly. This assessment adopts mean excess SSC as the basis as it is more representative of the environmental changes arising from the Project. 95th percentile values only occur for 5% of time.

It is noted that the change in mean SSC will be limited to a localised area around the jetty work and will likely be very transient in nature since the sediment plume inducing work will happen for only about 12 days as noted in Section 5.2.3. As such, sediment plume from the Project is assessed to cause **No Impact** on the intertidal areas in the study area.

Suspended Sediments Impacts on Mangrove Habitats

As described in Section 5.7.2, mangroves are generally tolerant to suspended sediments, and sedimentation as their typical estuarine environments are highly dynamic sedimentary environments. As such, they are not sensitive to SSC changes unless the sedimentation is expected to be prolonged. Due to the short-term nature (estimated construction over twelve (12) days) and small scale (with no major reclamation or infilling works) of the proposed construction works, no significant impacts are anticipated for the mangroves as a result of sediment plume; hence the impact significance is **No Impact.**

Suspended Sediment Impacts on Marine Fauna (including fish)

Even though fish have the mobility that allows them to practice avoidance behaviour, i.e., they can move away from areas that temporarily become unsuitable for them to inhabit during the Construction Phase, the potential impact of suspended sediment impacts was evaluated for a conservative assessment.

As presented in Section 5.2.4, sediment plume modelling results show that mean excess SSC in the Study area would be below 5 mg/l, excess SSC would exceed 5 mg/l for less than 5% of the time and exceed 25 mg/l for less than 2.5% of the time. Hence, it is estimated that there would be No Change to fish in the Study area due to suspended sediments from the construction works, resulting in a final impact significance of **No Impact**.

Impact of Cyst Release from Suspended Sediments on Marine Fauna (fish)

The eastern Johor Straits has a history of harmful algal blooms (see Trottet et al. (2022) for a review), including blooms of *Protoperidinium sp*., the second most abundant cyst genera found during the baseline studies. The blooms occurred back in 2017, likely due to high nutrient content in the waters and sediment of the eastern Johor Straits, values also observed in this EIA's baseline study. However, the amount of sediment stirred up by the piling and trimming works is low due to the small scale of the proposed marine works. Hence, the resultant impact Magnitude is proposed to be '-2', giving an impact significance of **Slight Negative Impact**.

Impact of Pollutant Release from Suspended Sediments on Marine Ecology and Biodiversity

Due to the detection of exceedance of Arsenic (compared with the MPA dumping guidelines, Section 5.3.4) in the sediment, the pollution release needs to be calculated and evaluated. The pollutant release from the sediment plumes generated during the construction phase is evaluated using a conservative approach. The calculation adopts the *maximum* concentration recorded in the seabed sediment for each heavy metal during the baseline survey. The highest modelled mean incremental SSC at each relevant receptor is also conservatively selected for this calculation.

The calculation formula is as follows:

Max. Incremental HM concentration in water column (mg/l)	=	Max. HM concentration in seabed (mg/kg)	X	2% release of the HM	X	Highest modelled mean excess SSC (mg/l)

**HM = heavy metals*

The calculation, and the determination of the 2% release of heavy metals, was adapted from a number of scientific studies. First, Petersen et al. (1997) found up to 2% of the particulate bound heavy metals were being remobilised from the sediment when they are stirred up. Similarly, an additional study from the University of Michigan by Eggleston (2012) also measured metal release from sediment during four-hour continuous resuspension experiments, and found that metal concentrations remained constant after the resuspension began, with less than 2% of total metal released into the water column for the majority of experimental runs.

The calculation results in Table 5.50 below show none of the calculated heavy metal content in the waters exceeded ASEAN MWQC. As a result, the impact significance of pollutant release into waters as a result of the sediment plume is **No Impact.**

Table 5.50 Calculated heavy metal content at the specific marine ecology and biodiversity receptor during the Construction Phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content in Water (µg/l)	ASEAN MQQC
Mangroves Habitats	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.33	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*
Intertidal Areas	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.33	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.14	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*
Macrobenthos	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content in Water (μg/l)	ASEAN MQQC
	Zinc as Zn	2.74	50*

*Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

Impact of Accidental Spills and Leaks on Marine Ecology and Biodiversity

There will be a designated onsite storage and handling of pollutive liquids and construction materials such as fuel, lubricant, grouting and cement at the land side. If these chemicals and construction materials are not properly stored or handled due to leakages, accidental spillage or poor handling and management practices, they could be washed into the surrounding marine waterbody during a rainfall event. Marine vessel collisions, marine vessel grounding and leaks onboard vessels can all result in the uncontrolled release of oil, diesel or oily wastes into the marine environment.

The assessment also considers the likelihood of such events. Oil spill risks presently exist in the current usage of slipways and jetties around Pulau Ubin. While the addition of a piling rig and a barge is expected in the Project area during construction, the likelihood of these oil spill events is relatively low. Although, there is some increase in the likelihood of these events compared to the baseline situation, the addition of a few construction vessels may not alter this risk much.

Spillage of chemicals and accidental release of waste materials can increase the concentrations of oil, grease, and COD and change water pH levels. If uncontrolled, the nature of this impact will be a negative one. For the EIA, it was assumed that no hazardous material management and mitigation measures are in place to encompass the worst case scenario. Therefore, the risk of spill and leak impacts to the various sensitive receptors is predicted to result in an impact Magnitude of '-1' or 'Slight change' for the scale of the planned construction.

The duration of these impacts is expected to be short-term (i.e., during the Construction Phase). Spills/leaks are also controllable with proper site management and/or reversible upon clean-ups. Therefore, the risk of spills and leak impact on marine ecology and biodiversity are not expected to exceed **Slight Negative Impact**, provided the recommended mitigation and preventive measures described in Section 5.7.4 are followed.

Underwater Noise Impacts on Marine Fauna (including fish)

Piling and trimming works for the jetty construction have the potential to create underwater noise disturbances to the marine fauna (including fish) in the vicinity of the construction area.

While no marine mammals are found in close proximity to the Construction area, they are active in the Chek Jawa area (eastern end of Pulau Ubin) and can transit marine areas close to the Construction area. Modelling results (Section 5.6.4) predicted that areas in the immediate vicinity of the Project area would experience maximum Sound Exposure Levels (SEL) of up to 190 dB re 1μPa^{2}s, exceeding the injury threshold for fish. However, Pulau Ketam would shield the main channel of the East Johor Straits from the underwater noise (Figure 5.79), keeping the sound relatively localised. For the mobile marine fauna transiting through Ketam Channel, it was estimated that they would receive SEL of up to 180 dB re $1\mu Pa^2 s$, which is classified as a 'Slight Negative Change' (Section 5.7.2). However, due to the motile nature of marine mammals and fishes, they are likely to vacate or avoid the construction area during the works. The displaced marine mammals will likely find refuge in adjacent areas, given the presence of large tracts of suitable marine habitats. As impacts are transient, it is assessed that resulting impacts from underwater noise are **Slight Negative Impact**.

5.7.4 Mitigation Measures

Accidental Spills and Leaks Mitigation Measures

A Waste Management Plan will be required to be prepared by the Contractor to estimate and log the waste types and volumes for the project and plan for proper handling, storage and disposal methods. Proper segregation and management for each type of waste are needed to sort out recyclable materials and allow cost-efficient treatment and disposal by licensed waste management organisations. Waste and hazardous materials management shall comply with local regulations and guidelines listed in Section 3.3. Below are some management and mitigation measures that shall be observed during construction in handling hazardous materials and wastes. Since the probability of occurrence, though very low, cannot be reduced to zero, the residual risk is therefore assessed as a Slight Negative Impact/risk.

Hazardous Materials Mitigation Measures

Table 5.51 presents an overview of the control measures that should be in place regarding hazardous materials during the Construction Phase of the Project.

Table 5.51 Mitigation measures to minimise impacts to marine ecology and biodiversity receptors during the Construction Phase

Aspect	Mitigation Measures
Management	• An inventory of all anticipated hazardous materials should be created with records of stock movements in accordance with formats specified by National Environment Agency – Chemical Control and Management Department (CCMD). • It is recommended that the construction environmental management plan include a hazardous material management plan with the following: o Dedicated hazardous material management procedures for transporting and handling of hazardous materials. o Dedicated hazardous material management procedures for refuelling. o Dedicated hazardous material management procedures for the storage of hazardous material. o Dedicated emergency response procedures specific to the itemised hazardous materials. • A training programme be provided for all personnel who handle hazardous material. • Standard Operating Procedures (SOPs) be put in place for the management of secondary containment structures, specifically in relation to the removal of any accumulated non-hazardous fluid to ensure that the intent of the system is not breached. • An inspection and maintenance program be implemented to verify the integrity of containment infrastructure.

<table>
<tr><th>Aspect</th><th>Mitigation Measures</th></tr>
<tr><td>General Handling and Storage</td><td>Materials should be stored in accordance with their Material Safety Data Sheets (MSDS).
Containers must be designed, manufactured and tested in accordance with internationally-acceptable standards and affixed with approved labelling.
Designated hazardous material storage areas should possess the following features:
Impervious or resistant flooring constructed of combustible, chemically resistant material.
Separate fire-resistant compartments for storing substances that can react dangerously with one another.
Provide sufficient protection to stored hazardous materials from environmental exposure.
Areas storing hazardous liquids should, at a minimum, include the following features:
Possess liquid-tight secondary containment structures capable of containing up to 110% of the largest tank or 25% of the combined storage volume, whichever is greater.
Have secondary containment structures designed to prevent contact between substances which can react dangerously with one another.
No apertures directly connecting to the sewage system, surface drainage or water body.
Fill points for hazardous liquids should be located inside the secondary containment reservoir.
Possess readily accessible spill kits and firefighting equipment appropriate for use with inventoried hazardous material (e.g., oil only, chemical only, general use).</td></tr>
<tr><td>Transport</td><td>It is required that hazardous material transportation methods are designed, constructed and maintained in accordance with the approved code of practice.
It is necessary to take adequate precautionary measures to prevent hazardous substances from exploding, catching fire, spilling, dropping or being released during transportation.
It is required that suitable and efficient fire extinguishers be located on an easily accessible section of the vehicle transporting the hazardous material.</td></tr>
<tr><td>Equipment Cleaning and Maintenance</td><td>Cleaning and maintenance activities that involve hazardous materials should be conducted over an impervious bunded surface.
Contaminated materials generated during cleaning and maintenance (e.g., oily rags, oil filters, spent oil) should be segregated and disposed of according to the waste management plan.</td></tr>
</table>

Aspect	Mitigation Measures
Terrestrial Refuelling Area Design	• The following physical measures are recommended for the refuelling area: ○ Automatic shut-off bowser nozzles be used when refuelling to decrease the risk of overfilling. ○ The refuelling area should be located within a secondary containment area isolated from surface water drainage. ○ The surface of the refuelling area should be constructed of non-combustible, fuel-resistant liquid-tight material. ○ Readily accessible spill kits and firefighting equipment.
Security Measures	• It is recommended that enhanced security measures be implemented for facilities storing hazardous substances. Security measures include but are not limited to: ○ Monitoring and detection systems such as CCTV cameras and human-based monitoring. ○ Security lighting to increase visibility at access points and sensitive locations (i.e., hazardous material storage). ○ Access control to limit access to hazardous materials (i.e., regulated key access, sign-in and sign-out procedures). ○ Documentation and reporting procedures for non-routine incidents.

The hazardous material impacts associated with the Project are primarily associated with the risk of loss of containment (LOC) events. The application of industry best practices, EHS guidelines and national code of practices are required to ensure that the residual risks do not result in LOC events and subsequent impacts on ecological receptors.

If diligently applied, the recommended mitigation measures can reduce the risk of hazardous material LOC events to satisfactory **Slight Negative Impact** levels. These impact levels are considered acceptable for the proposed project operations.

Waste Management Mitigation Measures

Table 5.52 outlines the recommended mitigation measures pertaining to waste management during the Construction Phase.

Table 5.52 Mitigation measures to minimise impacts to marine ecology and biodiversity receptors during the Construction Phase

Aspect	Mitigation Measures
Management Plans and Procedures	• It is recommended that a construction waste management plan be created with the following features: ○ An inventory of all anticipated wastes. ○ Standard operating procedures (SOPs) for segregation, storage, handling and disposal procedures for each relevant waste stream. ○ SOPs for the management of storage facilities. ○ A programme in place to avoid the generation of intractable wastes and encourage waste minimisation. ○ A programme in place to promote waste reuse, recovery and recycling. • Ensure that waste collection schedules are managed to prevent the over-capacity of waste storage on-site.
Storage Facilities	• Waste storage facilities should allow for the segregation of waste materials based on their waste type and classification. (e.g., concrete debris, metals, timber, plastics, recyclables, dredged material, hazardous materials). • Waste storage facilities should have measures in place to minimise the loss of waste material due to environmental conditions (e.g., enclosed skips, fencing). • At the minimum, the designated hazardous waste disposal area should take into account the following: ○ Impervious or resistant flooring constructed of a non-combustible, chemically resistant material with a perimeter bund or gully leading to a sump (reservoir). ○ Secondary containment for each incompatible hazardous/toxic liquid waste with a minimum containment capacity of 110% of the volume of the largest container. ○ The storage area shall be situated at sufficient distances from and have no apertures connecting directly to any sewage system or surface drainage and water body (except for the purpose of collecting accidental spillage). ○ Be fenced or walled, with a roof to limit access and loss of waste material due to environmental conditions. ○ Possess readily accessible spill kits and firefighting equipment appropriate for inventoried hazardous wastes (e.g., oil only, chemical only, general use).

Aspect	Mitigation Measures
Hazardous / Toxic Waste	• Ensure that a licensed toxic industrial waste collector is engaged for the collection and disposal of hazardous/toxic wastes. • Hazardous/toxic wastes should be stored in containers of material suitable for the relevant waste. • Hazardous/toxic wastes should be stored, taking into account their properties and compatibilities to prevent reactions during storage; incompatible materials should not be mixed in the same container. • Ensure that any potentially biohazardous medical wastes (e.g., bloody bandages, needles) are segregated, stored in containers fit for purpose and collected by a biohazardous waste collector.
Excavated / Dredged Material	• Excavated/dredged sediment, if stored on-site, should be stored at a bunded temporary stockpile area with sediment control measures at the outlet (e.g., sediment dewatering bag, sediment geotextile filters). • Excavated/dredged sediment should either be reused for land reclamation or dumped at offshore dumping and disposal sites. • Chemical testing of the sediment samples is recommended prior to reuse or dumping to assess sediment contamination as per MPA dredging and dumping guidelines.

The impacts associated with waste management at the Project are primarily associated with the risk of loss of containment (LOC) of stored hazardous/toxic waste and improper disposal, reuse and recycling of construction waste. The application of the above mitigation measures is recommended to ensure that the residual risks to the surrounding ecological receptors do not come to fruition.

If diligently applied, the recommended mitigation measures can reduce the risk associated with waste management to satisfactory **Slight Negative Impact** levels. These impact levels are considered acceptable for the proposed project operations.

Underwater Noise

Underwater noise impacts can be managed through a soft start (ramp up) to gradually increase sound pressure levels to drive fish and marine fauna away from the area.

5.7.5 Marine Ecology and Biodiversity Impact Summary

The Construction Phase impacts from the Project construction work on marine ecology and biodiversity receptors are summarised below in Table 5.53.

Table 5.53 RIAM results for Construction Phase (short-term) impacts from the Project on marine ecology and biodiversity receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Sediment Plume from Construction Activities	Intertidal areas	1	0	2	2	2	0	No Impact	-	-	-
	Mangrove habitat	5	0	2	2	2	0	No Impact	-	-	-
	Marine fauna (including fish)	2	0	2	2	2	0	No Impact	-	-	-
Algal Bloom due to Cyst Release from Suspended Sediments	Marine fauna (including fish)	2	-2	2	2	3	-28	Slight Negative Impact	-	-	-
Pollutant Release from Suspended Sediments	Marine fauna (including fish)	2	0	2	2	3	0	No Impact	-	-	-
Accidental Spills and Leaks	Intertidal areas	1	-1	2	2	3	-7	Slight Negative Impact	-1	-7	Slight Negative Impact
	Mangrove habitat	5	-1	2	2	3	-35	Slight Negative Impact	-1	-35	Slight Negative Impact
	Macrobenthos	1	-1	2	2	3	-7	Slight Negative Impact	-1	-7	Slight Negative Impact
	Marine fauna (including fish)	2	-1	2	2	3	-14	Slight Negative Impact	-1	-14	Slight Negative Impact
Underwater Noise	Marine fauna (including fish)	2	-2	2	2	2	-24	Slight Negative Impact	-1	-12	Slight Negative Impact

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

5.8 Terrestrial Ecology and Biodiversity

While construction works will largely be coastal, terrestrial fauna further inland can potentially face negative effects due to the works. Temporary construction laydown and operating equipment on terrestrial grounds can produce varying levels of noise (from noisy human activities (e.g., excavation) and air pollution (from the resuspension of particulate matter into the air) that propagate towards adjacent terrestrial habitats and cause impacts to terrestrial fauna. In order to ensure that the more sensitive forest fauna is not overlooked, terrestrial flora and fauna surveys were carried out as part of the baseline surveys for this Project.

Direct impacts of the project footprint, i.e., direct removal or change to the study area within the footprint of the proposed jetty, are addressed in Section 6 as long-term post-construction (operational) impacts.

5.8.1 Environmental Baseline, Relevant Key Receptors and Pressures

The following key receptor groups for terrestrial ecology and biodiversity include:

- Terrestrial Flora;
- Avifauna; and,
- Terrestrial Fauna (including Mammals, Herpetofauna, Butterflies, and Odonates).

From the nature of the proposed construction, the following sources of “pressure” on sensitive receptors in the terrestrial ecosystem have been assessed:

- Physical disturbances to the environment as a result of the coastal construction works;
- Secondary impacts due to changes to terrestrial environmental quality as a result of accidental spills and leaks;
- Atmospheric emissions from demolition, general construction works and vehicle movements; and
- Airborne noise pollution from mainly piling activities.

DHI has set tolerance limits for terrestrial ecology and biodiversity, particularly for changes in air quality and noise. Above this, there could be detrimental effects on these systems and the organisms living within them.

5.8.1.1 Terrestrial Flora

Methods

Terrestrial areas near the proposed jetty at ULL are thin strips of vegetation with roads, dirt tracks and public areas with easy access. Transects and plots were established north of ULL, the main forested areas around the proposed footprint. The flora study area was surveyed using the walking patrol method, with three (3) smaller 15 m x 15 m sampling plots and one (1) 50 m x 5 m flora transect established (Figure 5.93).

The survey was carried out using Transect tape, measuring tape, tree-diameter tape and binoculars will be used during the survey. Plants were identified based on field characters, with unidentified species sent to the Singapore Herbarium for further confirmation if needed. Species conservation status was based on the following references in the order:

1. NParks Flora and Fauna Web;
2. IUCN Red List or the Singapore Red Data Book by Davison *et al.* (2008); and

3. Flora of Singapore: Checklist and Bibliography (Lindsay *et al.*, 2022)

The order of references is based on the fact that not all species conservation has been updated. A handheld GPS was used to mark plants of interest, track the survey route, mark the centre point for each 5 m by 5 m plot as a reference point etc. Further information on terrestrial vegetation was obtained from published papers and historical satellite imagery.

The following details will be documented:

- Species composition
- Mapping out of flora identified as locally or internationally threatened to document the following:
  - Location (northing and easting)
  - Species identification
  - Conservation status

Additional details on the flora survey methodology and land use history documentation, are found in Appendix D.

Results

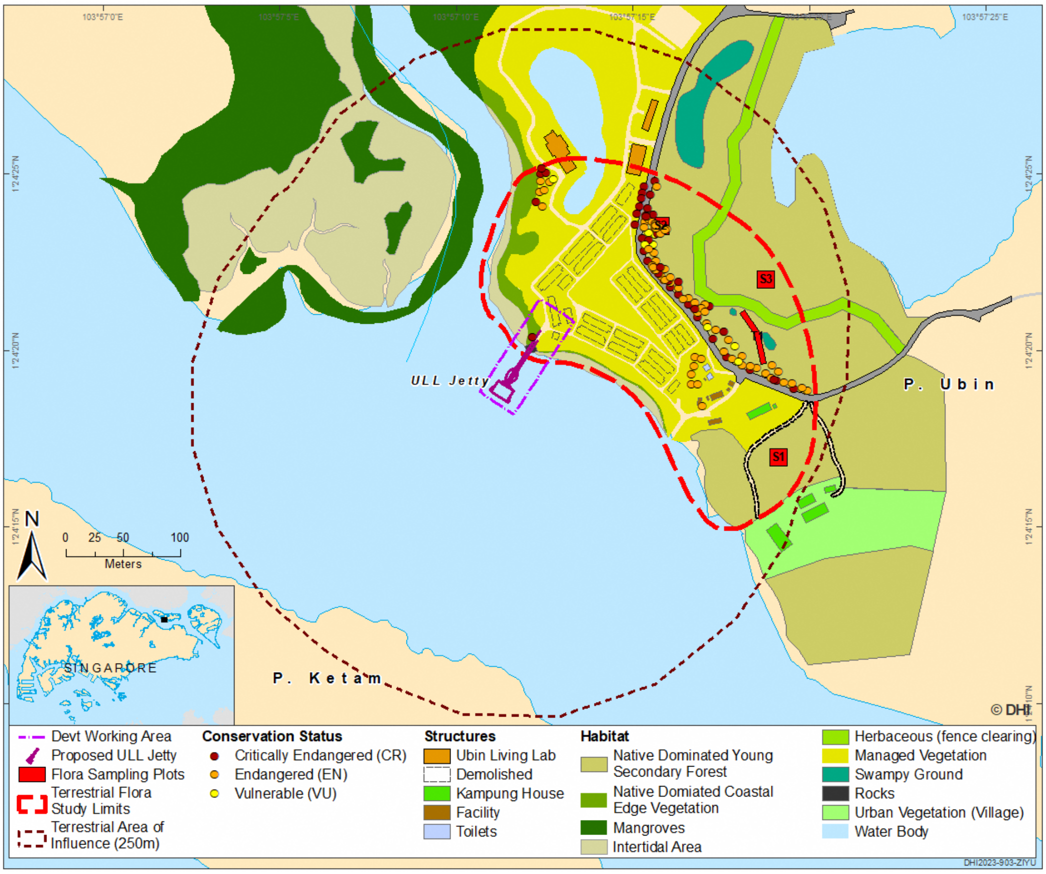


Figure 5.93 Map showing the locations of the flora study area and the three (3) sampling 15 x 15 m plots, and one (1) 50 x 5 m flora transect. Locations of various conservation significant species are shown at points on the map, this includes one conservation significant species within the project footprint and development working area.

The study area comprised of a total of sixty-nine (69) species of flora were found within the study area, which was comprised of four (4) key habitat types identified within (Table 5.54), out of which ten (10) are conservation significant species.

All three (3) sampling plots and the flora were carried out within the native-dominated young secondary forest in order to characterise the flora community better. All the sampled areas comprise of low to moderate richness, comprising of common natives with a scattering of conservation significant species (Table 5.55). Due to the presence of active enrichment planting carried out in the area, many conservation significant species (e.g., *Memecylon ovatum* ("Endangered")) are believed to be planted or the progeny of planted CS species. This is particularly for sampling plot 2, where the highest number of CS species was found, with six (6) out of twenty-four (24) species having local statuses.

A single individual of *Crinum asiaticum* was noted to be very near to the proposed jetty footprint. However, these species are extensively cultivated and are likely to be a progeny of cultivated plants. There is an option of transplanting this individual to a safe location.

Table 5.54 The different key vegetation types and their respective sizes found within the flora study area around the proposed jetty at ULL

Vegetation/Habitat Type	Size (ha)
Scrubland/Grassland (Herbaceous)	0.17
Managed and Urban Vegetation	1.32
Mangrove Forest and Coastal Vegetation	0.20
Native-Dominated Young Secondary Forest	2.04

Table 5.55 Flora species richness within the sample plots or transect, as well as the number of CS species detected within

Sample	Species Richness (CS Species)
Sampling plot 1	10 (2)
Sampling plot 2	24 (6)
Sampling Plot 3	23 (3)
Sampling Transect	24 (4)

5.8.1.2 Terrestrial Fauna: Transect Survey

Methods

A single-line transect, approximately 200 m in length, was established within the forested areas of the terrestrial study area (Figure 5.94). The terrestrial fauna taxonomic groups of interest for line transect surveys include non-volant mammals (i.e., excluding bats), avifauna, herpetofauna (reptiles and amphibians), odonates, and butterflies.

Surveys were conducted with surveyors walking along the line transects and documenting fauna encountered, either by visual sighting (with binoculars and telephoto lens if necessary) or by indirect evidence such as auditory calls (particularly for avifauna and amphibians) animal droppings or hoof marks. To account for the crepuscular activity pattern of many fauna species, both diurnal (dawn) and nocturnal (dusk) surveys were conducted (Table 5.56). Line transect surveys were replicated twice, with each sampling replicate minimally spaced a week apart to minimise temporal pseudoreplication and maximise sampling robustness. Should notable terrestrial fauna (e.g., conservation significant, keystone, or charismatic species) be observed beyond the line transects or stipulated survey window will be recorded as opportunistic sightings. Due to the proposed transect being a distance from the proposed jetty at ULL, care was taken to document opportunistic sightings within the ULL area.

The survey methods employed for each terrestrial fauna taxa of interest are detailed in Table 5.56.

Table 5.56 Terrestrial fauna taxa of interest and the corresponding survey methodology for line transect surveys

Taxon of Interest	Time of Day	Additional Details	Equipment
Mammals (Non-volant) and avifauna	Morning (7am-9am)	• 30 min sampling duration per transect • Seen and heard within 50 m on either side and in front of the transect	Binoculars, handheld GPS, camera with telephoto lens, torchlights, data sheet
	Dusk (7pm-9pm)		
Herpetofauna (Reptiles and Amphibians)	Morning (8am-10am)	• 30 min sampling duration per transect • Seen and heard within 10 m on either side and in front of the transect • Potential microhabitats (e.g., logs, crevices, hollows) may be surveyed as well	
	Dusk (30-60 mins after dark)		
Butterflies and odonates	Late morning (10am-12pm)	• 30 min sampling duration per transect • Within 10 m on either side and in front of the transect • To aid identification, capture-and-release of specimens may be carried out	Sweep nets, handheld GPS, binoculars, camera with telephoto lens, data sheet

Results

A total of forty-six (46) species of fauna were recorded from one (1) line transect established in the study area, as well as opportunistic recordings in the ULL pond and mangrove habitats (Figure 5.94). Out of these forty-six (46) species, the vast majority were Avifauna (twenty-four [24] species), followed by Butterflies (nine [9] species) and Odonates (four [4] species) (Table 5.57). This is typical of most forests, where birds are the most abundant taxa.

Out of these species, six (6) CS species were recorded. The majority of these species (three [3] out of six [6]) are birds, namely the Oriental Magpie-robin (*Copsychus saularis*, Figure 5.95), the Spotted Wood Owl (*Strix seloputo*) and the Common Kingfisher (*Alcedo atthis*). All three bird species are locally "Vulnerable". The other three CS species are local "Critically Endangered" species, such as the Malayan Crow butterfly (*Euploea camaralzeman malayica*), the Arrow Emperor dragonfly (*anax panybeus*, Figure 5.95) and the Greater Mousedeer (*Tragulus napu*).

The community at this site is common in parklands and secondary forests, where numerous generalist species exist, such as the Oriental Pied Hornbill (*Anthracoceros albirostris*) and Wild Boar (*Sus scrofa*). The higher richness of insects at the site, including two "Critically Endangered" species, could be due to the island's intentional creation of butterfly gardens and is a testament to Pulau Ubin being a refuge for threatened species in Singapore (Tan, 2020a). During stakeholder consultation, it was highlighted that the Leopard Cat (*Prionailurus bengalensis*) had previously been spotted in the study area. This species is nationally "Critically Endangered".

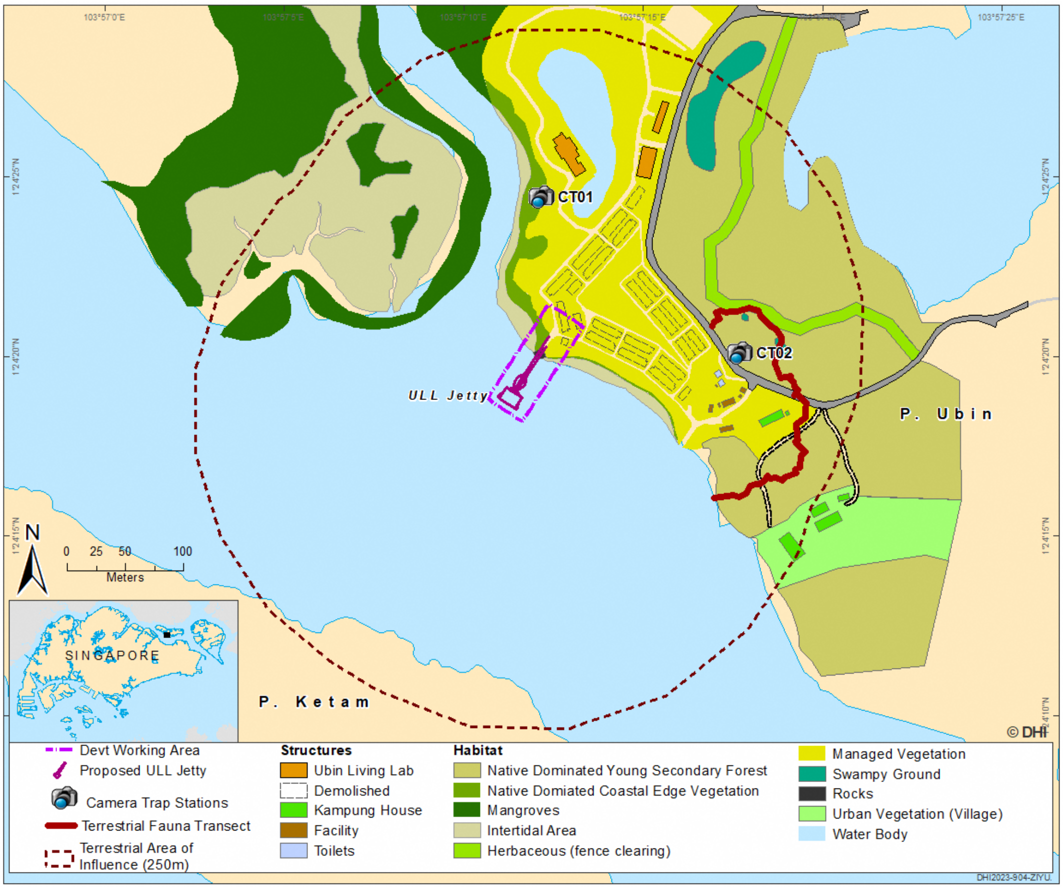


Figure 5.94 Locations of line transects and camera traps for terrestrial fauna surveys around ULL

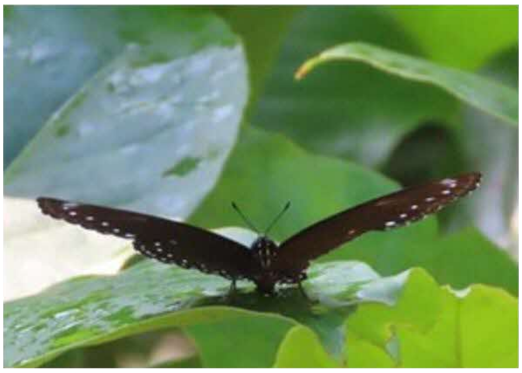
Table 5.57 Species richness of targeted terrestrial fauna taxa recorded within the fauna study area. The number of species with conservation status, as listed in the Singapore Red Data Book (SRDB) and International Union for Conservation of Nature (IUCN), is also shown

Taxon	Total Number of Species	Species in Transect	Species Opportunistically Recorded	Significant species sighted outside of surveys	No. of local CS species (SRDB)	No. of International CS species (IUCN)
Avifauna	24	23	11	0	3	0
Mammal	4	2	1	1	2	0
Amphibian	2	1	2	0	0	0
Reptile	3	1	2	0	0	0
Butterfly	9	9	3	0	1	0
Odonate	4	3	1	0	1	0
Fish	1	0	1	0	0	0
Total	**46**	**39**	**21**	**1**	**7**	**0**

Oriental Magpie-robin (*Copsychus saularis*)

Arrow Emperor (*Anax panybeus*)

Oriental Pied Hornbill (*Anthracoceros albirostris*)



Malayan Crow (*Euploea camaralzeman malayica*)

Figure 5.95 Images of selected fauna species found around ULL. The Arrow Emperor and Malayan Crow are both locally “Critically Endangered”, while the Oriental Magpie-Robin is locally “Vulnerable”

5.8.1.3 Terrestrial Fauna: Camera Trapping

Methods

Camera trapping was carried out to supplement fauna surveying efforts by targeting uncommon or cryptic fauna species that may not have been recorded during line transect surveys. Camera trapping is a useful fauna survey approach because it is non-invasive (not requiring capture and handling of animals) and provides a 24-hr sampling regime that captures both diurnal and nocturnal species. While camera traps are appropriate for surveying a variety of fauna taxa, their main usage in this study was to survey mammals, given the ease of identifying them readily through photographs or videos. Opportunistic captures of other fauna taxa, such as avifauna, reptiles, and amphibians, were also reported and analysed.

Two (2) camera traps (Model: Bushnell Core™ Low Glow Trail Camera) were deployed within the study area (Figure 5.94) for a period of seven (7) days. Deployment locations were selected based on the presence of obvious animal trails or signs or where animal usage was deemed most likely according to habitat characteristics. Each camera trap was mounted 30 to 50 cm off the ground and secured to a tree (see Figure 5.96 for an example). The cameras were programmed to record one 10-second video footage per motion trigger, with colour photographs taken during the day and infrared photographs taken at night. The camera traps were retrieved after the survey period.

Analysis of camera trap footage was conducted primarily using the R package ‘camtrapR’ v.2.0.3 (Niedballa *et al.*, 2016). Recorded footage was manually screened to identify species present and sorted into folders to be read by the ‘camtrapR’ package, which automatically extracts date and time information from the encoded metadata. Individuals were identified to the species level wherever possible, failing which they were identified to the genera level and suffixed with *sp*. Individuals belonging to the same species that were captured at least 30 minutes apart were treated and analysed as independent detections.

Camera Trap Deployment

Day and Night Camera Trap Footage

Figure 5.96 Example images of DHI Camera trap deployment and day and night footage captured by the Camera Trap

Results

A total of thirty (30) independent detections of fauna were recorded over seven (7) nights of camera trapping surveys using two (2) camera traps (Figure 5.94), giving a total of nine (9) species detected. Of the nine (9) species, four (4) mammals, three (3) avifauna and two (2) reptile species were detected (Table 5.58). This includes two CS fauna species: Oriental Magpie-robin (*Copsychus saularis*) and the Greater Mousedeer (*Tragulus napu*). It is well known that Pulau Ubin is a stronghold for a breeding population of Greater Mousedeers (Chua *et al.*, 2009), and the detection of this species during the camera trap surveys corroborates with Chua *et al.* (2019).

The most commonly detected species is the Wild Boar (*Sus scrofa*), which is one of the most abundant mammal species in Singapore (Koh *et al.*, 2018). Only the Wild Boar and the Zebra Dove (*Geopelia striata*) were found in both camera traps, a testament to both species being generalists that are found in a number of forested and park habitats in Singapore (Koh *et al.*, 2018).

Table 5.58 Number of independent detections for each fauna species captured from camera trap surveys. The number of camera traps (out of two traps) that captured each species is also shown. Locally conservation-significant species are indicated in bold

Taxon	Species	Common Name	Number of Independent Detections	Number of Camera Traps with Detections
Mammal	*Canis lupus*	Domesticated dog	1	1
	Rattus sp.	Rat species	2	1
	Sus scrofa	Wild boar	9	2
	Tragulus napu	**Greater mousedeer****	4	1
Avifauna	*Chalcophaps indica*	Common emerald dove	1	1
	Copsychus saularis	**Oriental magpie-robin***	3	1
	Geopelia striata	Zebra dove	3	2
Reptile	*Varanus salvator*	Malayan water monitor	5	1
	Varanus sp.	Monitor lizard	1	1
	Eutropis multifasciata	Many-lined sun skink	1	1
Total			**30**	N/A

* Listed as “Vulnerable” in the Singapore Red Data Book

** Listed as “Endangered” in the Singapore Red Data Book

5.8.2 Evaluation Framework

Air and noise emissions and changes have been predicted and discussed in Sections 5.4 and 5.5, respectively. Section 5.7.2 above also describes the relevant assessment framework for evaluating the Importance and Magnitude of Change to ecological receptors. The Magnitude scoring framework (Table 5.45) also includes the specific noise level thresholds at which a specific score should be given. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted in evaluating the Magnitude of Change.

5.8.3 Results and Discussion

An Importance score of ‘3’ was assigned to terrestrial flora within 50 m from the construction area; potential impacts on terrestrial flora due to project footprint and accidental spills and leaks are not expected to reach flora beyond this distance. Even though terrestrial flora within this 50 m buffer covers less than 5 ha, the Critically Endangered *Crinum asiaticum* was found near the Project footprint, hence the assigned Importance score. Note that the impacts of airborne noise on this group will not be evaluated due to the flora’s lack of sensitivity to that pressure.

An Importance score of '4' for Importance was assigned to terrestrial fauna receptors. Pulau Ubin represents a hotspot for mammals, birds, and amphibians in Singapore – taxa most sensitive to dust and air pollution. The results of terrestrial baseline surveys also found various CS species of flora, avifauna, mammals, butterflies and odonates, including within the vicinity of ULL itself. In addition, Pulau Ubin represents a stronghold for the locally and globally threatened bird species – the Straw-headed Bulbul (Chiok *et al.*, 2021). Locally "Critically Endangered" mammal species, such as the Malayan Porcupine and Leopard Cat, also inhabit the island (Ang, 2022; Fung *et al.*, 2017).

Impacts of Accidental Spills and Leaks on Terrestrial Ecology and Biodiversity

The containment of pollutive liquids and construction materials, and their potential negative impacts when accidentally released, are outlined previously in Section 5.7.3. Like marine systems, the risk of spills/leak impacts on terrestrial ecology and biodiversity would result in an impact Magnitude of '-1', giving **Slight Negative Impacts**. However, due to the controllable, small, and short-term nature of these impacts, the impact can be reduced to **Slight Negative Impact or No Impact**, provided the recommended mitigation and preventive measures described in Section 5.7.4 are followed.

Construction Vehicles Causing Roadkill Impacts to Terrestrial Biodiversity

Due to increased numbers and larger construction vehicles traversing the roads into ULL during the construction phase, there is potential roadkill impacts to terrestrial biodiversity around ULL. Taxa most sensitive to roadkill impacts are the ground-dwelling terrestrial fauna. Of particular concern are the mammals and amphibians, out of the six (6) species detected as part of this study, two are conservation significant species (i.e., the Greater Mousedeer and Leopard cat).

Little is known or published about Leopard cats in Singapore, including Pulau Ubin, with only one single population study on a nearby island in Pulau Tekong (Chua et al., 2016). Similarly, Greater Mousedeer was only recently rediscovered on Pulau Ubin in 2009 by Chua et al. Hence, the island is considered to be a stronghold of this species, home to a population that has re-established in the area with time. In consideration of this, the death of any individuals from these two threatened species has potential to impact the species' populations. Hence, the anticipated Magnitude of Change for the impact of roadkill to terrestrial biodiversity thought to be Minor, giving a final impact significance of **Minor Negative Impact**. With appropriate mitigation measures, this potential impact can be reduced to decrease potential roadkill from occurring as a result of the construction works. These measures are outlined in Section 5.8.4.

Air Pollution Impact on Terrestrial Fauna

As discussed in Section 5.4, following the IAQM guideline, the dust emission magnitude generated from the volume of the construction works and minimal demolition for this Project are all predicted to be Small, or in RIAM definition, 'Slight', and is given a magnitude score of '-1'. Therefore, the risk to terrestrial fauna receptors from dust is also correspondingly low (**Slight Negative Impact**).

The Magnitude of Change of air pollution impacts on terrestrial fauna is scored at '-1', given the low dust emission magnitude predicted and the limited spatial footprint of construction works, which does not directly overlap with significant terrestrial habitats. While prevailing southerly winds during the southwest monsoon can carry some of the emitted dust into the secondary forest habitats to the north, these impacts are expected to be transient in nature and primarily affect forest edges to a marginal extent. Exhaust emission from diesel-powered machines and construction vehicles is also expected to have insignificant impacts on terrestrial fauna. Therefore, the predicted impact significance of air pollution on terrestrial fauna is **Slight Negative Impact**.

Mitigation measures designed to reduce the potential impacts of vehicle emissions and dust generation from construction activities to terrestrial fauna receptors are outlined in Section 5.8.4 for the developer's consideration if desired.

Airborne Noise Impacts on Terrestrial Fauna

After predicting the cumulative noise level from the construction activities at terrestrial fauna receptors, it was found that the maximal noise level experienced by terrestrial fauna was 91 dBA at the coastal vegetation adjacent to the work area. The Magnitude of Change of airborne noise impacts on terrestrial fauna is scored at '-4', given the high predicted cumulative noise emitted from the demolition of the existing concrete slab, which could potentially result in death or injury of the terrestrial fauna receptors. Permanence was scored at '2' given that the increase in airborne noise is expected to be short-term (i.e., only during the Construction Phase). A score of '3' for Reversibility was attributed, given that terrestrial fauna is not likely to recover from short-term exposure to airborne noise. A score of '2' for Cumulative Impact was attributed, given that no known construction activities in the vicinity could have additive effects on ambient airborne noise at sensitive receptor areas. Therefore, the predicted impact significance of airborne noise on terrestrial fauna is **Moderate Negative Impact**.

Mitigation measures for the demolition of the concrete slab include setting up noise barriers between the equipment and the coastal vegetation, such that the top of the machine and reception point is obscured, can the reduce noise level by up to 10 dBA, and switching to quieter equipment such as a hand-held pneumatic breaker can reduce the noise level by up to 15 dBA. These measures designed to reduce the potential impacts of airborne noise from construction activities to terrestrial fauna receptors are outlined in Section 5.8.4 for the developer's consideration. With the application of these measures, the residual impact significance is expected to be reduced to **Minor Negative Impact** for terrestrial fauna.

5.8.4 Mitigation Measures

The mitigation measures for accidental leaks and leaks are as recommended in Section 5.7.4.

Considering the assessments above, the following mitigation measures in Table 5.59 are recommended to minimise the potential impacts on terrestrial fauna receptors.

Table 5.59 Mitigation measures to minimise impacts to terrestrial fauna receptors during the Construction Phase

Aspect	Mitigation Measures
Roadkill impacts on terrestrial fauna	• Install speed bumps and humps at fauna crossing hotspots. Traffic speed monitoring system can be installed at strategic locations, where practical (i.e., wildlife incident hotspots). • Implementing or retaining the use of artificial connectivity aids (e.g., rope crossings, box culverts) at strategic locations/hotspots areas of roadkill, where practical. Alternatively, present culverts in the area can be retained for the movement of small-bodied fauna such as amphibians and reptiles.
Air pollution on terrestrial fauna receptors	• Comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines that come into effect when the time of construction works commencement.

Aspect	Mitigation Measures
	• Suppress and minimise fugitive dust emissions by misting/spraying exposed earth, particularly during prolonged dry spells/windy conditions. • Wheel washing bay shall be provided, and all trucks/vehicles shall be washed before leaving the construction site. • Earth stockpiles should be covered with tarpaulin when not in use. • Machinery used on-site shall be properly and regularly inspected and maintained to control dust and air pollutants emission. • As part of the machinery's inspection, gaseous pollutants such as CO, NO_2 and SO_2 should be measured at the emission of machinery and compared against the equipment specification. • Minimise traffic delays caused by the movement of construction vehicles by planning transport routes and periods that avoid congested areas and peak hours of road use.

Airborne noise pollution on terrestrial fauna receptors	Key mitigation measures:
	• To comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines that come into effect when the time of construction works commencement.
	• Quieter construction equipment and method shall be adopted as much as possible, with reference to NEA's Guideline on Quieter Construction Fund Annex 1 and Annex 2.
	• Where possible and practicable, use the following equipment:
	  o Hydraulic and electric tools in place of pneumatic equipment such as concrete breakers.
	  o Quieter piling methods, for example, hydraulically driven equipment instead of hammers and pressed-in piling with low soil displacement piles.
	• Apply additional noise control such as mufflers and sound absorbers for noisy equipment operating near sensitive receptors.
	• Install localised noise barriers or noise enclosures for applicable construction machinery.
	• Limit the number of equipment operating concurrently on-site or switch to a quieter model where applicable.
	Key management measures:
	• Site noisy fixed-location equipment (generator sets) as far away from the site boundary as possible.
	• Portable noise monitoring device shall be provided to monitor the noise level during site works.
	• Noise generated from the construction equipment will be measured to verify that it operates within its noise specification. In the event of an exceedance, ascertain if the exceedance is due to the improper operation of the construction equipment. In the event of repeated and significant exceedances (i.e., more than 3 dB(A)), earmark construction equipment for maintenance.

Aspect	Mitigation Measures
	• All noise exceedances beyond the threshold shall be investigated, identifying the source(s) of noise where measurements exceed limits at the affected receptors. Corrective actions shall be undertaken to ensure that the mitigation measures listed above are properly implemented. Where mitigation measures have been properly implemented, and noise levels still result in exceedance, examine the feasibility of adapting construction activities, e.g., reducing the number of equipment deployed near the affected receptor location. • Position the powered equipment away from the site boundary as much as practical, especially for works near the sensitive receptors. • Ensure all workers are trained in noise-reduction behaviours, such as reducing the drop height of materials and turning off equipment and vehicle engines when not in use. • Regular toolbox briefings should include reminders on the need to implement noise-reduction behaviours during piling and demolition activities in particular.

5.8.5 Terrestrial Ecology and Biodiversity Impact Summary

The Construction Phase impacts from the Project construction work on terrestrial ecology and biodiversity receptors are summarised below in Table 5.60.

Table 5.60 RIAM results for Construction Phase (short-term) impacts from the Project on terrestrial ecology and biodiversity receptors

Predicted Impact	Sensitive Receptor	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Accidental Spills and Leaks	Terrestrial Flora	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
	Amphibians	1	-1	2	2	2	-6	No Impact	-	-	-
	Odonates	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
Roadkill Impacts	Mammals	4	-2	2	2	2	-48	Minor Negative Impact	-1	-24	Slight Negative Impact
	Amphibians	1	-2	2	2	2	-12	Slight Negative Impact	-1	-6	No Impact

Predicted Impact	Sensitive Receptor	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Atmospheric Emissions	Avifauna	4	-1	2	2	2	-24	Slight Negative Impact	0	0	No Impact
Airborne Noise	Avifauna	4	-4	2	3	2	-112	Moderate Negative Impact	-2	-56	Minor Negative Impact

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulatively; ES = Environmental Score

5.9 Marine Navigation

Changes in current conditions and the presence of construction vessels and equipment in the existing navigation space can affect vessels' safe passage and manoeuvring, potentially negatively affecting marine navigation while the construction of the proposed jetty at ULL is ongoing. This section describes the impact assessment of hydrodynamic changes and reduction in navigation space in the intermediate stage of the construction works to marine navigation within the Ketam Channel.

5.9.1 Relevant Key Receptors and Pressures

Key receptor groups of marine navigation for which relevant impacts were assessed include:

- Boating channel between Pulau Ketam and Pulau Ubin
- Serangoon Harbour (navigation channel)

To evaluate the short-term impacts of construction activities from the development on marine navigation in the area, the following "pressures" were assessed:

- Hydrodynamic changes; and
- Reduction in navigation space.

5.9.2 Evaluation Framework

Short-term hydrodynamic changes were predicted using robust numerical tools presented in Section 5.1. Potential impacts due to the anticipated changes in hydrodynamics during the Construction Phase were assessed as follows.

Magnitude: Hydrodynamic Changes

Various metrics describing the change in current speed were evaluated to score the Magnitude of Change. The main environmental changes affecting navigation and their thresholds indicating significant impact are presented in Table 5.61.

Table 5.61 Environmental changes affecting navigation to inform the Magnitude of Change for RIAM assessment

Environmental Change	Thresholds and Objectives for Navigation
Changes to mean current speeds	Changes in mean current speed less than 0.05 m/s are typically considered as "No Change"
Changes to maximum current speeds	Changes in 95th percentile current speed less than 0.1 m/s are typically considered as "No Change"
Exceedance of 2.0 and 3.5 knots	Minimal increases in current speeds. Changes in exceedance of these representative current statistics of less than 2 % to 4 % are typically considered as 'No Change.'
Slackwater duration	Maintenance of berthing and unberthing windows. Changes of less than 2 % to 4 % are typically considered as 'No Change.'
Shear zones and eddy currents	Their presence may indicate an impact

5.9.3 Results and Discussion

Hydrodynamic Changes

Model results presented in Section 5.1.4 show minimal changes to the current field induced by the Project's construction works. This is evident from the statistical parameters extracted in Table 5.62.

Table 5.62 Changes in various hydrodynamic measurements relating to hydrodynamic change, which are anticipated to be arising from Construction Phase during the "worst case" scenario (i.e., El Niño 2015, Northeast Monsoon), for each maritime transport receptor for the Project

Measurement	Receptor	
	Boating Channel Between Pulau Ketam and Pulau Ubin	Serangoon Harbour
Change in mean current speed (m/s)	<0.05	<0.05
Change in 95th percentile current speed (m/s)	<0.1	<0.1
Change in exceedance of 3.5 knots (% time)	<2 %	<2 %
Change in exceedance of 2 knots (% time)	<2 %	<2 %
Change in slackwater duration (% time)	<2 %	<2 %

Based on the evaluation framework presented in Section 5.9.2 above, the Magnitude of Change for the hydrodynamic measurements is assessed as 'No Change'. The final impact significance of hydrodynamic changes to marine navigation is anticipated to be **No Impact**.

Reduction in Navigation Space

During the Construction Phase, part of the sea space beyond the jetty footprint is required as a work area. This work area is meant to accommodate working barges and construction equipment such as piling rigs and excavators for the construction works. The relevant navigational maritime transport receptors of concern are limited to the pleasure craft boats navigating through the boating channel between Pulau Ketam and Pulau Ubin and recreational kayaking around the mangrove at Sungai Puaka.

The presence of the work area potentially affects marine transport and navigation along the boating channel primarily through the reduction of sea space available for vessels to navigate through the channel. This is because the traversable width of the channel will be reduced. Given that the area designated for construction works is not expected to be occupied 100% of the time, we evaluate that a large enough sea space for a vessel to navigate through remains available. In the worst case, where the work area and sea space are occupied, vessels could still navigate along Serangoon Harbour around Pulau Ketam, despite being a slightly longer route. Additionally, as the Project area and its vicinity are accessed only by pleasure craft boats, it is not expected that the other vessels (e.g., fish farmers) plying the nearby area will be affected. This effect is therefore assessed as 'Slight Negative Change' considering it is observable on-site during Construction Phase. The Impact significance of the reduction in navigation space to marine navigation is anticipated to be **Slight Negative Impact**.

5.9.4 Marine Navigation Impact Summary

The Construction Phase impacts from the Project construction work on marine navigation receptors have been summarised in Table 5.63.

Table 5.63 RIAM results for Construction Phase (short-term) impacts from the Project on marine navigation receptors

Predicted Impact	Sensitive Receptor	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Hydrodynamic Impacts	Boating Channel between Pulau Ketam and Pulau Ubin (Ketam Channel)	2	0	2	2	2	0	No impact	-	-	-
Changes to Sea Space for Navigation	Ketam Channel	2	-2	2	2	2	-24	Slight Negative Impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

5.10 Aquaculture

The short-term impacts arising from the Project development on aquaculture receptors located in the vicinity of the Project area are assessed in this section. The construction works of the Project may have the potential to impact the nearest aquaculture farms located south of Pulau Ubin.

5.10.1 Relevant Key Receptors and Pressures

Key sensitive receptors of aquaculture upon which relevant impacts will be assessed include:

- Fish farmers;
- Aquaculture water intake at Pulau Ketam; and
- Aquaculture farms south of Pulau Ubin and Pulau Ketam.

To evaluate the short-term impacts of construction activities from the development to aquaculture in the area, the following sources of “pressure” have been assessed:

- Increased suspended sediments (with reference to sediment plume modelling);
- Secondary impacts due to changes to marine environmental quality as a result of accidental spills and leaks;
- Airborne noise pollution from mainly piling activities
- Air pollution from demolition, general construction works and vehicle movements; and
- Underwater noise impacts from piling and other associated coastal works

Short-term increases in suspended sediment concentration (SSC) and underwater noise are predicted using robust numerical tools, as presented in Sections 5.2.4 and 5.6.3, respectively. Impacts from the anticipated changes during the Construction Phase, and the relevant assessment framework are presented below.

5.10.2 Evaluation Framework

The receptor Importance evaluation framework adopted for aquaculture receptors, follows the standard definitions of Importance in the RIAM framework (Section 4.2.2). To evaluate the Magnitude of Change, the tolerance limits of fish to suspended sediment are elaborated below, while their tolerance limits to underwater noise are elaborated earlier in Section 5.7.2. There are no tolerance limits for assessing impacts from accidental spills or leaks – the general definitions of Magnitudes of Change as per the RIAM framework apply.

Fish Tolerance to Suspended Sediment

The tolerance of fish to suspended sediments varies widely from species to species. Fish in open-water environments will generally move away from areas of high suspended sediment concentration (so-called turbidity barriers) to seek new habitats. If there has been no permanent damage to a fish’s natural habitat in a given area (e.g., coral reef), the fish will eventually return after the suspended sediment loading has been removed.

The situation is different for cage culture, as the fish cannot move out of the affected area. Elevated concentrations will predominantly affect the fish’s respiration, which will affect growth rates under sub-lethal loading. Other issues include the clogging of the nets surrounding the cages leading to resultant depression in water quality within the cage due to reduced flushing. This clogging will increase in areas with high SSC.

The limit above which an impact on aquaculture from incremental suspended sediment levels may occur is a daily mean incremental increase of 3.9 mg/l per continuous 7-day period (Table 5.64). Any incremental increase below 3.9 mg/l does not constitute an impact.

Table 5.64 Tolerance limits of aquaculture fish to suspended sediment

Severity	Definitions
No Impact	Excess Daily Suspended Sediment Concentration < 3.9 mg/l daily mean over continuous 7-day period
Slight Impact	Excess Daily Suspended Sediment Concentration > 3.9 mg/l daily mean over continuous 7-day period

Fish Tolerance to Underwater Noise

The tolerance limits for assessing the Magnitude of Change due to underwater noise have been presented in Section 5.7.2.

Marine Intake Tolerance to Suspended Sediments

Increased suspended solids may affect water intakes in terms of increased maintenance costs, for example filter cleaning and risk of sedimentation of fine material within the water system. The tolerance limits of intakes are very site specific and are usually determined based on the statistical 'No Change' in suspended sediment concentrations compared to the background at the intake location. This value is normally calculated following an intensive baseline monitoring period during the EMMP, before the start of works. The limits should also be agreed with the specific intake operators. For the purpose of the present study, monitoring data is available at some Singaporean intakes, but not all intakes affected by the project. A precautionary approach has therefore been adopted, by taking the strictest limits from the well-validated data sets available. Note that these limits are for process water intakes, which are relatively intolerant to changes in suspended sediments.

Based on baseline monitoring data near Jurong Island collected in 2009 and 2010, and supported by consultation with the facility operator, an impact severity of 'No Change' is defined as an excess suspended sediment concentration of less than 1 mg/l at process water intake locations (Table 5.65). This limit has previously been successfully applied for the management of SSC impacts on the sensitive process water intake.

Table 5.65 Tolerance limits for process water intakes to excess SSC

Magnitude	Definitions
No Change	Excess mean SSC < 1 mg/l
Slight Negative Change	Excess mean SSC 1 mg/l to < 3 mg/l
Minor Negative Change	Excess mean SSC 3 mg/l to < 6 mg/l
Moderate Negative Change	Excess mean SSC 6 mg/l to < 20 mg/l
Major Negative Change	Excess mean SSC ≥ 20 mg/l

5.10.3 Results and Discussion

Given that the closest aquaculture receptor is located roughly approximately 1.2 km southeast of the Project area, an Importance score of '3' was assigned due to the potential small scale of impacts to fish farms, should they occur.

Suspended Sediments Impacts on Aquaculture Farms and Seawater Intake

Section 5.2.4 showed that the increase in mean SSC was limited and confined to a localised area around the Project footprint. This is due to small trimming volumes along the seabed and shoreline, the small number of piles, and the relatively long construction duration. At the nearest aquaculture seawater intake (~400m away), the mean incremental SSC is predicted to be less than 1.0 mg/l, while the same value for the nearest aquaculture farm (1.2km away), the mean incremental SSC is less than 1.0 mg/l (Table 5.66).

According to the tolerance limits presented above, this level of change is assessed as 'No Change'; hence **No Impact** is expected on aquaculture farms during construction.

Table 5.66 Predicted mean incremental SSC (mg/l) (above background concentrations) at two aquaculture receptors of concern within and around the Ubin-Ketam Channel

Aquaculture Receptor	Mean Incremental SSC (mg/l)
Aquaculture seawater intake at Pulau Ketam (~400m from ULL Jetty location)	< 1.0
Aquaculture farms 1.2km southeast of Pulau Ubin	< 1.0

Impact of Pollutant Release from Suspended Sediments on Aquaculture Intake

Due to the detection of exceedance of Arsenic (compared with the MPA dumping guidelines, Section 5.3.4) in the sediment, the pollution release needs to be calculated and evaluated. This section uses the same calculation formula as shown previously in Section 5.7.3.

The calculation results in Table 5.67 below shows that none of the calculated heavy metal content in the waters at the seawater intake exceeded ASEAN MWQC. As a result, the impact significance of pollutant release into waters near the seawater intake as a result of the sediment plume is **No Impact.**

Table 5.67 Calculated heavy metal content at the seawater intake for the land farm on Pulau Ketam, during the construction phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content In Water (µg/l)	ASEAN MQQC
Aquaculture Seawater Intake at Pulau Ketam	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*

*Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

Impact of Accidental Spills and Leaks on Caged Fishes and Water Intakes

As mentioned previously, construction activities typically involve machinery and equipment with fuel inventory. In the event of accidents, the currents in the area may bring spilt fuel or chemicals to a water intake and fish farms. It is qualitatively assessed that an oil spill at the jetty construction area will likely cause a measurable change in water quality at the farms. However, the assessment also considers the likelihood of such events. Oil spill risks presently exist in the current usage of slipways and jetties around Pulau Ubin. The addition of a few construction vessels may not alter this risk much.

However, it should be noted that there are standard fuel and hazardous material handling practices and regulations that the contractor is expected to comply with (Section 5.7.4). These procedures will likely control the risk of water pollution, thus minimising its spread. With that, it is assessed that the risk of oil spill impact on caged fishes and the water intake in the southeast of Pulau Ketam as **Slight Negative Impact**.

Underwater Noise Impacts

Piling rigs and associated working barges will produce different levels of underwater noise and vibration, causing transient changes to the marine environment. This would cause secondary impacts on marine fauna, particularly marine mammals that use sound/echolocation to communicate. Changing the marine acoustics would therefore cause temporary disturbance to marine species, including caged fish in aquaculture farms. Nevertheless, the nearest unobstructed fish farm is approximately 1.2 km away from the Project area. Given that the piling rate and duration are relatively low and short, it is assessed that the resulting impact from underwater noise on the aquaculture facilities is **Slight Negative Impact**.

Airborne Noise Impacts on Land-based Aquaculture Farm on Pulau Ketam

The evaluation of the Importance of noise to sensitive human receptors follows the same framework as presented in Table 5.69. The evaluation of the Magnitude of Change of noise impact is based on the resulting exceedance compared against the permissible construction noise limits and categorised into different significance levels as described in Table 5.70.

Section 5.5.4 has identified the different construction activities and computed the respective construction noise emission level propagated over a distance to the receptor (i.e., in this case, to the land-based aquaculture farm on Pulau Ketam). The anticipated noise level at the Pulau Ketam aquaculture farm is equivalent to the baseline of 65 dBA, resulting in an impact of **No Impact** for the farm.

Air Pollution Impacts on Fish Farmers

Due to the nature of the sensitive receptor (potential impacts on the health of fish farmers) for this anticipated impact, the impact of air quality changes to this receptor is carried out in Section 5.11.3.

5.10.4 Mitigation Measures

The mitigation measures for underwater noise and accidental spills and trade effluent are as recommended in Section 5.7.4, helping to reduce the residual impact significance scores.

5.10.5 Aquaculture Impact Summary

The Construction Phase impacts from the Project construction work on aquaculture receptors have been summarised in Table 5.68.

Table 5.68 RIAM results for Construction Phase (short-term) impacts from the Project on aquaculture receptors

Predicted Impact	Sensitive Receptor	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Sediment Plume	Caged fishes in aquaculture farms	3	0	2	2	2	0	No Impact	-	-	-
	Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
Pollutant Release from Suspended Sediments	Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
Accidental Spills and Leaks	Caged fishes in aquaculture farms	3	-1	2	2	2	-18	Slight Negative Impact	0	0	No Impact
	Water Intake at SE of Pulau Ketam	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
Underwater Noise	Caged fishes in aquaculture farms	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
Airborne Noise	Land-based fish farm on Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
Atmospheric Emissions	Land-based fish farm on Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Fish Famers	2	0	2	2	2	0	No Impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

5.11 Socio-economic

Pulau Ubin and the ULL are often utilised by varying user groups, such as campers who stay in the ULL and recreational visitors who enter the area to kayak or stroll. Nearby are Pulau Ubin villagers whose homes are located near the proposed construction site. These user groups form the socio-economic receptors, a potential group that could be affected during the Construction Phase.

The short-term impacts arising from the Project development on the socio-economic receptors located in the vicinity of the Project area are assessed in this section.

5.11.1 Relevant Key Receptors and Pressures

Key receptor groups for socio-economic receptors include:

- Villagers of Pulau Ubin;
- Staff working at ULL; and
- Recreational users including persons with disabilities (e.g., campers at Endut Senin Campsite, sea sports participants).

To evaluate the short-term impacts of construction activities from the Project on the socio-economic receptors in the area, the following "pressures" have been assessed:

- Air pollution from demolition, general construction works and vehicle movements;
- Airborne noise pollution from demolition and general construction works; and
- Visual impact arising from sediment plume and accidental spills and leaks from construction activities.

Sediment plumes and air and noise emissions have been predicted. The following subsections describe the relevant assessment framework and discuss the effects of these environmental changes on the identified socio-economic receptors.

5.11.2 Evaluation Framework

Evaluation of Receptor Importance

The evaluation of the Importance in RIAM for socio-economic receptors adopts the framework presented in Table 5.69. The air quality impact assessment follows sensitivity definitions per the UK Institute of Air Quality Management (IAQM framework). This framework's definitions are mapped into the RIAM scoring system to facilitate the subsequent environmental scoring for the impact assessment.

Table 5.69 Evaluation framework for sensitivity and importance of socio-economic receptors. IAQM's definitions of receptor sensitivity are also included

Score	IAQM Site Sensitivity Classification	Generic Definition	Specific Definition
5	High	Important to national/ international interests	The receptors affected are specifically protected by national or international policies or legislation and are of significance at the regional or national scale.
4		Important to regional/national interests	Locations where more sensitive members of the public are exposed for eight hours or more in a day, e.g., hospitals and residential-care homes.

Score	IAQM Site Sensitivity Classification	Generic Definition	Specific Definition
3		Important to areas immediately outside the local condition	Locations where members of the public are exposed for eight hours or more in a day, for example, residential properties and schools.
2	Medium	Important only to the local condition (within a large direct impact area)	Locations where the people exposed are workers, and they may be exposed for eight hours or more in a day, for example, office and shop workers.
1	Low	Important only to the local condition (within a small direct impact area)	Receptors with transient exposure, e.g., recreational users of parks and playgrounds, visitors to place of worship.

Evaluation of Magnitude of Change

Air Quality
As stated previously, the Magnitude of Change for air quality is assessed in Table 5.21.

Airborne Noise
To assess the Magnitude of Change of noise impact on human receptors, the predicted noise levels are compared against the criteria stated in NEA's Environmental Protection and Management (Control of Noise at Construction Sites) Regulations. The resulting exceedance is interpreted and categorised into different significance levels, as described in Table 5.70. The thresholds presented take guidance from the Fundamentals of Acoustics adopted by WHO, which indicates that a change in sound pressure level of 3 dB is perceptible to the human ear and that of 5 dB is clearly noticeable (Hansen, 1951).

Table 5.70 Evaluation Framework for Magnitude of Change in noise level for human and fauna receptors. Where multiple criteria result in multiple possible scores, the more conservative score (higher Magnitude) is adopted in evaluating the Magnitude of Change

Score	Generic Criteria	Specific Criteria
-4	Major negative disadvantage or change	• Predicted noise level at NSR exceeded the limit by more than 10 dBA.
-3	Moderate negative disadvantage or change	• Predicted noise level at NSR exceeded the limit by between 5 to 10 dBA. • Or predicted noise level at NSR cause an increase of greater than 10 dBA as compared to baseline level.
-2	Minor negative disadvantage or change	• Predicted noise level at NSR exceeded the limit by between 3 to 5 dBA. • Or predicted noise level at NSR cause an increase of up to 10 dBA as compared to baseline level.

Score	Generic Criteria	Specific Criteria
-1	Slight negative disadvantage or change	• Predicted noise level at NSR exceeded the limit by between 1 to 3 dBA. • Or predicted noise level at NSR cause an increase of up to 5 dBA as compared to baseline level.
0	No change	• Predicted noise level at NSR exceeded the limit by up to 1 dBA. • Predicted noise level at NSR cause an increase of up to 3 dBA as compared to baseline level.

Suspended Sediments and Visual Impacts for Socio-Economic Receptors

Piling activities during the Construction Phase of the Project will generate suspended sediment plumes, which may affect the visual amenity of the area for relevant receptors; in the case of this Project, they are the socio-economic receptors. Such impacts are determined through a quantitative assessment based on the results of the sediment plume modelling (Section 5.2.5) and best environmental practices.

Regarding, the visual impact caused by suspended sediment plumes generated during construction activities at recreation and tourism locations, the tolerance limits for visual aesthetics provided in Table 5.71 will be adopted for this study.

Table 5.71 Magnitude of condition matrix for visual impact from suspended sediments on recreational receptors during daylight hours

Receptor Type	Definition of "No Visual Impact"
Recreational area	Excess SSC > 5 mg/l for less than 2.5% of the time

5.11.3 Results and Discussions

An Importance score of '2' was given to the socio-economic receptors as they mostly comprise visitors and recreational users to the island and the fish farmers. Residential properties exist in Pulau Ubin and near ULL, but they are relatively sparse compared to most urban areas in Singapore.

Air Pollution Impacts on Humans

IAQM framework classifies receptor sensitivity into High, Medium and Low (Table 5.69), which informs the Importance score for RIAM. The classification considers factors such as *exposure duration* (e.g., whether members of the public are expected to spend a substantial amount of time at the location), *sensitivity to exposure* (e.g., whether members of the public are more susceptible to the effects of dust such as in hospitals, schools and residential care homes), and *importance* (e.g., national parks and nature reserves would be considered sensitive receptors by nature of their importance).

The air sensitive receptors (ASRs) are office occupants, villagers, recreational users, and fish farmers. When considering *exposure duration*, working and visitation hours are considered. Office occupants and fish farmers may be exposed to construction dust for a limited number of hours a day. Similarly, the exposure for recreational users is highly transient as well. Although villagers of Pulau Ubin may be exposed to construction dust for more than eight hours a day, the number of villagers within the direct impact area is very low.

Recreational and community-sensitive receptors within the 350 m buffer from the Project area include the recreational users at Endut Senin Campsite, staff at the ULL office, villagers on the land side, and sea sports participants around Pulau Ubin on the marine side. ULL office occupants are about 190 m away, while the villagers are about 280 m away. With the construction activities at the site, the recreational receptors (sea sports activities) will likely be far from the site. It is reasonable to assume they will be at least 50 m away; hence after considering the distance, office occupants, villagers, and recreational users are classified as 'Medium' sensitivity while the fish farmers are classified as 'Low' sensitivity.

Separately, to quantify the Magnitude of Change, Table 5.20 is used. In summary, the sensitivity of the area to human health effects, ecological effects, and dust soiling effects are determined by assessing the classification of the receptor sensitivity (discussed above in Section 5.4.3) together with other considerations such as the *number of receptors*, *distance* from the source, and prevailing *background concentrations*.

Combining such information of distance, relatively low number of office occupants, recreational and residential receptors, and background concentration from the baseline study (Section 5.4.2), the risk of air quality impact on human health is assessed to be low. Therefore, the Magnitude for office occupants, villagers, recreational users, and the land-based aquaculture farm on Pulau Ketam is assessed to be 'Small' (according to IAQM) or 'Slight' according to RIAM, which translates to an impact significance of **Slight Negative Impact**. For fish farmers at the existing marine farms (around the south-eastern side of the Ketam-Ubin channel), the Magnitude is assessed as 'Negligible' (according to IAQM) or 'No Change' according to RIAM, which translates to an impact significance of **No Impact.**

Airborne Noise Pollution on Humans

The evaluation of the Importance of noise to sensitive human receptors follows the same framework as presented in Table 5.69. The evaluation of the Magnitude of Change of noise impact is based on the resulting exceedance compared against the permissible construction noise limits and categorised into different significance levels as described in Table 5.70.

Section 5.5.4 has identified the different construction activities and computed the respective construction noise emission level propagated over a distance at the receptor. The activity with the highest predicted cumulative noise emission level (demolition of the existing concrete slab) would generate 68 dBA to the nearest noise sensitive human receptor (ULL Office/Endut Senin Campsite). This is higher than the measured baseline noise level of 65 dBA. Although the predicted noise contribution from the works is below the defined threshold limit (75 dBA), there was a 3 dBA increase in noise level compared to the baseline. As such, the impact Magnitude is scored a '-1', resulting in the significance from noise attributable to the construction activities to human receptors to be considered a **Slight Negative Impact**.

Key mitigation and management measures proposed in Section 5.11.4 should be implemented throughout the works to ensure that construction noise levels are kept to a minimum as much as possible.

Visual Impact from Suspended Sediment Plumes on Recreational Users

The piling activities in the marine area have the potential to create visible sediment plumes that travel away from the project site and impact recreational users. Kayakers' or campers' recreational experience from observations of the visual aesthetics of the waters could be compromised by the incremental SSC because of the works. Visual aesthetic impacts on recreational receptors are primarily assessed based on the percentage of time incremental SSC exceeds 5 mg/l compared to the visual impact tolerance limits as described in Table 5.71.

Based on the sediment plume results of construction works (Section 5.2), the exceedance of 5 mg/l is generally confined within the vicinity of the piling works area due to the low current conditions and low piling production rate. This value was between 5 – 10 % in the vicinity of the jetty and upstream into Sungei Puaka (Figure 5.36). It was found that some kayakers do paddle into Sungei Puaka (Wanderlust, 2016), facilitating a pathway of potential visual impact on these recreational users. However, the route does not seem to be a popular one. In addition, the presence of construction works is also likely to act as a visual deterrence to kayakers in the area. It is hence assessed that this change is a 'Slight Change', resulting in an impact significance of **Slight Negative Impact.**

Pulau Ubin villagers and staff on the other hand are unlikely to encounter the visual impact due to a lack of direct access routes (e.g., roads) leading to the water edge for this group of receptors. As a result, this group of receptors would likely experience a Magnitude of 'No Change' and an impact significance of **No Impact.**

Visual Impact from Accidental Spills and Leaks

The containment of pollutive liquids and construction materials, as well as their potential negative impacts when accidentally released, are outlined previously in Section 5.7.3. Similar to marine and terrestrial systems, the risk of spills and leaks impacts to socio-economic receptors are assessed as having a **Slight Negative Impact**, provided the recommended mitigation and preventive measures described in Section 5.7.4 are followed.

5.11.4 Mitigation Measures

Considering the assessments above, the following mitigation measures in Table 5.72 are recommended to minimise the potential impacts on human receptors.

The mitigation measures for accidental spills and leaks are as recommended in Section 5.7.4.

Table 5.72 Mitigation and management measures to minimise SSC impacts on socio-economic receptors during the Construction Phase

Aspect	Mitigation/Management Measures
Air pollution on socio-economic receptors	• Comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines that come into effect when the time of construction works commences. • Suppress and minimise fugitive dust emissions by misting/spraying exposed earth, particularly during prolonged dry spells/windy conditions. • Earth stockpiles should be covered with tarpaulin when not in use. • Machinery used on-site shall be properly and regularly inspected and maintained to control dust and air pollutants emission. • As part of the machinery's inspection, gaseous pollutants such as CO, NO_2 and SO_2 should be measured at the emission of machinery and compared against the equipment specification.
Airborne noise pollution on socio-economic receptors	Key mitigation measures: • To comply with relevant environmental regulations, including the Environmental Protection and Management Act and any

Aspect	Mitigation/Management Measures
	other regulations and guidelines that come into effect when the time of construction works commences. • Quieter construction equipment and method shall be adopted as much as possible, with reference to NEA's Guideline on Quieter Construction Fund Annex 1 and Annex 2. • Where possible and practicable, use the following equipment: o Hydraulic and electric tools in place of pneumatic equipment such as concrete breakers. o Quieter piling methods, for example, hydraulically driven equipment instead of hammers and pressed-in piling with low soil displacement piles. • Apply additional noise control such as mufflers and sound absorbers for noisy equipment operating near sensitive receptors. • Install localised noise barriers or noise enclosures for applicable construction machinery. • Limit the number of equipment operating concurrently on-site or switch to a quieter model where applicable. Key management measures: • Site noisy fixed-location equipment (generator sets) as far away from the site boundary as possible. • Portable noise monitoring device shall be provided to monitor the noise level during site works. • Noise generated from the construction equipment shall be measured to verify that it operates within its noise specification. In the event of an exceedance, ascertain if the exceedance is due to the improper operation of the construction equipment. In the event of repeated and significant exceedances (i.e., more than 3 dB(A)), earmark construction equipment for maintenance. • All noise exceedances beyond the threshold shall be investigated, identifying the source(s) of noise where measurements exceed limits at the affected receptors. Corrective actions shall be undertaken to ensure that the mitigation measures listed above are properly implemented. Where mitigation measures have been properly implemented, and noise levels still result in exceedance, examine the feasibility of adapting construction activities, e.g., reducing the number of equipment deployed near the affected receptor location. • Position the powered equipment away from the site boundary as much as practical, especially for works near sensitive receptors. • Ensure all workers are trained in noise-reduction behaviours, such as reducing the drop height of materials and turning off equipment and vehicle engines when not in use. • Regular toolbox briefings should include reminders on the need to implement noise-reduction behaviours during piling and demolition activities in particular.

5.11.5 Socio-economic Impact Summary

The Construction Phase impacts from the Project construction work on socio-economic receptors have been summarised in Table 5.73, including values of re-evaluated Magnitude of Change and the residual impact significance score, after consideration of the abovementioned mitigation measures.

Table 5.73 RIAM results for Construction Phase (short-term) impacts from the Project on socio-economic receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Atmospheric emission on human receptors	• Villagers of Pulau Ubin • Staff of ULL • Recreational users (including persons with disabilities)	2	-1	2	2	2	-12	Slight Negative Impact	0	0	No Impact
Airborne noise pollution on human receptors		2	-1	2	2	2	-12	Slight Negative Impact	0	0	No Impact
Visual impact from SSC on human receptors		2	-1	2	2	2	-12	Slight Negative Impact	-	-	-
Visual impact from accidental spills and leaks on human receptors		2	-1	2	2	2	-12	Slight Negative Impact	-1	-12	Slight Negative Impact

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

5.12 Transboundary Impact

Transboundary impacts refer to any potential impacts which may extend or occur across an international border with a neighbouring country. In order to address stakeholder feedback on concerns over potential transboundary impacts, this section focuses on the assessment of potential short-term transboundary changes during the Construction Phase. The assessments related to transboundary impacts are guided by the same tolerance limits used for the receptors in Singapore.

5.12.1 Relevant Key Receptors and Pressures

The Singapore Port Limit is used as a proxy for the International Border with Malaysia in this EIA. The location of the Singapore Port Limit in relation to the Project is shown in Figure 5.97. There is no direct flow path from the Project to the Singapore Port Limit. The distance from the Project jetty to the Singapore Port Limit is approximately 4.5 km in the northwest direction of the Project. To the north, the Project is separated from the Singapore Port Limit by Pulau Ubin. The shortest flow path from the Project to the Singapore Port Limit to the east is more than 6 km long.

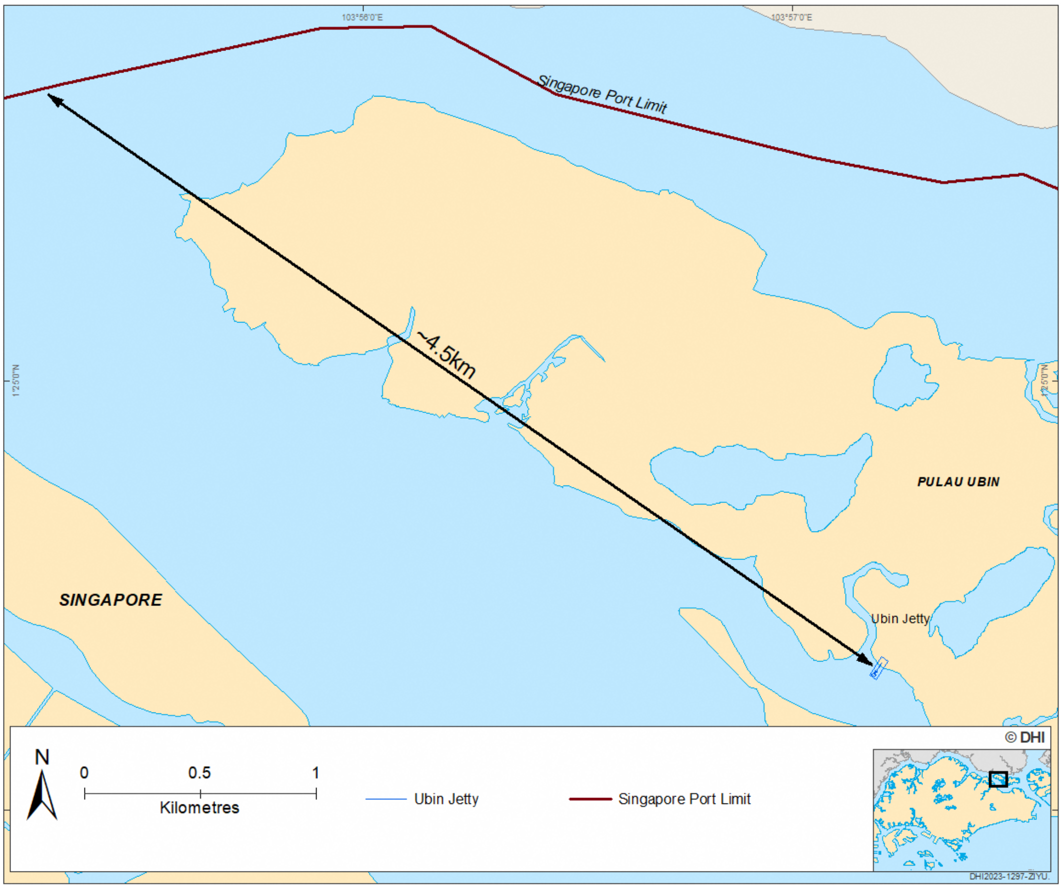


Figure 5.97 Singapore Port Limit and proximity to study area

To evaluate the short-term impacts of the Project construction activities on receptors across the Port Limit, the following “pressures” have been assessed:

- Hydrodynamic changes;
- Visual changes or pollution arising from sediment plume and potential spills and leaks from construction activities;

- Pollutant release from the suspended sediments;
- Air pollution from demolition, general construction works and vehicle movements; and
- Underwater noise impacts from piling and other associated coastal works.

5.12.2 Evaluation Framework

Potential impacts on transboundary receptors are assessed via evaluating the predicted changes across the border, i.e., in relation to currents, water quality, suspended sediments, against their tolerance limits. The same sets of tolerance limits as presented in the earlier sections are adopted in this assessment.

For visual transboundary impacts due to suspended sediment concentrations, given the marine and shoreline usage in the Malaysian waters closest to the proposed development are pre-dominantly non-recreational, a tolerance limit of “exceedance of 5 mg/l for less than 5 % of the time” is considered appropriate.

5.12.3 Results and Discussions

Hydrodynamic Changes and Transboundary Navigation

As presented in Section 5.1, DHI’s hydrodynamic simulations predicted that the construction phase will not result in any changes in currents. Therefore, **No Impact** is predicted to result on transboundary navigation.

Suspended Sediment and Transboundary Visual Impact

As presented in Section 5.2, the sediment plume simulations show that the piling works will only result in localised and minimal sediment plume. No change is predicted for areas beyond the immediate vicinity of the construction. Hence, **No Impact** is predicted in terms of transboundary visual impact due to suspended sediments from the construction works.

Accidental Spills and Leaks and Transboundary Visual Impact and Pollution

Any mismanagement of waste and hazardous materials or vessel collision along the East Johor Strait can lead to spillage of chemicals or materials and measurable change in water quality. It is noted that the quantities and types of wastes and hazardous materials to be used during the construction phase will be limited due to the relatively small scale of the project. With proper handling, storage, transport and disposal procedures and compliance to local regulations and SOPs, environmental impacts caused by waste management can be minimised or eliminated. Hence, **No Impact** is predicted in terms of transboundary visual impact or pollution due to accidental spills and leaks.

Water Quality and Transboundary Aquatic Life

As presented in Section 5.2, the sediment plume simulations show that the piling works will only result in localised and minimal sediment plume. As such, any potential pollutant release from the sediment plumes generated will be localised and minimal. Hence, no change in heavy metal concentrations is predicted at the Singapore Port Limit and this corresponds to **No Impact** to transboundary water quality and aquatic life.

Air Quality and Transboundary Human Health

As presented in Section 5.4, the construction works are expected to have only a minimal transient impact on air quality, which should be maintained through application of the management and mitigation measures as recommended in the respective receptor sections. Hence, **No Impact** is predicted in terms of transboundary air quality impact due to the construction works.

Underwater Noise and Transboundary Aquatic Life

It is unlikely that any fish species/marine ecology found across the international border will suffer mortality given the relatively low noise levels (less than 100 dB re $1\mu Pa^2 s$) predicted towards the northwest of the Project, and the significant distance from the Project site. Hence, **No Impact** is predicted in terms of transboundary underwater noise impact due to the construction works.

5.12.4 Transboundary Impact Summary

The Construction Phase impacts from the Project construction work on Transboundary receptors have been summarised in Table 5.74.

Table 5.74 RIAM results for Construction Phase (short-term) impacts from the Project on transboundary receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Hydrodynamic impacts	Transboundary navigation	5	0	2	2	2	0	No Impact	-	-	-
Visual impact from SSC	Transboundary human receptors	5	0	2	2	2	0	No Impact	-	-	-
Visual impact from accidental spills and leaks		5	0	2	2	3	0	No Impact	-	-	-
Pollutant release	Transboundary aquatic life	5	0	2	2	3	0	No Impact	-	-	-
Atmospheric emissions	Transboundary human receptors	5	0	2	2	2	0	No Impact	-	-	-
Underwater noise	Transboundary aquatic life	5	0	2	2	2	0	No Impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

6 Post-Construction Phase (Long-Term) Impacts

The assessment of impacts at this Post-Construction Phase is aimed at analysing the level of changes in the surrounding marine areas due to the operation of the development, i.e., the anticipated use of the new jetty by ships and boats, potential long-term changes to the boating channel etc. Other long-term impacts, such as losses to sensitive receptors as a result of the project footprint, are also outlined in this section.

6.1 Hydrodynamics

This section presents the methodology for analysing changes to currents in the vicinity of the ULL jetty after the completion of the entire structure (as opposed to earlier section 5.1, which assessed changes between the baseline and intermediate stages of the jetty while it was still undergoing construction).

6.1.1 Relevant Key Receptors

The relevant key receptor for changes to hydrodynamics was described previously in Section 5.1.1.

6.1.2 Environmental Baseline

The environmental baseline for hydrodynamics in the Project area was described previously in Section 5.1.1.

6.1.3 Evaluation Framework

Similar to Section 5.1.3, DHI's MIKE 21 Hydrodynamics (HD) FM was used to quantify the changes to the hydrodynamic conditions (current speeds, flow patterns) as a result of the Project. For the Post-Construction assessment, a simplified morphological assessment was conducted to assess areas with expected erosion and sedimentation in the vicinity of the Project area. The bed shear stress generated by the existing current conditions was calculated and presented to identify the areas of relative erosion and sedimentation.

Modelling Scenarios

As seen from the jetty design (Section 2.2), the final profile of the proposed jetty at ULL will have four (4) marine steel pipe piles and two (2) trimming locations (i.e., seabed and shoreline) to modify the bathymetry to the desired bed level. Hence, the four (4) piles and both trimmed areas were simulated in the hydrodynamic model. The modelling period and ENSO conditions for the post-construction simulation covered the same period as the Construction Phase stimulation, as described previously in Section 5.1.4. Table 6.1 shows a summary of the modelled scenarios for the Post-Construction Phase. The baseline scenario remains the same in the Construction Phase hydrodynamics modelling.

Table 6.1 Modelling scenarios for current impact assessment during Post-Construction Phase

Scenarios	Phase	ENSO Condition	Year	Monsoon
1	Baseline	El Niño	2015	NE
2		La Niña	2010	NE
3		Neutral	2013	NE
4		Neutral	2013	SW
5	Post-Construction	El Niño	2015	NE
6		La Niña	2010	NE
7		Neutral	2013	NE
8		Neutral	2013	SW

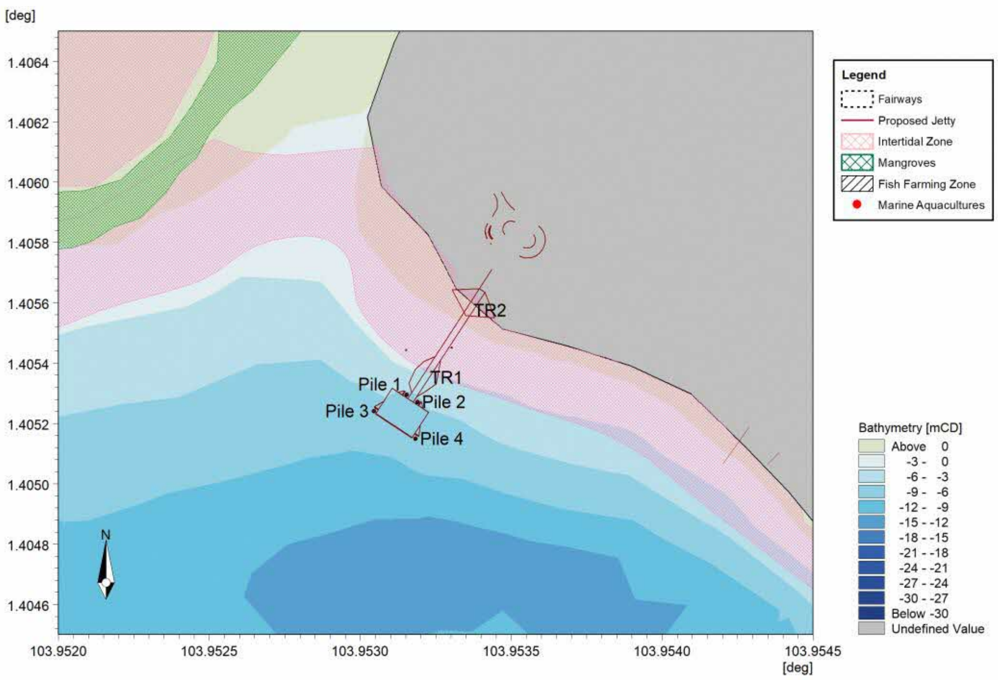


Figure 6.1 Post-Construction Phase final profile for assessment of hydrodynamic impacts. The profile includes four (4) piling locations (i.e., Pile 1, Pile 2, Pile 3, and Pile 4) and two (2) trimming locations (i.e., TR1 in the seabed and TR2 in the shoreline) with a trimming volume of 200 m^3 each

Similar to in Section 5.1.3, chosen current characterisation metrics include:

- Mean current speeds;
- Maximum (95th percentile) current speeds; and
- Representative current speeds (<0.5 knots, >2.0 knots and >3.5 knots).

As for the simplified morphological assessment, the following statistics describing sedimentation and erosion were extracted:

- Mean Bed Shear Stress (BSS); and
- Maximum (95th percentile) BSS.

6.1.4 Results and Discussion

The changes to currents around the Project area are represented by changes to current statistics (mean and 95th percentile), representative current speeds, and BSS (mean and 95th percentile). Overall:

- Current speeds are generally low in the study area due to its sheltered location;
- The proposed jetty at ULL is predicted to cause negligible change to hydrodynamic parameters in the study area. This observation holds for both ENSO and the Neutral year; and
- The BSS change due to the footprint of the proposed jetty at ULL is relatively small in the study area for both ENSO and the Neutral year.

These changes are described in the following subsections.

Change in Mean Current Speeds

Figure 6.2 illustrates the mean current speeds during the NE Monsoon for El Niño and La Niña year (on the left and right columns, respectively), and the top, middle, and bottom figures represent the Baseline, Post-Construction Phase; and finally, the predicted change in the mean current speeds (between Baseline and Post-Construction Phase) respectively. Figure 6.3 presents the model results for the Neutral year during the NE and SW monsoons.

The Project is predicted to result in less than 0.05 m/s change in mean current speed in both the local Project area and the entire study area.

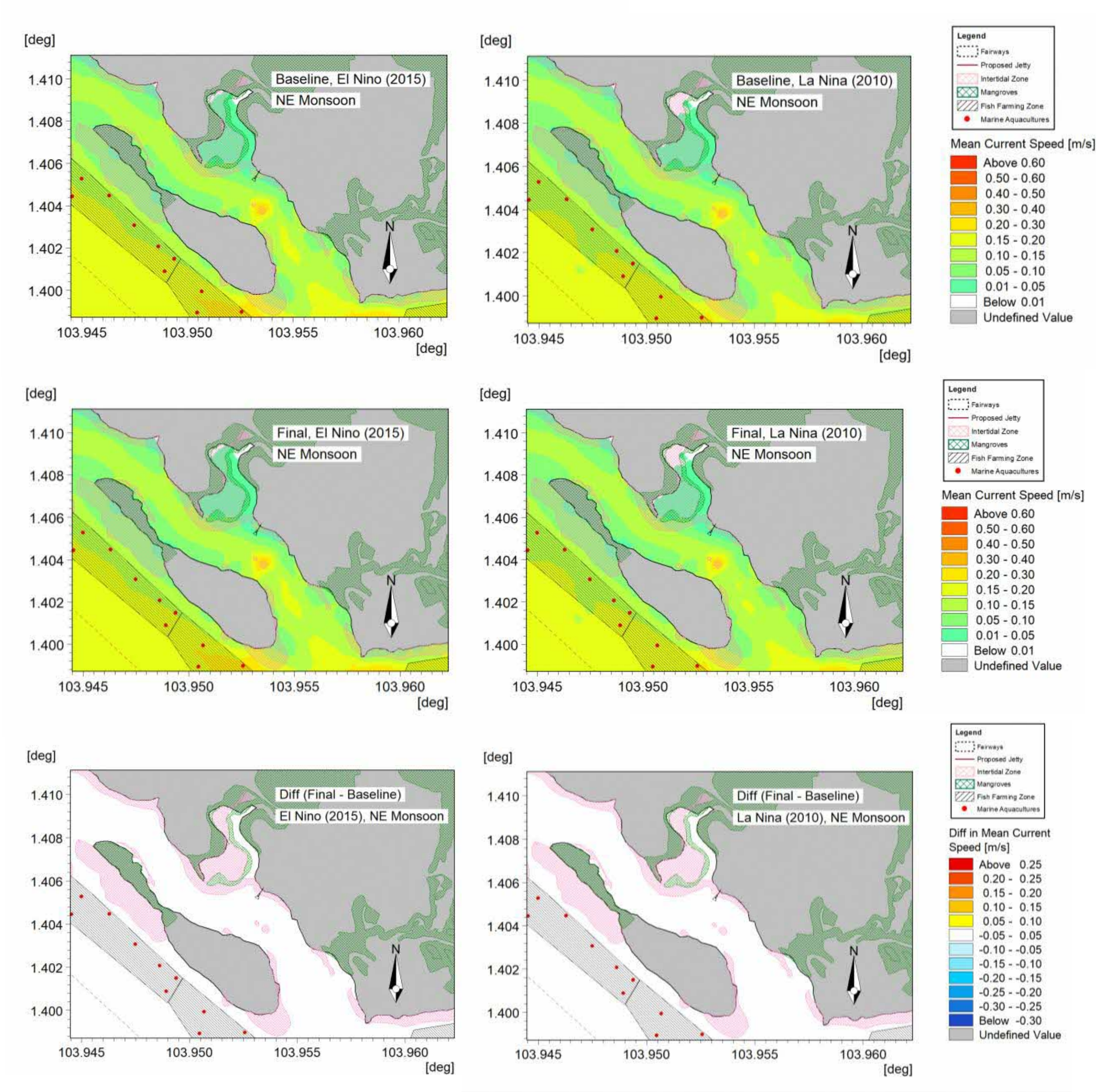


Figure 6.2 Mean current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

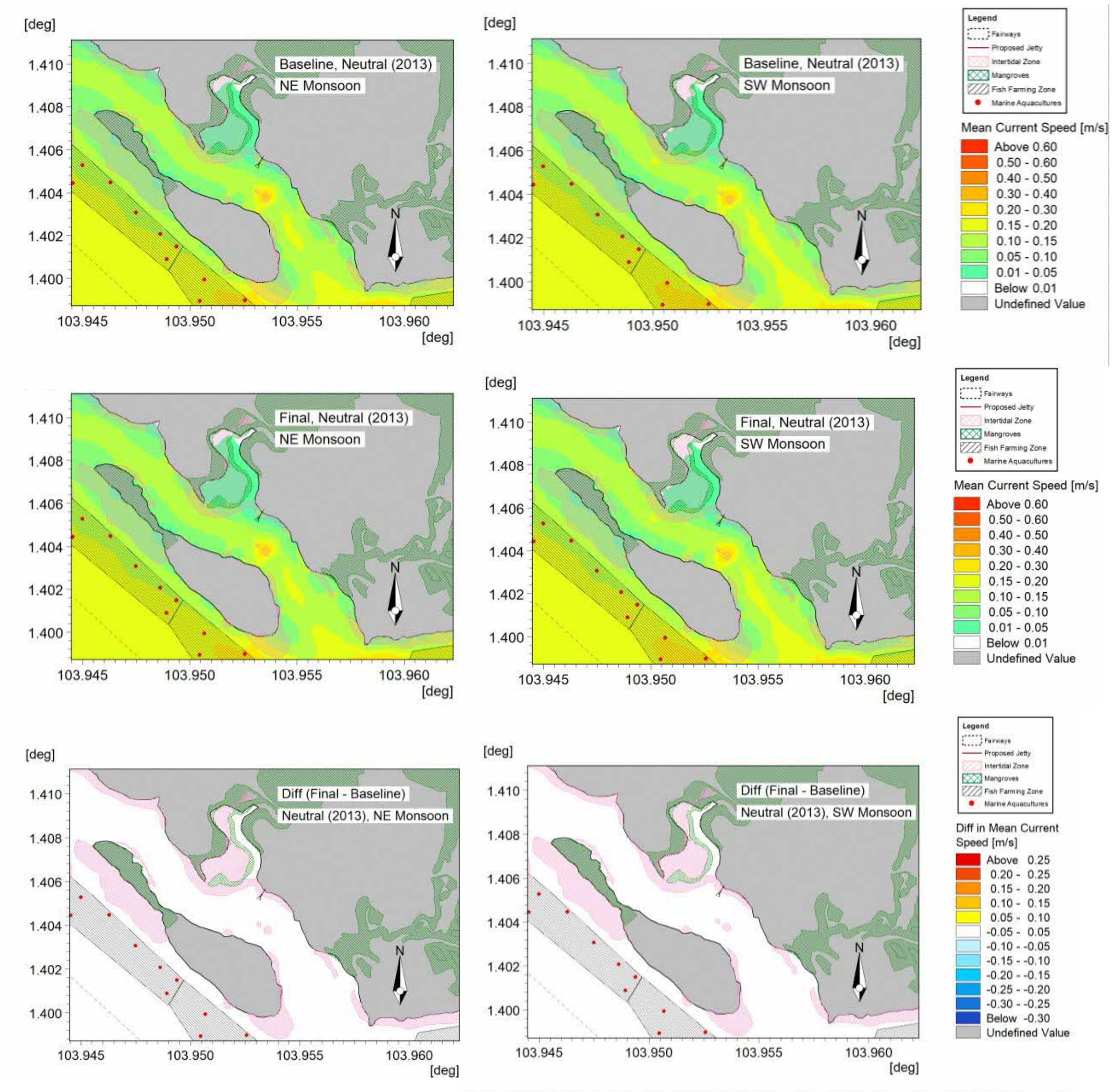


Figure 6.3 Mean current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Change in 95th Percentile Current Speeds

Figure 6.4 illustrates the maximum (95th percentile) current speeds during the NE Monsoon for El Niño and La Niña year (on the left and right columns, respectively), with the top, middle, and bottom figures representing the Baseline, Post-Construction Phase, and the predicted change in the maximum current speeds (between Baseline and Post-Construction Phase) respectively. Figure 6.5 shows model results for the Neutral year during NE and SW Monsoons.

Predicted maximum current speeds in both the Baseline and Post-Construction Phase are generally low along the shore of Pulau Ubin, with currents attaining speeds of up to 0.60 m/s. The predicted difference in maximum current speed between the Baseline and Post-Construction Phase (i.e., with the trimming and pile driving) during ENSO or the Neutral year is less than 0.10 m/s.

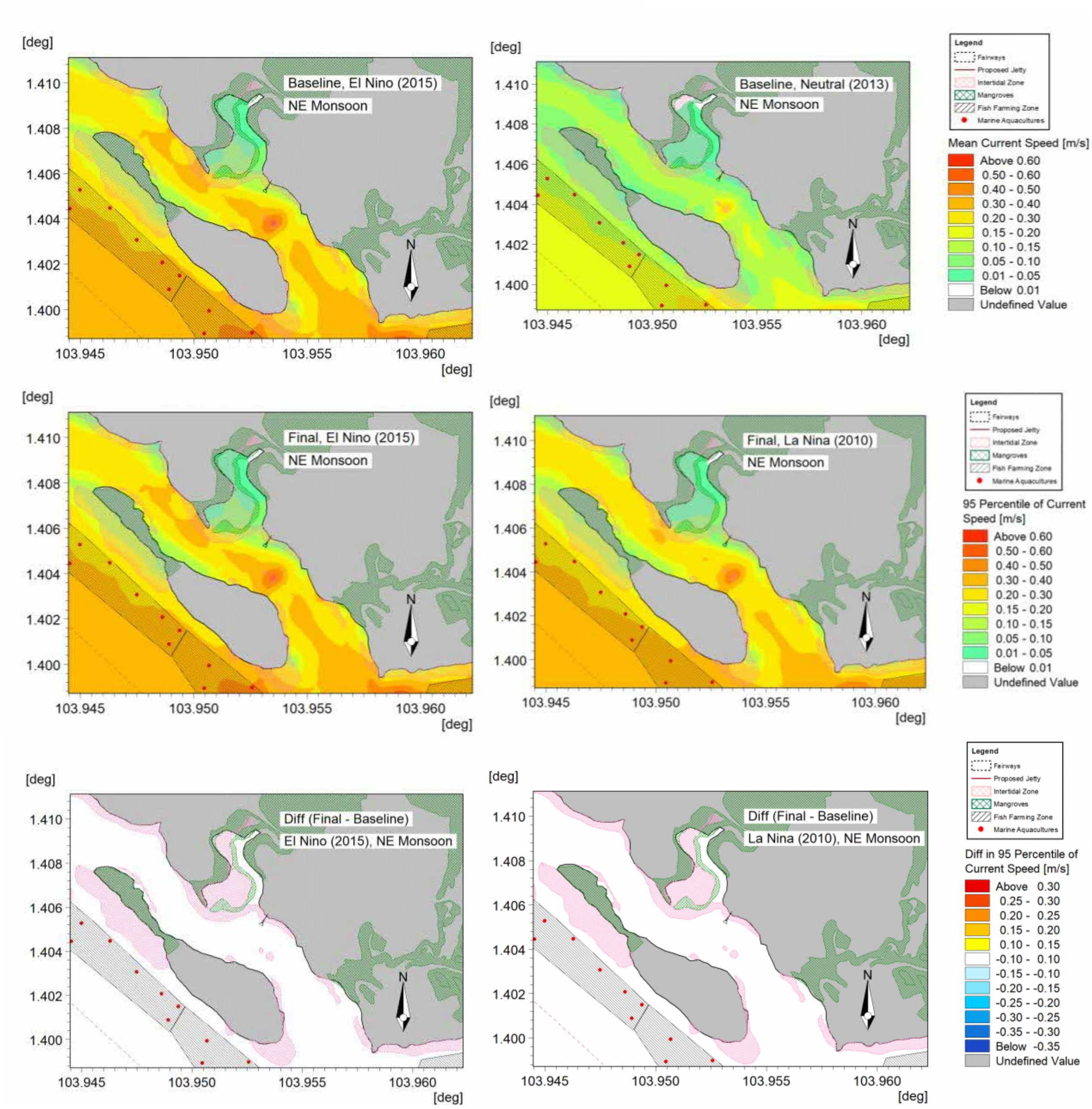


Figure 6.4 95th percentile current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

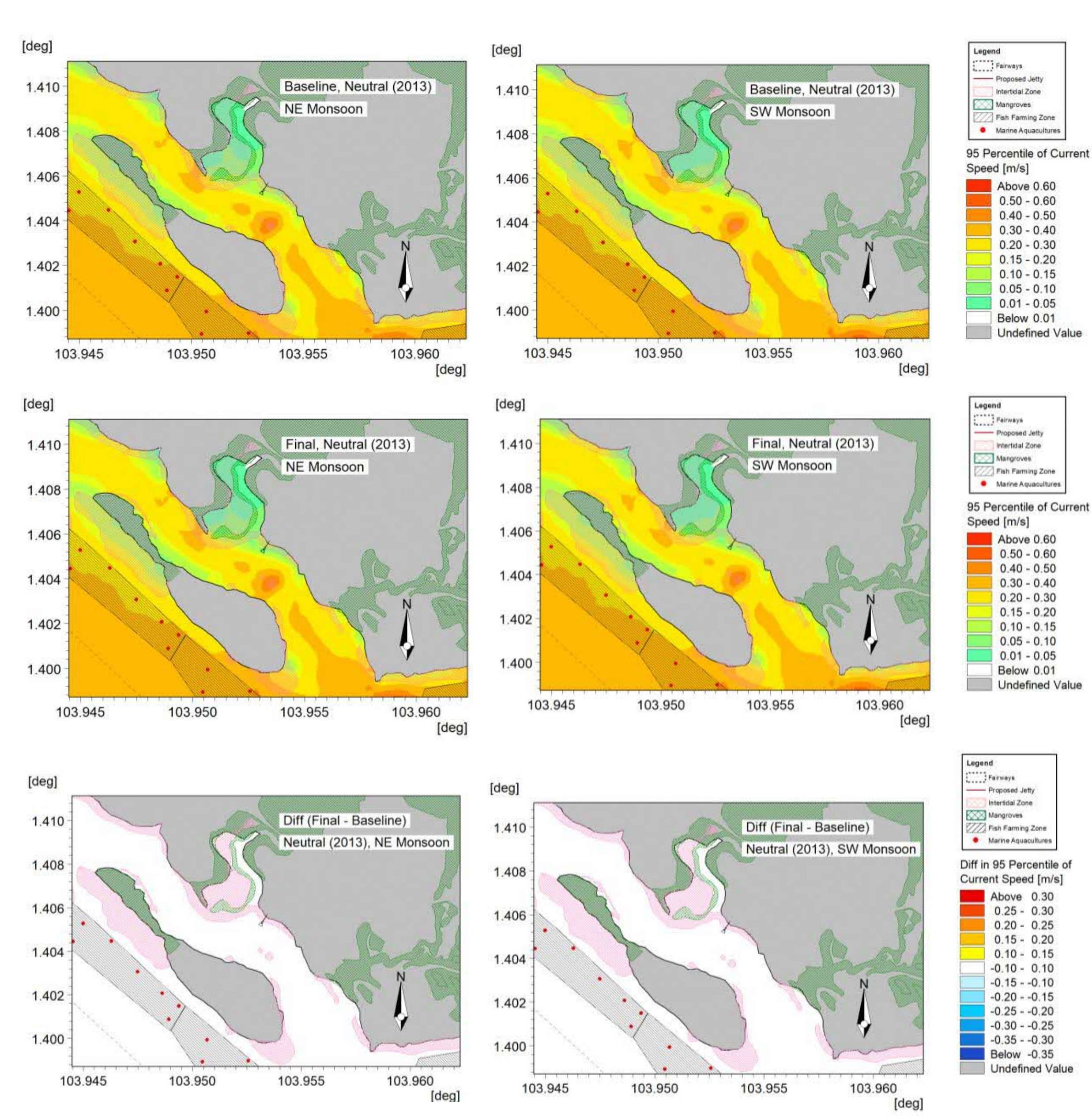


Figure 6.5 95th percentile current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Representative Current Speeds: Slackwater (<0.5 knots), exceedances of 2.0 knots and 3.5 knots

As an alternative to the analysis of mean and 95th percentile current speeds, a measure of the level of change to the exceedance of selected representative current speeds is provided in this section. This alternative is meant to provide additional understanding of the scale of change in current speeds, and for this purpose, the speeds of 3.5 knots (1.8 m/s), 2.0 knots (1 m/s) and below 0.5 knots (0.25 m/s) were used. A current speed lower than 0.5 knots is generally referred to as slackwater.

Figure 6.6 and Figure 6.7 present slackwater duration in the study area during ENSO and the Neutral year, respectively. The presence of the proposed jetty at ULL is predicted to cause less than a 0.5 % change in slackwater duration in the entire study area (from baseline levels of 98% of the time).

With regards to exceedance of 2.0 knots and 3.5 knots, model results (Figure 6.8 to Figure 6.11) show that the completed construction of the proposed jetty at ULL will result in no change (0 %) to the duration current speed exceeding 2.0 knots and 3.5 knots in the study area.

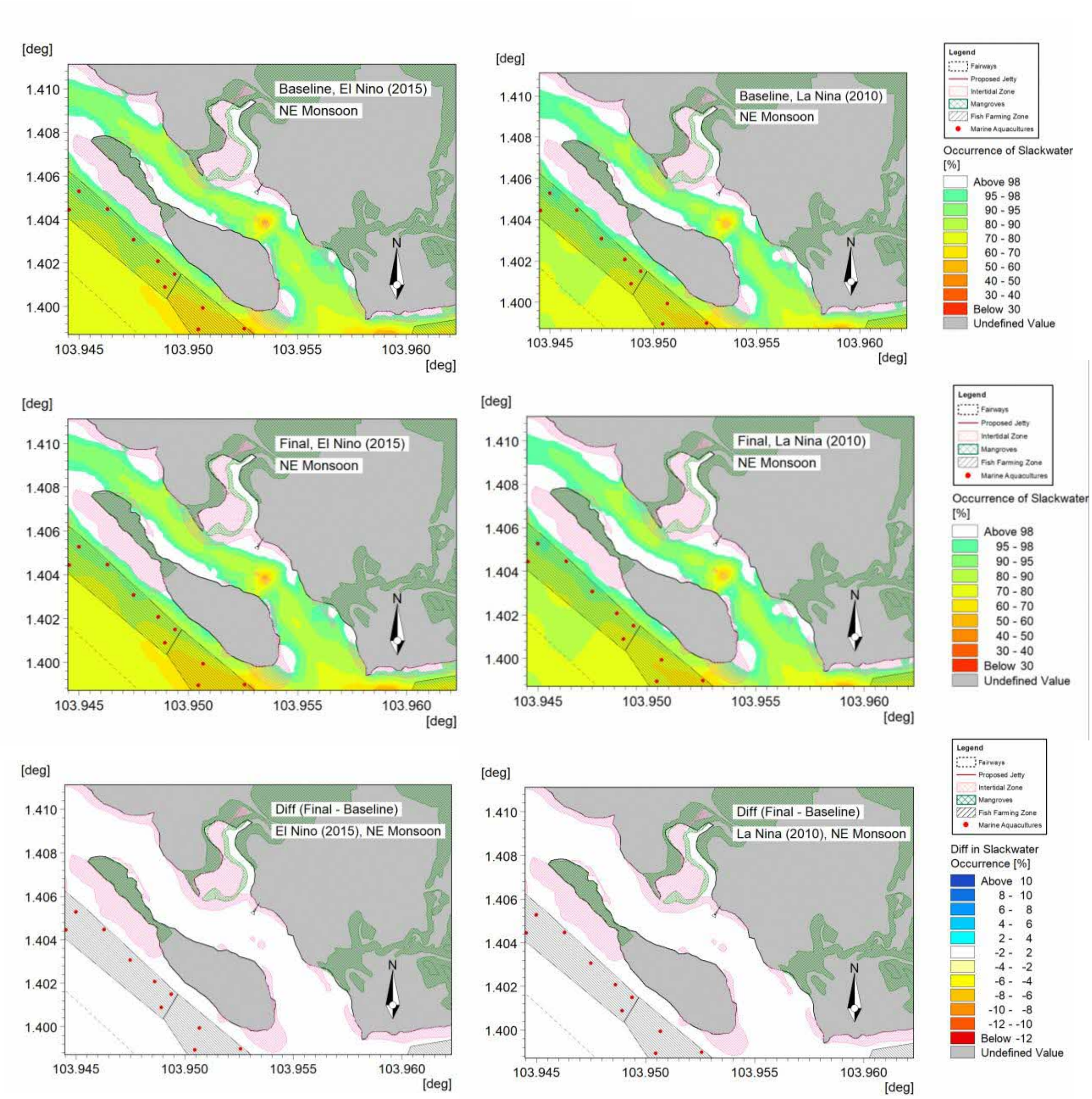


Figure 6.6 Slackwater duration (Current speeds <0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

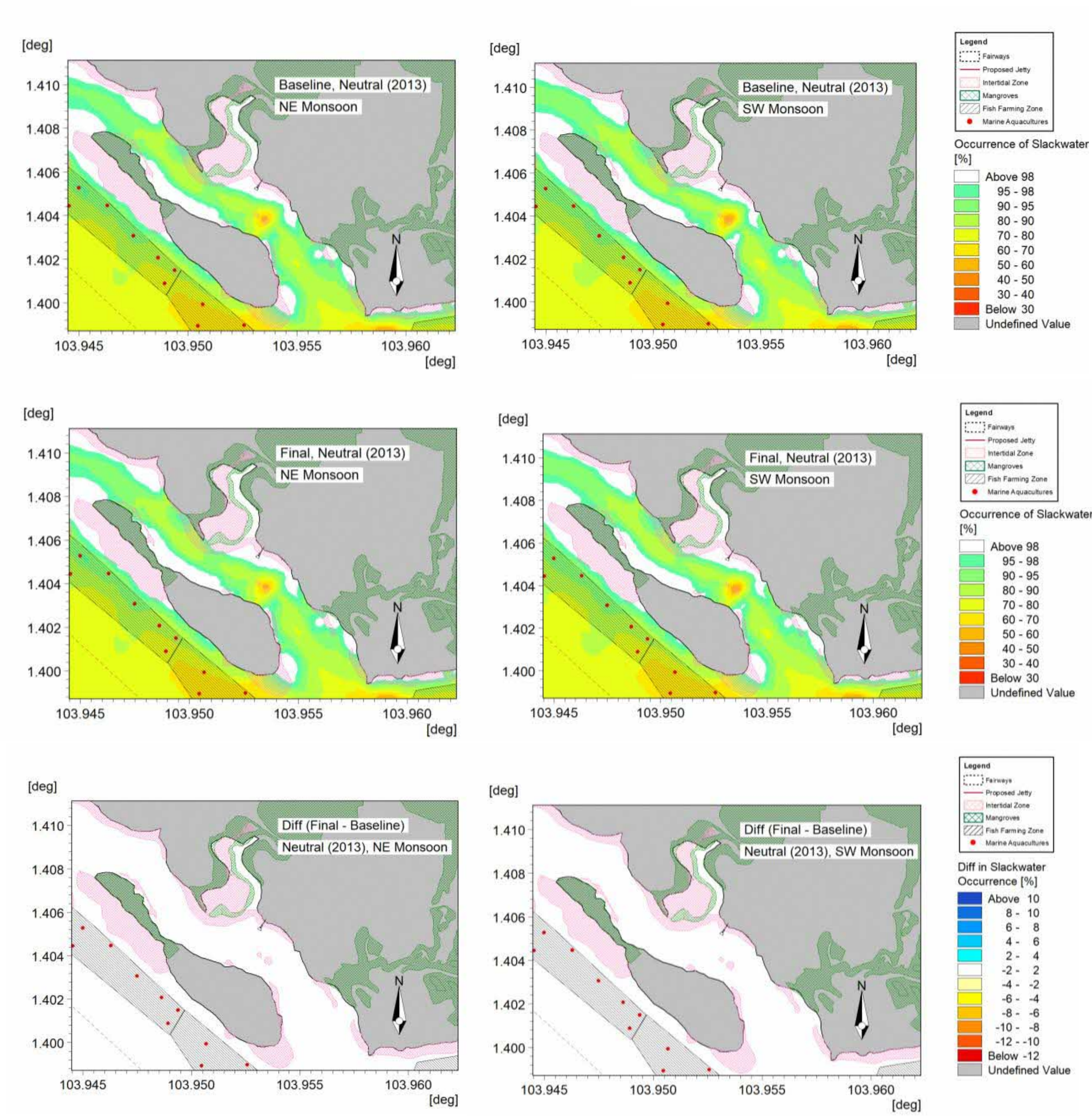


Figure 6.7 Slackwater duration (currents <0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

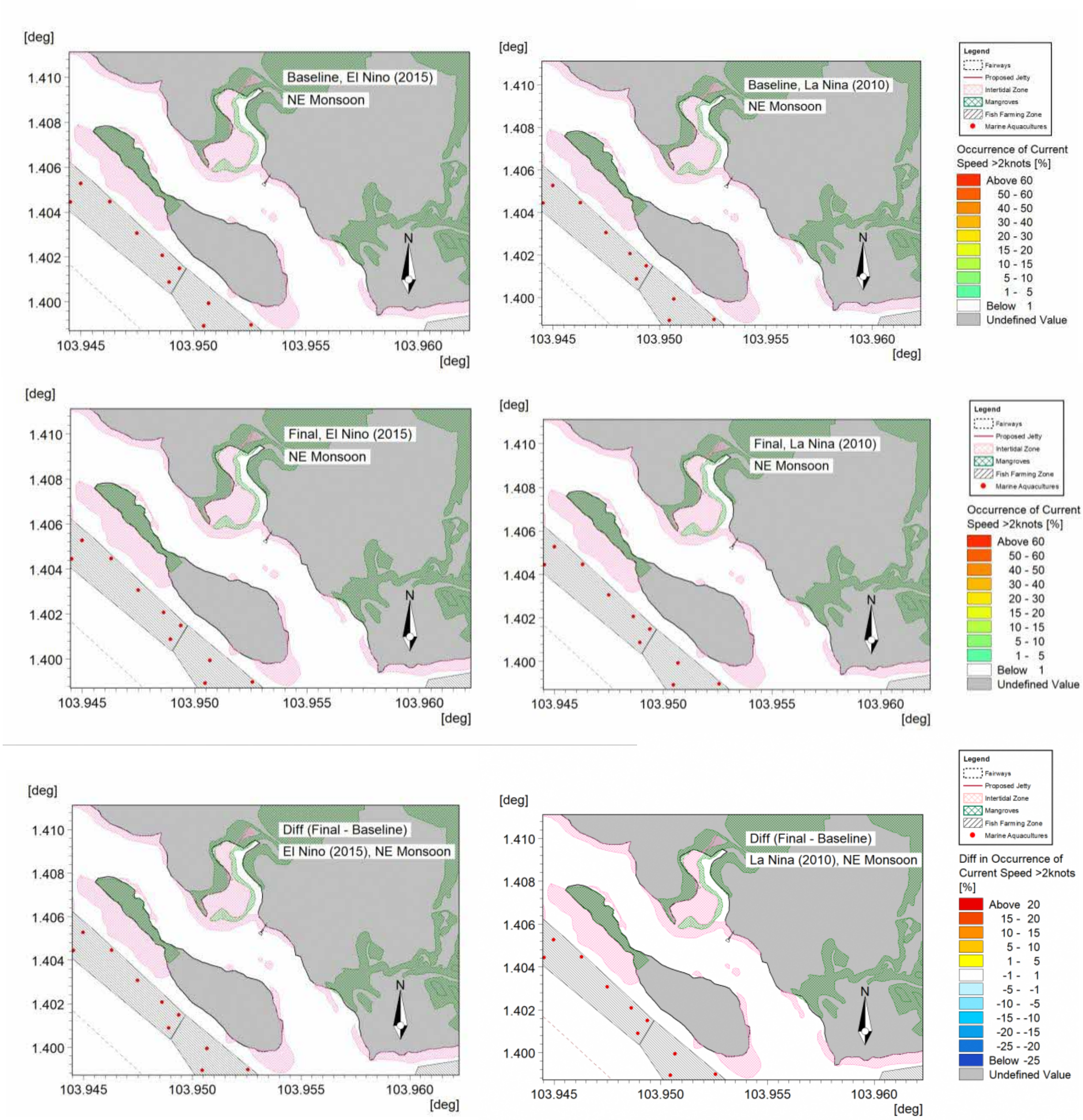


Figure 6.8 Percentage of time when current speeds exceeded 2.0 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

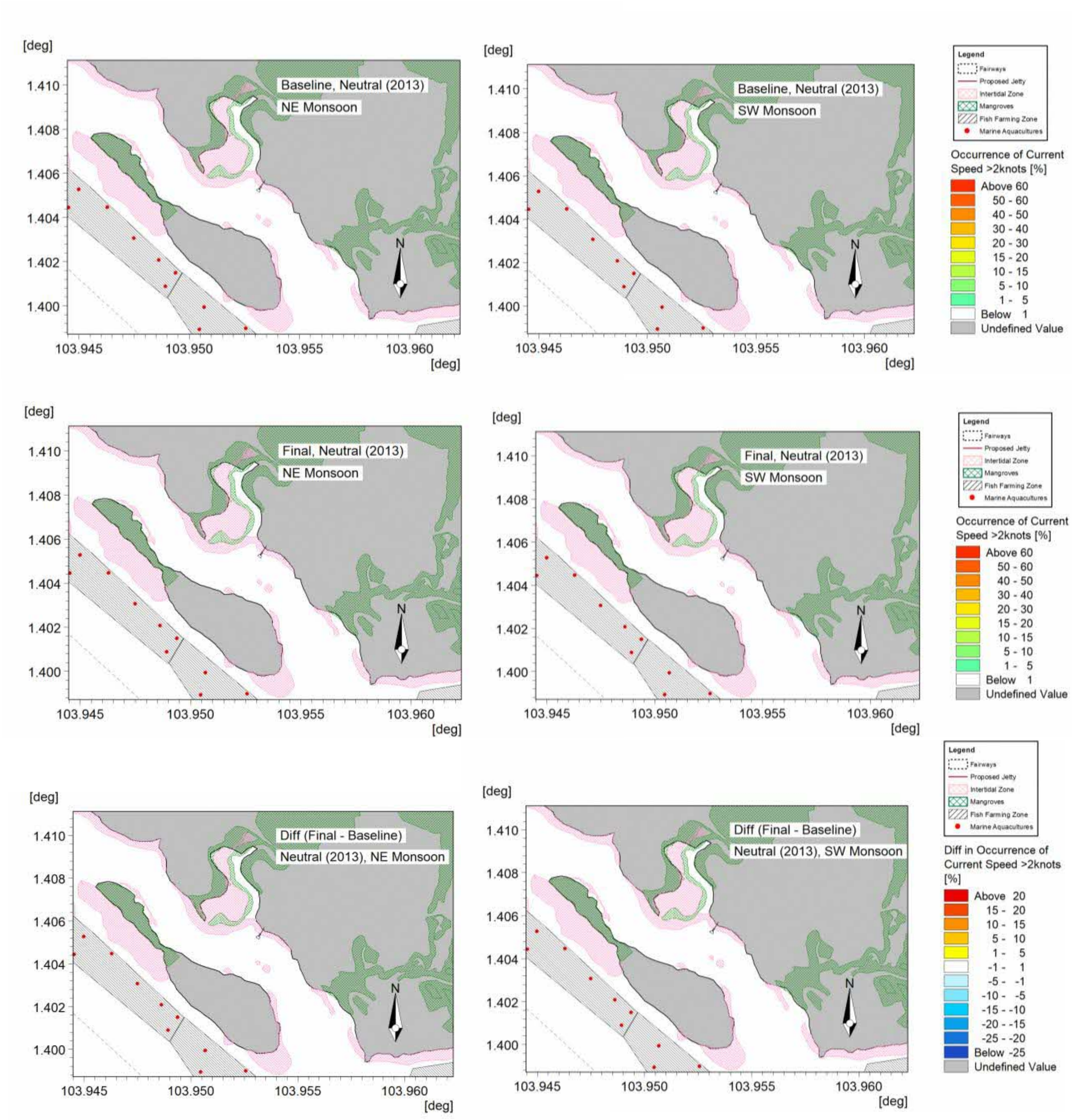


Figure 6.9 Percentage of time when current speeds exceeded 2.0 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

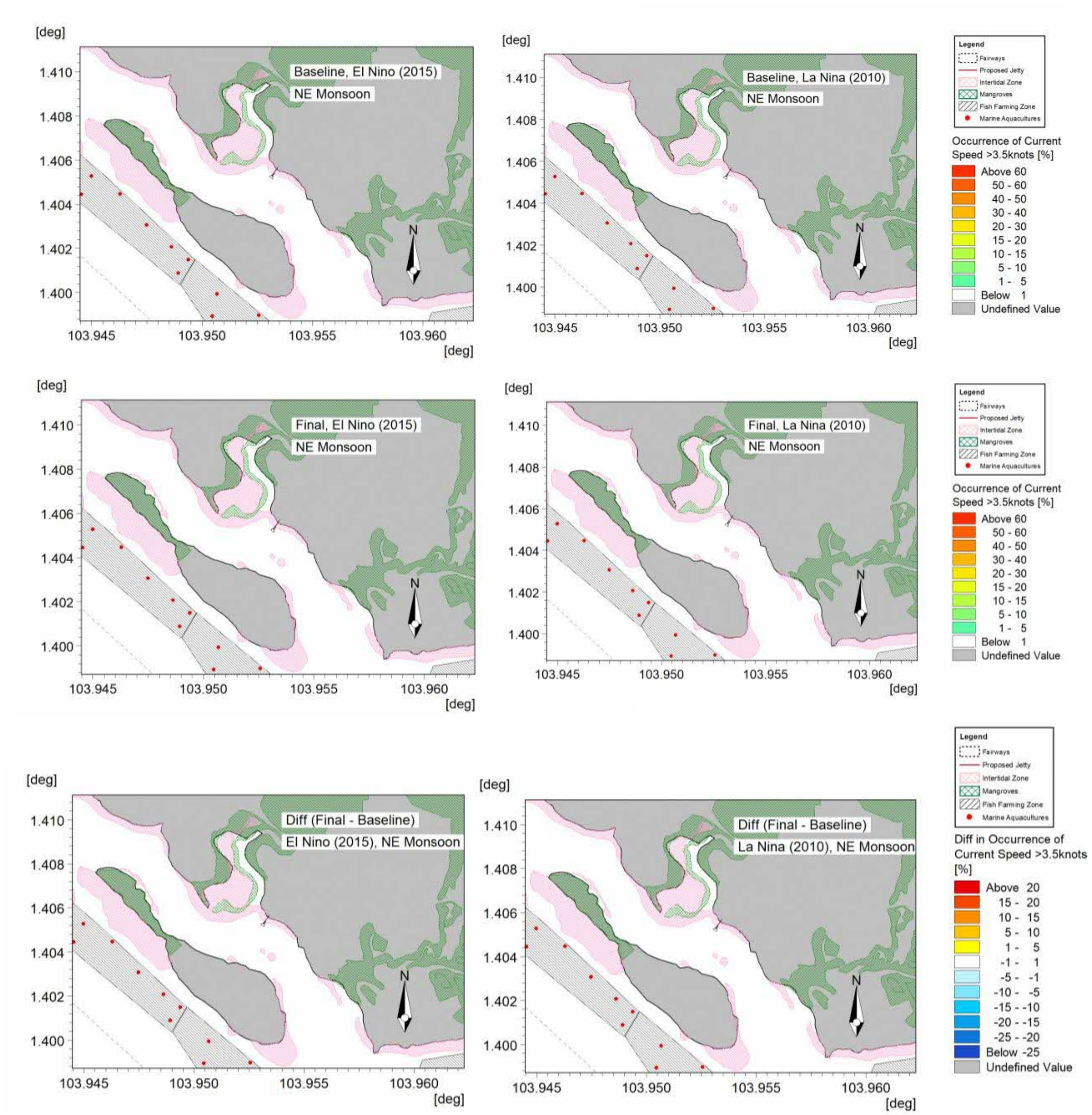


Figure 6.10 Percentage of time when current speeds exceeded 3.5 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

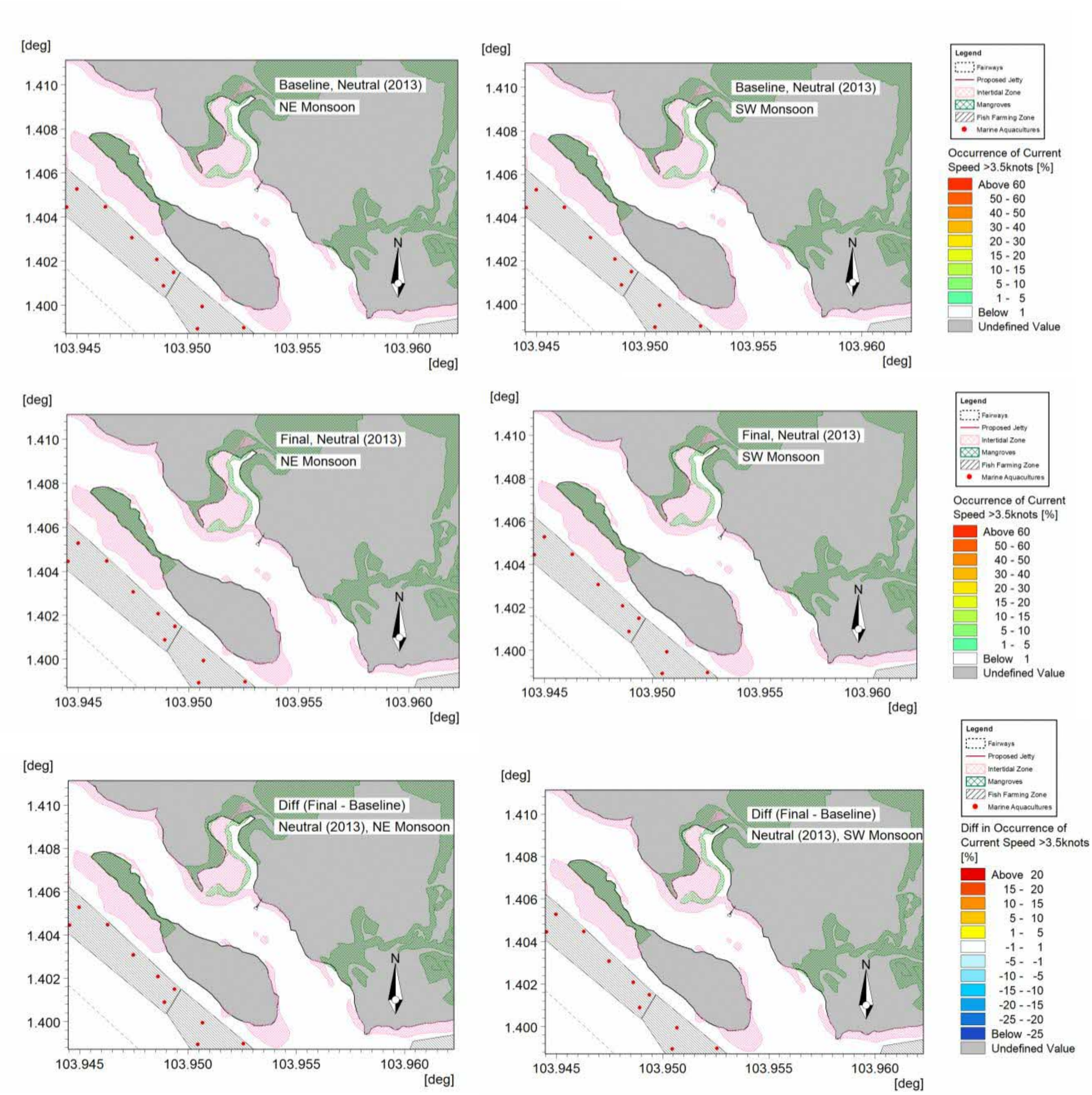


Figure 6.11 Percentage of time when current speeds exceeded 3.5 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Change in Mean Bed Shear Stress

Bed shear stress (BSS) is often calculated to assess areas of relative erosion and accretion/sedimentation. While calculating the actual magnitude of sedimentation and erosion is complex, this approach is considered a reliable preliminary assessment of potential erosion or accretion due to the changes in hydrodynamic conditions. Figure 6.12 illustrates the mean BSS during the NE Monsoon for El Niño and La Niña year (on the left and right columns, respectively), with the top, middle, and bottom figures representing the Baseline, Post-Construction Phase and the predicted change in the mean BSS (between Baseline and Post-Construction Phase) respectively. Figure 6.13 presents the model results for the Neutral year during NE and SW monsoons.

The Project is predicted to result in less than 0.01 N/m^2 change in mean bed shear stress in both the local Project area and the entire study area, which is considered negligible.

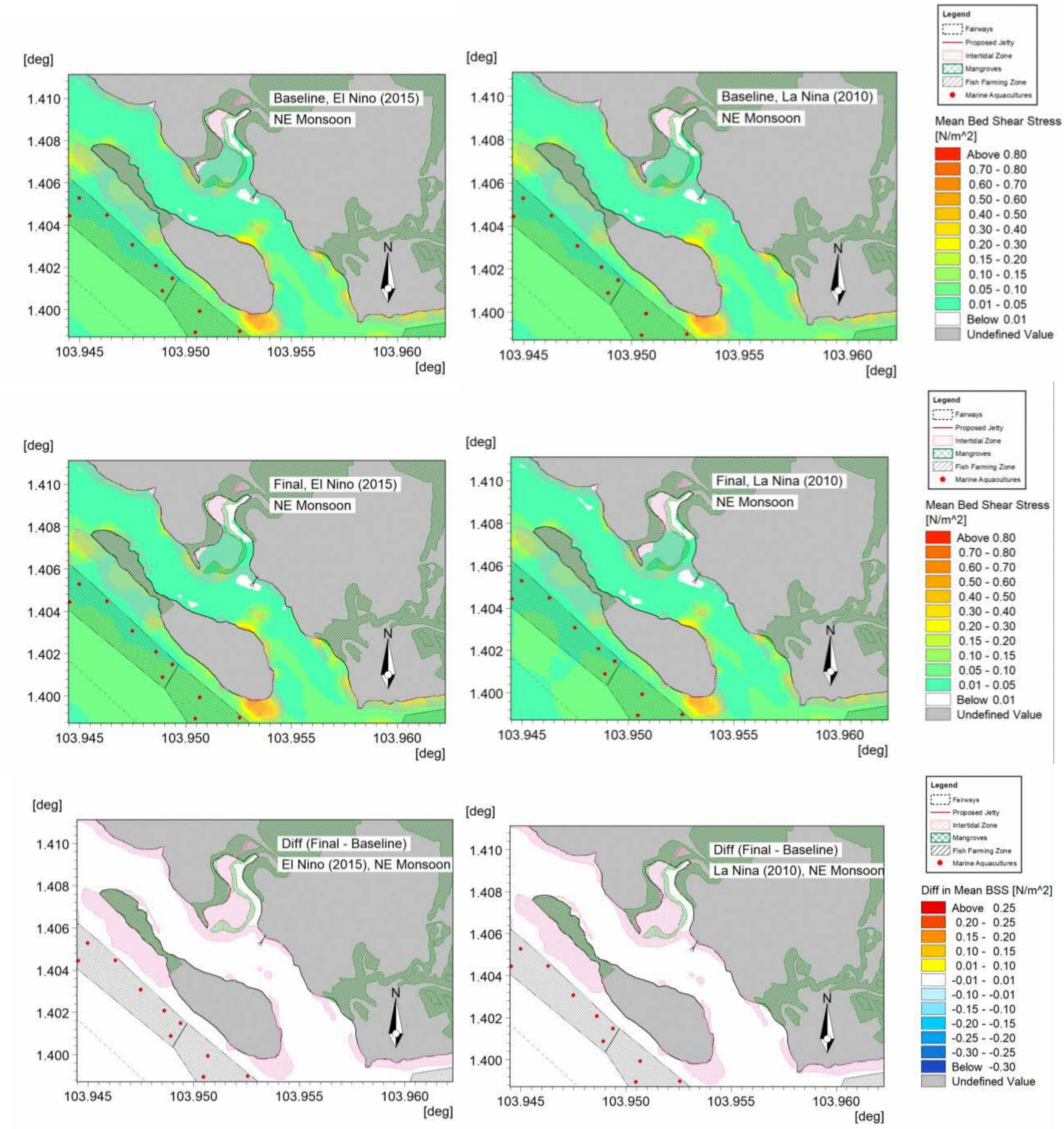


Figure 6.12 Mean BSS during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

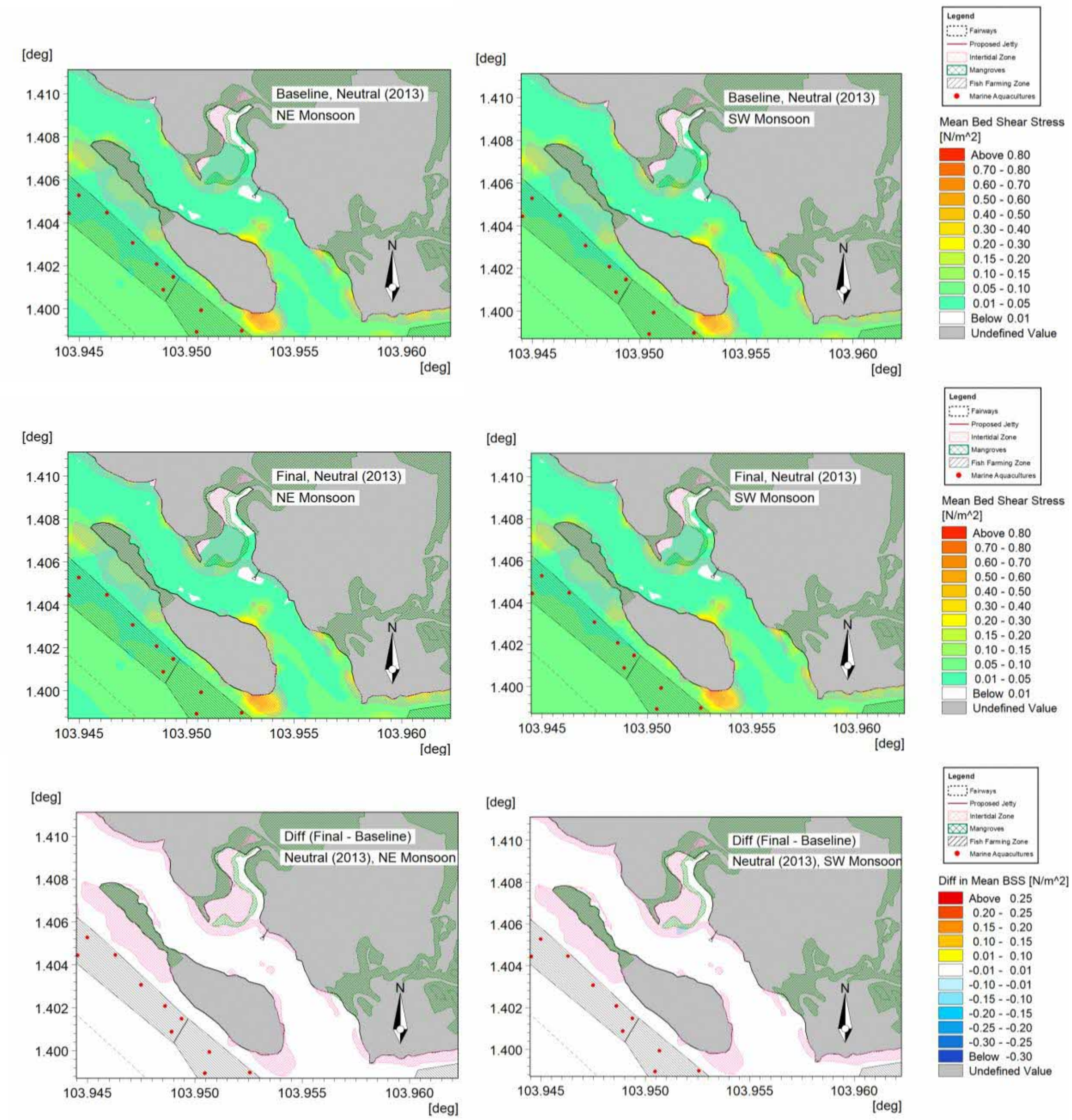


Figure 6.13 Mean BSS during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Change in 95th Percentile Bed Shear Stress

Figure 6.14 illustrates the maximum (95th percentile) BSS during the NE Monsoon, for El Niño and La Niña year (on the left and right columns, respectively), with the top, middle, and bottom figures representing the Baseline, Post-Construction Phase, and the predicted change in the maximum bed shear stresses (between Baseline and Post-Construction Phase) respectively. Figure 6.15 shows model results for the Neutral year during NE and SW Monsoons.

The predicted difference in maximum BSS between the Baseline and Post-Construction Phase (i.e., with the trimming and pile driving) during ENSO or the Neutral year is less than 0.05 N/m^2, which is considered negligible.

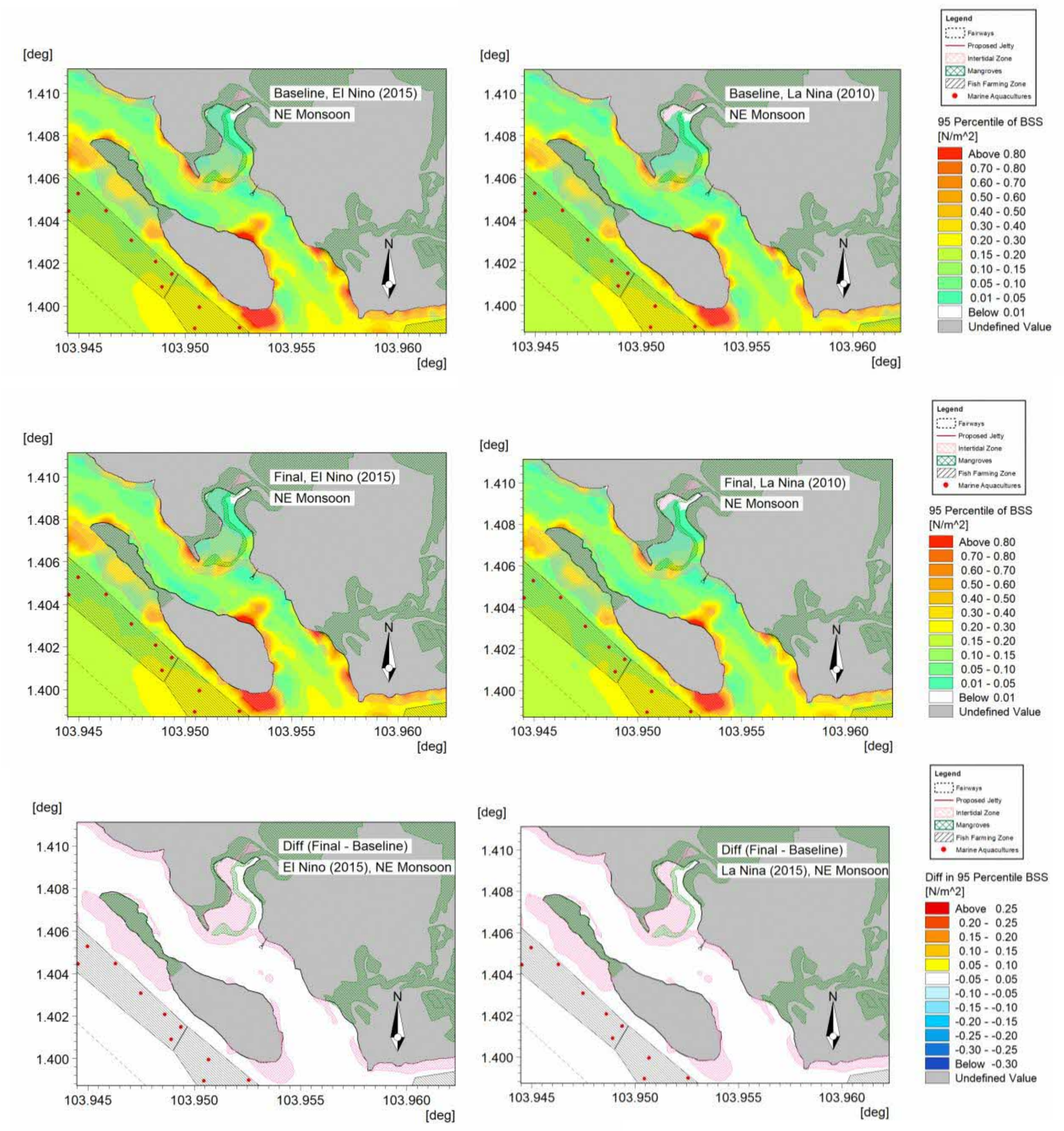


Figure 6.14 95th percentile BSS during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

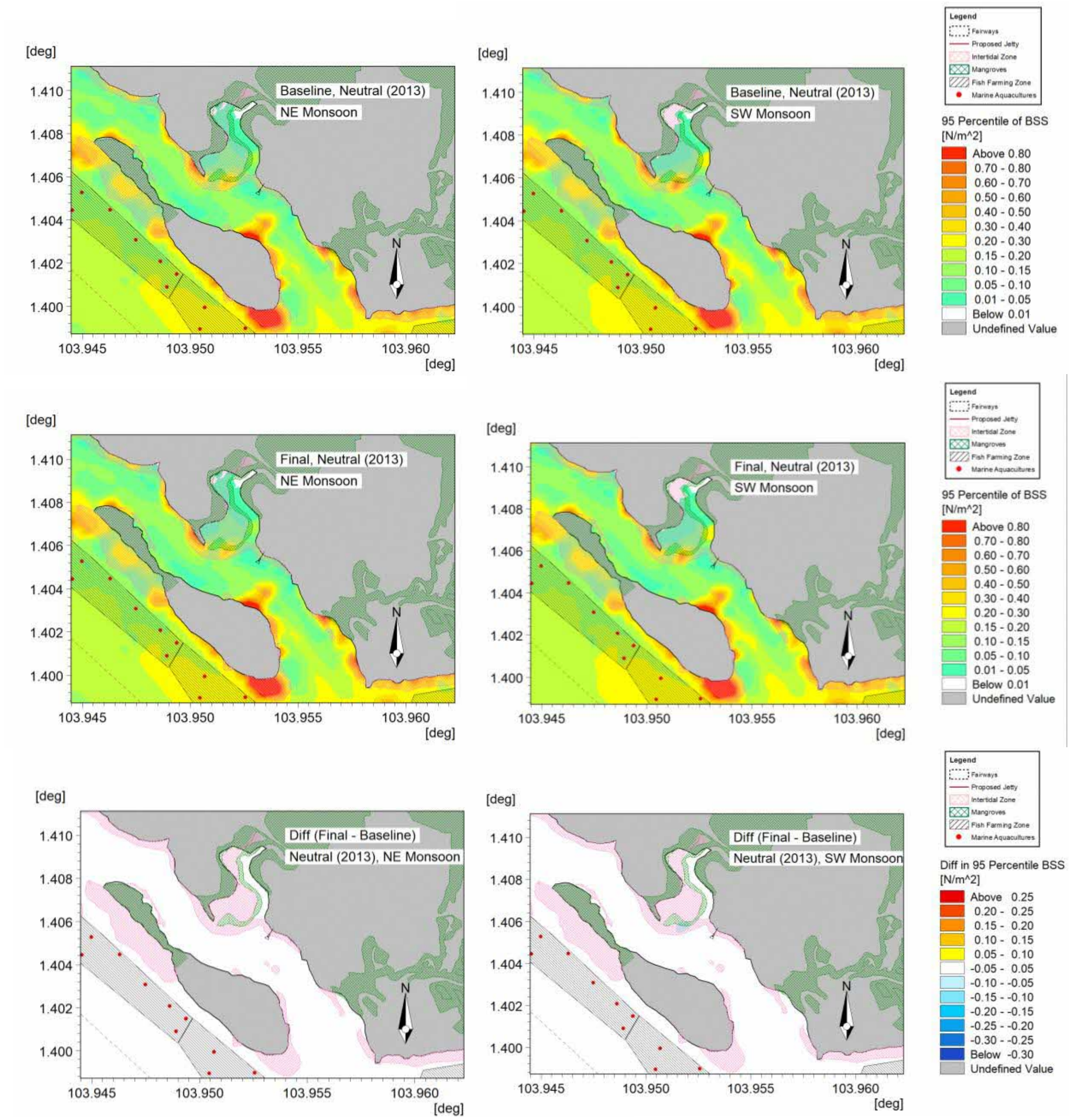


Figure 6.15 95th percentile BSS during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

6.1.5 Hydrodynamics Summary

Overall, the Project is located in a sheltered area and characterised by low current speeds. DHI's MIKE 21 HD hydrodynamic simulations predict that the Post-Construction Phase will result in negligible changes to mean, 95th percentile and representative current speeds, mean and 95th percentile bed shear stress within the study area. Assessment of the impact arising from these changes in currents due to the jetty operation is presented in the relevant receptor sections (Section 6.5).

6.2 Ship Wake

Ship wakes are generated by the displacement of water induced by a passing vessel. Apart from increasing wave heights at sensitive receptors such as aquaculture facilities, the wake waves generated by a ship moving can exert a morphological impact by potentially causing shoreline erosion. This section presents the methodology for analysing potential ship wake impacts to the shoreline (i.e., erosion) and other sensitive marine and coastal receptors.

6.2.1 Relevant Key Receptors

The receptors that are considered sensitive to the ship wake impacts include:

- Intertidal habitats;
- Mangroves; and
- Aquaculture facilities.

6.2.2 Evaluation Framework

Based on the proposed future vessel tracks (Figure 6.16) and selected simulated vessel dimensions and speed (Table 6.2 and

Table 6.3), the propagation and transformation of the ship-generated waves (i.e., ship wake) towards the shore were assessed. Empirical formulas by Kriebel and Seelig (2005) and Sorensen and Weggel (1984) were used to predict the maximum ship wake generated by the vessels. This maximum ship wake will then be propagated across the area of interest using DHI's MIKE 21 Spectral Wave (SW) model.

The MIKE 21 SW is a spectral wave model that describes the physical processes which affect waves as they propagate from the shipping route towards the coast. The model predicts the spatial variation of a characteristic wave height, period and direction within the defined domains thereby describing the "strength" or severity of the wake wash in shallow waters. Processes such as refraction, shoaling, bottom friction, and wave breaking are also included. The comprehensive ship wake model description and setup can be found in Appendix C.

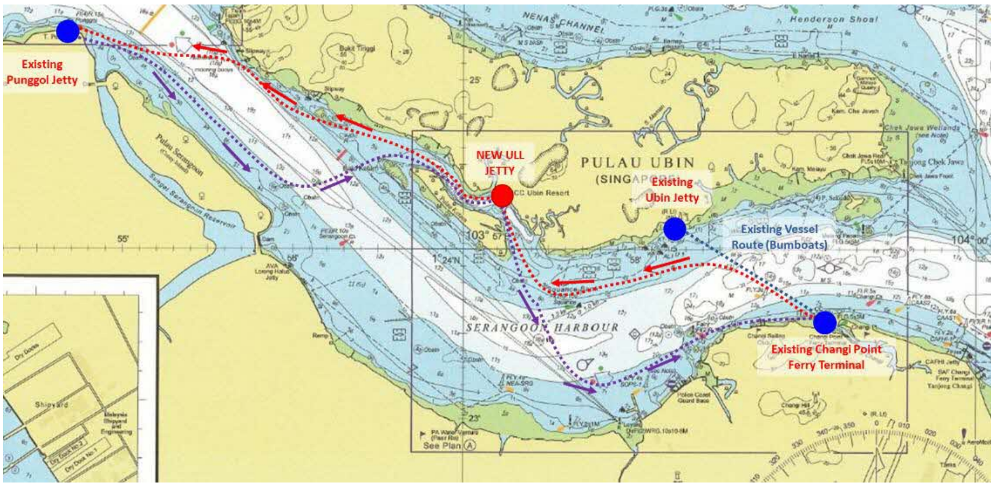


Figure 6.16 Proposed future vessel routes by MPA (Source: Client)

The potential ship wakes impact on sensitive receptors was evaluated via two key methods. The first, primarily for aquaculture receptors, evaluated ship wake height results from the models. The second method examined the potential erosional impact of these ship wakes, mainly on ecological receptors and sensitive shorelines.

Modelling Scenario

Forty-eight (48) ship wake scenarios were simulated in this study along the Ketam Channel. For ease of understanding and better clarity when modelling, the assessment of ship wake height was first divided into two (2) shorelines, Pulau Ubin and Pulau Ketam, and each shoreline was subsequently subdivided into three (3) areas (Figure 6.17). The simulated vessel dimensions were selected based on the proposed future vessel specifications provided by the client (Table 6.2).

Scenarios were simulated with inbound (vessel going towards the proposed jetty at ULL) or outbound (vessel going away from the proposed jetty at ULL) direction. Vessels inbound/outbound from Changi Point Ferry Terminal to the ULL jetty are Bumboats, while vessels inbound/outbound from Punggol jetty to the ULL jetty are Ferries (Figure 6.16 and Figure 6.17). Detailed shoreline area and inbound/outbound vessel tracks for each shoreline are shown in Figure 6.18 and Figure 6.19. AIS data in the project area (presented in Section 6.6.1.1) suggests that the 95th percentile of Speed Over Ground (SOG) for passenger vessels is 6.2 knots, while the information provided by the client indicated a maximum vessel speed of 12 knots. Hence, results from the models/calculations were extracted for vessel speeds of 5 knots, 7 knots, 10 knots, and 12 knots so that the effects of a range of vessel speeds can be understood. The ship wake simulation is based on the single trip going back and forth from the proposed jetty at ULL at the respective vessel speed. A summary of modelling scenarios for ship wake assessment is presented in

Table 6.3.

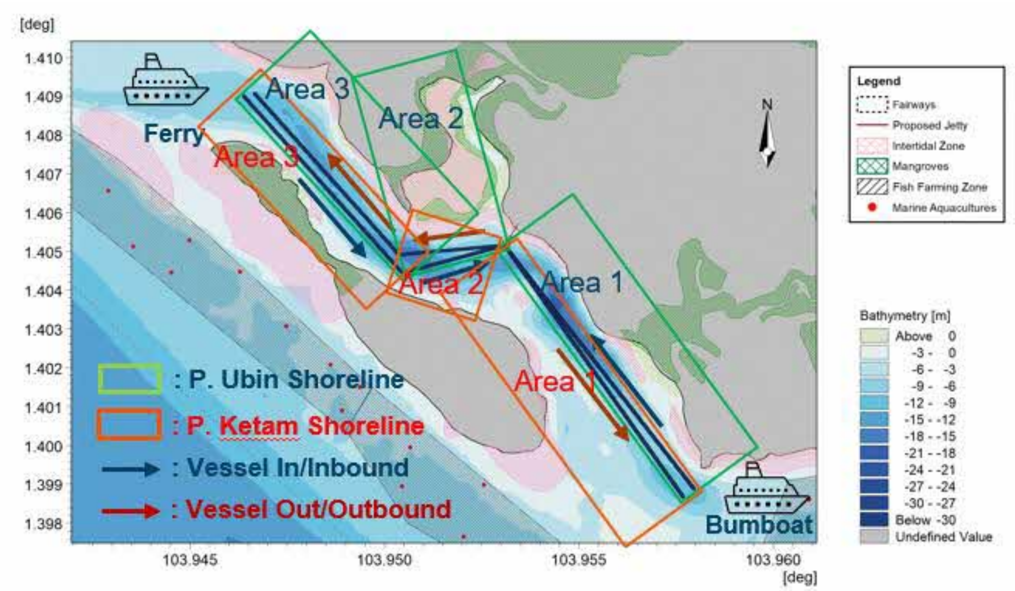


Figure 6.17 Ship wake assessment area for Pulau Ubin and Pulau Ketam shorelines

Table 6.2 Properties of the vessels applied for ship wake assessment

Vessel	LOA (m)	Width (m)	Draft (m)
Bumboat	13.0	3.0	1.0
Ferry	18.7	5.2	2.2

Table 6.3 Modelling scenarios for the ship wake assessment

Scenarios	Shoreline	Vessel Direction	Area	Vessel Type	SOG (knots)
1	Pulau Ubin	Vessel In	Area 1	Bumboat	12
2					10
3					7
4					5
5			Area 2	Ferry	12
6					10
7					7
8					5
9			Area 3	Ferry	12
10					10
11					7
12					5
13		Vessel Out	Area 1	Bumboat	12
14					10
15					7
16					5
17			Area 2	Ferry	12
18					10
19					7
20					5
21			Area 3	Ferry	12
22					10
23					7
24					5
25	Pulau Ketam	Vessel In	Area 1	Bumboat	12
26					10
27					7
28					5
29			Area 2	Ferry	12
30					10
31					7
32					5
33			Area 3	Ferry	12
34					10
35					7
36					5
37		Vessel Out	Area 1	Bumboat	12
38					10
39					7
40					5
41			Area 2	Ferry	12
42					10
43					7
44					5
45			Area 3	Ferry	12
46					10
47					7
48					5

In a separate analysis, the potential ship wakes impact on shoreline erosion was evaluated by calculating the Bed Shear Stress (BSS) generated from the single trip ship wake and combining it with a 14-day period of BSS result extracted from HD modelling outputs (generated by currents, Section 6.1). The assessment conservatively adds a single trip's ship wake induced BSS consistently over the 14-day period. Yet, in reality a change in the BSS only occurs when a vessel passes by; a duration that typically lasts for a few minutes. The analyses subsequently gave the resultant BSS value along the shoreline, which was used to provide a preliminary assessment to document relative areas of potential morphological change (sedimentation or erosion).

Nine (9) analysis points at three different areas were selected to extract the bed shear stress value for impact assessment (Figure 6.20). These points were near primary areas of erosion, including southeast of Pulau Ubin (near the southern tip of the island) and the north-western tip of Pulau Ketam, or near/at mangrove or intertidal receptors. The coordinates of the analysis point in each area are provided in Table 6.4. A Critical BSS threshold for erosion risk (τ_c) of 0.14 N/m^2 (Shi *et al.*, 2015) was used in this study to estimate occurrences of erosion from the graphs. The calculation of BSS generated by ship wake followed the formula by Nielsen (1992). After the resultant BSS was obtained, the potential ship wake impact on erosion was assessed through comparison of resultant BSS along the shoreline against the Critical BSS (τ_c) for erosion. Exceedance of Critical BSS indicates potential for shoreline erosion. Additional details on the assessment of potential ship wake impact on shoreline erosion can be found in Appendix C.

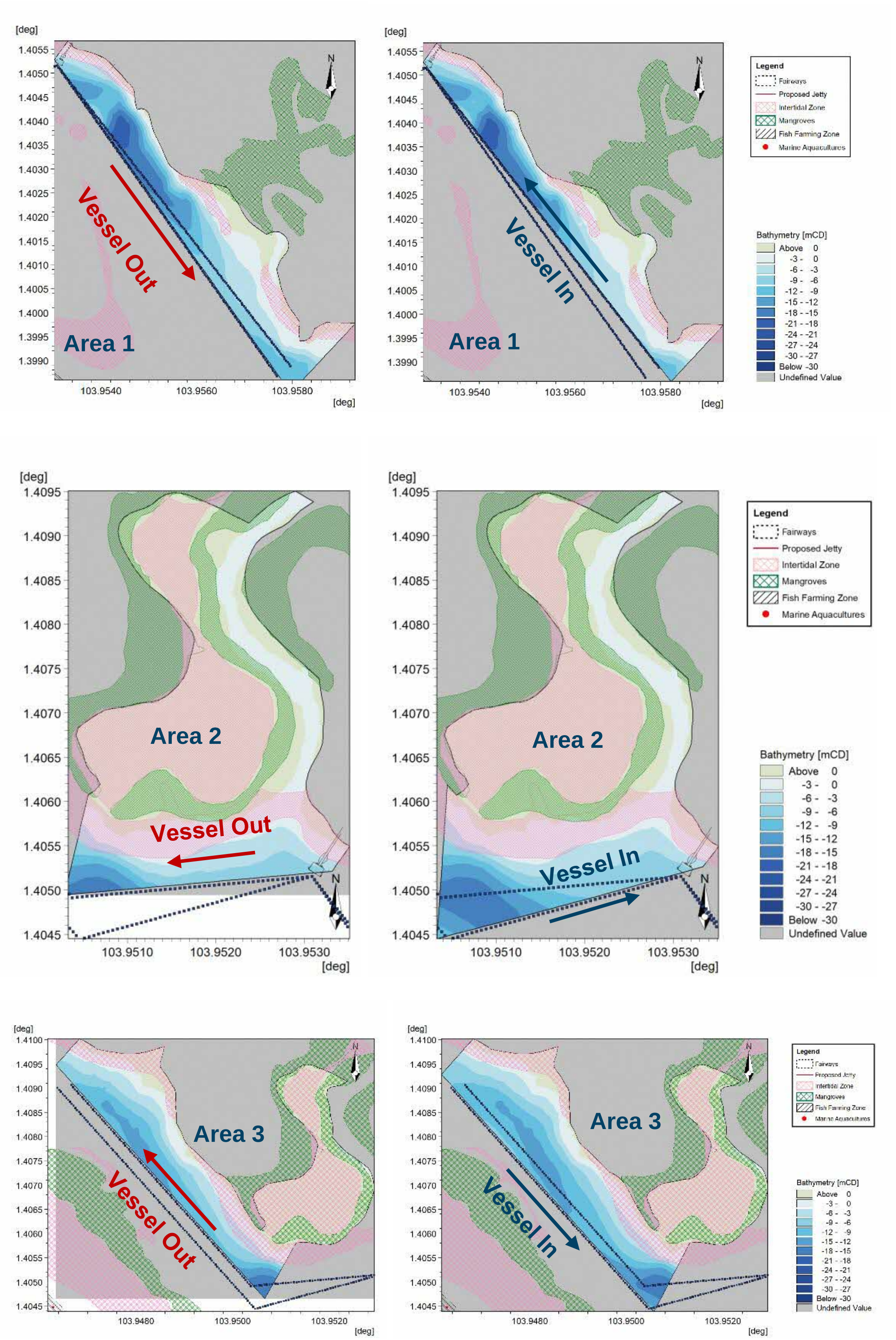


Figure 6.18 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ubin shoreline

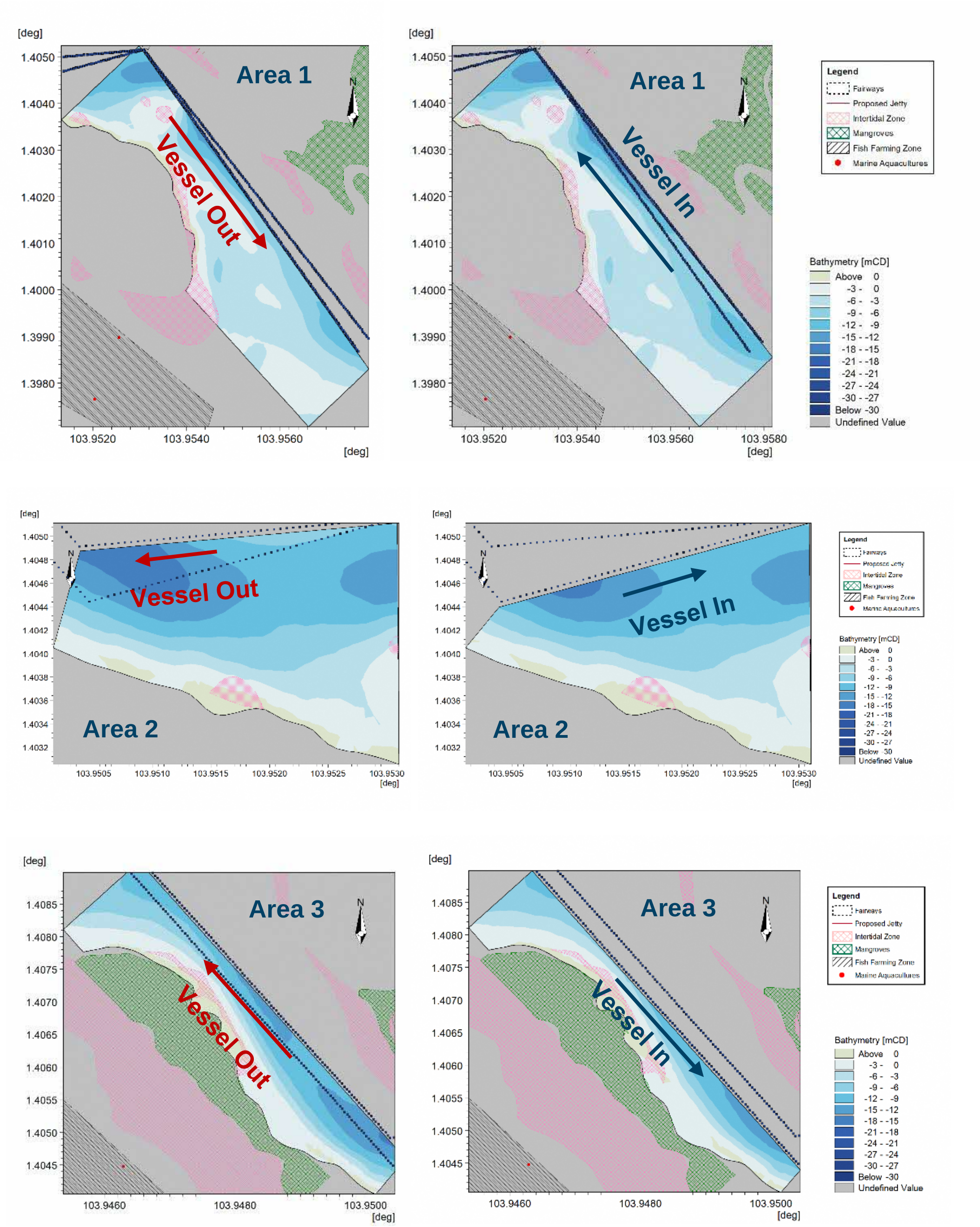


Figure 6.19 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ketam shoreline

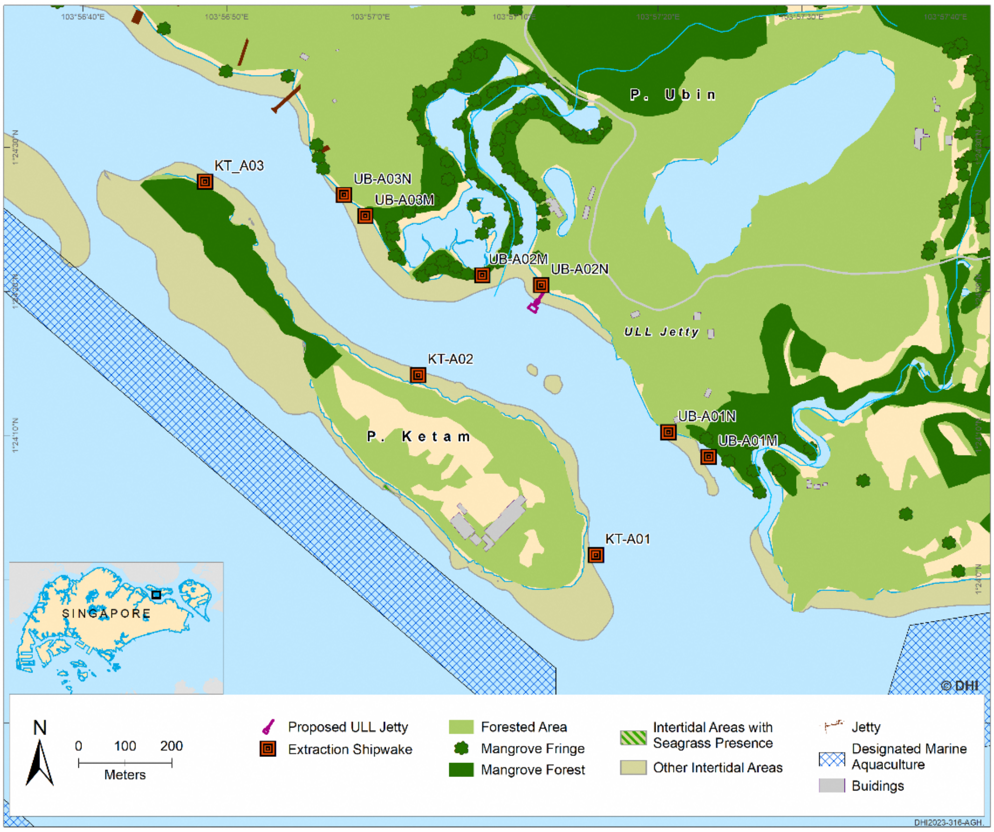


Figure 6.20 Location of BSS extraction points for impact assessment of ship wake impacts on the shoreline

Table 6.4 Coordinates of the nine (9) extract points

Area	Point Extraction	Shoreline	Geographical Coordinate	
			Longitude (°)	Latitude (°)
1	UB-A01M	Pulau Ubin	103.956535	1.402367
	UB-A01N	Pulau Ubin	103.955760	1.402840
	KT-A01	Pulau Ketam	103.954355	1.400467
2	UB-A02M	Pulau Ubin	103.952160	1.405870
	UB-A02N	Pulau Ubin	103.953300	1.405680
	KT-A02	Pulau Ketam	103.950923	1.403942
3	UB-A03M	Pulau Ubin	103.949900	1.407020
	UB-A03N	Pulau Ubin	103.949490	1.407425
	KT-A03	Pulau Ketam	103.946803	1.407679

A set of ship wake metrics was selected to characterise the waves to assess ship wake impacts on shoreline erosion. These characteristics were chosen according to the tolerance limits of the relevant receptors listed in Section 6.2.1. Ship wake model results in this EIA are analysed according to the following descriptors:

- Ship wake height;
- BSS (generated by currents); and
- BSS (generated by ship wake).

6.2.3 Results and Discussion

This section presents and discusses ship wake model results in terms of ship wake height and bed shear stress.

Ship Wake Height (Pulau Ubin Shoreline)

Ship wake height model results from the Pulau Ubin shoreline are presented in Figure 6.21 to Figure 6.26. Figure 6.21 to Figure 6.23 illustrate ship wake height for inbound direction along the Pulau Ubin shoreline (Area 1, Area 2, and Area 3) from vessels going at 12 knots, 10 knots, 7 knots, and 5 knots, respectively. Figure 6.24 to Figure 6.26 present the model results for the outbound direction.

The noticeable trend of increasing vessel speed for both inbound and outbound directions is the increase of ship wake height near the shoreline due to the incoming and reflected waves. The maximum ship wakes near Pulau Ubin shoreline area for inbound and outbound directions is <0.16 m for 5 knots, <0.40 m for 7 knots, <0.48 m for 10 knots, and up to 0.88 m for 12 knots.

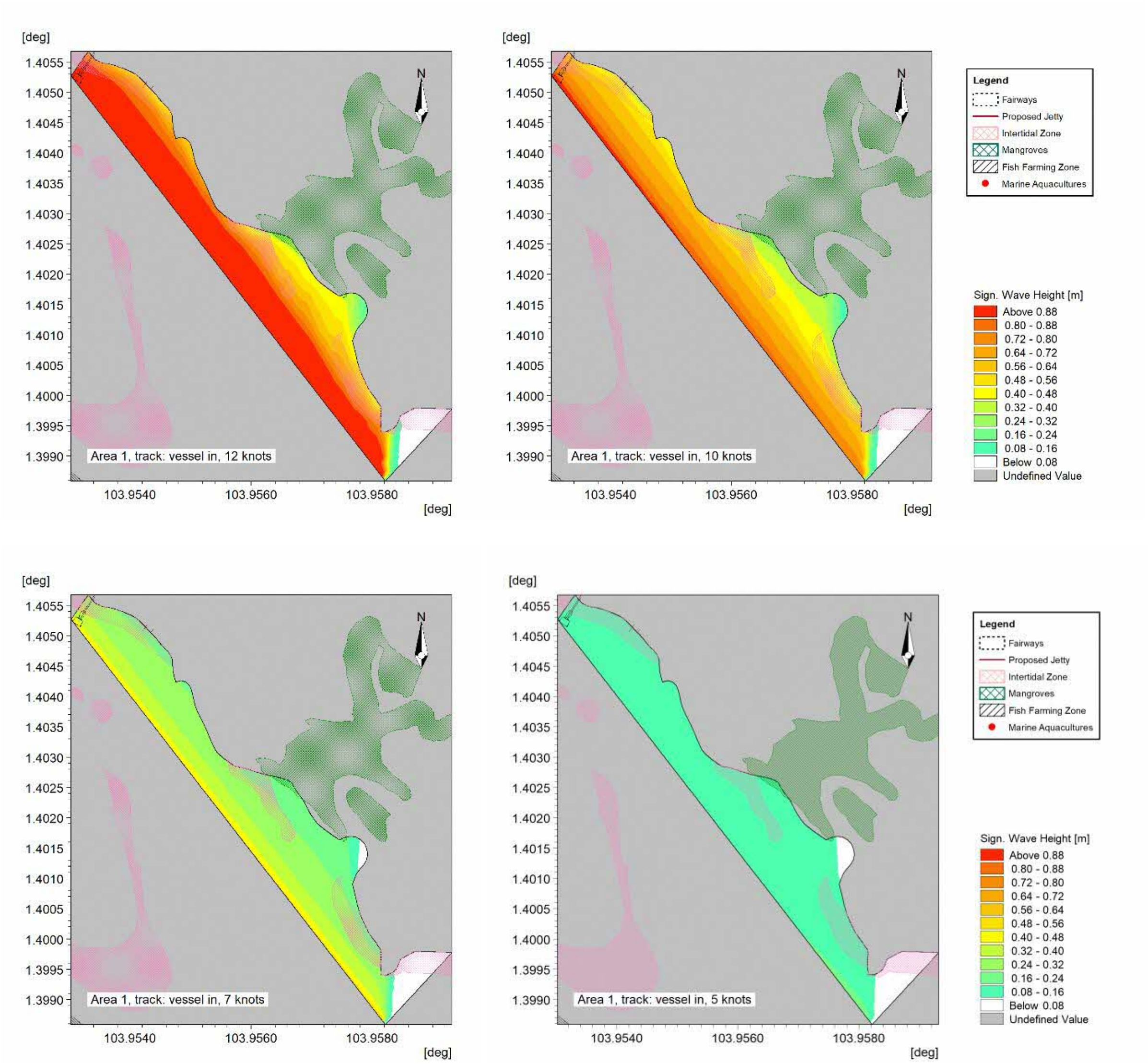


Figure 6.21 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 1 for varying vessel speeds of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

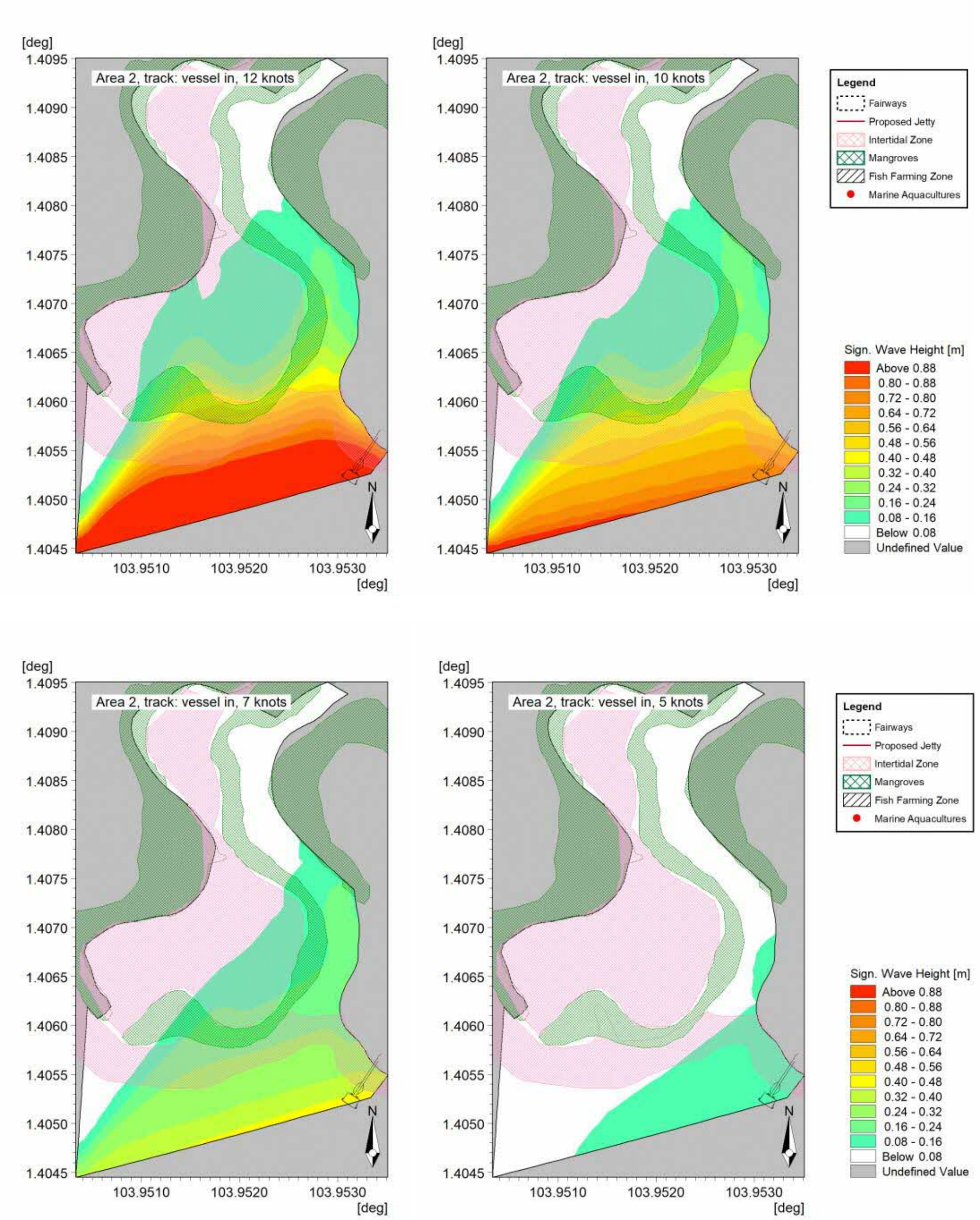


Figure 6.22 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

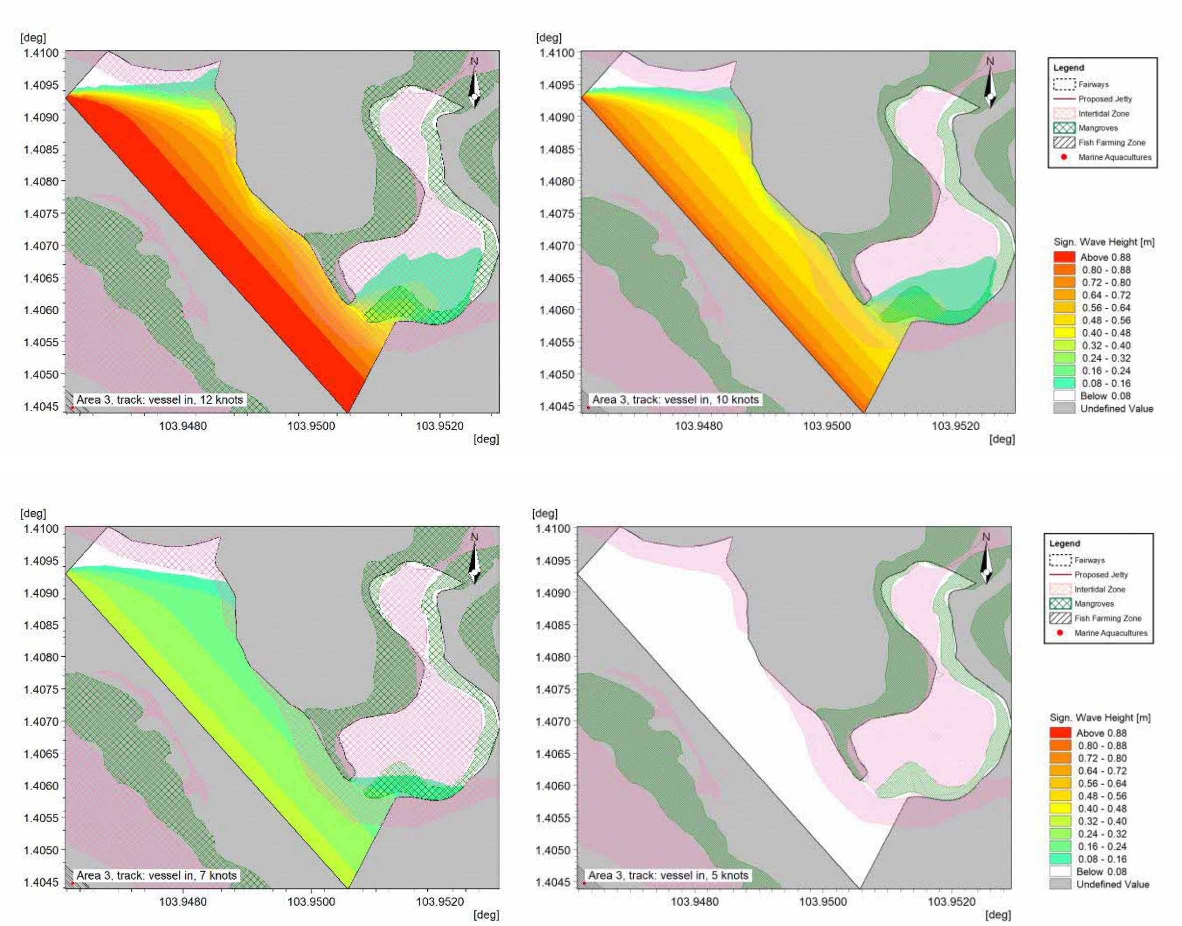


Figure 6.23 Ship wake height for inbound direction along Pulau Ubin shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

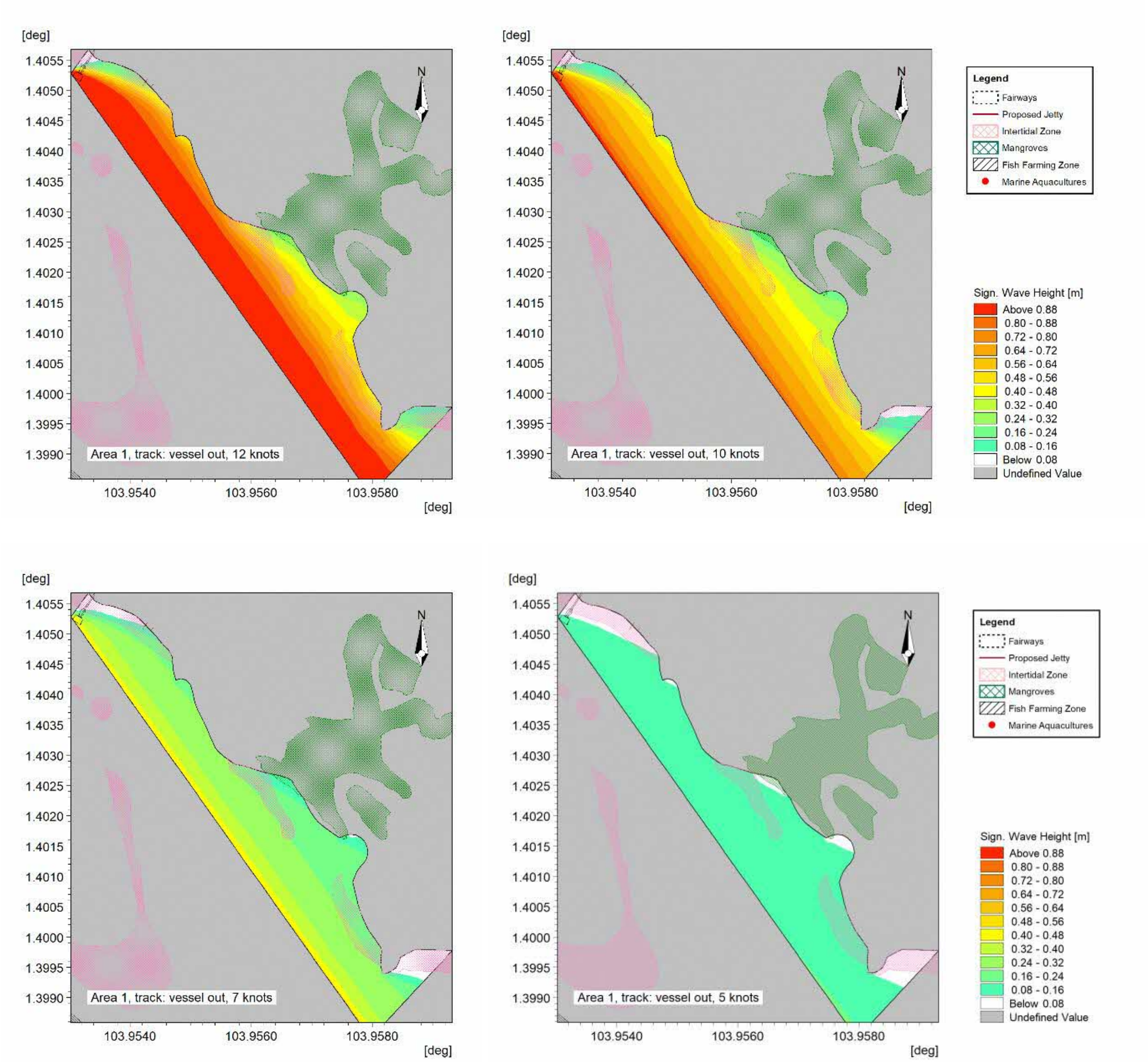


Figure 6.24 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

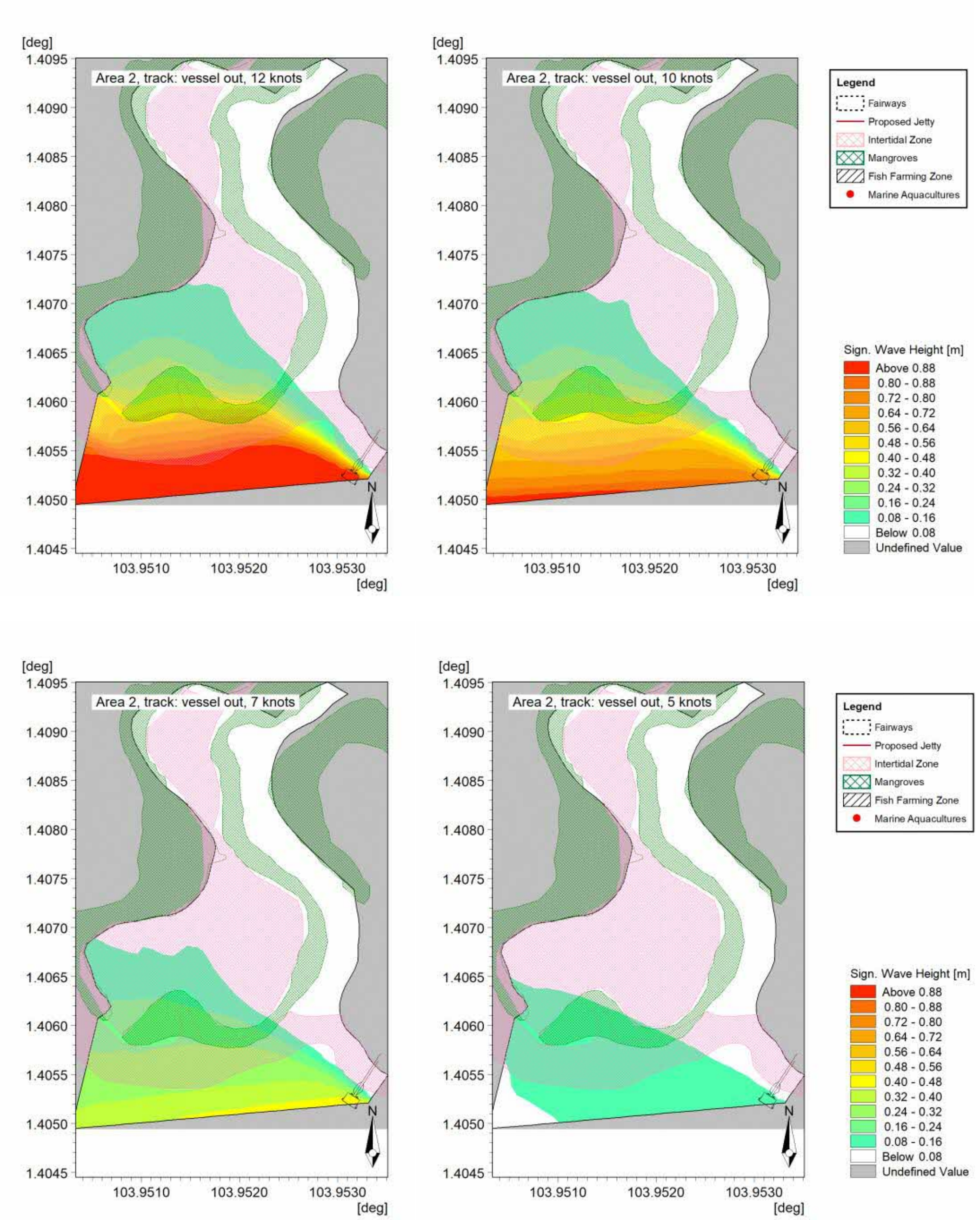


Figure 6.25 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

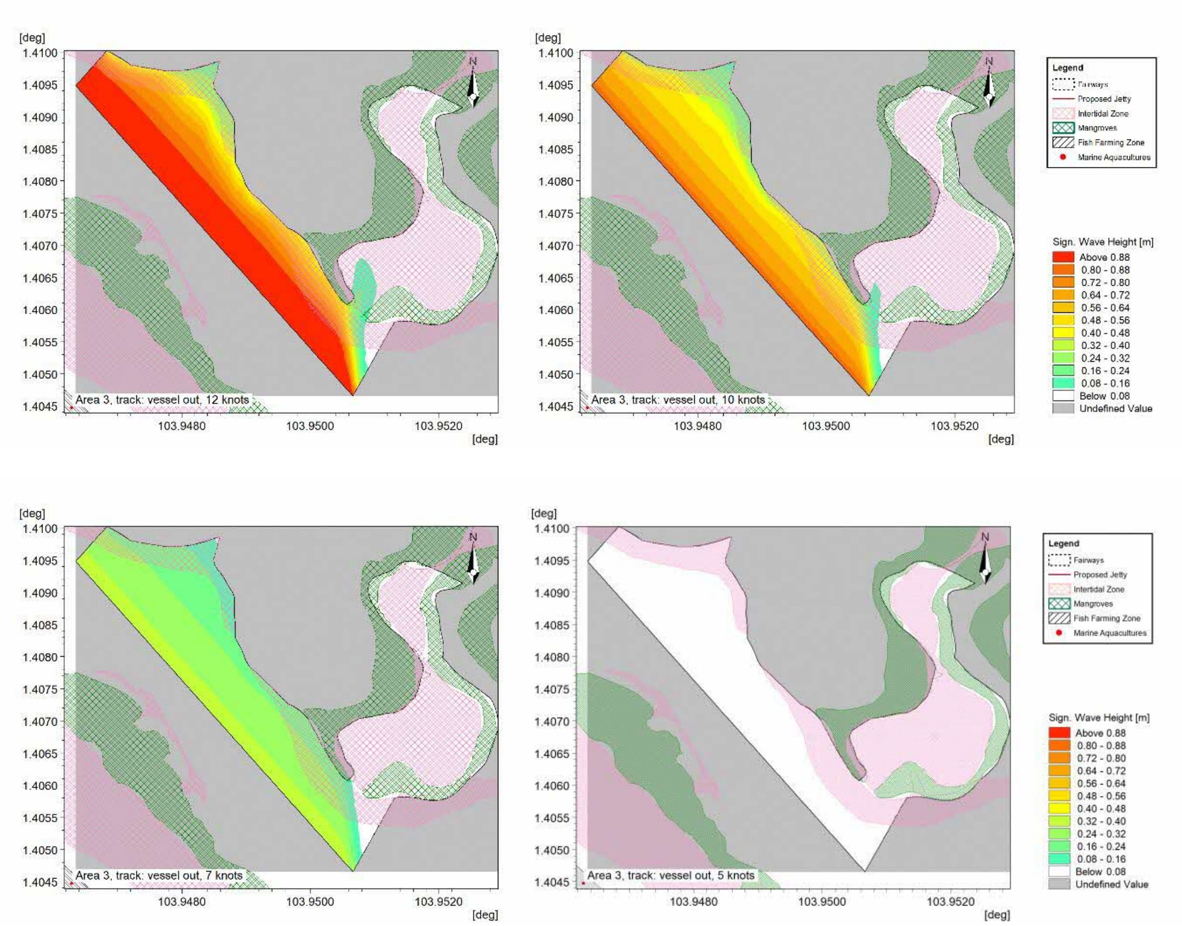


Figure 6.26 Ship wake height for outbound direction along Pulau Ubin shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

Ship Wake Height (Pulau Ketam Shoreline)

Ship wake height model results from the Pulau Ketam shoreline are presented in Figure 6.27 to Figure 6.32. Figure 6.27 to Figure 6.29 illustrate ship wake height for inbound direction along the Pulau Ketam shoreline (Area 1, Area 2, and Area 3) from vessel speeds of 12 knots, 10 knots, 7 knots, and 5 knots, respectively. Figure 6.30 to Figure 6.32 present the model results for the outbound direction.

Contrary to the trend at Pulau Ubin Shoreline, there was a lower ship wake height near the Pulau Ketam shoreline. The maximum ship wakes near Pulau Ketam shoreline area for inbound and outbound directions is <0.16 m for 5 knots, <0.32 m for 7 knots, <0.64 m for 10 knots, and up to 0.80 m for 12 knots. This trend is likely due to the greater water depth along the Pulau Ketam shoreline compared to Pulau Ubin. The height of ship wakes is typically smaller in deeper water because more water is available to absorb the energy produced by the ship's movement (Liu *et al.*, 2018).

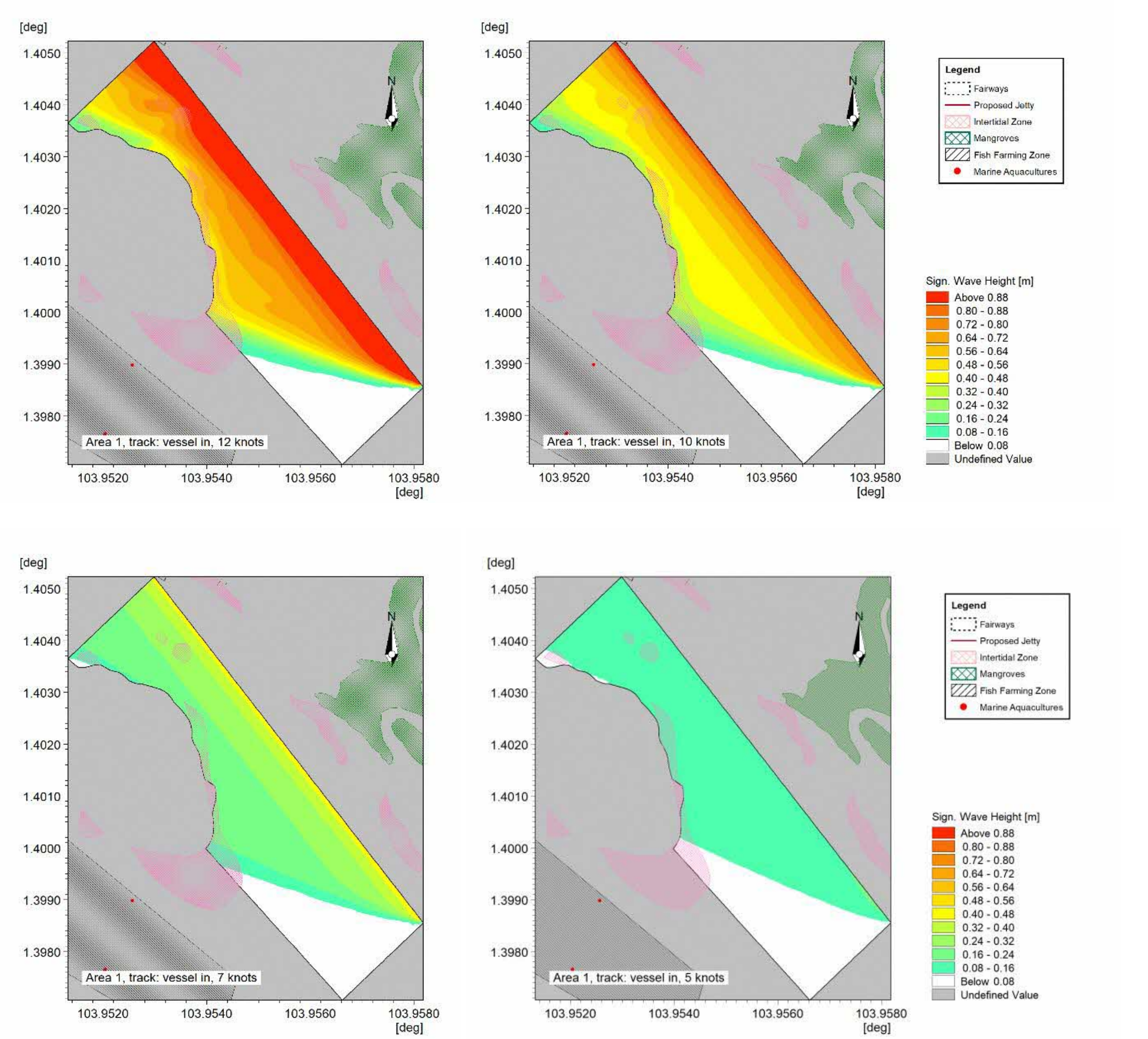


Figure 6.27 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

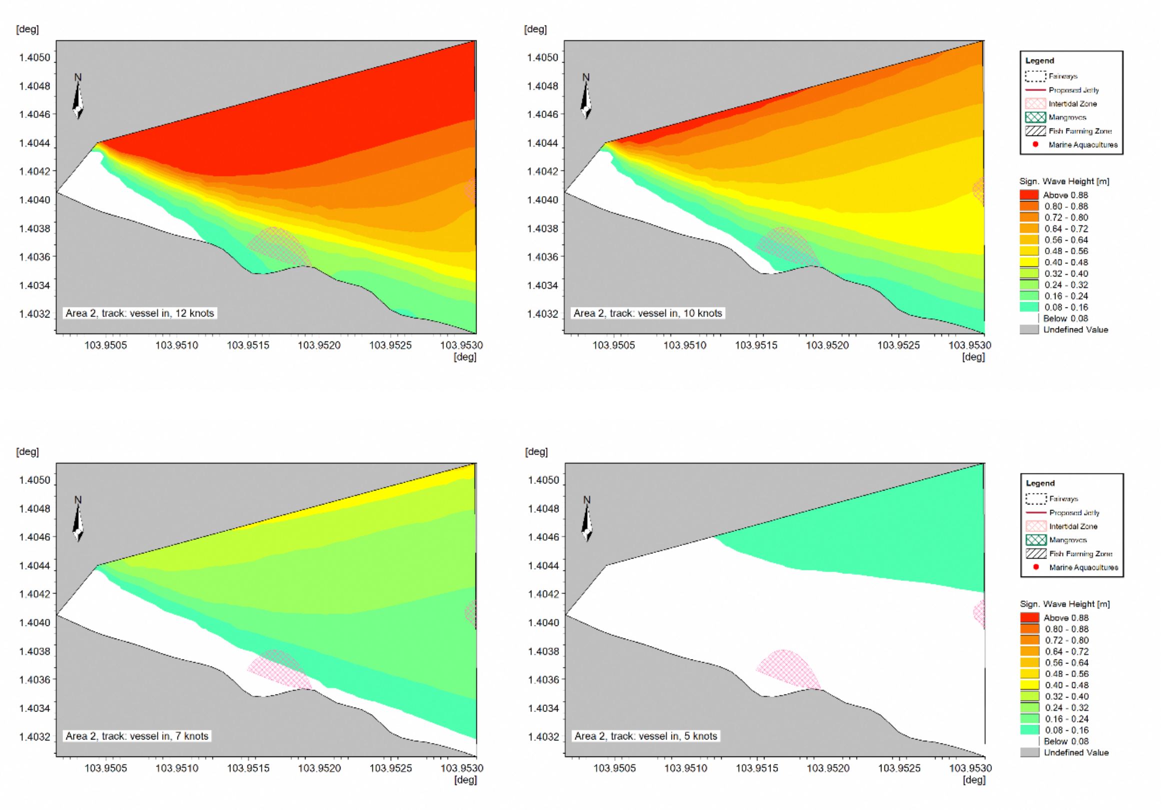


Figure 6.28 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

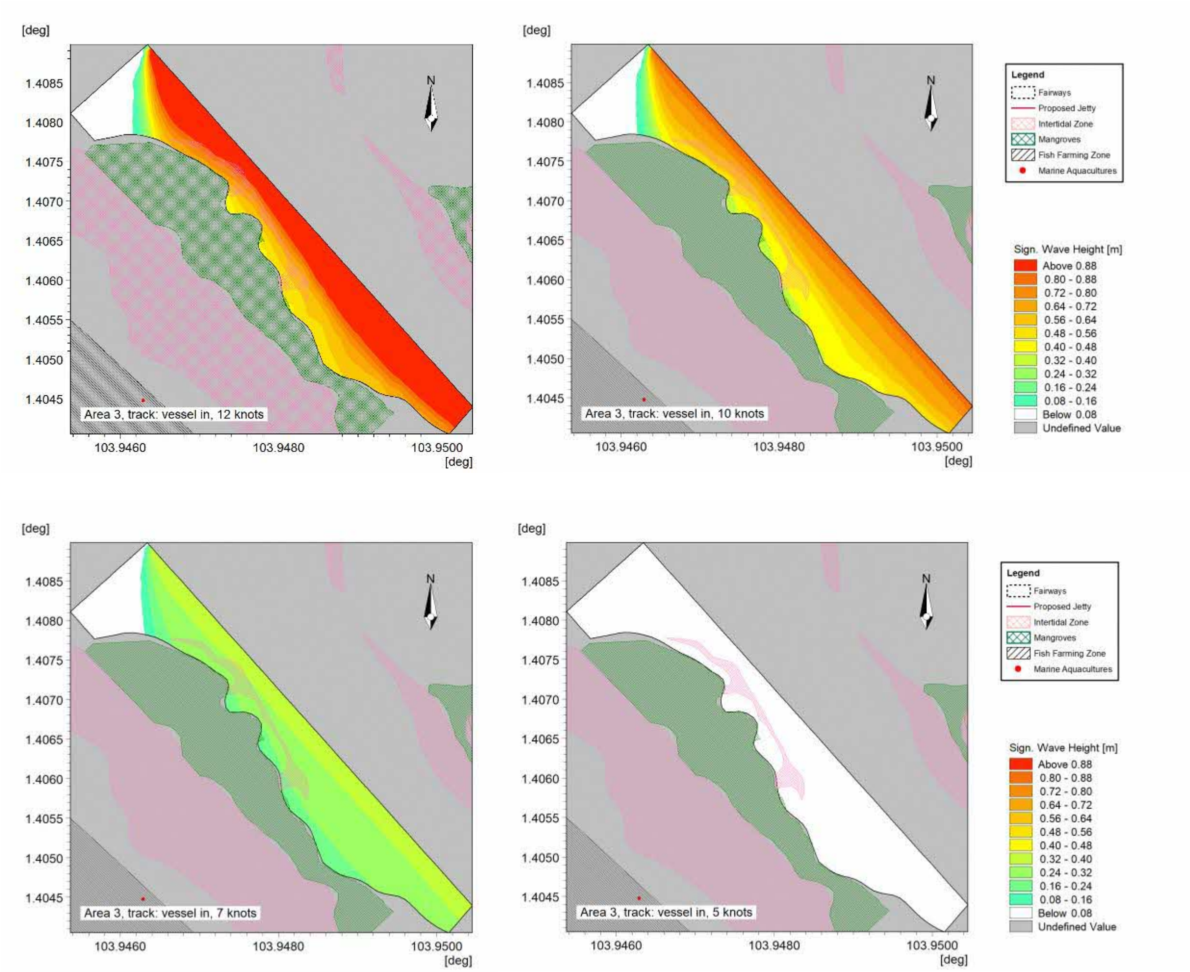


Figure 6.29 Ship wake height for inbound direction along Pulau Ketam shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

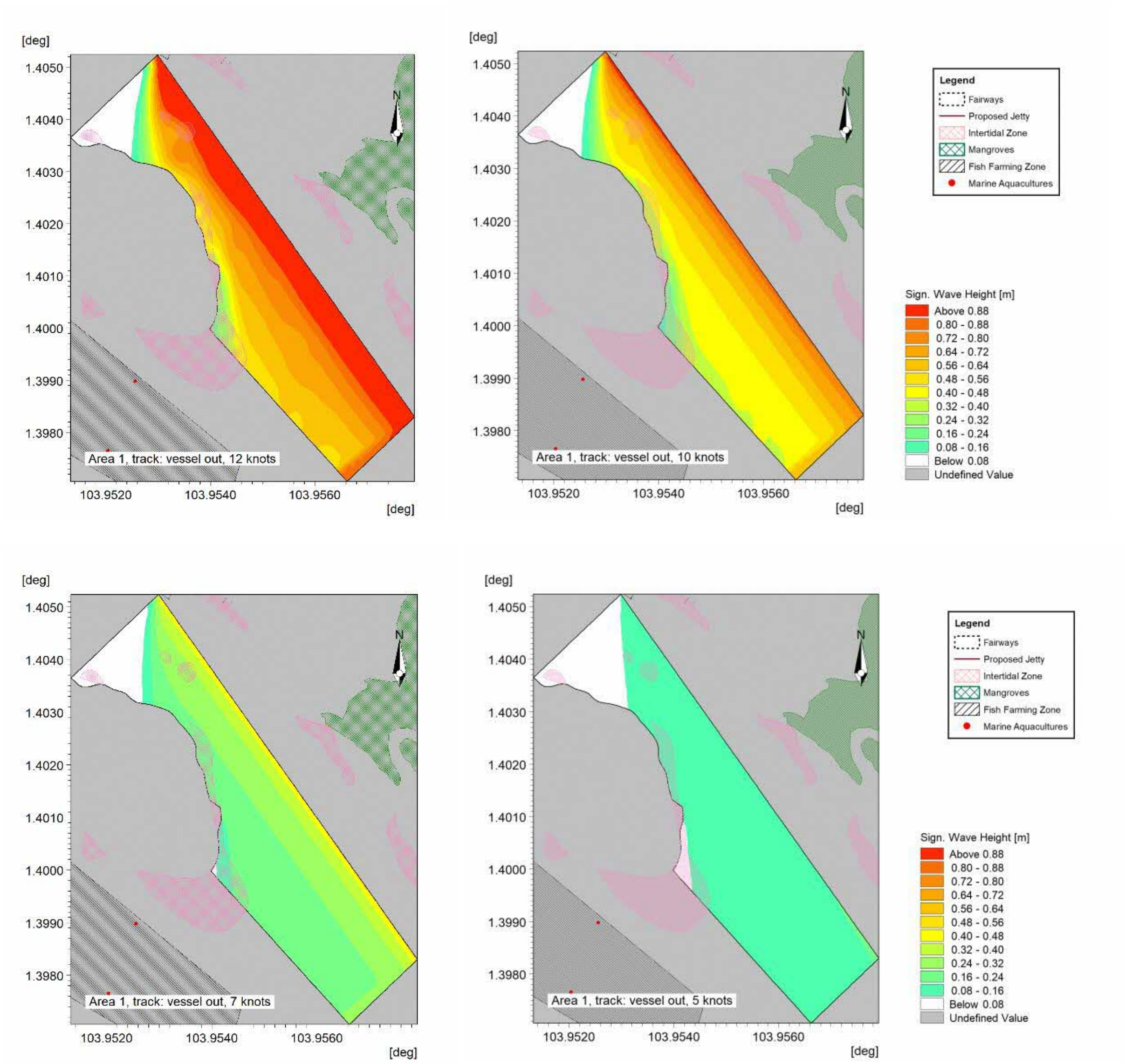


Figure 6.30 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 1 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

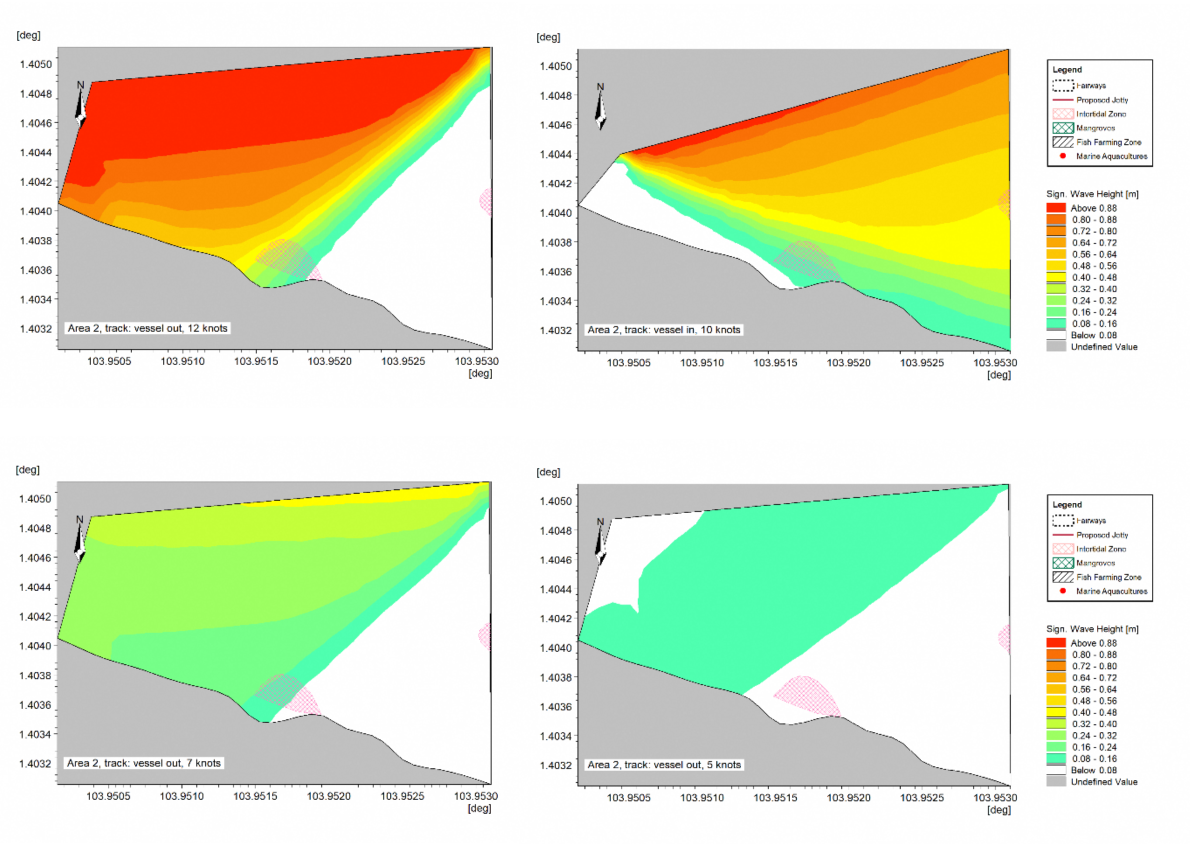


Figure 6.31 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 2 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

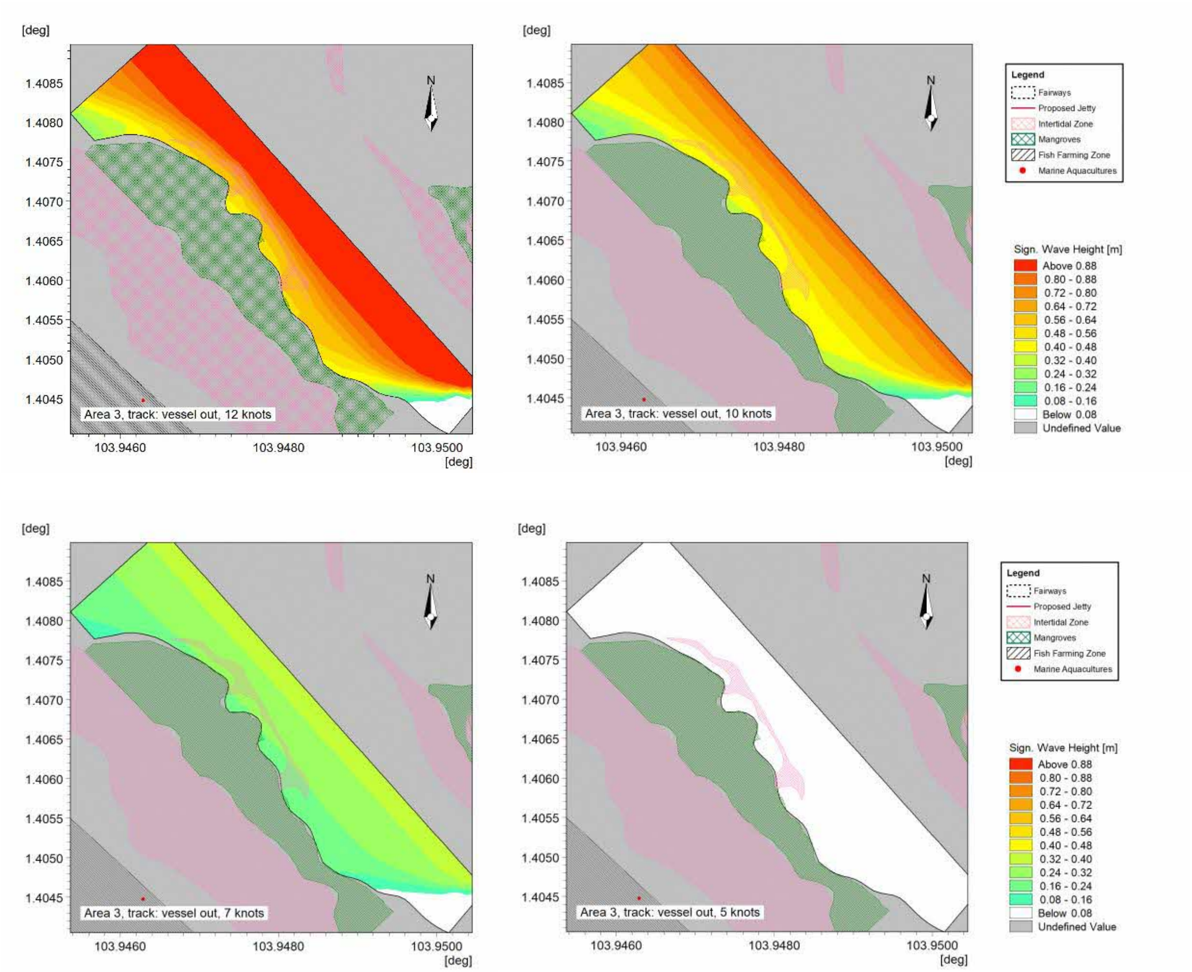


Figure 6.32 Ship wake height for outbound direction along Pulau Ketam shoreline at Area 3 for vessel speed of 12 knots (top-left), 10 knots (top-right), 7 knots (bottom-left), 5 knots (bottom-right)

Ship Wake Height (Aquaculture Farms)

Due to consideration of the direct impact of these shipwakes on aquaculture receptors, specific wake heights were extracted at the nearest aquaculture farms near the mouth of the Ketam Channel, one to the east and one to the west (Figure 4.1; Table 6.5) Aquaculture farms to the east of the channel, along the Pulau Ubin shoreline, would experience shipwakes of between 0.057 to 0.433m in height, depending on the speed of the passing boat. Aquaculture farms to the west of the channel, along the Pulau Ketam shoreline, would experience shipwakes of between 0.037 to 0.291m in height (Table 6.5) depending on the speed of the passing boat.

Table 6.5 Ship wakes simulated to be experienced by the nearest fish farms, at varying boat speeds

Magnitude	5 Knots	7 Knots	10 Knots	12 Knots
Nearest Aquaculture Farm to the East	0.057 m	0.159 m	0.330 m	0.433 m
Nearest Aquaculture Farm to the West	0.037 m	0.100 m	0.221 m	0.291 m

Resultant Bed Shear Stress (BSS)

Evidence of erosion was found from the shoreline survey baseline studies described in Section 5.1.1. Once the ULL jetty enters the operational phase, the increased frequency of passing vessels in this area could the increase potential erosion risk due to ship-generated waves. This section describes the potential ship wake impact on shoreline erosion, which was qualitatively assessed based on resultant BSS. This assessment conservatively adds that ship wake-induced BSS constantly change over time. However, in reality, the reported BSS change only occurs briefly when a vessel passes by (i.e., a few minutes).

Figure 6.33 illustrates the time series of mean BSS generated by currents for the Pulau Ubin (blue line) and Pulau Ketam (green line) shorelines, respectively, providing an average baseline BSS at each shoreline. The baseline results show that the potential occurrence of erosion (BSS >0.14 N/m^2) prior to any ship wake contribution is typically found during peak flood/ebb, under spring and neap conditions for both shorelines (Figure 6.33). Conversely, less erosion risk (BSS < 0.14 N/m^2) is indicated during low ebb/flow conditions.

Three locations were selected for this analysis, as they were highlighted in previous sections (e.g., Section 5.1.1) to be undergoing erosion and are considered sensitive areas. Area 2 is not discussed as the area was generally found to be accreting.

Figure 6.34 and Figure 6.35 present time series of BSS generated by currents and ship wake at two eroding areas on the Pulau Ubin shoreline, UB-A01M and UB-A03N. In contrast, Figure 6.36 shows a similar time series for the eroding area on the Pulau Ketam shoreline, KT-A03. It is also noted that UB-A01M is the location of mangrove receptors, while UB-A03N is the location of intertidal receptors.

From Figure 6.34 (see blue and pink-dashed line), vessels travelling at 5 knots in Area 1 (UB-A01M) will result in BSS similar to baseline BSS, indicating a negligible change to the baseline coastal dynamics. However, boats travelling at speeds of >5 knots (i.e., 7, 10 or 12 knots) would likely increase the erosion risk to the Pulau Ubin shoreline (Figure 6.34, green, cyan and black lines). This suggests that BSS contribution from ship wake with vessel speeds of >5 knots significantly adds to baseline BSS, inducing higher erosion risk to the Pulau Ubin shoreline. Note that the actual resultant erosion rate will depend on the frequency of vessel movements.

In Area 3, the Ketam shoreline was found to be experiencing erosion (see Section 5.1.1). For both UB-A03N and KT-A03 (Figure 6.35 and Figure 6.36, pink-dashed and green lines), the BSS produced by ship wake from vessels travelling at 5 to 7 knots will have a minimal impact. However, vessels travelling at >10 knots will considerably increase resultant BSS along the Pulau Ubin shoreline and increase the frequency of exceeding critical BSS along the Ketam shoreline (Figure 6.35 and Figure 6.36, cyan and black lines). Hence, there is a possibility that both the Ketam and Ubin shorelines in Area 3 would experience an increase in erosion processes. However, this will depend on the frequency of vessel movements during the jetty operational stage.

Hence, the results from this ship wake assessment show that the recommended vessel speed to traverse within the Ketam Channel to minimise the risk of shoreline erosion is <5 knots.

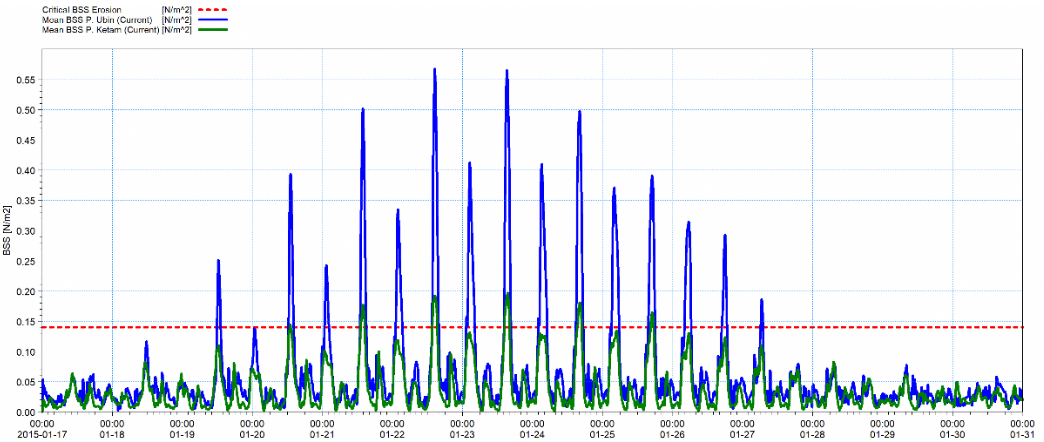
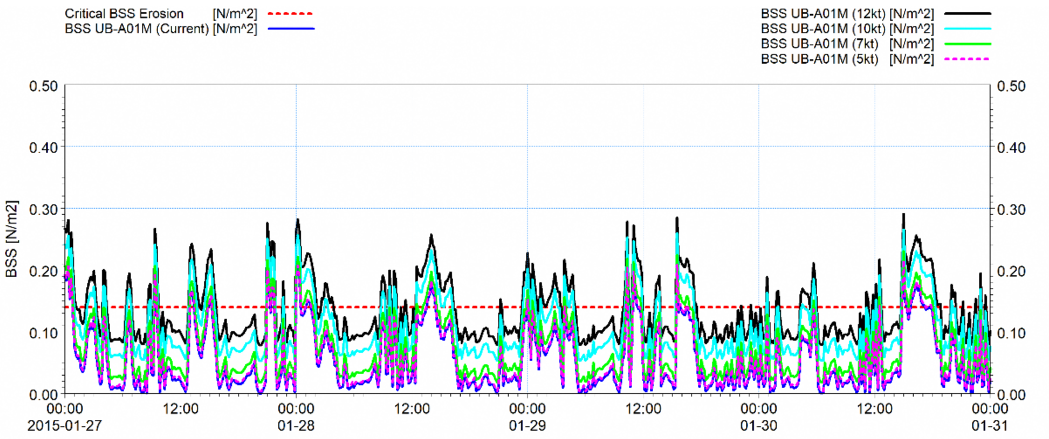


Figure 6.33 Time series of mean BSS generated by currents (derived from HD) for Pulau Ubin and Pulau Ketam shorelines. Potential erosion occurs when BSS is >0.14 N/m^2



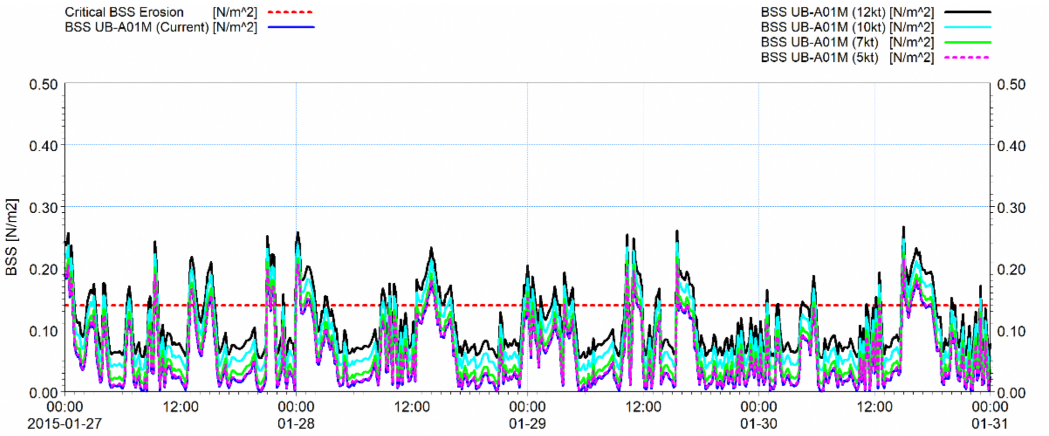


Figure 6.34 Time series of BSS generated by current (HD) and ship wake at Area 1 mangrove for Pulau Ubin shoreline (UB-A01M). Each line represents the calculated BSS caused by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2

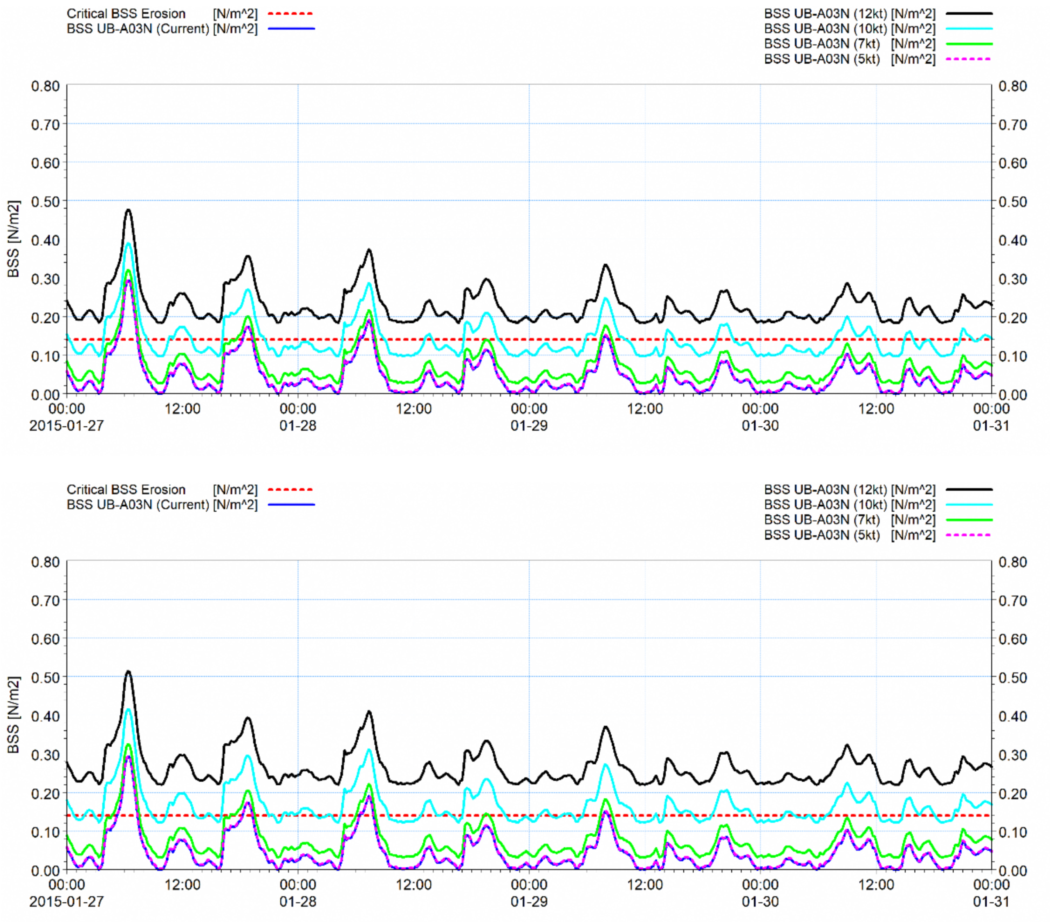


Figure 6.35 Time series of BSS generated by current (HD) and ship wake at Area 3 intertidal zone for Pulau Ubin shoreline (UB-A03N). Each line represents BSS at different vessel speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2

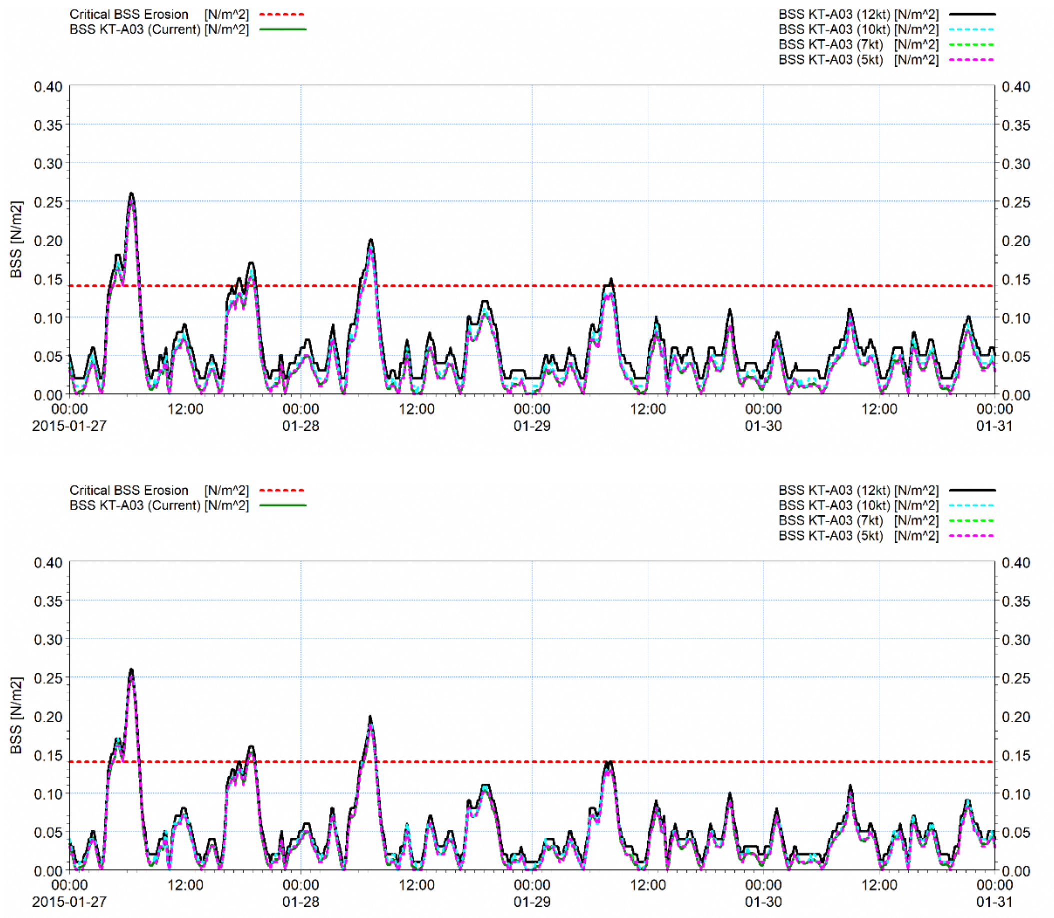


Figure 6.36 Time series of BSS generated by current (HD) and ship wake at Area 3 Pulau Ketam shoreline (KT-A03). Each line represents BSS at different vessel speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS >0.14 N/m^2

6.2.4 Ship Wake

Ship wake from the future vessels passing in and out in the channel between Pulau Ubin and Pulau Ketam region was modelled using DHI's MIKE 21 SW model. The detailed anticipated ship wake impacts (both ship wake heights and their erosional impact to different sections of the shoreline) were discussed (Section 6.2.3), with focus on extraction of ship wake heights near aquaculture receptors, and the effect of ship wake-induced erosion on presently eroding areas within the Ketam Channel. Limiting vessel speeds to 5 knots within the Ketam Channel is recommended to reduce potential erosion risk along the shorelines at Pulau Ubin and Pulau Ketam.

6.3 Propeller Wash-Induced Sediment Plume

The predicted increase in future vessel traffic plying along the boating channel between Pulau Ketam and Pulau Ubin may incur additional erosion/sedimentation of seabed sediments caused by the vessels' propeller wash in the boating channel. This would introduce additional suspended sediments into the water column and sedimentation in the vicinity of the project site. These sediments may disperse and settle at nearby sensitive receptors if not managed properly.

6.3.1 Relevant Key Receptors

The receptors that were considered sensitive to propeller wash-induced sediment plume include:

- Intertidal habitats;
- Mangroves; and
- Marine navigation.

6.3.2 Evaluation Framework

The modelling of propeller wash-induced suspended sediments was carried out with MIKE 21 Mud Transport (MT) module. The model used the project information (i.e., future vessel traffic, type, pathway, etc.) as input for the simulation to predict the level of impact to the nearby sensitive receptors. This section presents the methodology for assessing propeller wash-induced suspended sediments from future vessel traffic activities. Details of the propeller wash-induced sediment plume model setup are described in Appendix B.

Modelling Scenario

In this assessment, one (1) representative scenario was developed, and the production period for the sediment propeller wash modelling covered a period of 14 days, a single spring-neap tidal cycle. Since there was no significant difference in current speed during El Niño compared to La Niña year, the scenario was simulated during El Niño year and the northeast monsoon to cover the worst peak ebb/flood in currents that may affect the model results.

The simulated vessel trips were based on the routes shown in Figure 6.37, where vessels inbound/outbound from Changi Point Ferry Terminal to the ULL jetty are Bumboats, while vessels inbound/outbound from Punggol jetty to the ULL jetty are Ferries. The specific frequency, speed, and type of future vessel traffic assumptions correspond to the scenario described in Table 6.6. These values are much higher and hence more conservative, compared to the anticipated visits to the jetty, which is a maximum of two (2) visits a day during the school holiday and possibly zero (0) visits a day during the school term (Source: Client).

Table 6.6 Frequency, type, and speed of future vessel traffic assumption used as model input for the propeller wash assessment

Vessel	LOA (m)	Width (m)	Draft (m)	SOG (knots)	No. of Trips per Day
Bumboat	13.0	3.0	1	10	10 (Weekdays) 18 (Weekend)
Ferry	18.7	5.2	2.2	12	2 (Weekdays) 6 (Weekend)

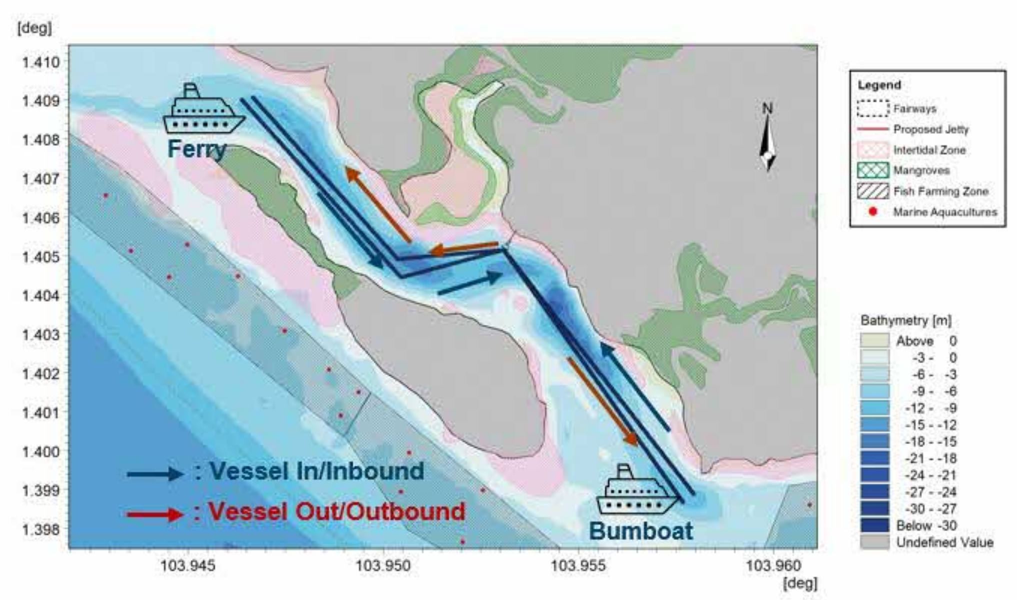


Figure 6.37 Vessel track for propeller wash-induced sediment modelling

A set of characteristics was selected to assess of sediment plumes from propeller wash impacts. These characteristics were chosen according to the tolerance limits of the relevant receptors against suspended sediments and erosion/sedimentation (Section 6.3.1).

Model Outputs

As the model ran for a 14-day period, the boats traversed their designated paths at the frequencies specified in Table 6.6, and the following statistical descriptors over a 14-day period were obtained:

- Mean and 95th percentile incremental SSC (mg/l);
- Percentage of time SSC concentrations exceeding 5 mg/l; and
- 14-day erosion/sedimentation (mm/14-day).

6.3.3 Results and Discussion

This section presents and discusses propeller wash-induced sediment plume model results in terms of suspended sediment concentration (SSC) and erosion/sedimentation rates.

Suspended Sediment

Propeller wash-induced sediment model results are presented in Figure 6.38 to Figure 6.40. Figure 6.38 and Figure 6.39 shows the mean and 95th percentile incremental SSC respectively, while Figure 6.40 illustrates the percentage of time in exceedance of 5 mg/l for SSC.

Overall, propeller wash-induced suspended sediment from future vessel traffic activities were predicted to be minimal and localised along the vessel tracks and areas around the proposed jetty. It was evident from the model plots that incremental mean and 95th percentile SSC will be less than 5 mg/l throughout the model domain.

The model predicted that a small extent to the east of the jetty would experience mean incremental SSC of up to 0.02 mg/l and there would be no more than 0.01 mg/l increase in mean SSC in the rest of the study area. Sungei Puaka and the southern shoreline of Pulau Ubin around the Project will likely be exposed to 0.02 mg/l incremental 95th percentile SSC, with some localised areas to 0.06 mg/l. There is no more than 0.01 mg/l change in 95th percentile SSC in the rest of the study area. The percentage of time that incremental SSC exceeded 5 mg/L was predicted to be 0%.

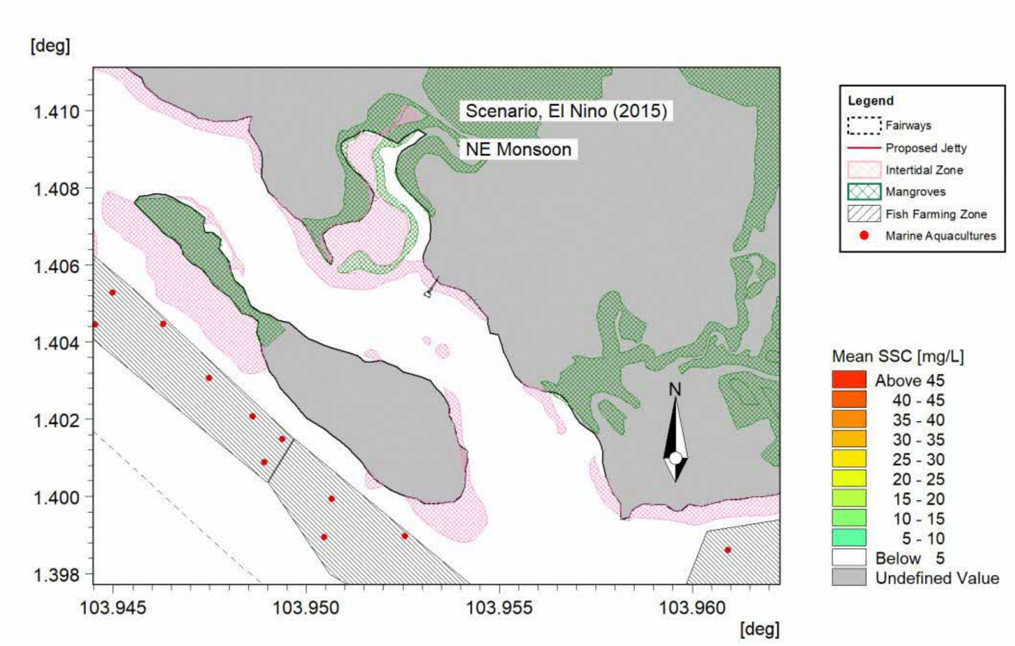


Figure 6.38 Mean incremental SSC from the future vessel traffic activities during El Niño year, NE monsoon

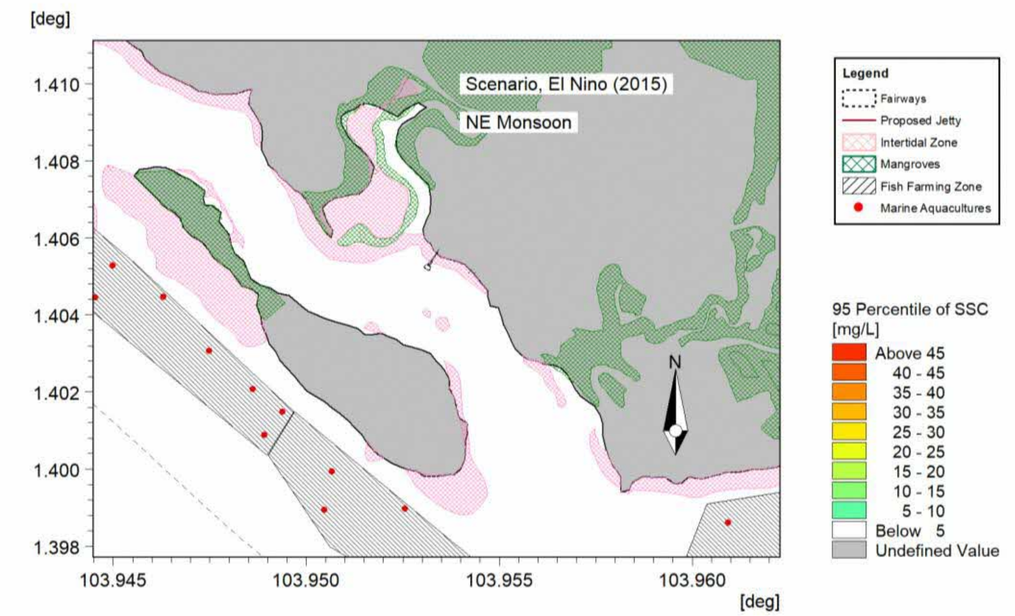


Figure 6.39 95th percentile incremental SSC from the future vessel traffic activities during El Niño year, NE monsoon

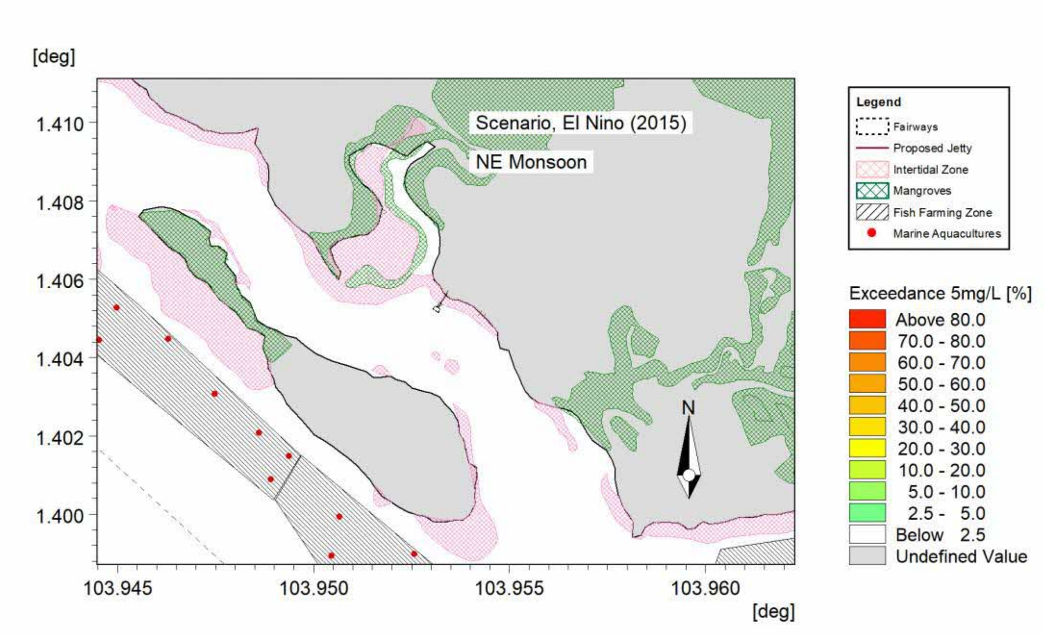


Figure 6.40 Percentage of time in exceedance of 5 mg/l for SSC from the future vessel traffic activities during El Niño year, NE monsoon

Erosion/sedimentation

The prolonged presence of sediment-induced propeller wash may result in settling sediments in another area causing erosion/sedimentation beyond the Project area. Therefore, a related parameter to assess the erosion/sedimentation is in terms of total bed thickness change (in mm/14-days).

Figure 6.41 shows the total bed thickness change resulting from the forthcoming vessel traffic activities for a period of 14 days. Sedimentation change is shown as positive values, whereas negative values indicate changes in erosion. Overall, the rates of erosion/sedimentation are minimal and localised along the vessel tracks and areas around the proposed jetty. Predicted sedimentation rates are up to 0.018 mm/14-day towards the east and west of the proposed jetty. Erosion is expected to occur along the vessel track at a rate of up to 0.045 mm/14-day and around 1 mm/year. Due to the deeper drafts of ferries, the ferry vessel track is anticipated to experience more significant erosion compared to the bumboat vessel track in shallower water depths in that region.

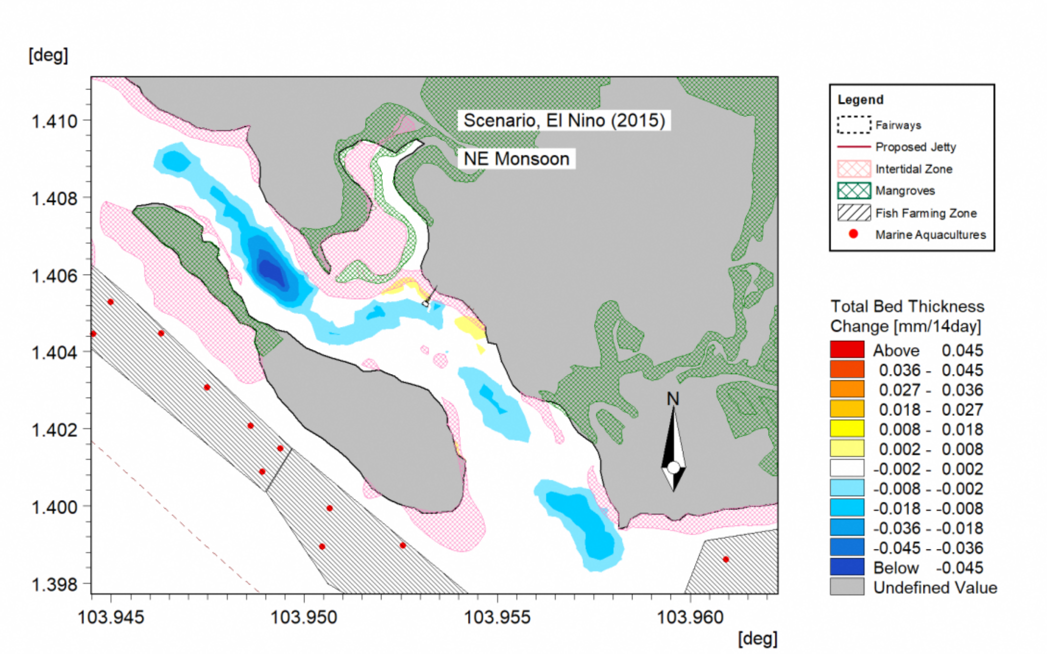


Figure 6.41 Total bed thickness change from the future vessel traffic activities during El Niño year, NE monsoon. Positive (yellow to red colour) and negative (blue colour) values indicate changes in sedimentation and erosion respectively

6.3.4 Propeller wash-induced Sediment Plume Summary

Propeller wash-induced sediment plume due to the future vessel traffic activities passing in and out of the channel between Pulau Ubin and Pulau Ketam was modelled using DHI's MIKE 21 MT model. Simulations showed that the propeller wash from the future vessel traffic would result in a localised and minimal plume. Changes in the maximum SSC (95th percentile), percentage time of SSC exceeds 5 mg/l, and increase in erosion/sedimentation is considered low in the vicinity of the jetty and the vessel tracks.

6.4 Marine Biodiversity and Shorelines

This section will cover the long-term impacts of the proposed jetty on the marine ecology and biodiversity around the Project site, including any direct footprint impacts and anticipated long-term sediment plume, erosion or sedimentation impacts.

6.4.1 Relevant Key Receptors and Pressures

Relevant key receptors groups within marine ecology and biodiversity during the operational phase of the proposed jetty at ULL include:

- Intertidal areas and sensitive shorelines;
- Mangrove habitat; and
- Macrobenthos.

The following sources of "pressure" on sensitive receptors in the marine ecosystem have been assessed:

- Project footprint;
- Propeller wash-induced sediment plume due to future additional vessel traffic;
- Potential pollutant release from propeller wash-induced suspended sediments;
- Erosion/sedimentation due to hydrodynamic changes or ship wake; and
- Lighting impacts.

6.4.2 Evaluation Framework

The relevant evaluation criteria for marine ecology and biodiversity are the same as in the Construction Phase, outlined earlier in Section 5.7.2.

6.4.3 Results and Discussion

During the operation, or Post-Construction, phase of the proposed jetty at ULL, the anticipated long-term impacts would come from the direct footprint of the jetty as well as the longer-term changes to known sensitive shoreline. These include erosion or sedimentation which may result from long-term hydrodynamic changes, and from propeller wash-induced sediment plumes and ship wake caused by new boating traffic (including larger boats as well as their increased frequency) to and from the newly operational jetty.

The Importance scores for the specific marine ecology and biodiversity receptors are outlined earlier in Section 5.7.3 (the same scores as during the Construction Phase).

Direct Footprint Impacts on Marine Ecology and Biodiversity

There will be a direct loss of intertidal, subtidal and macrobenthos communities directly within the footprint of the jetty. This area will be less than 200 m^2 (including about 90 m^2 of intertidal area); the size of the jetty is small, and the berthing pontoon will be a floating structure. The direct impact areas will be around the four (4) marine piles and the gangway, a small, localised loss. One main concern of direct footprint impact was whether corals or seagrass in the subtidal areas would be negatively impacted. The dive survey results in Section 5.7.1.2 showed no significant coral or seagrass communities. Individual corals and a small patch of seagrass were found outside the direct footprint of the jetty. However, some Conservation Significant (CS) species were detected (Section 5.7.1.20). As a result, the impact significance of direct footprint impact on marine ecology and biodiversity is **Slight Impact**.

Propeller Wash-induced Sediment Plume Impacts on Marine Ecology and Biodiversity

Future vessels are anticipated to wash up sediments from intertidal and subtidal areas, increasing the suspended sediment concentration (SSC) of the waters. The predominant mode of this increase is thought to be via the propellers of the increased shipping traffic to the new jetty. This could negatively impact the already sensitive shoreline around Pulau Ubin and Pulau Ketam.

The mean and 95th percentile SSC contributed by propeller wash was predicted to be up to 0.02 mg/l and 0.06 mg/l respectively (in the immediate vicinity of the ULL jetty), which is very low. The model also predicted no exceedance over 5 mg/l. Hence, the impact significance of propeller wash-induced SSC on marine ecology and biodiversity is **No Impact**.

Impact of Pollution Release on Water Quality

Due to the detection of exceedance of Arsenic (compared with the MPA dumping guidelines, Section 5.3.4) in the sediment, pollution release from propeller wash-induced sediment plume was calculated and evaluated. As seen from the calculation results in Table 6.7 below, due to the very low suspended sediment concentrations predicted, none of the calculated heavy metal content in the waters exceeded the ASEAN MWQC. As a result, the impact significance of pollutant release into waters as a result of the sediment plume is **No Impact.**

Table 6.7 Calculated heavy metal content at the specific marine ecology and biodiversity receptor during the jetty Post-Construction Phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection.

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content In Water (µg/l)	ASEAN MQQC
Mangroves Habitats	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*
Intertidal Areas	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*
Macrobenthos	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content In Water (µg/l)	ASEAN MQQC
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*
Subtidal Habitats	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*

*Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

Morphological Impacts on Nearby Shorelines

According to previous studies, Pulau Ubin, particularly its northern shores, is experiencing significant erosion. As such, one of the concerns is that shoreline erosion and sedimentation dynamics could potentially be affected by long-term hydrodynamic changes, or ship wakes and propeller wash from the anticipated increase in size and frequency of ships that will be entering the Ketam Channel to utilise the proposed jetty at ULL.

From the results of hydrodynamics modelling (detailed in Section 6.1.4), the change in mean and 95th percentile bed shear stress (BSS) was predicted to be less than 0.01 N/m^2 and 0.05 N/m^2 respectively, which would result in an impact significance of **No Impact.**

From the results of the propeller wash modelling (detailed in Section 6.3.3), most of the values were relatively low, i.e., sedimentation and erosion rates of 0.018 mm/14-day and 0.045 mm/14-day, respectively. As these values will not be detectable on-site, they would result in an impact significance of **No Impact**.

While the ship wake height analysis was carried out for four (4) different vessel speeds, this impact assessment will only be for the 5 and 7 knots scenarios (Section 6.2.3). This is due to cross-checking with the AIS data, which showed that the mean and maximum (95th percentile) boat speeds were 4.5 knots and 6.2 knots, respectively (Section 6.6.1). As such, 5 and 7 knots are the most reasonable scenarios to be assessed. For the bed shear stress (BSS) generated by ship wakes, only selected points of BSS data were extracted, and depending on the sensitive receptor under consideration, only selected points were assessed.

Ship Wake Impacts on Intertidal Areas and Sensitive Shorelines

The intertidal areas around the proposed jetty at ULL are anticipated to experience ship wake heights of a maximum of 0.16 m for the Pulau Ubin shoreline and 0.40 m for the Pulau Ketam shoreline. Values of up to 0.4 m have been previously documented in Singapore's waters in areas of heavy boat traffic (Browne et al., 2017), so these values are not considered high.

Table 6.8 Maximum ship wake height created by vessels for 5 and 7 knots at the respective shorelines around the proposed jetty at ULL

Shoreline	5 Knots	7 Knots
Pulau Ubin shoreline	Up to 0.16 m	Up to 0.40 m
Pulau Ketam shoreline	Up to 0.16 m	Up to 0.32 m

For the resultant BSS, the relevant extraction points are UB-A02 and UB-A03, KT-A01 to KT-A03, as these points are located near or over intertidal areas around Ketam Channel. Most of the chosen extraction points did not exceed the critical BSS threshold for erosion (τ_c) of 0.14 N/m^2, except for UB-A03 and KT-A03. At UB-A03, the risk of erosion of the shoreline increases with vessel speed (Section 6.2.3), from 7 knots or higher. At KT-A03, the trend is slightly different. At this location, baseline BSS was already exceeding τ_c during certain times of the day, likely contributing to the erosion over time there, as seen from the shoreline survey results. The ship wakes created by travelling boats through this area were found not to increase the BSS above baseline levels significantly. As such, the intertidal area around UB-A03 would likely experience 'Minor Changes' from the erosion effects from ship wakes, giving an impact significance of **Slight Impact**.

Ship Wake Impacts on Mangrove Habitats

Similar to the intertidal areas, the mangrove areas around the proposed jetty at ULL are anticipated to experience ship wake heights of a maximum of 0.16 m for the Pulau Ubin shoreline and 0.40 m for the Pulau Ketam shoreline. As mentioned previously, these values are low.

For the BSS, the relevant extraction points are UB-A01 and UB-A02, KT-A03, as these points are located near or over mangrove habitat areas around Ketam Channel. BSS for UB-A02 was below τ_c. While BSS for KT-A03 was above τ_c at some points in time, ship wakes from boats, regardless of speed, did not significantly increase the BSS above baseline levels. However, UB-A01 has a high risk of erosion caused by ship wakes from passing ships/boats (Section 6.2.3). This is because, as seen in Figure 6.34, passing boats of above 5 knots will increase the proportion of time at which BSS > τ_c, which increases the risk of shoreline erosion in that area. In addition, there is clear evidence of erosion in this part of the coastline from baseline studies.

However, it is important to note that the modelling methodology is a conservative assessment, as it examines the potential change to BSS of a single boat (travelling at a specified speed), assuming it to be consistent across a period of time (i.e., 14 days). Two key points can be observed from the methodology and the results: 1) Figure 6.34 to Figure 6.36 show BSS over two weeks, whereas in reality, a boat traveling through the Ubin-Ketam channel will induce the modelled BSS for a few minutes at most; and 2) vessel speed, and not frequency, is the major factor affecting impacts to sensitive habitats. As a result, it was assessed that the anticipated changes to mangrove areas are likely 'Minor', giving an impact significance of **Moderate Impact**; and the mitigating measure of controlling vessel speed was selected and elaborated upon below (Section 6.4.4).

Lighting Impacts on Marine Fauna

As with most developments, lighting at night is required at the jetty in order to maintain safety and security. At the time of writing, the development team was in the midst of confirming the lighting requirements for the ULL Jetty. Due to this, the team has made the following assumptions to encompass the worst-case impact scenario. The assumptions are as follows: (1) the lighting at the jetty is proposed to be 24 hours (i.e., the lights are lit even in the night from 7pm to 7am); (2) the entire jetty including the gangway is going to be lit up by floodlights and; (3) an approximate area of 500 m^2 estimated at the Ubin-Ketam Channel will also be lit up for security reasons.

Whilst there are minimum criteria for maintaining a level of safety and security for humans, there are no maximum criteria with respect to lighting impacts on marine wildlife. Studies into the impacts of lighting for marine fauna are still in the preliminary stages as well (Convention on Migratory Species (CMS), 2020). This literature base is growing, and challenges remain for elucidating ecosystem-wide effects from studies that are often conducted on much smaller-scales (CMS, 2020).

For marine systems, artificial light is primarily known to disrupt the diel vertical migration (DVM) of zooplankton, likely affecting food chains and predation interactions (Gibson et al., 2016). Other aspects of light impacts on fauna include affecting reproductive and predatory dynamics, through altering phenology and/or success rates (Davis et al., 2014; Brüning et al., 2018). The severity and nature of these impacts are dependent on many factors such as proximity, intensity and duration of the light sources, baseline community composition and natural light levels (Commonwealth of Australia, 2023).

From the assumption mentioned above, 24-hour, direct floodlight lighting would definitely result in a change to the original ambient, natural lighting over the marine waters (which typically experience low ambient light levels). There would, therefore, be a degree of influence on the behaviour in the waters around the ULL jetty. As such, the anticipated changes of the lighting at the jetty are likely “Minor”, giving an impact significance of **Slight Negative**. Due to the permanence and potential cumulative impact of this, mitigation measures are suggested below in Section 6.4.4.

6.4.4 Mitigation Measures

DHI’s prior understanding was that the previous Ubin and Ketam shoreline studies (SJ, 2015 & 2016) had made recommendations for shoreline protections, which would subsequently be implemented. Similar measures were hence initially adopted as part of the mitigation measures for this EIA. There was also uncertainty regarding the implementation of boat speed limit within the channel. Subsequently, DHI consulted with the Marine Port Authority (MPA) on 06 June 2023 for a comprehensive set of measures to take for the control of boat speeds within the Ubin-Ketam Channel, in an attempt to ensure that it is adhered to during the operation of the ULL Jetty.

Minimising Occurrence of High Ship Wakes

One of the mitigation measures proposed for controlling the ship wake heights (and subsequently limiting the rate of erosion of sensitive mangroves or shorelines in the vicinity) is the limitation of ships travelling speeds to 5 knots and below. This is because the BSS of the surrounding shorelines does not increase above the baseline when boats travel at speeds of 5 knots and under. While there was initial uncertainty regarding the implementation of this measure, discussions with the client and MPA have confirmed that this was the most practical and reasonable way forward for the development.

The following measures are suggested:

- post up large signages at and around the new jetty showing the recommended speed limit of 5 knots
- Work with boatmen from Changi Point Ferry Terminal and Punggol Marina (with MPA’s assistance), emphasising the new speed limit along the proposed jetty route and around the new jetty.

After implementation of the above suggested measures, the anticipated Magnitude of Change is expected to decrease by 1 for each receptor (mangroves and sensitive shorelines), giving impact significance between **No Impact to Minor Negative Impact**.

Mitigating Lighting Impacts on Marine Ecology

More recently, guidelines for light pollution are emerging, such as the Conservation of Migratory Species Light Pollution Guidelines for Wildlife (UNEP/CMS/13.5; 2022) and Australia's National Light Pollution Guidelines for Wildlife (Commonwealth of Australia, 2023).

In general, the following best practices shall be followed when designing outdoor lightings:

1. Start with natural darkness and only add light for specific purposes.
2. Use adaptive light controls to manage light timing, intensity and colour (potentially explore motion-sensitive lights)
3. Light only the object or area intended – keep lights close to the ground, directed, and shielded to avoid light spill.
4. Use the lowest intensity lighting appropriate for the task.
5. Use non-reflective, dark-coloured surfaces.
6. Use lights with reduced or filtered blue, violet and ultraviolet wavelengths. For example, Carr (2021) recommends the use of red (longer wavelength) light as it attenuates faster in water and is not detected as easily by marine organisms.

6.4.5 Marine Biodiversity and Shorelines Impact Summary

The Post-Construction Phase impacts from the operations of the ULL jetty on Marine Biodiversity and Shorelines have been summarised in Table 6.9.

Table 6.9 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine biodiversity and shorelines' receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Project Footprint	Intertidal areas and macrobenthos	1	-2	3	2	2	-14	Slight Negative Impact	-	-	-
Sediment Plume from Propeller Wash	Intertidal areas	1	0	3	2	2	0	No Impact	-	-	-
	Mangrove habitat	5	0	3	2	3	0	No Impact	-	-	-
	Marine fauna (including fish)	2	0	3	2	2	0	No Impact	-	-	-
Erosion/ Sedimentation due to Hydrodynamic Changes or Propeller Wash	Intertidal areas (including sensitive shorelines)	2	0	3	3	3	0	No Impact	-	-	-
	Mangrove habitat	5	0	3	3	3	0	No Impact	-	-	-
Erosion/ Sedimentation due to Ship Wake	Intertidal areas (including sensitive shorelines)	2	-2	3	3	3	-36	Slight Negative Impact	-1	-18	Slight Negative Impact

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Mangrove habitat	5	-2	3	3	3	-90	Moderate Negative Impact	-1	-45	Minor Negative Impact
Change in light environment	Marine Fauna	2	-2	3	2	3	-32	Slight Negative Impact	-1	-16	Slight Negative Impact

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

6.5 Terrestrial Biodiversity

6.5.1 Relevant Key Receptors and Pressures

The key receptor groups for terrestrial ecology and biodiversity include

- Terrestrial Flora; and
- Terrestrial Fauna.

The following sources of "pressure" on sensitive receptors in the terrestrial ecosystem have been assessed:

- Project footprint; and
- Lighting impacts.

6.5.2 Evaluation Framework

The relevant evaluation criteria for terrestrial ecology and biodiversity are the same as in the Construction Phase, outlined earlier in Section 5.8.2.

6.5.3 Results and Discussion

At the Operation, or Post-Construction, phase of the proposed jetty at ULL, the anticipated long-term impacts would come from the direct footprint of the jetty onto the terrestrial systems present around. For this Project, the key impact is the loss of flora around the jetty footprint. The Importance scores for the specific marine ecology and biodiversity receptors are outlined earlier in Section 5.8.3.

The Importance score for Terrestrial Flora for this section is a '3' due to the small impact area on flora due to the jetty operation (See Section 2.2), and the presence of a conservation significant species.

Direct Footprint Impacts on Terrestrial Flora

There is anticipated direct loss of flora in areas proposed to establish the jetty and conduct earthworks and some surrounding areas. These areas are a small subset of the present coastal edge forest and managed vegetation within the ULL. Only one Conservation Significant (CS) species was detected within this area – one individual of *Crinum asiaticum*, which is likely of cultivated origin. Hence, the impact significance of the ULL jetty on terrestrial flora is **Slight Impact**.

Lighting Impacts on Terrestrial Fauna

As mentioned in Section 6.4.3, a number of assumptions were made for the lighting operations of the ULL jetty, to account for the worst-case situation for this impact assessment. From these assumptions, the impact of additional lighting in the area on terrestrial fauna is assessed. At present, the ULL area is occasionally used by campers and hence, lit up in the night via typical street lighting for safety reasons. Once the ULL jetty comes into operation, the floodlights will introduce a slightly brighter lighting that could influence terrestrial fauna. However, given the attenuation of elevated ambient light levels with distance, the affected habitats or feeding grounds of terrestrial fauna is expected to be highly spatially limited. Moreover, the direction of lighting installed will be towards the jetty or facing the sea.

Nonetheless, the elevated ambient light levels during nocturnal hours could potentially affect the behaviour or spatial distribution of nocturnal fauna species, which were recorded from baseline surveys or are known from previous studies to inhabit the area. These fauna include the Black-crowned Night Heron, which feed mainly during nocturnal hours on intertidal areas. Besides resulting in potential avoidance from light-intolerant species, the attraction of insects and light-tolerant species can occur, potentially altering prey-predator dynamics, e.g., insects and hence insectivorous bats can be attracted to artificial light sources. Taken together, the Magnitude of Change to terrestrial fauna from lighting impacts is anticipated to be “Slight”, resulting in a **Slight Negative** impact.

The implementation of best practice lighting guidelines is recommended to ensure the impacts are restricted (see below).

6.5.4 Mitigation Measures

There is the option of relocating the one individual *C. asiaticum*, to another location where the construction works will not impact it. Note that this mitigation action will not change the Magnitude of Change, as it is only a single individual of the numerous other flora that will be lost due to the project footprint; hence the impact significance remains at **Slight Impact**.

Mitigation measures for minimising the impact of lighting on terrestrial fauna are similar to those for marine fauna and are outlined in Section 6.4.4. More specifically for terrestrial fauna (e.g., avifauna and insects), are guidelines such as The Interim Guidance: Recommendations to Help Minimise the Impact Artificial Lighting (Bat Conservation Trust, 2014) and Singapore’s Land Transport Authority (LTA)’s recommendations for street lighting (LTA, 2019).

From the former, in addition to similar measures suggested in Section 6.4.4, they have more specific recommendations for wavelengths of light to be used, including:

- Usage of narrow spectrum light sources to lower the range of species affected by lighting
- Usage of light sources that emit minimal ultra-violet light
- Avoid white and blue wavelengths of the light spectrum to reduce insect attraction and where white light sources are necessary, they should be of a warm / neutral colour temperature <4,200 kelvin in order to manage the blue short wavelength content
- Lights used should peak higher than 550 nm

The Interim Guidance’s recommendations are also concurred by the guidelines published by Bruce-White & Shardlow (2011) (Buglife), which has further details and recommendations that are more specific to invertebrates. Invertebrates form the base of terrestrial food webs and hence any impacts to them also have knock-on effects across ecological trophic levels.

LTA local street lighting guidelines are found in Table 6.10 below.

Table 6.10 LTA Guidelines for public street lighting.

Road Lighting Levels		
Type of Roads	**Minimum Average Illuminance (at floor level)**	
Expressway and Major Road	20 lux	
Expressway and Major Road conflict area	1.5x (e.g., 30 lux)	
Minor and Residential Road	10 lux	
Minor and Residential Road conflict area	1.5x (e.g., 15 lux)	
Footpath Lighting Levels		
Type of Footpath	**Minimum Average Illuminance (at floor level)**	**Uniformity**
Alongside with public streetlights (without dedicated footpath lightings)	5 lux	NA
Footpath (with dedicated footpath lightings)	10 lux	0.25

6.5.5 Terrestrial Biodiversity Impact Summary

The Post-Construction Phase impacts from the operations of the ULL jetty on Terrestrial Biodiversity receptors have been summarised in Table 6.11.

Table 6.11 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine ecology and biodiversity receptors

Predicted Impact	**Sensitive Receptors**	**Predicted Impacts Without Mitigation Measures**							**With Mitigation Measures**		
		I	**M**	**P**	**R**	**C**	**ES**	**Impact Significance**	**M**	**ES**	**Impact Significance**
Project Footprint	Terrestrial Flora	3	-1	3	2	2	-21	Slight Negative impact	-1	-21	Slight Negative impact
Change in light environment	Terrestrial Fauna	4	-1	3	2	2	-28	Slight Negative Impact	-1	-28	Slight Negative Impact

6.6 Marine Navigation

6.6.1 Relevant Baseline Features, Key Receptors and Pressures

The following key receptors for marine navigation include:

- Boating channel between Pulau Ketam and Pulau Ubin; and
- Serangoon Harbour (navigation channel).

To evaluate the long-term impacts of post-construction operational activities from the development of the ULL jetty, the following “pressures” were assessed:

- Hydrodynamic changes; and
- Sedimentation.

Baseline data for marine navigation is obtained from the Automatic Identification System (AIS), an automatic tracking system used on ships for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations and satellites. The International Maritime Organization’s International Convention for the Safety of Life at Sea requires AIS to be fitted aboard all international voyaging ships with gross tonnage (GT) of 300 or more and all passenger ships regardless of size. As such, this data is often used to understand the pre-existing vessel traffic within a study area.

6.6.1.1 Environmental Baseline

AIS data from 2019 was chosen as this was prior to the COVID-19 pandemic and would have been more representative of typical boating traffic compared to post-COVID-19 (2020 or 2021).

The AIS data packet includes the following information:

- Vessel identity (Maritime Mobile Service Identity [MMSI]);
- Vessel spatial properties (heading, position, speed);
- Vessel temporal properties (time);
- Vessel physical properties (length overall (LOA), beam, draught); and
- Vessel class (general class type (e.g., tanker), hazard type).

The chosen area to extract more detailed AIS data was the Ketam Channel and boating areas to the north up until the Outward Bound Singapore (OBS) Jetty (the black polygon in Figure 6.42). Additional data that was processed include vessel sizes, frequency, speed (e.g., Speed Over Ground (SOG)) and type.

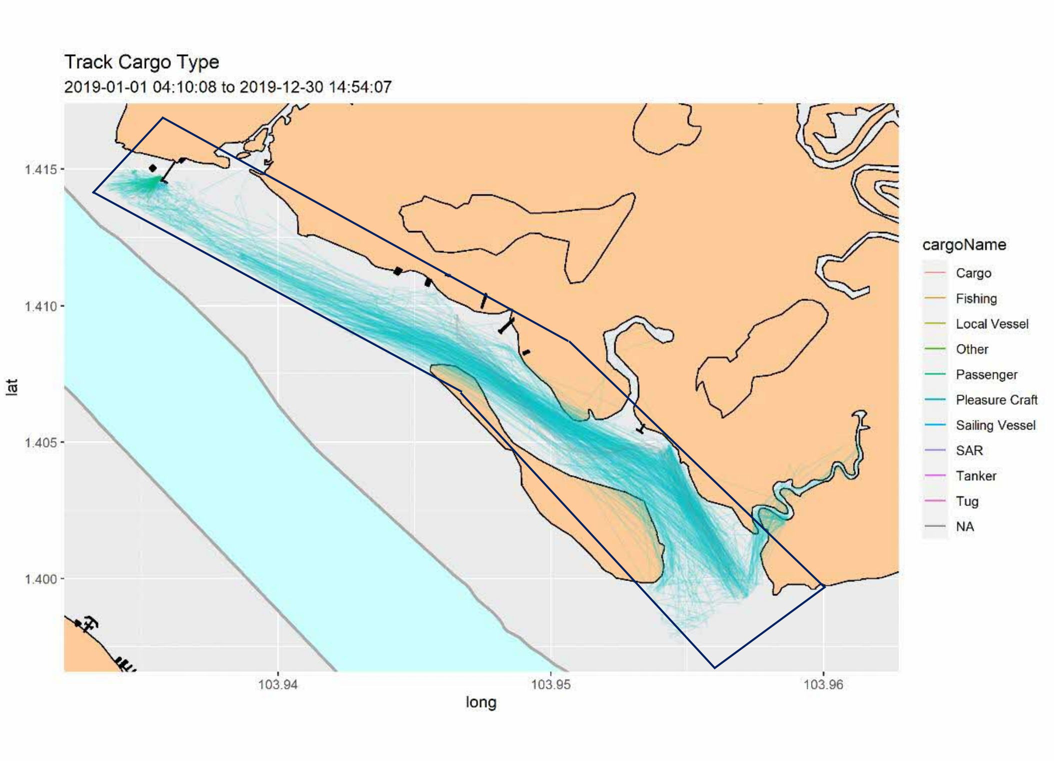


Figure 6.42 The black polygon indicating the area where the subset AIS data around the Project area was extracted for more detailed analyses

Vessel Traffic

Results of AIS data extracted from the 2019 period are presented in Figure 6.43 to Figure 6.47. Figure 6.43 and Figure 6.44 show graphics depicting mean SOG and LOA, respectively, of the subset data obtained from within the black polygon presented in Figure 6.42. The distribution of vessel LOA vs SOG and vessel type vs SOG are displayed in Figure 6.45 and Figure 6.46, respectively. Figure 6.47 shows the total number of vessels' tracks for each month in 2019 within the subset AIS data.

The vessels in this area are primarily small vessels of LOA < 50 m (85 % with LOA <18 m) and are largely pleasure crafts with a mean SOG of 4.5 knots, as shown in Figure 6.44 and Figure 6.46. Additionally, most vessels recorded to be travelling at SOG of >12 knots were dominated by smaller vessels, i.e., pleasure crafts and fishing vessels with LOA of <13 m (Figure 6.45 and Figure 6.46).

The statistics for passenger vessels (excluding vessels at berths) are reported to be 2.1 knots for the median SOG and 6.2 knots for the 95th percentile of SOG. These provide insight into the typical and maximum speeds of passenger vessels in the Project area and can be useful in assessing factors such as travel time and potential risks associated with these vessels. The total frequency of vessels passing along the Ketam Channel is less than 500 trips/month, which can be categorised as a non-busy route (Figure 6.47). It was noted from stakeholder engagements there have been observations of boats travelling in excess of 10 knots in the Ubin-Ketam Channel.

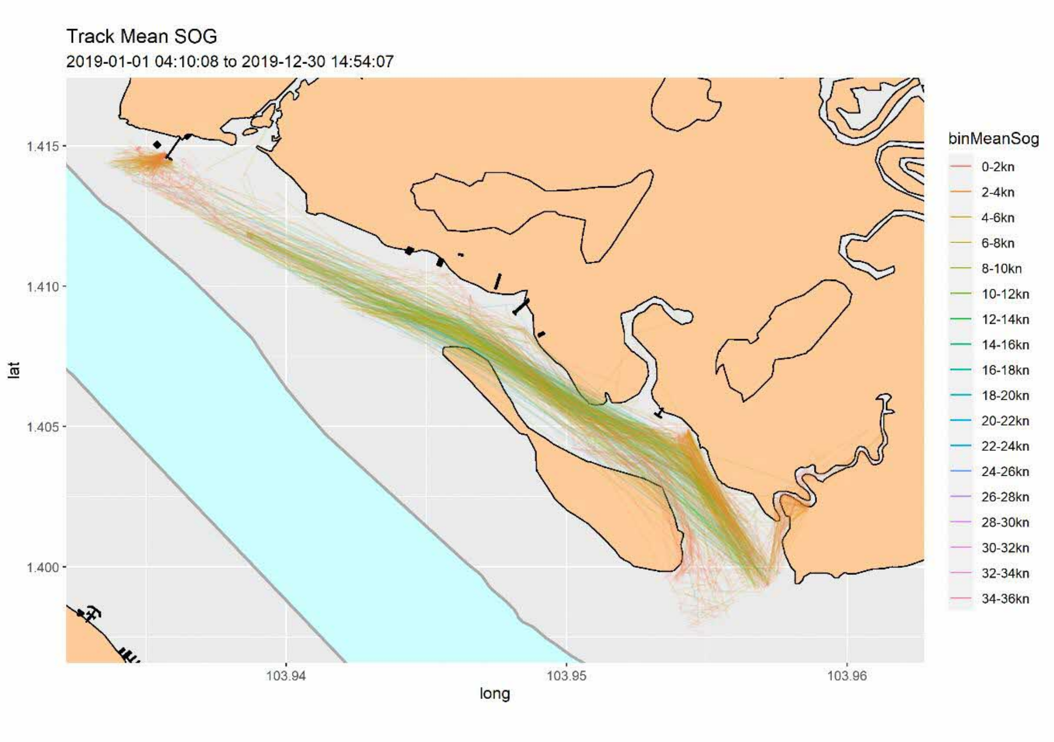
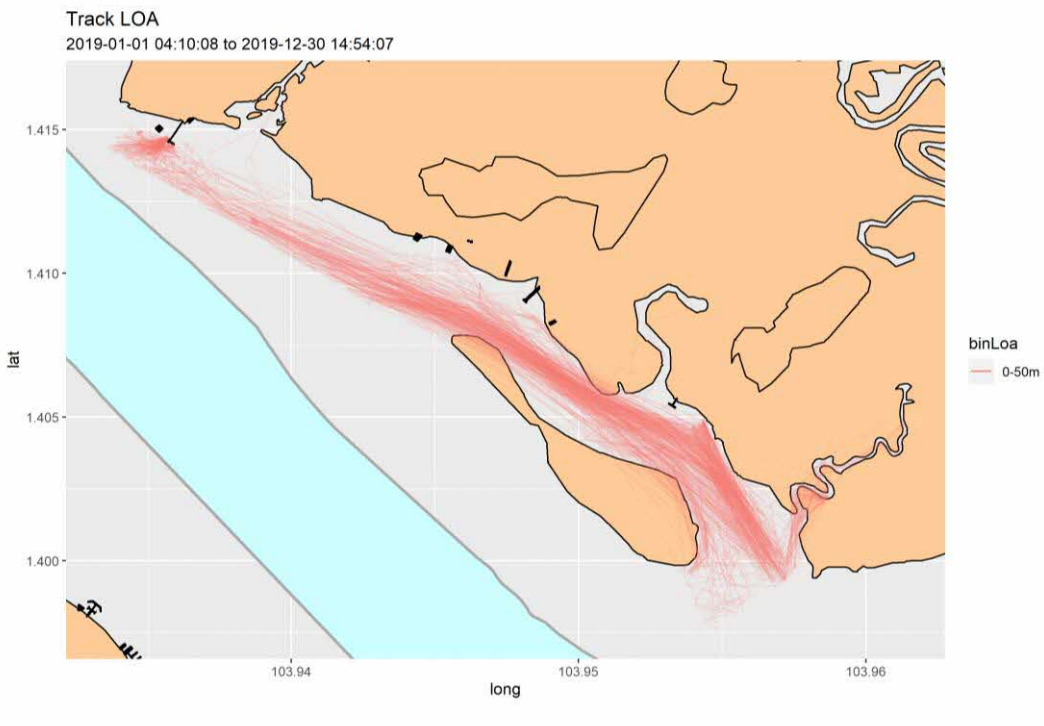


Figure 6.43 Distribution of vessel tracks based on mean Speed Over Ground (SOG) from the subset 2019 AIS data



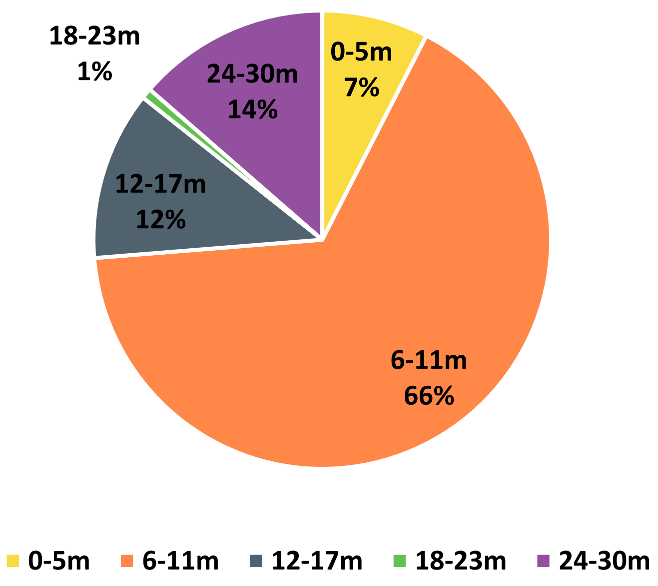


Figure 6.44 Distribution of vessel tracks (top) and percentage (bottom) based on Length Overall (LOA) from the subset 2019 AIS data

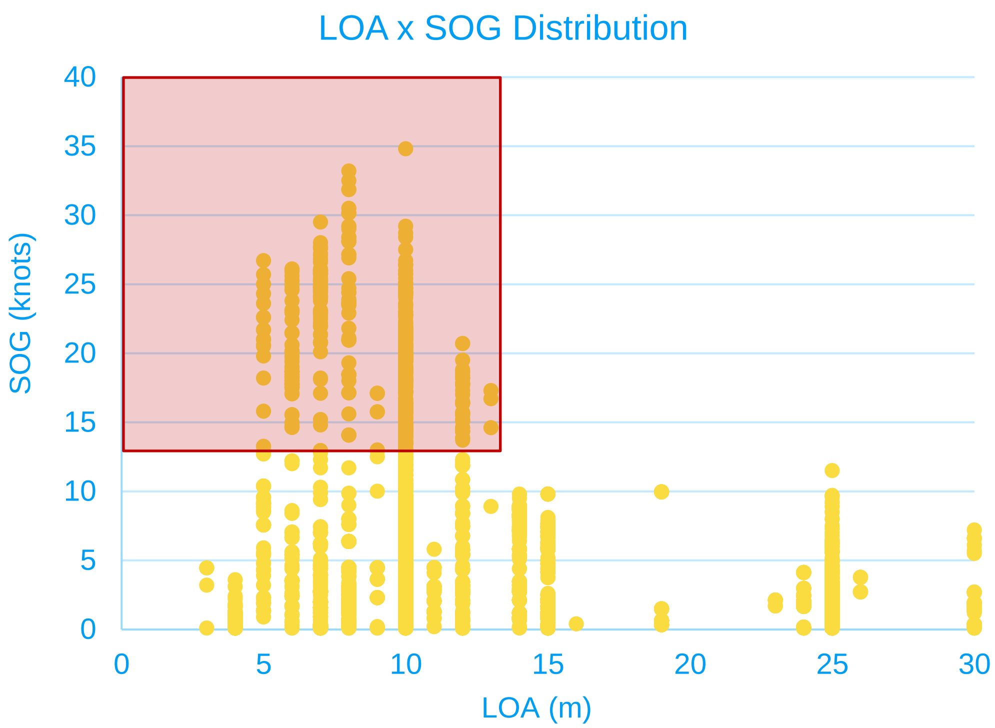


Figure 6.45 Distribution of vessel Length Overall (LOA) and Speed Over Ground (SOG) from the subset AIS data. The red box indicates typical vessel sizes, with LOA of <13 m, for SOG >12 knots

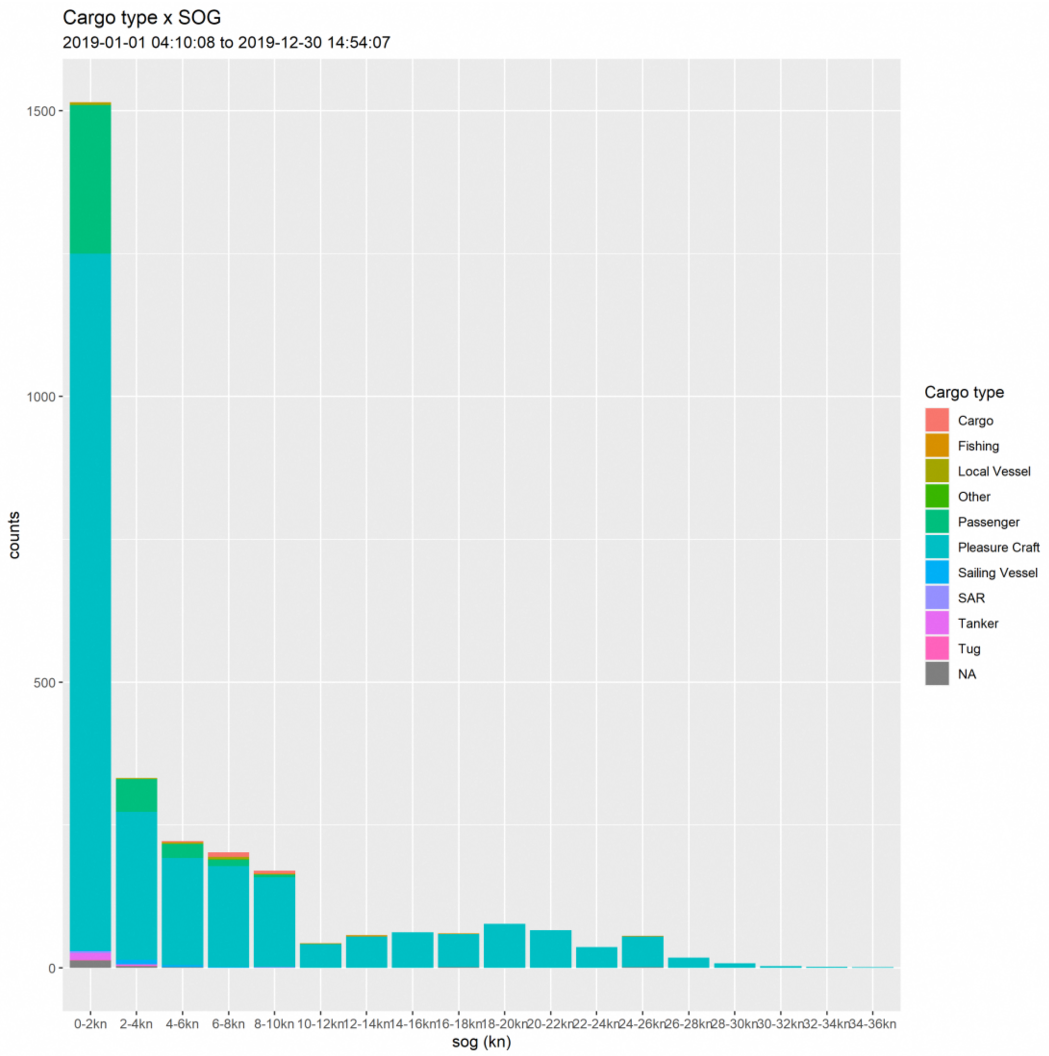


Figure 6.46 Distribution of vessel type and Speed Over Ground (SOG) from the subset AIS data

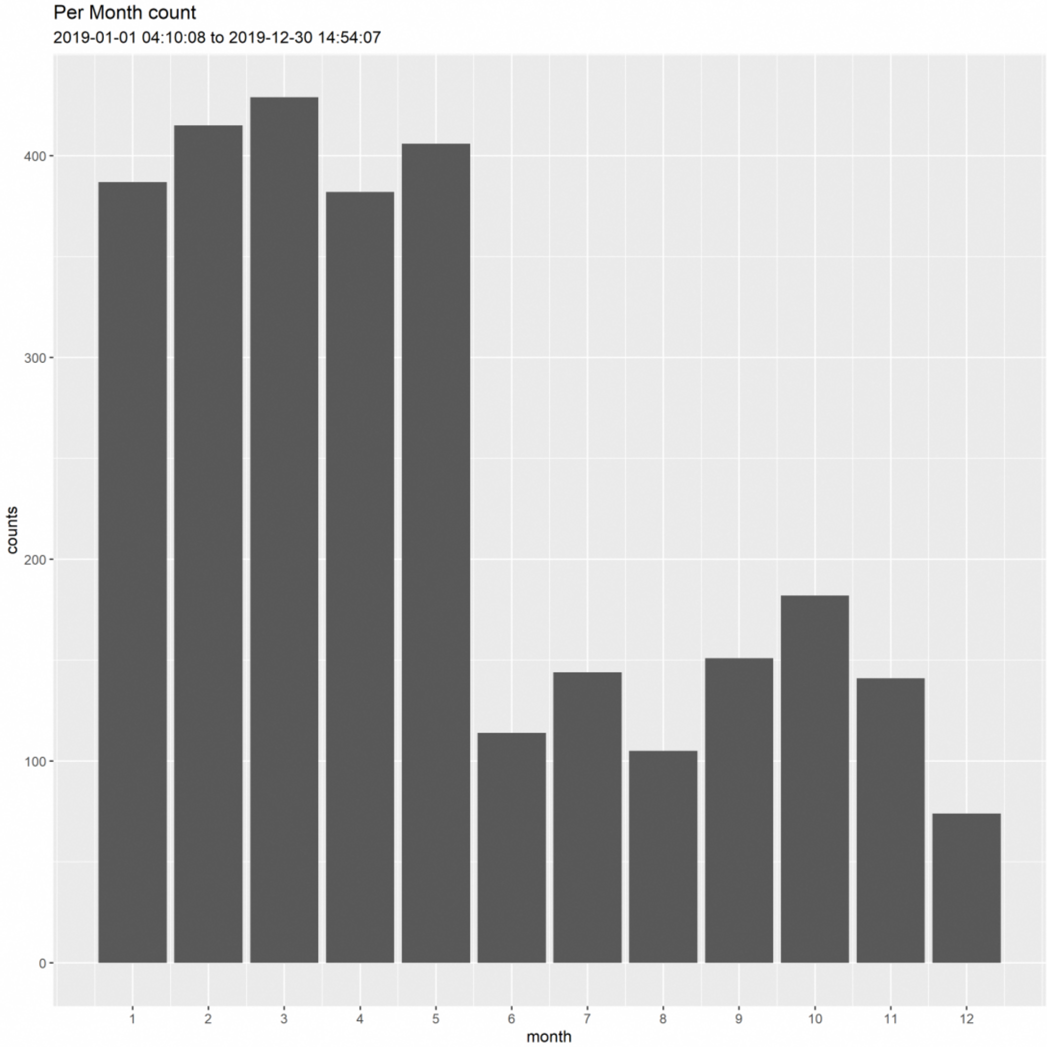


Figure 6.47 Distribution of the total number of vessels' tracks per month in 2019, obtained from the subset AIS data

6.6.2 Evaluation Framework

Hydrodynamic Changes

The evaluation framework for the impact assessment of changes to currents is described previously in Section 5.9.2.

Sedimentation

Navigation channels and berthing areas 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 difficult, with a potential measurable change typically being taken as about 150 mm. For this Study, 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 6.12.

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 they realised impacts for changes in the order of 10 mm/year or less. Whilst standard practice cannot support 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 in the application of the proposed tolerance limits for EIA/ES purposes.

Table 6.12 Tolerance limits for marine infrastructure to excess (i.e., in addition to background) sedimentation

Magnitude	Definition
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

6.6.3 Results and Discussion

Hydrodynamic Changes to Navigation

Model results presented in Section 6.1.4 show minimal changes to the current field induced by the Project. Changes to other hydrodynamic statistical parameters are tabulated in Table 6.13.

Table 6.13 Changes in various hydrodynamic measurements relating to hydrodynamic change, which are anticipated to be arising from Post-Construction Phase during the "worst case" scenario (i.e., El Nino 2015, Northeast Monsoon), for each maritime transport receptor for the Project

Measurement	Receptor	
	Boating Channel between Pulau Ketam and Pulau Ubin	Serangoon Harbour
Change in mean current speed (m/s)	< 0.05	< 0.05
Change in 95th percentile current speed (m/s)	< 0.1	< 0.1
Change in exceedance of 3.5 knot (% time)	< 2	< 2
Change in exceedance of 2 knot (% time)	< 2	< 2
Change in slackwater duration (% time)	< 2	< 2

Based on the evaluation framework presented in Section 5.9.2 above, the Magnitude of Change for the hydrodynamic measurements is assessed as 'No Change'. As such, the final impact significance of hydrodynamic changes to marine navigation is anticipated to be **No Impact**.

Morphological Change Impacts to Ketam Channel

The results presented in Section 6.2.3 show that sedimentation due to propeller wash is highly confined to the Ketam Channel, showing a maximum value of -0.045 mm/14-days of sedimentation south of the Project area and 0.018 mm/14-days of sedimentation towards the east and west of the Project. Given that the increase in the number of trips by vessels navigating along the boating channel is low (~6-8 more), the predicted impact significance is therefore assessed to be **No Impact**.

Sea Space for Navigation Impacts (Including Collision Risks)

Movements of future vessel traffic from Serangoon Harbour might increase the risk of collision with the fish farms south of Pulau Ubin and Pulau Ketam as these vessels move into marine spaces near the fish farms. There might also be collision risk towards fish farmers' boats plying in this area. However, the estimated number of additional trips to the ULL jetty is estimated to be a maximum of 2 visits/day during school holidays and possibly none during the school term. As such, these additional vessels are not a significant addition to the current vessel traffic at Ketam Channel. It is also assumed that vessels will comply with navigation and safety guidelines from MPA, so navigation risk, including additional vessel traffic entering and leaving Serangoon Harbour, is expected to be minimal. As such, the impact significance for sea space navigation impacts is assessed to be **No Impact**.

6.6.4 Marine Navigation Impact Summary

The Post-Construction Phase impacts from the operations of the ULL jetty on marine navigation receptors have been summarised in Table 6.14.

Table 6.14 RIAM results for Post-Construction Phase (long-term) impacts from the Project on marine navigation receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Hydrodynamic Impacts	Boating Channel between Pulau Ketam and Pulau Ubin (Ketam Channel)	2	0	3	3	2	0	No impact	-	-	-
Erosion/ Sedimentation due to propeller wash	Ketam Channel	2	0	3	3	2	0	No impact	-	-	-
Sea space for navigation	Serangoon Harbour	4	0	3	3	2	0	No Impact	-	-	-
Sea space for navigation (including risks of collision)	Ketam Channel	2	0	3	3	2	0	No impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

6.7 Aquaculture

The long-term impacts arising from the Project on aquaculture receptors are assessed within this section. Increased marine traffic from the operation of the jetty has the potential to impact the nearest aquaculture farms located around Pulau Ubin, for example, by causing ship wake and propeller wash, and potentially increasing suspended sediment concentrations (SSC) in waters.

6.7.1 Relevant Key Receptors and Pressures

Relevant aquaculture receptors include the aquaculture farms south of Pulau Ubin and Pulau Ketam and the land-based farm seawater intake on the southeastern edge of Pulau Ketam.

The following "pressures" to these receptors for the Post-Construction phase were assessed:

- Ship wake;
- Propeller wash-induced sediment plume; and
- Future additional vessel traffic.

Anticipated changes to the marine environment due to ship wakes and propeller wash were predicted using robust numerical tools (presented in Sections 6.2.3 and 6.3.3).

6.7.2 Assessment Framework

The main potential sources of impact on aquaculture and fisheries are related to the increase in marine traffic during the operational stage of the jetty. Downstream effects from increased marine traffic include the influence of ship wakes on farmed fish, and the release of sediments from the vessel's propeller wash.

The receptor Importance evaluation framework adopted for aquaculture receptors follows the standard definitions of Importance in the RIAM framework (Section 4.2.2). For evaluating the Magnitude of Change, the tolerance limits referenced were previously described in Section 5.10.2 (relevant for suspended sediments). There are no tolerance limits for assessing ship wakes impacts on fish farms and collision risks. Hence, the general definitions of Magnitudes of Change per the RIAM framework apply.

6.7.3 Results and Discussions

The assessment also requires a framework for ranking the importance of this group of receptors. For this purpose, the standard definitions of Importance in the RIAM framework (Section 4.2.2) are adopted.

Given that the aquaculture receptor that is the closest, unobstructed by Pulau Ketam and in direct line of sight from the Project area, is located roughly approximately 1.2 km away from the Project area, hence an Importance score of '3' was assigned. It is also unlikely that any impacts would be felt. However, for a thorough assessment, these receptors have been considered within the following assessment subsections to determine whether increased marine traffic expected from the Post-Construction Phase could potentially affect aquaculture facilities through ship wakes, increased SSC from vessel's propeller wash, and risk of collisions.

Impact of Ship Wakes on Fish Farms

Ship wake heights generated are dependent on the speed of the traversing vessel. As mentioned in Section 6.2, the heights of the ship wakes were measured for four different vessel speeds. The respective ship wake heights experienced by the farms on both the east and western ends of Pulau Ketam are shown in Section 6.2.3.

While ship wake heights of 0.4m are not unusual for Singapore's waters (Browne et al., 2017), there could be some impact of these ship wakes on fish farms nearby. Notably, boats travelling at 5 knots (inducing ship wake heights of <0.057m) will likely not have a measurable effect on ship wake measurements in the field, but aquaculture farmers could likely feel some effect for boats travelling past at 7 knots (ship wake heights <0.159m; e.g., temporarily short-term disruption of activities while waiting for the wake to pass), particularly for the nearest farm to the east. At above 7 knots, ship wakes of 0.221m up to 0.433m height can be felt at the fish farms, which will likely affect the fish farmers as they go about their daily operation and maintenance.

As mentioned in Section 6.4.3, this impact assessment will assess the impact on fish farms for the most reasonable boat speed scenarios (5 to 7 knots). From Table 6.8, the impacts expected from an increase in ship wakes would have some measurable change and are assessed to have a Magnitude of 'Slight', giving an impact significance of **Slight Negative Impact**.

Impact of Propeller-wash Induced Suspended Sediments on Caged Fish

The sediment plumes generated from the propeller wash of vessels have the potential to affect aquaculture in the vicinity of the ULL jetty negatively. Farmed fish confined within stationary cages are particularly susceptible to increased Suspended Sediment Content (SSC), as they cannot move away from these areas. Signs of physiologic deterioration in farmed fish exposed to higher SSC include a decrease in feeding abilities in visual feeders and breathing difficulties due to clogged gills. Ultimately, this could result in decreased productivity for the farms.

The sediment plume created by the vessels' propeller wash was discussed in Section 6.3.3. Due to the generation of a very localised plume that is well away from the nearest aquaculture receptor (~1km away), the predicted SSC levels at the nearest aquaculture farm to the vessel track are anticipated to be negligible, with model results indicating that the 95th percentile incremental SSC was less than <0.01 mg/l. Since the predicted mean changes in SSC levels are negligible, the impacts of propeller wash-induced suspended sediments are expected to result in **No Impact** for this receptor.

Impact of Suspended Sediments and Pollutant Release due to Propeller-wash Induced Suspended Sediments on Aquaculture Seawater Intake

For suspended sediments impacts on the seawater intake, most of the SSC is localised around the jetty area (See section 6.3.3). The mean incremental SSC at the aquaculture seawater intake is less than 1.0 mg/l (Table 5.66). Hence according to the tolerance limits presented in Section 5.10.2, this level of change is assessed as 'No Change'; hence **No Impact** is expected on the intake during operation of the jetty.

Table 6.15 Predicted mean incremental SSC (mg/l) (above background concentrations) due to Propeller-wash, at the aquaculture seawater intake and around the Ubin-Ketam Channel.

Aquaculture Receptor	Mean Incremental SSC (mg/l)
Aquaculture seawater intake at Pulau Ketam (~400m from ULL Jetty location)	< 1.0

For pollutant release impacts on the water intake, due to the detection of exceedance of Arsenic (compared with the MPA dumping guidelines, Section 5.3.4) in the sediment, the pollution release needs to be calculated and evaluated. This assessment uses the same calculation formula as shown previously in Section 5.7.3. The calculation results in Table 6.16 below showing that none of the calculated heavy metal content in the waters at the seawater intake exceeded ASEAN MWQC. As a result, the impact significance of pollutant release into waters near the seawater intake as a result of the propeller-wash induced suspended sediments is **No Impact.**

Table 6.16 Calculated heavy metal content at the seawater intake for the land farm on Pulau Ketam, during the operation phase, benchmarked against the ASEAN Marine Water Quality Criteria (MWQC) for aquatic life protection

Marine Ecology and Biodiversity Receptor	Heavy Metals	Calculated Heavy Metal Content In Water (µg/l)	ASEAN MQQC
Aquaculture seawater intake at Pulau Ketam (~400m from ULL Jetty location)	Arsenic as As	2.13	120*
	Cadmium as Cd	0.14	10
	Chromium as Cr	2.32	50
	Copper as Cu	0.99	8
	Lead as Pb	0.15	8.5
	Nickel as Ni	3.13	N/A
	Mercury as Hg	0.09	0.16
	Zinc as Zn	2.74	50*

*Not formally adopted by ASEAN. This value is from the Thailand Marine Water Quality Class Designators and Beneficial Uses

Collision Risk to Aquaculture Farms from Future Additional Vessels

The impact assessment for this was combined into the impact assessment in Section 6.6.3, which assessed changes to sea space for navigation during the operation of the ULL jetty.

6.7.4 Mitigation Measures

It is recommended that boats entering the Ketam Channel not travel above 5 knots in order to minimise the impact on fish farm operations as the boats pass by the aquaculture receptors.

6.7.5 Aquaculture Impact Summary

The Post-Construction Phase impacts from the operations of the ULL jetty on aquaculture receptors have been summarised in Table 6.17.

Table 6.17 RIAM results for Post-Construction Phase (long-term) impacts from the Project on aquaculture receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Increased ship wakes from boats entering Ketam Channel	Aquaculture farms	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-
Propeller wash-induced sediment plume	Caged fishes	3	0	2	2	2	0	No Impact	-	-	-
	Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
Pollutant Release from propeller wash-induced sediment plume	Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

6.8 Socio-economic

6.8.1 Relevant Key Receptors and Pressures

The long-term, post-construction impacts arising from the Project on social and recreational receptors located in the vicinity of the Project area are assessed within this section. Specifically, impacts on the following receptors will be assessed:

- Villagers of Pulau Ubin;
- Staff working at ULL; and
- Recreational users including persons with disabilities (e.g., campers at Endut Senin Campsite, sea sports participants).

To evaluate the post-construction impacts from the development on these socio-economic receptors in the area, " have been assessed:

- Potential increase in suspended sediments from future vessels' propeller wash in relation to the visual impact; and
- Potential increase in visitors to Pulau Ubin.

The results of the propeller-induced sediment plumes have been modelled and reported in Section 6.3.3. The following subsections describe the relevant assessment frameworks and discuss the effects of the environmental changes resulting from the ULL jetty operations on the nearby social and economic receptors.

6.8.2 Evaluation Framework

The evaluation of receptor Importance of socio-economic receptors follows Table 5.69, previously highlighted in Section 5.11.2. The assessment of the Magnitude of Change for visual impacts on recreational receptors is also mentioned in Section 5.11.2.

6.8.3 Results and Discussion

Visual Impact from Propeller-induced Sediment Plumes

The propellor wash of future marine traffic to the jetty has the potential to generate visible sediment plumes that travel away from the project site and are seen by recreational users. As seen from the results in Section 6.3.3, the sediment plumes generated by the anticipated additional traffic to the ULL jetty were in the vicinity of Sungei Puaka and the jetty. However, an exceedance of 5 mg/l was not detected. As such, the impact significance of the anticipated visual impact is assessed as **No Impact**.

Future Vessel Traffic and Visitors

The newly constructed jetty has the potential to bring economic benefits to the local community by increasing the accessibility of areas that were previously difficult to access (due to distance from the jetty at Ubin Village), such as Ketam Quarry. Due to the design of the jetty, there will also be increased accessibility in Pulau Ubin for people with disabilities. With additional visitors, there could also be improvements to the businesses that cater for these visitors – mainly the shops around Ubin Village jetty. As a result, the impact significance of increased accessibility for visitors to the island and increased accessibility bringing economic changes to businesses is assessed as a **Slight to Minor Positive Impact.**

6.8.4 Mitigation Measures

Establishing no-wake and slow-speed protocols for marine traffic along the coast of Pulau Ubin and in its approach to the jetty will mitigate the impacts of future marine vessel traffic on sea sports users and visitors to the coastal areas near the jetty.

6.8.5 Socio-economic Impact Summary

The Post-Construction impacts from the operations of the ULL jetty on socio-economic receptors are summarised in Table 6.18.

Table 6.18 RIAM results for Post-Construction Phase (long-term) impacts from the Project on socio-economic receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Visual impact from propellor wash induced SSC	• Villagers of Pulau Ubin • Staff working at ULL • Recreational users (including persons with disabilities)	2	0	2	2	2	0	No Impact	-	-	-
Increased accessibility to areas around ULL		2	3	3	3	2	48	Minor Positive Impact	-	-	-
Increased accessibility bringing economic changes to businesses	• Shops at Ubin Village	2	2	3	3	2	32	Slight Positive Impact	-	-	-

I = Importance; M = Magnitude; P = Permanence; R = Reversibility; C = Cumulativity; ES = Environmental Score

6.9 Transboundary Impacts

Transboundary impacts refer to any potential impacts which may extend or occur across an international border with a neighbouring country. In order to address stakeholder feedback on concerns over potential transboundary impacts, this section focuses on the assessment of potential long-term transboundary changes after the jetty is completed. The assessments related to transboundary impacts are guided by the same tolerance limits used for the receptors in Singapore.

6.9.1 Relevant Key Receptors and Pressures

To evaluate the post-construction impacts from the development on the transboundary receptors across the Port Limit, the following "pressures" have been assessed:

- Hydrodynamic changes;
- Visual changes arising from future vessels' propeller wash induced suspended sediments;
- Erosion/sedimentation due to future vessels' propeller wash; and
- Potential pollutant release from propeller wash-induced suspended sediments.

6.9.2 Evaluation Framework

Any transboundary change in relation to currents, erosion/sedimentation, water quality that is likely to be detectable in the field are assessed against the tolerance limits reported for various types of receptors in the respective sections.

For visual transboundary impacts due to suspended sediment concentrations, given the marine and shoreline usage in the Malaysian waters closest to the proposed development are pre-dominantly non-recreational, a tolerance limit of < 5 % exceedance of 5 mg/l is considered appropriate.

6.9.3 Results and Discussions

Hydrodynamic Changes and Transboundary Navigation

As presented in Section 6.1, DHI's hydrodynamic simulations predict that the presence of the completed jetty will not result in any changes in currents. Therefore, **No Impact** is predicted to result on transboundary navigation.

Propeller-wash Induced Suspended Sediment and Transboundary Visual Impact

As presented in Section 6.3, the sediment plume simulations predict that the presence of the completed jetty will not result in any increase in suspended sediments due to propeller action of the vessels using the jetty. Hence, **No Impact** is predicted in terms of transboundary visual impact due to propeller-wash induced suspended sediments.

Morphological Change Impacts and Transboundary Marine Infrastructure

As presented in Section 6.3, it has been proven through sediment plume simulations that propeller wash will result in localised erosion or sedimentation, with No Change beyond the Project area. Therefore, **No Impact** is predicted to the morphology and transboundary marine infrastructure.

Water Quality and Transboundary Aquatic Life

As presented in Section 6.3, the sediment plume simulations show that there will be no increase in suspended sediments from propeller-wash action. As such, there will be no pollutant release from sediment plumes. Hence, no change in heavy metal concentrations is predicted at the Singapore Port Limit and this corresponds to **No Impact** to transboundary water quality and aquatic life.

6.9.4 Transboundary Impact Summary

The Post-Construction impacts from the operations of the ULL jetty on transboundary receptors are summarised in Table 6.19.

Table 6.19 RIAM results for Post-Construction Phase (long-term) impacts from the Project on transboundary receptors

Predicted Impact	Sensitive Receptors	Predicted Impacts Without Mitigation Measures							With Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Hydrodynamic impacts	Transboundary navigation	5	0	2	2	2	0	No Impact	-	-	-
Sediment plume from propeller wash	Transboundary human receptors	5	0	2	2	2	0	No Impact	-	-	-
Erosion/ Sedimentation due to propeller wash	Transboundary marine infrastructure	5	0	2	2	2	0	No Impact	-	-	-
Pollutant release from propeller wash-induced sediment plume	Transboundary aquatic life	5	0	2	2	3	0	No Impact	-	-	-

6.10 RIAM Impact Significance Summary

6.10.1 Construction Phase

A summary of the predicted impacts from the Project's Construction Phase before and after mitigation for each of the main receptors is presented in Table 6.20. The proposed EQOs for the project are presented in Section 7.1.

Table 6.20 RIAM table for Construction (short-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Marine Ecology and Biodiversity											
Section 5.7	Sediment Plume Impact on Intertidal Areas	1	0	2	2	2	0	No Impact	-	-	-
	Sediment Plume Impact on Mangrove Habitats	5	0	2	2	2	0	No Impact	-	-	-
	Sediment Plume Impact on Marine Fauna (including Fish)	2	0	2	2	2	0	No Impact	-	-	-
	Algal Bloom Impact due to Cyst Release from Suspended Sediments on Marine Fauna (including Fish)	2	-2	2	2	3	-28	Slight Negative Impact	-	-	-
	Pollutant Release Impact from Suspended Sediments on Marine Fauna (including Fish)	2	0	2	2	3	0	No Impact	-	-	-
	Accidental Spills and Leaks Impacts on Intertidal Areas	1	-1	2	2	3	-7	Slight Negative Impact	-1	-7	Slight Negative Impact
	Accidental Spills and Leaks Impacts on Mangrove Habitats	5	-1	2	2	3	-35	Slight Negative Impact	-1	-35	Slight Negative Impact

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Accidental Spills and Leaks Impacts on Macrobenthos	1	-1	2	2	3	-7	Slight Negative Impact	-1	-7	Slight Negative Impact
	Accidental Spills and Leaks Impacts on Marine Fauna (including Fish)	2	-1	2	2	3	-14	Slight Negative Impact	-1	-14	Slight Negative Impact
	Underwater Noise Impacts on Marine Fauna (including Fish)	2	-2	2	2	2	-24	Slight Negative Impact	-1	-12	Slight Negative Impact
Terrestrial Ecology and Biodiversity											
Section 5.8	Accidental Spills and Leaks Impacts on Terrestrial Flora	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
	Accidental Spills and Leaks Impacts on Terrestrial Fauna (including Amphibians)	1	-1	2	2	2	-6	No Impact	-	-	-
	Accidental Spills and Leaks Impacts on Terrestrial Fauna (including Mammals, Herpetofauna, Butterflies, and Odonates)	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
	Atmospheric Emissions Impacts on Avifauna and Terrestrial Fauna (including Mammals, Herpetofauna, Butterflies, and Odonates)	4	-1	2	2	2	-24	Slight Negative Impact	0	0	No Impact
	Airborne Noise Impacts on Avifauna and Terrestrial Fauna (including Mammals, Herpetofauna, Butterflies, and Odonates)	4	-4	2	3	2	-112	Moderate Negative Impact	-2	-56	Minor Negative Impact
Marine Navigation											
Section 5.9	Hydrodynamics Changes Causing Impacts to the Boating Channel between Pulau Ketam and Pulau Ubin (Ketam Channel)	2	0	2	2	2	0	No Impact	-	-	-

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Changes to the Sea Space for Navigation Affecting Ketam Channel	2	-2	2	2	2	-24	Slight Negative Impact	-	-	-
Aquaculture											
Section 5.10	Sediment Plume Impacts on Caged Fishes in Aquaculture Farms	3	0	2	2	2	0	No Impact	-	-	-
	Sediment Plume Impacts on Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Pollutant Release from Suspended Sediments on Water Intake at SE of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Accidental Spills and Leaks Impacts on Caged Fishes in Aquaculture Farms	3	-1	2	2	2	-18	Slight Negative Impact	-1	-18	Slight Negative Impact
	Accidental Spills and Leaks Impacts on Water Intake at SE of Pulau Ketam	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Underwater Noise Impacts on Caged Fishes in Aquaculture Farms	3	-2	2	2	2	-36	Slight Negative Impact	-1	-18	Slight Negative Impact
	Airborne Noise Impacts on Land-based Fish Farm on Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Atmospheric Emission Impacts on Land-based Fish Farm on Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Atmospheric Emission Impacts on Fish Famers	2	0	2	2	2	0	No Impact	-	-	-

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Socio-economic											
Section 5.11	Atmospheric Emission Impacts on Socio-economic Receptors	2	-1	2	2	2	-12	Slight Negative Impact	0	0	No Impact
	Airborne Noise Impacts on Socio-economic Receptors	2	-1	2	2	2	-12	Slight Negative Impact	0	0	No Impact
	Visual Impact from Sediment Plume on Socio-economic Receptors	2	-1	2	2	2	-12	Slight Negative Impact	-	-	-
	Visual Impact from Accidental Spills and Leaks on Socio-economic Receptors	2	-1	2	2	2	-12	Slight Negative Impact	-1	-12	Slight Negative Impact
Transboundary											
Section 5.12	Hydrodynamics Changes Causing Impacts to Transboundary Navigation	5	0	2	2	2	0	No Impact	-	-	-
	Visual Impact from SSC on Transboundary Human Receptors	5	0	2	2	2	0	No Impact	-	-	-
	Visual Impact from Accidental Spills and Leaks on Transboundary Human Receptors	5	0	2	2	3	0	No Impact	-	-	-
	Pollutant Release Impact from Suspended Sediments on Transboundary Aquatic Life	5	0	2	2	3	0	No Impact	-	-	-
	Atmospheric Emission Impacts on Transboundary Human Receptors	5	0	2	2	2	0	No Impact	-	-	-
	Underwater Noise Impacts on Transboundary Aquatic Life	5	0	2	2	2	0	No Impact	-	-	-

6.10.2 Post-Construction Phase

Table 6.21 RIAM table for the Post-Construction (long-term) impacts from the Project without mitigation and after implementation of the recommended mitigation measures

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
Marine Biodiversity and Shorelines											
Section 6.4	Project Footprint Impacts on Intertidal Area (No Presence of Coral or Seagrass) and Macrobenthos (Loss of Habitat)	1	-2	3	2	2	-14	Slight Negative Impact	-	-	-
	Propeller Wash-Induced Sediment Plume Impact on Intertidal Areas	1	0	3	2	3	0	No Impact	-	-	-
	Propeller Wash-Induced Sediment Plume Impact on Mangrove Habitats	5	0	3	2	3	0	No Impact	-	-	-
	Propeller Wash-Induced Sediment Plume Impact (including Pollutant Release) on Marine Fauna (including Fish)	2	0	3	2	2	0	No Impact	-	-	-
	Erosion/Sedimentation Impact due to Long-Term Hydrodynamic Changes or Propeller Wash on Intertidal Area (including Sensitive Shorelines)	2	0	3	3	3	0	No Impact	-	-	-
	Erosion/Sedimentation Impact due to Long-Term Hydrodynamic Changes or Propeller Wash on Mangrove Habitats	5	0	3	3	3	0	No Impact	-	-	-
	Erosion/Sedimentation Impact due to Ship Wake on Intertidal Areas (including Sensitive Shorelines)	2	-2	3	3	3	-36	Slight Negative Impact	-2	-18	Slight Negative Impact

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Erosion/Sedimentation Impact due to Ship Wake on Mangrove Habitats	5	-2	3	3	3	-90	Moderate Negative Impact	-1	-45	Minor Negative Impact
	Change in light environment due to lighting requirements at jetty pontoon, for Marine Fauna	2	-2	3	2	3	-32	Slight Negative Impact	-1	-16	Slight Negative Impact
Terrestrial Biodiversity											
Section 6.5	Project Footprint Impacts on Terrestrial Flora	3	-1	3	2	2	-21	Slight Negative Impact	-1	-21	Slight Negative Impact
	Change in light environment due to lighting requirements at jetty, for terrestrial fauna	4	-1	3	2	2	-28	Slight Negative Impact	-1	-28	Slight Negative Impact
Marine Navigation											
Section 6.6	Hydrodynamics Changes Causing Impacts to the Boating Channel between Pulau Ketam and Pulau Ubin (Ketam Channel)	2	0	3	3	2	0	No Impact	-	-	-
	Erosion/sedimentation Impacts in Ketam Channel	2	0	3	3	2	0	No Impact	-	-	-
	Changes to Sea Space for Navigation in Serangoon Harbour	4	0	3	3	2	0	No Impact	-	-	-
	Changes to Sea Space for Navigation in Ketam Channel (including Risks of Collision)	2	0	3	3	2	0	No Impact	-	-	-
Aquaculture											
Section 6.7	Increased Ship Wake Impacts to Aquaculture Farms	3	-1	3	2	2	-21	Slight Negative Impact	-	-	-

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Propeller Wash-Induced Sediment Plume Impact on Caged Fishes	3	0	2	2	2	0	No Impact	-	-	-
	Propeller Wash-Induced Sediment Plume Impact on the Water Intake at Southeast of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
	Pollutant Release Impact from Propeller Wash-Induced Sediment Plume on the Water Intake at Southeast of Pulau Ketam	3	0	2	2	2	0	No Impact	-	-	-
Socio-economic											
Section 6.8	Visual Impact from Propeller Wash-Induced Sediment Plume on Socio-economic Receptors	2	0	2	2	2	0	No Impact	-	-	-
	Increased Accessibility to Areas around ULL for Socio-economic Receptors	2	3	3	3	2	48	Minor Positive Impact	-	-	-
	Increased Accessibility bringing Economic Changes to Businesses at Ubin Village	2	2	3	3	2	32	Slight Positive Impact	-	-	-
Transboundary											
Section 6.9	Hydrodynamics Changes Causing Impacts to Transboundary Navigation	5	0	2	2	2	0	No Impact	-	-	-
	Visual Impact from Propeller Wash-Induced Sediment Plume on Transboundary Human Receptors	5	0	2	2	2	0	No Impact	-	-	-
	Erosion/Sedimentation Impact due to Propeller Wash on Transboundary Marine Infrastructure	5	0	2	2	2	0	No Impact	-	-	-

EIA Section	Predicted Impact	Predicted Impact Significance Before Mitigation							After Mitigation Measures		
		I	M	P	R	C	ES	Impact Significance	M	ES	Impact Significance
	Pollutant Release Impact from Propeller Wash-Induced Sediment Plume on Transboundary Aquatic Life	5	0	2	2	2	0	No Impact	-	-	-

7 Environmental Management Framework

7.1 Environmental Quality Objectives

Preliminary EQOs were established during internal scoping and presented at the Agency Scoping Meeting on 19 February 2021. It is not the purpose of the EIA to formally set the EQOs; these are to be defined by the competent authorities based on the findings of the EIA and the cost-benefit of mitigation and spill budget control against environmental impact.

The recommended EQOs for the EMMP are as follows:

- No more than **Minor Impact** for the following receptors:
  - Maritime transport and facilities
  - Marine and terrestrial ecology and diversity
- No more than **Slight Impact** for the following receptors:
  - Socio-economic receptors
  - Aquaculture facilities
- **No Impact** on receptors outside of the Study area

7.2 Environmental Monitoring and Management Plan

This Environmental Management and Monitoring Plan (EMMP) section provides a cohesive framework to ensure that the environmental impacts of the proposed project construction activities be mitigated to the lowest practicable level through the application of the standard 'Plan-Do-Act-Check' principle (Figure 7.1)

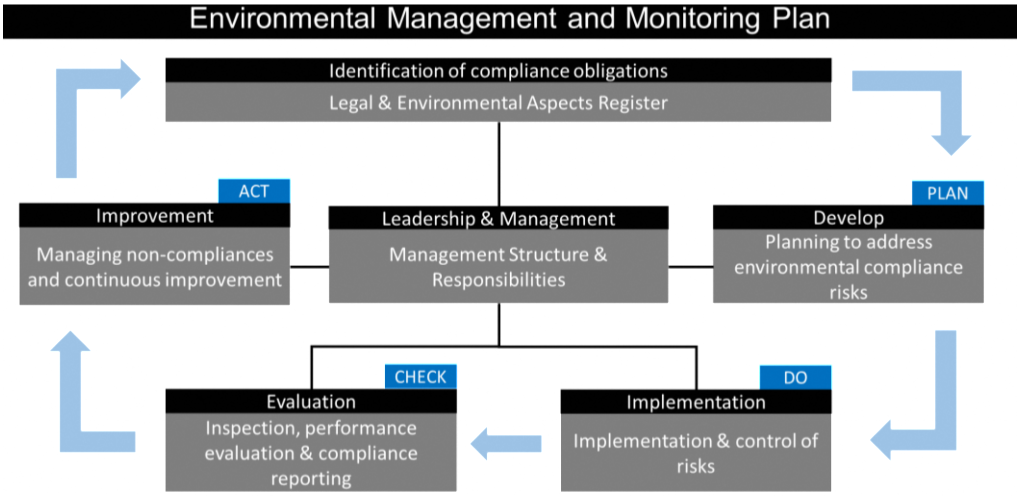


Figure 7.1 EMMP Framework

To ensure that the elements of the EMMP are properly implemented and produce the desirable benefits and/or outcomes, the present framework provides an overview of the following pertinent components, which are further described below:

- EMMP Roles and Responsibilities;
- Impact Mitigation and Monitoring;
- Grievance Management;
- Management of Change;

- Environmental Auditing;
- Non-Compliance and Remedial Action; and
- Environmental Impact Register.

7.2.1 EMMP Roles and Responsibilities

7.2.1.1 Employer

The Employer will be responsible for ensuring the implementation of the EMMP by the Contractors or any third party during the construction periods of the proposed project. References within the EMMP to the “Employer” are to NParks as the proposed Project Developer. References to the “Contractor” are to the main contractors for the Construction Phase and also include any sub-contractors under their control.

7.2.1.2 Contractor

The Contractor will be responsible for establishing an Environmental Team comprising different relevant environmental specialists to work with the regulatory authorities in Singapore to comply with regulations, policies and guidelines related to environmental affairs. This includes formulating an EMMP that covers all proposed construction activities during the Construction Phase. The Contractor will take ownership of the EMMP and ensure that all staff are familiar with the relevant parts of the EMMP.

While the EMMP sets out the requirements for environmental management during the Construction Phase and the responsibilities for meeting them, the details of the actions to be taken in order to implement each aspect of the EMMP will need to be developed and specified by the Contractor in its method statements. These method statements demonstrate how compliance with the requirements of the EMMP is to be achieved. These method statements must be submitted to the Employer for approval and distributed to relevant regulatory authorities as appropriate.

The Contractor will also be responsible for the provision and installation of all monitoring instruments required under the EMMP specifications, together with the necessities to ensure smooth operation and accurate data and results, such as power supply, mounting, protective or weather-proof casing.

The Contractor will be responsible for developing and training staff in Emergency Management Procedures covering potential incidents such as human-wildlife conflicts and spills and leaks.

7.2.1.3 Environmental Control Officer

The Contractor shall engage a full-time Environmental Manager (EM) and Environmental Control Officer (ECO). The ECO shall be registered with the Commissioner of Public Health and discharge the duties set out in the Code of Practice for ECO. The ECO will contribute to devising practicable implementation plans for outlined mitigation measures and conduct daily site inspections in the following main areas:

- Control of disease-bearing vectors and rodents;
- Proper management and disposal of solid waste and liquid waste;
- Control of noise and dust pollution;
- Drainage control;
- General housekeeping; and
- Earth control measures and silt control.

At least three weeks before construction works commencement, the ECO will submit an Environmental Control Program. After works commence, an ECO Report should be submitted every two (2) weeks (on the 1st and 15th of the month) to the Director General of Public Health. The ECO Report and Plan contains the information required by the Singapore Code of Practice for Environmental Control Officers.

7.2.1.4 Environmental Specialists

The Contractor will also be responsible, where applicable, for appointing Qualified Erosion Control Professional (QECP) (as required by PUB), Earth Control Measures Officer (ECMO), NEA-licensed Pest Control Officer (PCO), Public Relations Officer (PRO), ISA-certified Arborist, Wildlife Specialist, SINGLAS accredited laboratory, and waste collectors to implement the EMMP requirements.

The Contractor will be responsible for appointing qualified personnel (e.g., Fire Safety Manager, QECP, Traffic Management Specialist, etc.) to prepare a fire protection plan, flood protection plan, and traffic management plan and obtain all necessary approvals from relevant government agencies and stakeholders for the plans.

Any environmental specialist or company engaged by the Contractor to undertake the works under the EMMP must be adequately experienced. The equipment or instrument used must be maintained and calibrated at manufacturer-recommended frequencies. All the certifications, accreditation and quality assurance records must be gathered and documented if and when required by the Contractor.

7.2.1.5 EMMP Consultant

The EMMP Consultant is a third party to verify and audit the effectiveness of EMMP and will report to the Contractor. Where audit findings highlight a non-conformance, there will be an investigation, and appropriate corrective action will be taken. All environmental audits will be clearly documented and filed internally. The EMMP Consultant is responsible for the overall quality and effectiveness of the EMMP, organising the EMMP audits and provision of comment clarifications and presentations when required with stakeholders and authorities.

7.3 Environmental Monitoring

Based on the assessed level of impacts in Sections 5 and 6, it is clear that most impacts can be managed through the proper application of the recommended mitigation measures. In addition to the regular site housekeeping and checks, environmental monitoring, as tabulated in Table 7.1 below, shall be followed to ensure that the mitigation measures applied are effective and to monitor if there could be potential impacts on water quality.

Table 7.1 Recommended Environmental Monitoring

Environmental Parameter	Monitoring Requirements	Frequency
Sediment Flux	Take sediment flux transects with a vessel-mounted ADCP to monitor suspended sediment concentrations and the presence/absence of sediment plumes during the piling and trimming works.	Twice a week while marine construction works are being carried out
Water Quality	Water quality measurements should be taken at mid-depth for the following parameters: • pH • Temperature • Conductivity • Dissolved Oxygen • Turbidity • Secchi Disk Water samples shall also be taken for testing of the following parameters at SINGLAS accredited laboratory: • Oil & Grease • Total Suspended Solids • Nitrate • Nitrite • Total Nitrogen • Phosphate • Total Phosphorus • Chlorophyll-*a* • Faecal Coliform	Once a week during the construction phase
Presence of marine fauna	Stop piling works if marine fauna is spotted within 100 m of work area boundary.	During piling works only
Airborne Noise	Continuous noise monitoring at the coastal vegetation adjacent to the work area to monitor compliance with threshold for terrestrial fauna receptors (Section 5.7.2).	Continuous during the construction phase

7.4 Grievance Management

The Contractor will establish a grievance management process to ensure that any complaints or feedback received from stakeholders are appropriately recorded, investigated, and resolved where required throughout the Project. The main components of the grievance process should include:

- Prompt acknowledgement and response to stakeholder complaints, keeping them informed of the progress and outcomes;
- Accurate records of complaints, investigations and outcomes are maintained;
- Resolution within a specified timeframe (proposed two-three weeks);
- An escalation mechanism in the event that grievance cannot be resolved within the specified timeframe;
- Assign responsibility and accountability to individual(s) such as Public Relations Officer (PRO) within the Developer(s) for administering the grievance procedure; and
- Government Agencies to be kept informed of complaints, where required.

7.5 Management of Change

Deviations from the scope of work might occur during the project execution. Change is an inevitable part of project execution, so managing and reviewing change during this phase is an important factor in project success. The overall aim of the EMMP is to ensure that environmental management is implemented, and its performance monitored. This means there must be scope for corrective action to be taken if required. It may be necessary to make modifications to the EMMP over the course of the Project when:

- Unanticipated environmental impacts are identified that require additional mitigation;
- When mitigation proposed proves ineffective or unable to be implemented; and
- When the Project changes in a way that is substantially different to that described in the EIA (e.g., internal changes initiated by the project team, external changes initiated by the client, or external changes that result from third-party stakeholders).

The overall responsibility for the management of change to the EMMP during the Construction Phase rests with the Employer in consultation with the relevant specialists and/or technical agencies where required. The steps for managing change to the EMMP are as follows:

- Identify and describe unanticipated impacts, ineffective mitigation or changes in the Project construction that requires updates to the EMMP;
- Suggest mitigation to manage the identified issues ;
- Concerns/issues could, for example, be highlighted in site inspection reports or progress calls on an ongoing basis;
- Review and update the EMMP in consultation with the relevant specialists and/or technical agencies; and
- Record recommended corrective action in the Minutes of Meeting.

7.6 Environmental Auditing

An independent check will be conducted to ensure that appropriate environmental management is in place in accordance with statutory requirements and the EMMP. The environmental audit will review the results of monitoring undertaken during the Construction Phase to identify if there is a need to heighten the environmental management or mitigation measures. The scope of the Environmental Audit should cover all of the environmental issues relating to construction that are addressed in the EIA Report and by the EMMP.

The audit should be undertaken by the Employer. The activities to be undertaken as part of an environmental audit minimally include:

- Visual examination of the site to examine working practices, environmental effects, mitigation measures and monitoring activities;
- Examination of the environmental incidents and complaints log;
- Examination of the Environmental Impact Register, including results of monitoring works;
- Interviews with the Contractor’s Environmental Manager and other site staff as required; and
- Consultation with relevant statutory authorities, where appropriate.

The frequency of the environmental audits should be specified by the Employer and should consist of a minimum of two (2) unscheduled visits during the 10-month construction period.

7.7 Non-Compliance and Remedial Action

In the event of non-compliance, the following process/actions are recommended:

- The Employer is to issue a notice of non-compliance to the Contractor, stating the nature and magnitude of the contravention;
- The Contractor is to provide the Employer with a written statement describing remedial actions to be taken to rectify the non-compliance, and expected results of the actions; and
- The Contractor is to correct the non-compliance within a period stipulated by the Employer, to provide the Employer with documented evidence of the completed remedial actions and obtain the Employer’s approval for closure of the non-compliance notice.

If the Contractor fails to remedy the non-compliance within the predetermined timeframe or if the non-compliance gives rise to physical environmental damage, the Employer may take action (e.g., impose a penalty, require specific remedial action to be undertaken or stop work) based on the conditions of the contract.

7.8 Environmental Impact Register

The objective of environmental monitoring will be to check for compliance with the EMMP by monitoring the construction activities of the Project. This includes monitoring the actual impact of activities on selected sensitive receptors so that impacts which are not anticipated in the EIA or impacts which exceed Environmental Quality Objectives can be identified and appropriate mitigation measures can be adopted promptly. The Environmental Impact Register outlined in Table 7.2 is recommended as a management and monitoring tool. Compliance monitoring is recommended throughout the proposed Project by both the Employer and Contractor.

Table 7.2 Environmental Impact Register

Environmental Aspect	Description of Receiver		Description of Potential Impact		Proposed Mitigation Measures	Implementation Agent	Impact Significance	Proposed Monitoring Requirement	Reporting Requirements
	Receiver	Importance	Impact	Impact Significance					
Hydrodynamics	Boating Channel between Pulau Ketam and Pulau Ubin	Low	Hydrodynamic Impacts	No Impact	None required	NIL	NIL	NIL	NIL
			Sea Space for Navigation	Slight Negative Impact	None required	NIL	Slight Negative Impact	NIL	NIL
	Transboundary navigation	High	Hydrodynamic Impacts	No Impact	None required	NIL	NIL	NIL	NIL
Sediment Plume	Marine ecology	High	Increased suspended sediments	No Impact	None required	NIL	NIL	NIL	NIL
			Cyst release causing algal bloom impacts	Slight Negative Impact	None required	• Contractor/ECO • EMMP Consultant	Slight Negative Impact	• Sediment flux monitoring of parameters listed in Table 7.1	• Sediment flux monitoring results • Environmental Control Report • Monthly Environmental Performance Report
			Pollution release	No Impact	None required	NIL	NIL	NIL	NIL
	Aquaculture	Moderate	Increased suspended sediments	No Impact	None required	NIL	NIL	NIL	NIL
	Recreational users (e.g., sea sports participants)	Low	Visual impact due to construction	Slight Negative Impact					
	Transboundary Human Receptors	High	Visual impact due to construction	No Impact	None required	NIL	NIL	NIL	NIL
Water Quality	Marine ecology	Moderate	Accidental spill leakage and trade effluent	Slight Negative Impact	• Implement a Major Accident Prevention Plan (MAPP) / Emergency Response Plan for general site activities that covers all incidences of a potential spill or leaks resulting from project activities and equipment. • Implementation of the recommendations listed in Section 5.7.4 in managing risks associated with	• Contractor/ECO • EMMP Consultant	Slight Negative Impact	• Water quality monitoring of parameters listed in Table 7.1	• Water quality monitoring results • Environmental Control Report • Monthly Environmental
	Terrestrial fauna	High	Accidental spill leakage and trade effluent	Slight Negative Impact			Slight Negative Impact		

Environmental Aspect	Description of Receiver		Description of Potential Impact		Proposed Mitigation Measures	Implementation Agent	Impact Significance	Proposed Monitoring Requirement	Reporting Requirements
	Receiver	Importance	Impact	Impact Significance					
	Aquaculture	Moderate	Accidental spill leakage and trade effluent	Slight Negative Impact	construction waste and the use of hazardous material. • Communication to be established with MPA for reporting any oil spill incidents.		Slight Negative Impact		Performance Report
	Transboundary Aquatic Life	High	Accidental spill leakage and trade effluent	No Impact	None required	NIL	NIL	NIL	NIL
Air Quality	Terrestrial fauna	High	Deterioration of air quality due to construction activities	Slight Negative Impact	• Plants and machinery used on-site shall be properly and regularly inspected and maintained to control dust and air pollutants emission. • Wheel washing bay shall be provided, and all trucks/vehicles shall be washed before leaving the construction site.	• Contractor/ECO • EMMP Consultant	No Impact	• Contractor to conduct daily visual inspection of dark smoke emissions from construction fuel burning equipment and transport. • ECO to conduct site inspection and to submit a site environmental control report to the occupier of the construction at each site inspection every 2 weeks. • EMMP Consultant to conduct monthly site inspection ensure environmental mitigation measures have been effectively implemented by the Contractor	• ECO Site Environmental Control Report • Monthly Environmental Performance Report
	• Villagers of Pulau Ubin • Staff at ULL office • Recreational users (e.g., sea sports participants)	Low		Slight Negative Impact	• Earth stockpiles should be covered with tarpaulin when not in use. • Minimise traffic delays caused by the movement of construction vehicles by planning transport routes and periods that avoid congested areas and peak hours of road use. • Where applicable, manual or mechanical methods shall be adopted for the demolition works instead of blasting to reduce the volume of dust released. • Where applicable, all structures to be demolished shall be enclosed, and demolition chutes and waste receptacles shall be deployed. • Wet the working area prior to, during and after demolition		No Impact		
	Aquaculture	Moderate		No Impact	None required	NIL	NIL	NIL	NIL
	Fish Farmers	Low		No Impact	None required	NIL	NIL	NIL	NIL
	Transboundary Human Receptors	High		No Impact	None required	NIL	NIL	NIL	NIL
Airborne Noise	Terrestrial fauna	High	Noise pollution generated from construction activities	Moderate Negative Impact	• To comply with relevant environmental regulations, including the Environmental Protection and Management Act and any other regulations and guidelines that come into effect	• Contractor/ECO • EMMP Consultant	Minor Negative Impact	• Contractor to plan, monitor and mitigate noise emissions according to the construction schedule. • ECO conduct a daily visual inspection of the noise barrier	• Environmental Control Report • Noise monitoring records

Environmental Aspect	Description of Receiver		Description of Potential Impact		Proposed Mitigation Measures	Implementation Agent	Impact Significance	Proposed Monitoring Requirement	Reporting Requirements
	Receiver	Importance	Impact	Impact Significance					
	• Villagers of Pulau Ubin • Staff at ULL office • Recreational users (e.g., sea sports participants)	Low		Slight Negative Impact	when the time of construction works commencement. • Quieter construction equipment and method shall be adopted as much as possible, with reference to NEA's Guideline on Quieter Construction Fund Annex 1 and Annex 2. • Where possible and practicable, use the following equipment: ○ Hydraulic and electric tools in place of pneumatic equipment such as concrete breakers. ○ Quieter piling methods, for example, hydraulically driven equipment instead of hammers and pressed-in piling with low soil displacement piles. • Apply additional noise control such as mufflers and sound absorbers for noisy equipment operating near sensitive receptors. • Install localised noise barriers or noise enclosures for applicable construction machinery. • Limit the number of equipment operating concurrently on-site or switch to a quieter model where applicable.		No Impact	integrity and performance of the machinery. • ECO to conduct a site inspection and submit a site environmental control report to the occupier of the construction at each site inspection every two (2) weeks. • EMMP Consultant to conduct monthly site inspections to ensure the Contractor has effectively implemented environmental mitigation measures. • Conduct continuous noise monitoring at the nearest affected NSRs to show compliance with the maximum allowable limits stated in the EPM (Control of Noise at Construction Sites) Regulations.	• Monthly Environmental Performance Report
Underwater Noise	Marine ecology	Moderate	Underwater noise generated from construction activities	Slight Negative Impact	• Soft start (ramp up) to gradually increase sound pressure levels to drive fish and marine fauna away from the area.	• Contractor	Slight Negative Impact	NIL	NIL
	Aquaculture	Moderate		Slight Negative Impact			Slight Negative Impact		
	Transboundary Aquatic Life	High		No Impact	None required	NIL	NIL	NIL	NIL
Accidental Spills and Leaks	Marine ecology	High	• Generation of non-hazardous waste such as soil from excavation and used packaging material that cannot be recycled or reused onsite	Slight Negative Impact	• The construction site must be maintained clean; construction wastes must be disposed of quickly in bulk trash containers, which must be emptied daily. • Contractor shall engage ECO to prepare and implement environmental control plan and programme specific to the construction works undertaken by the Contractor according to the LTA Safety, Health and Environment (General	• Contractor/ECO	Slight Negative Impact	• Contractor to conduct a daily visual inspection of the construction site to prevent the generation of hazardous waste. • ECO to monitor and record all outgoing construction wastes to be transported licensed toxic industrial waste collector for hazardous wastes.	• ECO Site Environmental Control Report • Waste manifest record • Monthly Environmental Performance Report

<table>
<tr><th rowspan="2">Environmental Aspect</th><th colspan="2">Description of Receiver</th><th colspan="2">Description of Potential Impact</th><th rowspan="2">Proposed Mitigation Measures</th><th rowspan="2">Implementation Agent</th><th rowspan="2">Impact Significance</th><th rowspan="2">Proposed Monitoring Requirement</th><th rowspan="2">Reporting Requirements</th></tr>
<tr><th>Receiver</th><th>Importance</th><th>Impact</th><th>Impact Significance</th></tr>
<tr><td rowspan="3"></td><td>Terrestrial ecology</td><td>High</td><td rowspan="2">and need to be sent for offsite disposal
• Generation of hazardous waste such as used lubricating oil that cannot be recycled or reuse onsite and need to be sent for offsite disposal</td><td>Slight Negative Impact</td><td rowspan="2">Specifications Appendix A), and NEA COP for Environmental Control Officers
• The construction contractor should be required by contract to establish a solid waste management strategy that addresses the collection, recycling, and eventual disposal of all produced wastes in an ecologically appropriate way.
• Wherever possible, excess excavated material and inert wastes (soil, shattered rock, etc.) will be utilised on-site as structural fill, landscaping, erosion control, and restoration elements.
• Metal scrap (welding rods, end caps, off-cuts, etc.) can be recovered and recycled as scrap.
• On-site waste must be kept separate from construction and hazardous materials in covered bins or compaction units. To minimise smell, pest, and litter impacts, the Contractor should use a licensed general trash collector to remove general garbage daily or every other day.
• Appropriate disposal of any toxic waste by licensed toxic waste collectors as per required in the Environmental Public Health Regulations</td><td rowspan="2"></td><td>Slight Negative Impact</td><td rowspan="2">• ECO to conduct a site inspection and to submit a site environmental control report to the occupier of the construction at each site inspection every two (2) weeks.
• EMMP Consultant to conduct monthly site inspections to ensure environmental mitigation measures have been effectively implemented by the Contractor.</td><td rowspan="2"></td></tr>
<tr><td>Socio-economic receptors</td><td>Moderate</td><td>Slight Negative Impact</td><td>Slight Negative Impact</td></tr>
<tr><td>Transboundary Human Receptors</td><td>High</td><td>Accidental spill leakage and trade effluent</td><td>No Impact</td><td>None required</td><td>NIL</td><td>NIL</td><td>NIL</td><td>NIL</td></tr>
</table>

.

8 Conclusion

The following changes and impacts were predicted for the Construction Phase:

- **Hydrodynamics**: No change is expected due to changes in current fields and statistics. No mitigation is required.
- **Sediment Plume:** Highly localised increased suspended sediments and sedimentation are predicted from piling works. No mitigation is required.
- **Pollution Release**: Arsenic content within the sediments exceeded recommended guidelines for sediment quality; hence a pollution release impact assessment was carried out. The works will only result in a localised and small plume; hence the impact of pollution release is assessed as **No Impact**.
- **Air Quality:** The construction works are expected to have only a minimal transient impact on air quality, which should be maintained through the application of the recommended management and mitigation measures.
- **Noise Quality:** The construction works are expected to have some transient impact on noise quality. However, they can be managed to acceptable levels through the application of the recommended management and mitigation measures.
- **Marine Ecology and Biodiversity:** Highly localised increased SSC and sedimentation rates during construction are predicted to have **No Impact** on the immediate adjacent intertidal, mangroves and subtidal habitats. **Minor Negative Impacts** are associated with construction disturbance (underwater noise and spill impact to subtidal habitats and the stirring up of cysts), some of which could be reduced to **Slight Negative Impact** through suitable mitigation.
- **Terrestrial Ecology and Biodiversity:** The key construction pressures to terrestrial sensitive receptors are spills, atmospheric emissions and airborne noise impacts. The impact of spills is assessed as **Minor Negative Impact**, which can be reduced to **Slight Negative Impact** with appropriate mitigations. Atmospheric emission impacts on terrestrial ecology are assessed as **Slight Negative Impact** and can be mitigated to **No Impact**. Finally, airborne noise impacts are assessed as **Moderate Negative Impact** due to the anticipated loud noises due to the proposed equipment used. However, with the proposed mitigation measures, these impacts will be reduced to **Minor Negative Impact**.
- **Marine Navigation: No Impact** is expected on marine navigation as a result of hydrodynamic changes due to jetty construction. Additionally, changes to sea space are anticipated to cause **Slight Negative Impact**. No mitigation measures are required.
- **Aquaculture: No Impact** is expected on aquaculture receptors due to suspended sediment, pollutant release airborne noise and atmospheric emissions, while **Slight Negative Impact** is anticipated for the impact of spills and underwater noise on caged fishes. Through the application of the recommended management and mitigation measures, these impacts can be reduced.
- **Socio-economic:** It is anticipated that the impact from the construction works would be small. Atmospheric emissions and airborne noise were assessed to result in **Slight Negative Impacts** on socio-economic receptors, after which appropriate mitigation measures will reduce this to **No Impact**. Visual impact from SSC to receptors is assessed to be **No Impact**, while visual changes due to spills are assessed to be **Slight Negative**. Mitigation measures for spills can also be applied.

- **Transboundary:** No impact

The following changes and impacts were predicted for the Post-Construction Phase:

- **Hydrodynamics:** No change is expected due to changes in current fields due to ULL Jetty. No mitigation is required.
- **Ship Wake-Induced Erosion/Sedimentation:** Ship wake-induced erosion/sedimentation was assessed for boats going at speeds of 5 and 7 knots as they are more closely reflected in the mean and maximum speeds of boats presently travelling within Ketam Channel. Ship wakes experienced by the Pulau Ubin shoreline were higher than the Pulau Ketam shoreline. From the Bed Shear Stress (BSS) time series at selected points, it was concluded that to the southeast of the jetty, the Ubin shoreline would experience higher erosion risk from boats travelling at more than 5 knots. In contrast, to the northwest, both the Ubin and Ketam shorelines could experience higher erosion risk from boats travelling at more than 10 knots. As such, it is recommended that boats travelling within the Ketam Channel travel at less than 5 knots and post up signages stating the speed limit at the new jetty to mitigate this impact.
- **Propeller Wash-Induced Sediment Plume:** The propeller wash-induced plumes from future vessel traffic resulted in minimal and localised sediment plumes and some erosion within the Ketam Channel in the northwest. Changes were considered low.
- **Marine Biodiversity and Shorelines:** The presence of the new jetty creates a long-term permanent impact on intertidal and macrobenthic habitats. This is therefore assessed as **Slight Negative Impact**. The impact on marine biodiversity from propeller wash-induced sediment plumes was assessed as **No Impact**. The change in lighting environment to marine fauna was assessed as **Slight Negative Impact**. Finally, the erosion/sedimentation from ship wakes resulted in **Slight Negative Impact** on Intertidal areas and sensitive (presently eroding) shorelines, and **Major Negative Impact** on mangrove habitats. With the implementation of appropriate shoreline protection measures, these impacts can be reduced to **Slight to Minor Negative Impact.**
- **Terrestrial Biodiversity:** Both the effect of direct footprint losses and changes to lighting environment from the jetty were assessed as **Slight Negative Impact.**
- **Marine Navigation: No Impact** are anticipated for hydrodynamic change, erosion/sedimentation and changes to sea space impacts to marine navigation. No mitigation measures are required.
- **Aquaculture**: The impact of increased shipping traffic and pollutant release to the newly operational ULL Jetty to Aquaculture farms and caged fishes is assessed as **No Impact.** No Mitigation measures are required.
- **Socio-economic:** The visual impacts from SSC to the receptors are assessed as **No Impact**. The increased accessibility and economic changes for local businesses in Pulau Ubin were assessed as **Minor Positive and Slight Positive Impacts,** respectively.
- **Transboundary:** No impact

9 References

/1/ Ang, Q. (2022). Hope for saving S'pore's last wild cat. The Straits Times. Accessed on 06 March 2023. https://www.straitstimes.com/singapore/environment/hope-for-saving-spores-last-wild-cat

/2/ Bat Conservation Trust. (2014). Artificial Lighting and Wildlife (Interim Guidance: Recommendations to help minimise the impact artificial lighting). Accessed on 15 August 2023. https://cdn.bats.org.uk/uploads/pdf/BCT_Interim_Guidance_Artificial_Lighting_June_2014.pdf?v=1541085199

/3/ Bearer, S., & Sargent, S., 2015. Reducing Ecological Impacts of Shale Development: Recommended Practices for the Appalachians.

/4/ Bellmann M. A., Brinkmann J., May A., Wendt T., Gerlach S., Remmers P. 2020 Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie (BSH)), Technical Report, Order No. 10036866.

/5/ Brown, L. (2001). Overview of research on the effects of noise on wildlife. ALIS.

/6/ Browne, N. K., Yaakub, S. M., Tay, J. K., & Todd, P. A. (2017). Recreating the shading effects of ship wake induced turbidity to test acclimation responses in the seagrass *Thalassia hemprichii*. Estuarine, Coastal and Shelf Science, 199, 87-95.

/7/ Bruce-White, C., & Shardlow, M. (2011). *A review of the impact of artificial light on invertebrates*. Buglife-The Invertebrate Conservation Trust.

/8/ Brüning, A., Kloas, W., Preuer, T., & Hölker, F. (2018). Influence of artificially induced light pollution on the hormone system of two common fish species, perch and roach, in a rural habitat. *Conservation Physiology*, *6*(1), coy016.

/9/ Carlson, T. J. (2012). Barotrauma in fish and barotrauma metrics. In *The effects of noise on aquatic life* (pp. 229-233). Springer New York.

/10/ Carr, S. (2021). Artificial light may be changing marine ecosystems. *Octo*. Retrieved July 27, 2023 from https://octogroup.org/news/artificial-light-may-be-changing-marine-ecosystems/

/11/ Chiok, W. X., Ng, E. Y., Tang, Q., Lee, J. G., & Rheindt, F. E. (2021). A distance sampling survey of the Critically Endangered Straw-headed Bulbul *Pycnonotus zeylanicus* in Singapore. Bird Conservation International, 31(3), 468-480.

/12/ Chua, M., Sivasothi, N., & Teo, R. (2009). Rediscovery of greater mouse deer, Tragulus napu (Mammalia: Artiodactyla: Tragulidae) in Pulau Ubin, Singapore. Nature in Singapore, 2, 373-378.

/13/ Commonwealth of Australia. (2023) National Light Pollution Guidelines for Wildlife 2.0. Retrieved July 27, 2023, from https://www.dcceew.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

/14/ Construction noise control. National Environment Agency. (2011). Retrieved February 9, 2023, from https://www.nea.gov.sg/our-services/pollution-control/noise-pollution/construction-noise-control

/15/ Convention on Migratory Species (CMS). (2020). Light Pollution Guidelines for Wildlife. Resolution 13.5. 13th Conference of Parties (COP13). Retrieved July 27, 2023, from https://www.cms.int/sites/default/files/document/cms_cop13_res.13.5_light-pollution-guidelines_e.pdf

/16/ Davies, T. W., Duffy, J. P., Bennie, J., & Gaston, K. J. (2014). The nature, extent, and ecological implications of marine light pollution. *Frontiers in Ecology and the Environment*, *12*(6), 347-355.

/17/ Davison GWH, Ng PKL and Ho HC (2008). The Singapore Red Data Book: Threatened Plants and Animals of Singapore. 2nd edition. Nature Society (Singapore), Singapore.

/18/ Din, Z., Ahamad, B.A., Jamaliah, M.R.S.N., Wan Mustapha, W.D., (1996). Water and sediment quality of west coast Peninsula Malaysia. In: Conference on ASEAN Marine Environmental Management: Quality Criteria and Monitoring for Aquatic Life and Human Health Protection, 24–28 June 1996, Penang, Malaysia, p. 21.

/19/ Duarte, C. M. (1991). Seagrass depth limits. *Aquatic botany*, *40*(4), 363-377.

/20/ Eggleston, M. R. (2012). Impact of Sediment Resuspension Events on the Availability of Heavy Metals in Freshwater Sediments [Masters' Thesis, Albion College]. https://deepblue.lib.umich.edu/

/21/ Ellinger, N., & Hödl, W. (2003). Habitat acoustics of a neotropical lowland rainforest. Bioacoustics, 13(3), 297–321. https://doi.org/10.1080/09524622.2003.9753503

/22/ Environmental Protection Agency. (2022). *What are volatile organic compounds (VOCs)?* US EPA. Retrieved February 13, 2023, from https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs

/23/ FHWA. (2017). Noise Effect on Wildlife. Retrieved May 19, 2017, from https://www.fhwa.dot.gov/ENVIRONMENT/noise/noise_effect_on_wildlife/effects/wild04.cfm

/24/ Fung, T. K., Chua, M. A. H, Teo, R. C. H., Sivasothi, N. (2017). Mainland leopard cat on Pulau Ubin. Singapore Biodiversity Records, 160-161.

/25/ Gibson, R. N., Atkinson, R. J., & Gordon, J. D. (2016). Zooplankton diel vertical migration-a review of proximate control. Oceanogr. Mar. Biol, 47, 77-110.

/26/ Gin K Y H., Lin XH & Zhang S., 2000, Dynamics and size structure of phytoplankton in the coastal waters of Singapore., Journal of Plankton Research., 22(8):1465-1484.

/27/ Hamel, J.-F., Mercier, A., Conand, C., Purcell, S., Toral-Granda, T.-G. & Gamboa, R. 2013. Holothuria scabra. The IUCN Red List of Threatened Species 2013: e.T180257A1606648.http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T180257A1606648.en

/28/ Hansen, C. H., (1951). Fundamentals of acoustics. American Journal of Physics, Vol 19.

/29/ Kilminster, K., McMahon, K., Waycott, M., Kendrick, G. A., Scanes, P., McKenzie, L., ... & Udy, J. (2015). Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of the Total Environment, 534, 97-109.

/30/ Koh, J. J. M., Webb, E. L., & Leung, L. K. P. (2018). Using a spatial mark-resight model to estimate the parameters of a wild pig (*Sus scrofa*) population in Singapore. Raffles Bulletin of Zoology, 66.

/31/ Kotani, Y., Matsuyama, Y., Hayashi, M., & Matsuoka, K. (2006). Distribution and Abundance of resting cysts of *Alexandrium tamarense* and/or *A. catenella* (Dinophyceae) in Tokyo Bay, Japan. Plankton and Benthos Research, 1(3), 147-154.

/32/ Kriebel, D. L., Seelig, W. N. (2005). An empirical model for ship-generated waves. Ocean Waves Measurement and Analysis, Fifth International Symposium WAVES 2005, 3rd-7th, July, 2005. Madrid, Spain Paper number: 58

/33/ Land Transport Authority (LTA). (2019). Guidelines to the submission of design drawings for public street lighting, cycling path lighting, footpath lighting and zebra crossing flashing beacon lighting system. Accessed on 15 August 2023. https://onemotoring.lta.gov.sg/content/dam/onemotoring/Driving/Road_Safety/LTA_Streetlighting_Guidelines-05Apr19.pdf

/34/ Larkin, R. P., Pater, L. L., & Tazik, D. J. (1996). Effects of Military Noise on Wildlife. A Literature Review.

/35/ Lee Kong Chian Natural History Museum (2017a). Freshwater Marsh/Pond. Retrieved from The DNA of Singapore: https://www.lkcnhm.nus.edu.sg/dna/habitats/details/8

/36/ Lee Kong Chian Natural History Museum (2017b). Open Country. Retrieved from The DNA of Singapore: https://www.lkcnhm.nus.edu.sg/dna/habitats/details/10

/37/ Lindsay, S., Ho, B. C., Chong, K. Y., Turner, I. M., Ibrahim, A., Alonso-García, M., ... & Er, K. B. H. (2022). Flora of Singapore: checklist and bibliography. *Gardens' Bulletin Singapore*, *74*(S1).

/38/ Liu, H., T. E. Baldock, J. W. Chai, and L. Q. Yang. (2018). Ship-generated Waves and Ship Wakes: A Review of Parameters, Predictive Models, and Full-scale Observations. Applied Ocean Research, 74: 67-81.

/39/ Liu, H., Wu, C., Xu, W., Wang, X., Thangaraj, S., Zhang, G., ... & Sun, J. (2020). Surface phytoplankton assemblages and controlling factors in the Strait of Malacca and Sunda Shelf. *Frontiers in Marine Science*, *7*, 33.

/40/ Matsuoka, K., & Fukuyo, Y. A. S. U. W. O. (2000). Technical guide for modern dinoflagellate cyst study. WESTPAC-HAB, Japan Society for the Promotion of Science, Tokyo, Japan, 47.

/41/ National Environment Agency (NEA). (2023). Beach Short-term Water Quality Information. Accessed on 06 March 2023. https://www.nea.gov.sg/our-services/pollution-control/water-quality/recreational-beaches/beach-short-term-water-quality-information

/42/ National Parks Board (NParks) (2020). Biodiversity Impact Assessment (BIA) Guidelines. https://www.nparks.gov.sg/biodiversity/urban-biodiversity/biodiversity-impact-assessment-guidelines

/43/ NParks. (2022). Species List (Red Data Book List). Accessed on 06 March 2023. https://www.nparks.gov.sg/biodiversity/wildlife-in-singapore/species-list

/44/ Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). camtrapR: an R package for efficient camera trap data management. Methods in Ecology and Evolution, 7(12), 1457-1462.

/45/ Nielsen, P. (1992). Coastal bottom boundary layers and sediment transport. World Scientific Publishing Co.

/46/ Ortega, C. P. (2012). Chapter 2: Effects of noise pollution on birds: A brief review of our knowledge. Ornithological Monographs, 74(1), 6-22. doi:10.1525/om.2012.74.1.6

/47/ Parris, K. M., & Schneider, A. (2009). Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecology and society, 14(1).

/48/ Pastakia, C. M. R., & Jensen, A. (1998). The Rapid Impact Assessment Matrix (RIAM) for EIA. Environmental Impact Assessment Review, 18(5), 461–482. https://doi.org/10.1016/s0195-9255(98)00018-3

/49/ Petersen, W., Willer, E., & Willamowski, C. (1997). Remobilization of trace elements from polluted anoxic sediments after resuspension in oxic water. *Water, Air, and Soil Pollution*, *99*, 515-522.

/50/ Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., ... & Tavolga, W. N. (2014). Sound exposure guidelines (pp. 33-51). Springer International Publishing.

/51/ Rhodes, L., McNabb, P., De Salas, M., Briggs, L., Beuzenberg, V., & Gladstone, M. (2006). Yessotoxin production by *Gonyaulax spinifera*. Harmful Algae, 5(2), 148-155.

/52/ Shi, B., Wang, Y.P., Yang, Y., Li, M., Li, P., Ni, W., Gao, J. (2015). Determination of critical shear stresses for erosion and deposition based on in situ measurements of currents and waves over an intertidal mudflat. Journal of Coastal Research, 00(0), 000–000.

/53/ Slabbekoorn, H., & Ripmeester, E. A. P., 2008. Birdsong and anthropogenic noise: Implications and applications for conservation. Molecular Ecology, 17(1), 72–83. http://doi.org/10.1111/j.1365-294X.2007.03487.

/54/ Sorensen, R. M., Weggel, J. R. (1984). Development of ship wave design information. Proceeding of the 19th International Conference on Coastal Engineering, Texas, USA. 3(216): 3227-3243.

/55/ Surbana Jurong Consultants Pte Ltd (2015). Feasibility Study for Shoreline Protection and Restoration at Pulau Ubin, Data Collection Site Assessment Report, Final report prepared for National Parks Board.

/56/ Surbana Jurong Consultants Pte Ltd (2016). Feasibility Study for Shoreline Protection and Restoration at Pulau Ubin, Coastal Dynamic Assessment Report. Prepared for National Parks Board.

/57/ Tagliapietra, D., & Sigovini, M. (2010). Benthic fauna: collection and identification of macrobenthic invertebrates. Terre et Environnement, 88, 253-261.

/58/ Tan, H. T. W., Chou, L. M., Yeo, D. C. J., & Ng, P. K. L. (2007). The Natural Heritage of Singapore. Prentice Hall.

/59/ Tan, A. (2020a) Go wild over 20 new animal species on Pulau Ubin. Accessed 30 December 2020. https://www.straitstimes.com/singapore/environment/go-wild-over-20-new-animal-species-on-pulau-ubin.

/60/ Tan. R. (2022b). How much sh*t is in our waters? Accessed on 06 March 2023. https://wildshores.blogspot.com/2020/10/how-much-sht-is-in-our-waters.html#.ZAWUI3ZBxPY

/61/ Terrados, J., Thampanya, U., Srichai, N., Kheowvongsri, P., Geertz-Hansen, O., Boromthanarath, S., ... & Duarte, C. M. (1997). The Effect of Increased Sediment Accretion on the Survival and Growth of Rhizophora apiculata seedlings. *Estuarine, Coastal and Shelf Science*, *45*(5), 697-701.

/62/ Thampanya, U., Vermaat, J. E., & Terrados, J. (2002). The effect of increasing sediment accretion on the seedlings of three common Thai mangrove species. Aquatic Botany, 74(4), 315-325.

/63/ Thampanya, U., Vermaat, J. E., Sinsakul, S., & Panapitukkul, N. (2006). Coastal erosion and mangrove progradation of Southern Thailand. Estuarine, coastal and shelf science, 68(1-2), 75-85.

/64/ Trottet, A., Wilson, B., Sew Wei Xin, G., George, C., Casten, L., Schmoker, C., ... & Drillet, G. (2018). Resting stage of plankton diversity from Singapore coastal water: Implications for harmful algae blooms and coastal management. Environmental management, 61(2), 275-290.

/65/ Trottet, A., George, C., Drillet, G., & Lauro, F. M. (2022). Aquaculture in coastal urbanized areas: A comparative review of the challenges posed by Harmful Algal Blooms. Critical Reviews in Environmental Science and Technology, 52(16), 2888-2929.

/66/ The Nature Conservancy. (2015). Our World - 2015 Annual Report. 23. https://doi.org/10.1016/j.jpeds.2010.06.037

/67/ United Nations Environment Programme (UNEP) Convention on Migratory Species (CMS) Resolution 13.5. Light Pollution Guidelines for Wildlife (February 2022). Available from https://www.cms.int/sites/default/files/document/cms_cop13_res.13.5_light-pollution-guidelines_e.pdf

/68/ Urick, R.J. (1983). Principles of underwater sound, 3rd ed. McGraw-Hill, New York. 423 p.

/69/ Wanderlust. (2016). Kayaking Pulau Ubin mangrove via Sungei Puaka. Kayaking Pulau Ubin Mangrove via Sungei Puaka. Retrieved 13 5, 2023, from http://wanderlustpaddling.blogspot.com/2016/05/kayaking-pulau-ubin-mangrove-via-sungei.html

/70/ Wilhelm, F. M. (2009). Pollution of aquatic ecosystems I. Encyclopedia of Inland Waters, 110–119.

/71/ Wolanski, E. (1995). Transport of sediment in mangrove swamps. In Asia-Pacific Symposium on Mangrove Ecosystems: Proceedings of the International Conference held at The Hong Kong University of Science & Technology, September 1–3, 1993 (pp. 31-42). Springer Netherlands.

/72/ Yang, S., Lim, R. L., Sheue, C. R., & Yong, J. W. (2011, October). The current status of mangrove forests in Singapore. In Proceedings of Nature Society, Singapore's Conference on 'Nature Conservation for a Sustainable Singapore'16th October (Vol. 2011, pp. 99-120).

/73/ Yee, A. T. K., Ang, W. F., Teo, S., Liew, S. C., & Tan, H. T. W. (2010). The present extent of mangrove forests in Singapore. Nature in Singapore, 3(3), 139-145.

/74/ Yee, A. T. K., Chong, K. Y., Neo, L., & Tan, H. T. (2016). Updating the classification system for the secondary forests of Singapore. Raffles Bulletin of Zoology.

/75/ Zaccheus, M. (2014). Pulau Ubin coast faces erosion risk. The Straits Times. Singapore.

APPENDICES

APPENDIX A

Hydrodynamic Modelling

A Hydrodynamic Modelling

Tide is the principal force that drives the dynamics of Singapore’s waters, generated by the combination of tides propagating from the South China Sea and those produced in the Indian Ocean. The rising tide moves westward and the falling tide eastward.

In the Singapore Straits, the tide is dominated by four semi-diurnal and diurnal components: M2, S2, O1 and K1. The semi-diurnal tides mainly originate from the Andaman Sea, while the diurnal components mainly originate from the South China Sea, though with a contribution from the Java Sea. The tide in Singapore is generally semi-diurnal with two high tides and two low tides occurring each day.

During the northeast monsoon, the prevailing winds pile-up water at the south-western portion of the South China Sea, thus setting up a steric gradient between the eastern and western ends of the Singapore Strait. The phenomenon produces a slight seasonal increase in the local MSL, which, in combination with direct wind forcing from the prevailing monsoon, produces a slow net westward current in the Singapore Strait. Conversely, during the southwest monsoon, water mass is forced out into the South China Sea, producing a slight depression in the local MSL between April and September and a net current that travels west to east.

Currents around the areas of interest are complicated by a number of factors including tides, storm surge, seasonal surge and local eddy formation, and therefore a two-dimensional hydrodynamic (HD) MIKE 21 Flexible Mesh (FM) model was set up and forced by tides, seasonal surge and local wind extracted from Changi wind station.

A.1 MIKE 21 Flow Model FM

The MIKE 21 Flow Model is a modelling system for 2D free-surface depth-integrated flows that is developed and maintained by DHI and offered as part of MIKE Powered by DHI. The model system is based on the numerical solution of the two-dimensional (2D) incompressible Reynolds-averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure. The model is applicable for the simulation of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas, and seas wherever stratification can be neglected. The model can be used to simulate a wide range of hydraulic and related items, including tidal exchange and currents and storm surges. For further details, see DHI 2020 /1/.

The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow Model FM. The HD module simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries, and coastal regions. The effects and facilities include:

- Barometric pressure gradients
- Sources and sinks (e.g. rivers, intake and outlets from power plants)
- Flooding and drying
- Momentum dispersion
- Tidal potential
- Coriolis force
- Precipitation/Evaporation
- Ice coverage
- Wave radiation stresses

The model uses a flexible mesh (FM) based on unstructured triangular or quadrangular elements and applies a finite volume numerical solution technique.

A.2 Regional Hydrodynamic Model

A.2.1 Set-up and parameters

The model domain covers the Singapore Straits, and its resolution increases towards the project area, reaching approximately 25 m. The overall flexible mesh set up for the study area is shown in Figure A.1.

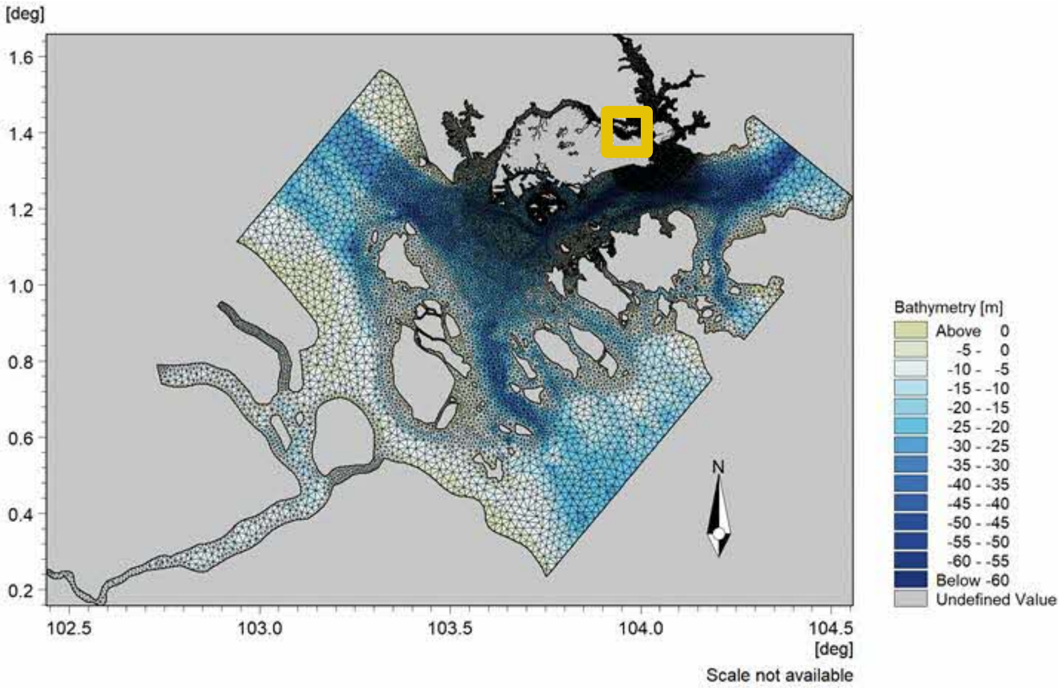


Figure A.1 Singapore Straits model domain and mesh. Location of the study site is indicated by yellow box

The bathymetry data set applied in the project vicinity consist of survey data from Client. The coverage of the surveyed data is depicted in Figure A.2. The survey data were supplemented by MIKE C-MAP for areas outside of the project site (see Figure A.1). MIKE C-MAP provides access to digital nautical charts from Jeppesen Norway. In order to obtain a consistent dataset, a common vertical reference relative to local chart datum (CD) was applied for the surveyed bathymetry and data from MIKE C-MAP.

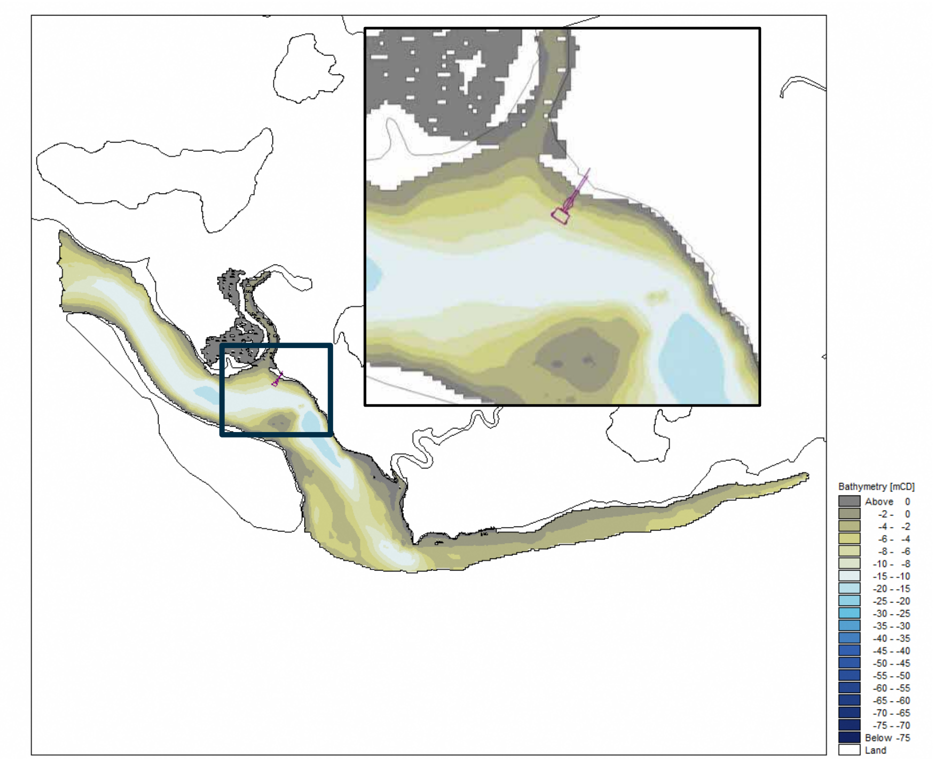


Figure A.2 Surveyed bathymetry data (in CD) available in the vicinity of the project site.

The boundaries of the hydrodynamic model were configured to align with the tidal phase of the study area. Setting the boundary line parallel to the tidal phase is preferred for a uniform description of the flow across the boundary line.

Water level predictions were imposed at the open boundaries to generate the tidal stream in the hydrodynamic model. The water level predictions are available from the following sources:

- 1979 Four Nation Joint Hydrographic Survey (JHS) water level constituents. This study utilised water level measurement taken from 1978 to 1979 at a number of tidal stations along the Malacca Straits and Singapore Straits. Fifty-four constituents are used to specify the water level variation using the IOS method.
- Admiralty Tide Table (ATT) water level constituents, which is published by the UK Hydrographic Office for tidal stations around the world. Water level variations are specified using six main constituents using the ATT method.

Additional boundary condition included in the model are the residual water level (SSH) extracted from Global Ocean Physics Reanalysis (GLORYS12V1), see below. Local storm surge was accommodated by applying wind force based on the wind data from Changi wind station.

Global Ocean Physics Reanalysis (GLORYS12V1)

The GLORYS12V1 product is the CMEMS global ocean eddy-resolving (1/12° horizontal resolution, 50 vertical levels) reanalysis covering the altimetry. The reanalysis is generated using the 'Nucleus for European Modelling of the Ocean' (NEMO) ocean model driven at the surface by the ECMWF ERA-Interim reanalysis. It assimilates along track altimeter observations (sea level anomaly), satellite sea surface temperature (SST), sea ice concentration and in situ temperature and salinity vertical profiles from the 'Coriolis Ocean database ReAnalysis' (CORA) dataset using a reduced-order Kalman Filter scheme. In addition, it uses a 3D-Var scheme for the correction of large-scale biases in temperature and salinity. The reanalysis covers the satellite era from 1993 to 2018. More details on GLORYS can be found in product page at the CMEMS website http://marine.copernicus.eu/services-portfolio/access-to-roducts/?option=com_csw&view=details&product_id=GLOBAL_REANALYSIS_PHY_001_030.

GLORYS12V1 /2/ provides non-tidal water levels and other ocean-related parameters at 1/12° resolution global coverage from 1993 to present at a timestep of one day. Output items of relevance to the present application include non-tidal water level, which also includes the contribution of the steric gradient between west and east of Singapore as well as the seasonal variations in water level.

A.2.2 Model Setup

Summary of model setup applied for production run is summarized inTable A.1

Table A.1 Summary of the HD model settings applied for the production period

Setting	Value
Mesh resolution	Element face size around the project site ~25 m
Simulation period	14 days during Northeast and Southwest monsoon (with 10-min timestep)
Eddy viscosity	Smagorinsky formulation with constant = 0.28
Wind forcing	Changi wind data. Wind friction: linear variation of 0.001255 at 7 m/s wind speed and 0.002425 at 25 m/s wind speed
Bed resistance	Spatially varying
Boundary conditions	Water level boundary condition: Predicted water level time-series superimposed with GLORYS12V1

A.2.3 Model Calibration

A.2.3.1 Calibration Performance Criteria

The evaluation of whether an established model provides a sufficiently accurate description of the environment depends in general on the specific objective for the individual model. Conventionally, the evaluation of performance has been based on visual comparisons, e.g. by time series plots or instantaneous plan/transect plots of modelling results and monitoring data. An appropriate internationally accepted standard for the validation of hydrodynamic model performance can be found in the UK Foundation for Water Research Publication Ref FR0374 “A framework for marine and estuarine model specification in the UK” /3/.

In broad terms, this can be categorised by the following performance limits:

- Tidal elevations: RMS (error) < 10% of the spring tidal range for measured time series water level station;
- Current speed deviation RMS (error) < 10 to 20% of the peak spring tide depth integrated with current strength >0.2 m/s; and
- Direction error RMS (error) < 20 degree for period with current strength >0.2 m/s.

To obtain an objective and quantitative measure of how well the model data compared to the observed data, a number of statistical parameters so-called quality indices (QI's) are also calculated. Prior to the comparisons, the model data are synchronized to the time stamps of the observations so that both time series had equal length and overlapping time stamps. For each valid observation, measured at time *t*, the corresponding model value is found using linear interpolation between the model time steps before and after *t*. The comparisons of the synchronized observed and modelled data are illustrated in (some of) the following figures:

- Time series plot including general statistics; and
- Scatter plot including quantiles, QQ-fit and QI's (dots coloured according to the density).

A.2.3.2 Calibration of Hydrodynamic Model

Model calibration is the process where the main governing conditions of the model are adjusted to produce the best reflection of measured data from the calibration control period. The performance of the model is then verified against an independent set of data (often a different survey period) whilst holding the previously determined calibration parameters constant. If the validation is unsuccessful, the process returns to the calibration stage and the cycle is repeated.

The main governing conditions that affect the performance of the hydrodynamic model are:

- Boundary conditions
- Bathymetry
- Bottom Resistance
- Eddy Viscosity

A.2.3.3 Calibration of Current Speed and Direction

The scatter validations of the local model results at ADCP1 station is presented in Figure A.4 to Figure A.7 and the model performance is tabulated in Table A.2 and Table A.3. The location of the calibration point (ADCP1) and transect ADCP (T1, T2, T3) are shown in Figure A.3. Do note that transect ADCP presents only the visual comparison of current speed and direction along the transect (Figure A.8).

Overall, the current speed and direction are well represented and reproduced. The scatter plots show good quantile alignments and low scatter index. Both the current speed and direction RMSEs fulfil the calibration criteria as outlined in A.2.3.1. In general, the tidal phases (timings) is well captured in the model (Figure A.6). The current speed and direction along the three (3) transect locations is also align with measured current speed and direction observation as shown in Figure A.8.

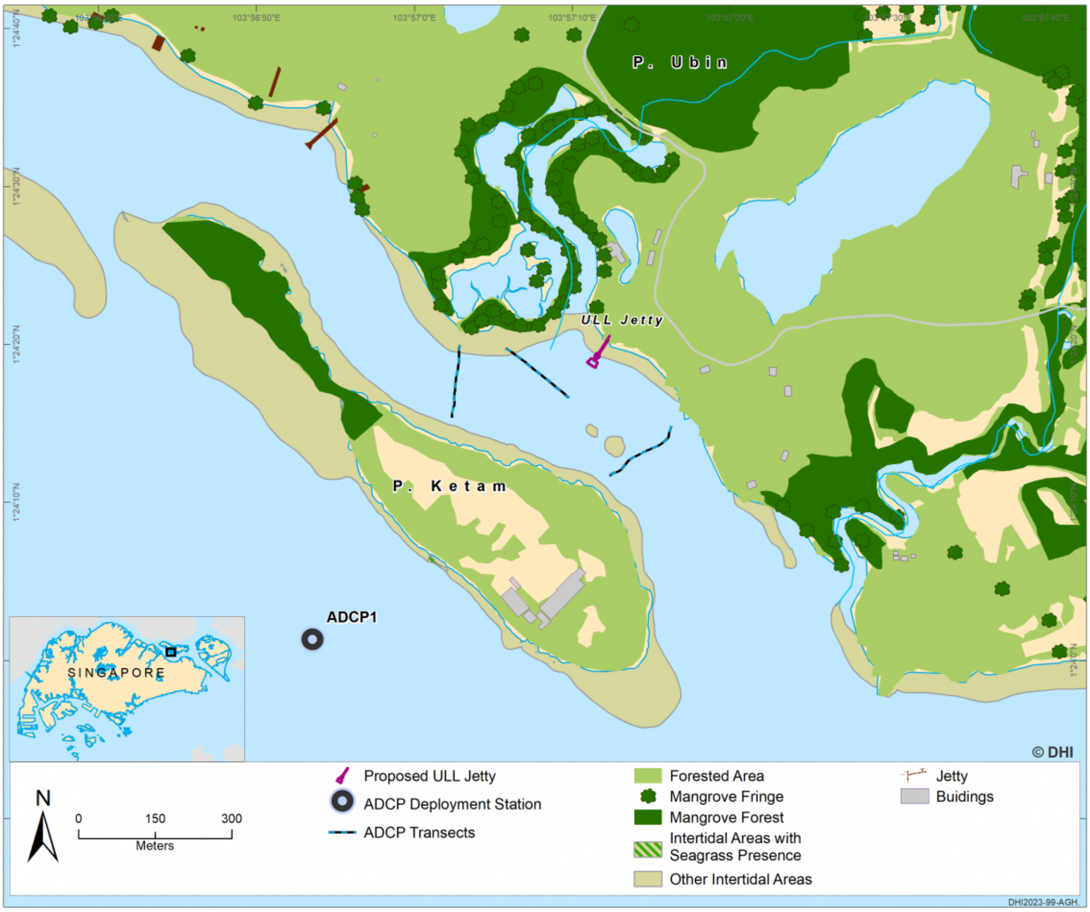


Figure A.3 Locations of ADCP for model calibration (ADCP1, T1, T2, T3)

Table A.2 Statistical analysis of current speed (RMSE)

ADCP	RMSE (m/s) Current Speed	RMSE (%) Current Speed
ADCP1	0.08	14

Table A.3 Statistical analysis of current direction (RMSE)

ADCP	RMSE Current Direction (deg)
ADCP1	4.88

Current Speed

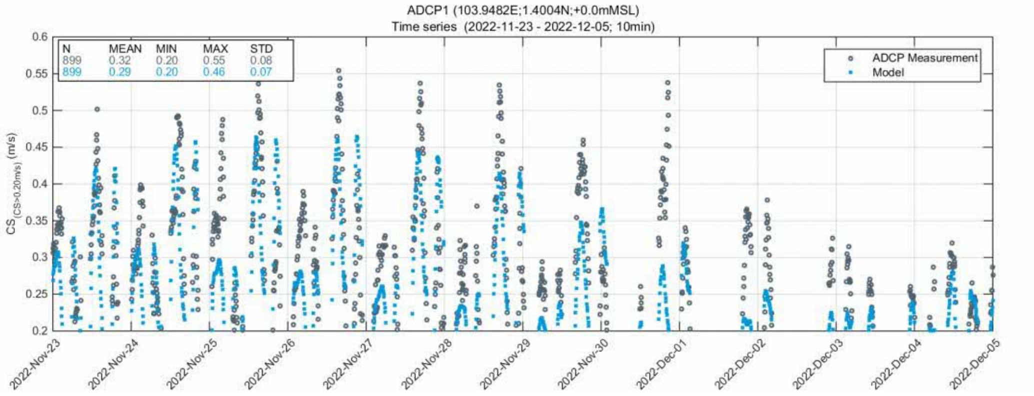


Figure A.4 Time series comparison of modelled and measured current speed at ADCP1 station

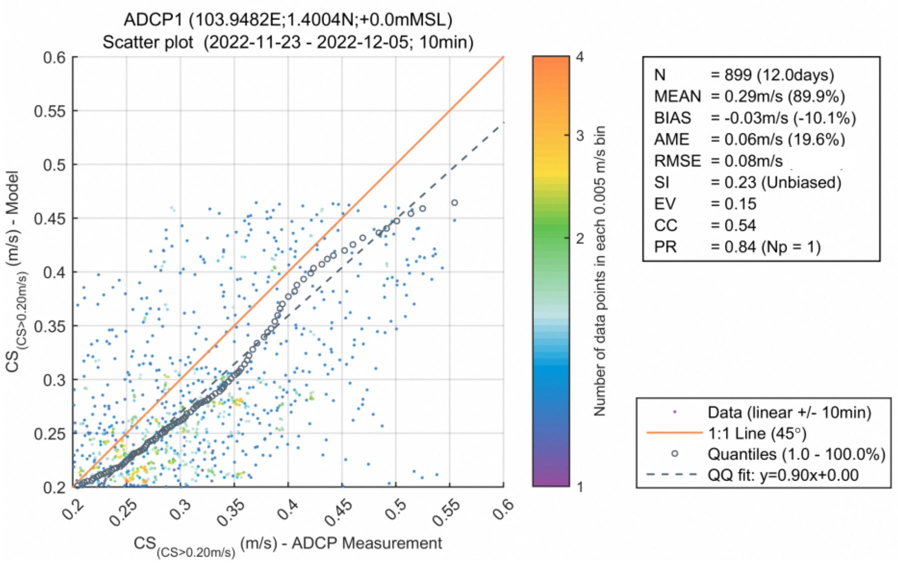


Figure A.5 Scatter comparison of modelled and measured current speed at ADCP1 station

Current Direction

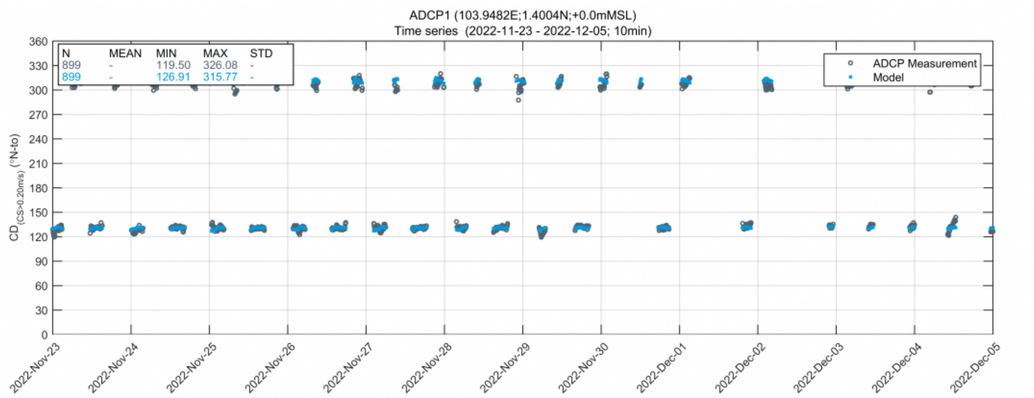


Figure A.6 Time series comparison of modelled and measured current direction at ADCP1 station

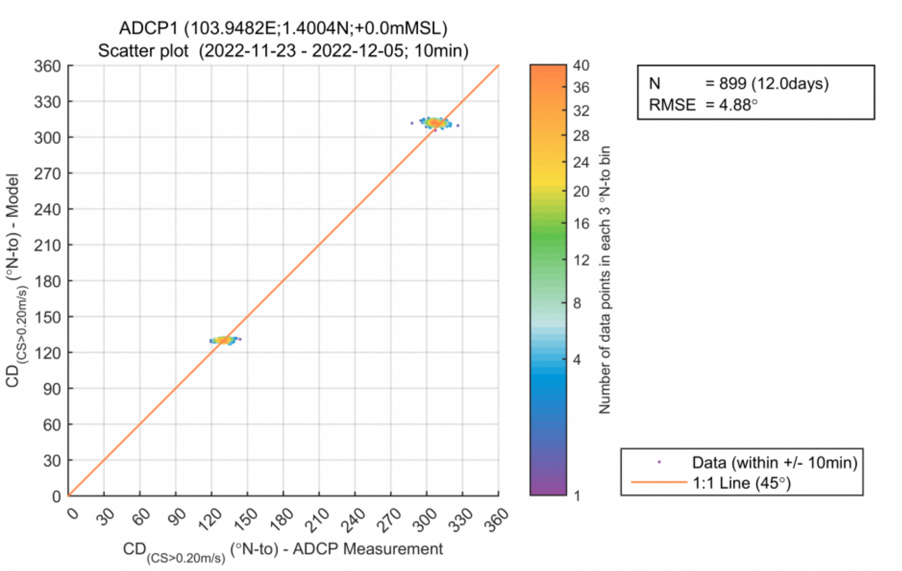


Figure A.7 Scatter comparison of modelled and measured current direction at ADCP1 station

Current Transect

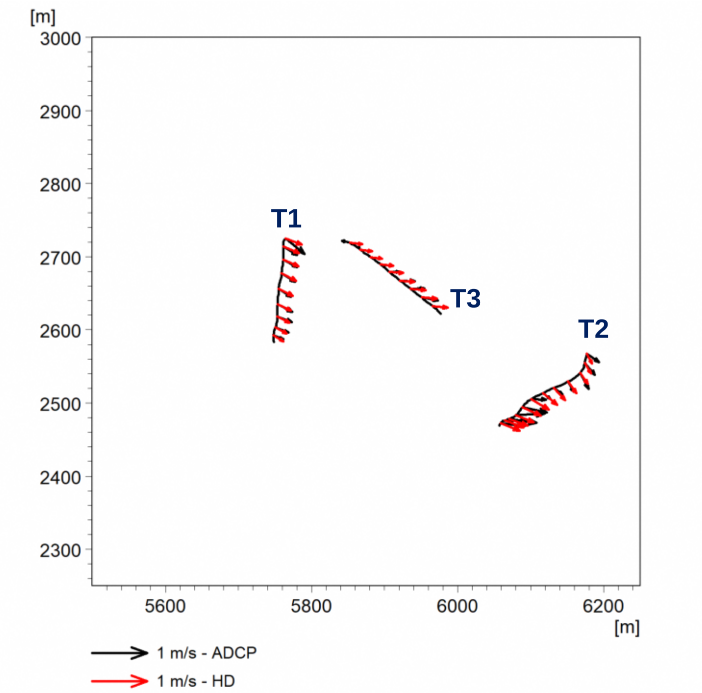


Figure A.8 Trasect current comparison of modelled and measured current speed and direction at T1, T2, and T3 ADCP transect location

A.2.3.4 Calibration of Water Level

The time series and scatter validation of the local model results at ADCP1 station is presented from Figure A.9 to Figure A.10, whilst the model performance is tabulated in Table A.4. Overall, the water level is well represented and reproduced. The scatter plot shows good quantile alignment and low scatter index. The comparisons have illustrated that the RMSE fulfil the calibration criteria as outlined in A.2.3.1.

Table A.4 Statistical analysis of water levels (RMSE)

Tidal Station	RMSE (m) Water Level	RMSE (%) Water Level
ADCP1	0.16	5

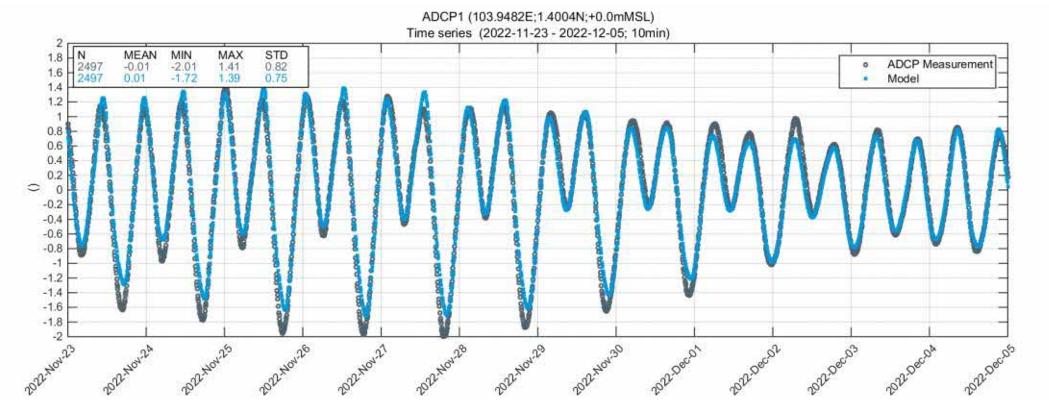


Figure A.9 Time series comparison of modelled and measured water level at ADCP1 station

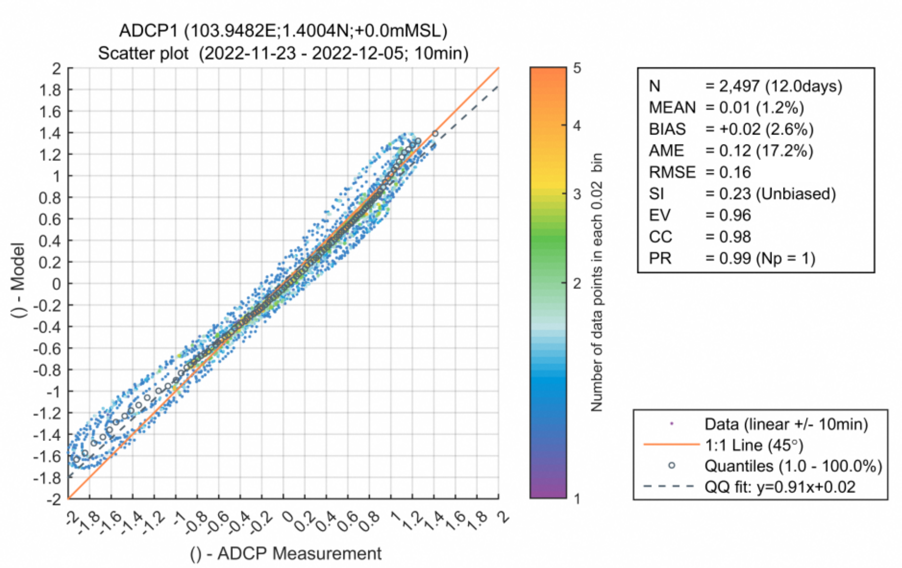


Figure A.10 Scatter comparison of modelled and measured water level at ADCP1 station

A.2.4 Output Specifications

The output of the local HD model included depth-integrated current components covering the entire model area (all grid cells) and water level at 10-minute intervals.

Table A.5 Specifications of current parameters

Abbreviation	Unit	Description
CS	m/s	Depth-integrated current speed
CD	°N (going to)	Depth-integrated current direction

A.2.5 Model Scenarios

For the EIA, the following modelling scenarios have been assessed for a period of 14 days, covering one spring-neap tidal cycle, during El Niño/La Niña (ENSO) events, a Neutral year, as well as both Northeast (NE) and Southwest (SW) monsoons. Do note that for the El Niño and La Niña year, only the NE Monsoon is simulated as these are the worst-case scenarios based on the intensity of an ENSO related index. The simulations also included a 1-day initialisation (warm-up) period. The selected production period is as follow:

- El Nino (NE monsoon): 16/01/2015, 00:00 - 31/01/2015, 00:00
- La Nina (NE monsoon): 25/12/2009, 00:00 - 09/01/2010, 00:00
- Neutral year (NE monsoon): 05/01/2013, 00:00 - 20/01/2013, 00:00
- Neutral year (SW monsoon): 18/06/2013, 00:00 - 03/07/2013, 00:00

A summary of the modelled scenarios is shown in Table A.6, whilst the profile for each scenario is displayed from Figure A.11 to Figure A.13. The baseline profile refers to existing land profile without ULL jetty construction. Construction Phase profile includes Baseline profile with the proposed two (2) marine steel pipe piles, and two (2) trimmed areas. Whereas, the final profile is defined as Baseline with the proposed four (4) marine steel pipe piles, and two (2) trimmed areas (i.e., seabed and shoreline).

Table A.6 Modelling scenarios for Hydrodynamics EIA study

Scenarios	Phase	ENSO Conditions	Year	Monsoon
1	Baseline	El Niño	2015	NE
2		La Niña	2010	NE
3		Neutral	2013	NE
4		Neutral	2013	SW
5	Construction (short-term)	El Niño	2015	NE
6		La Niña	2010	NE
7		Neutral	2013	NE
8		Neutral	2013	SW
9	Final (long-term)	El Niño	2015	NE
10		La Niña	2010	NE
11		Neutral	2013	NE
12		Neutral	2013	SW

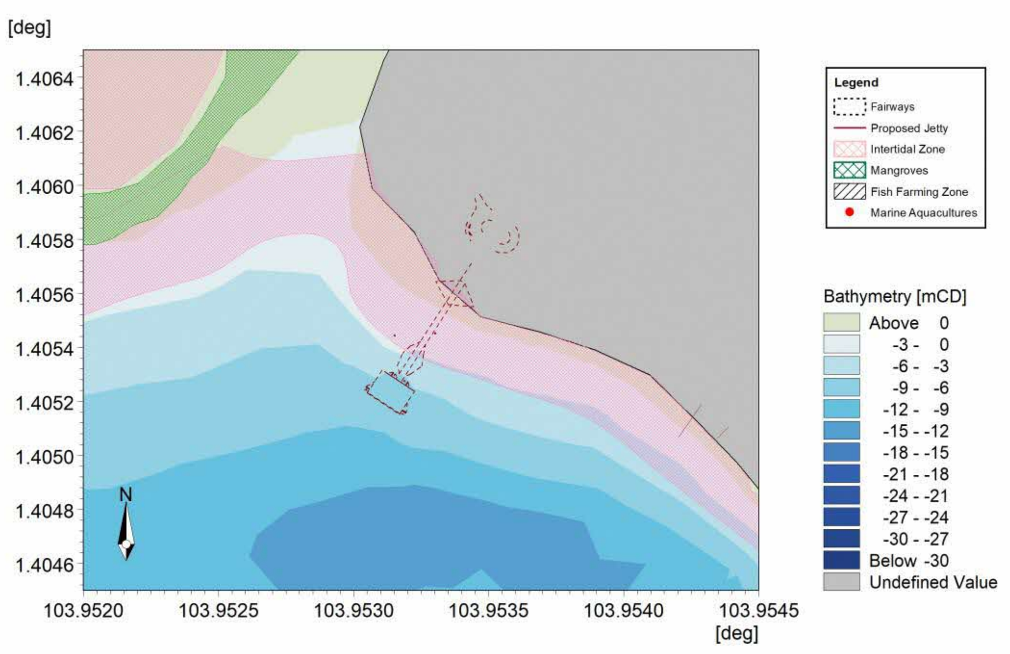


Figure A.11 Bathymetry and land profiles for Baseline phase profile for assessment of hydrodynamic impacts. An outline of the jetty is provided for visual context.

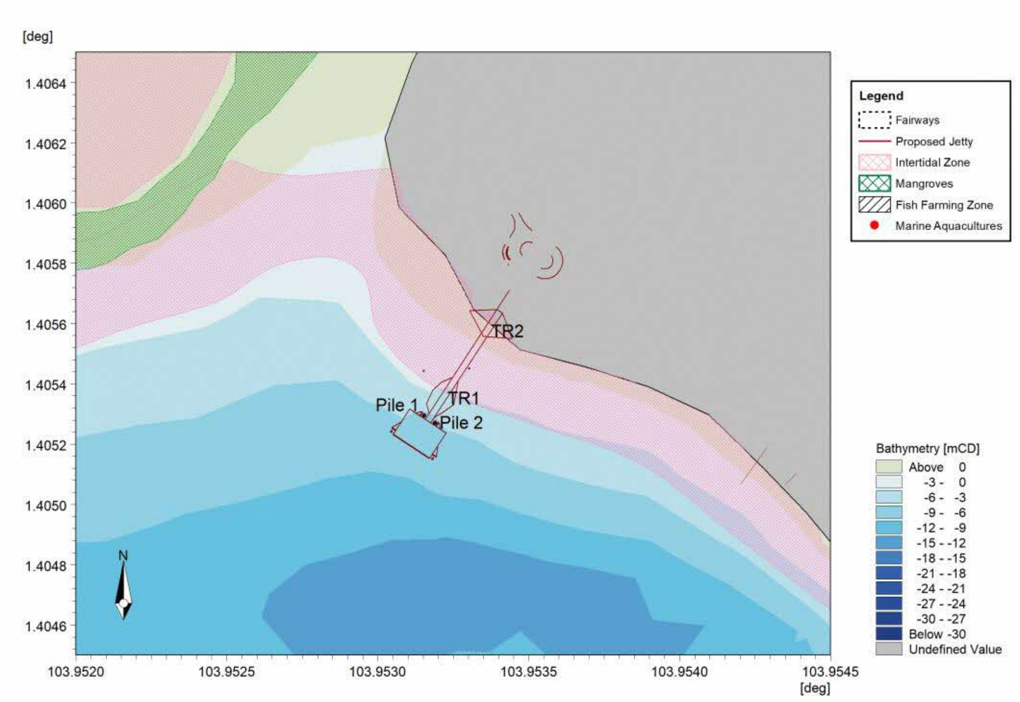


Figure A.12 Bathymetry and land profiles for Construction Phase for assessment of hydrodynamic impacts. The Construction Phase profile includes two (2) piling locations (i.e., Pile 1 and Pile 2) and two (2) trimming locations (i.e., TR1 in the seabed, and TR2 at the shoreline) with a trimming volume of 200 m^3 each

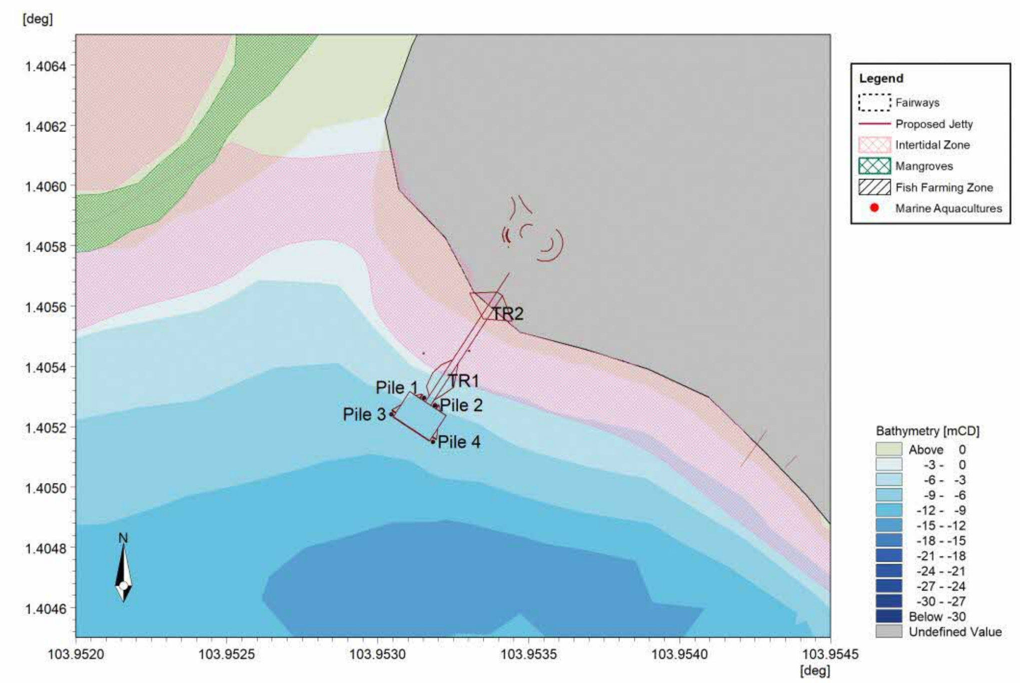


Figure A.13 Bathymetry and land profiles for Post-Construction final phase for assessment of hydrodynamic impacts. The Post-Construction Phase final profile includes four (4) piling locations (i.e., Pile 1, Pile 2, Pile 3, and Pile 4) and two (2) trimming locations (i.e., TR1 in the seabed, and TR2 in the shoreline) with a trimming volume of 200 m^3 each

A.3 Model Results

The results from the hydrodynamic model include:

- 2D maps for mean current speeds;
- 2D maps for maximum (95th percentile) current speeds; and
- 2D maps for representative current speeds (<0.5 knots, >2.0 knots and >3.5 knots)

The model results for Construction and Post-Construction Phase are presented in Section A.3.1 and Section A.3.2 below.

A.3.1 Model Results for Construction Phase

Change in Mean Current Speeds

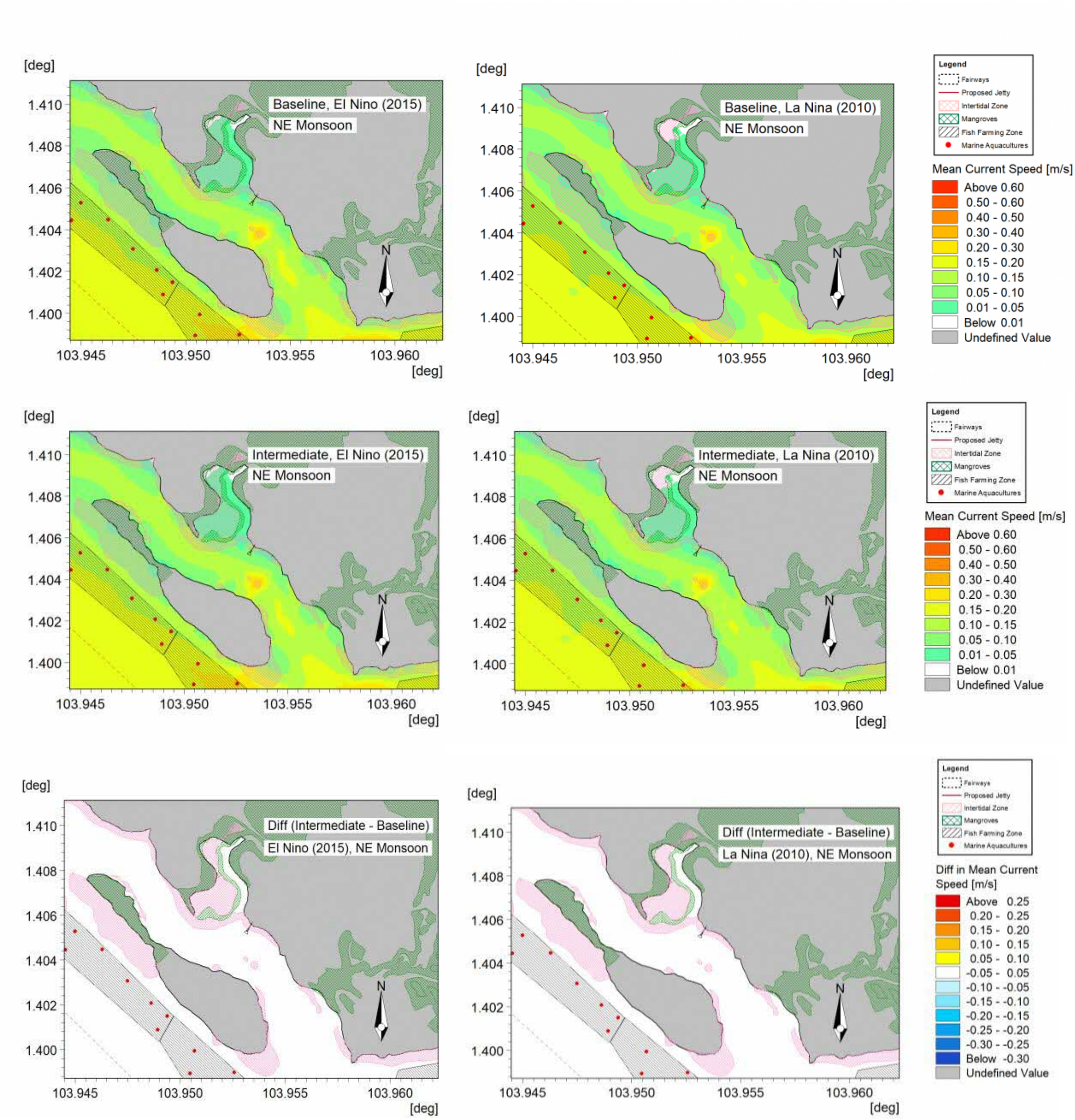


Figure A.14 Mean current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña.

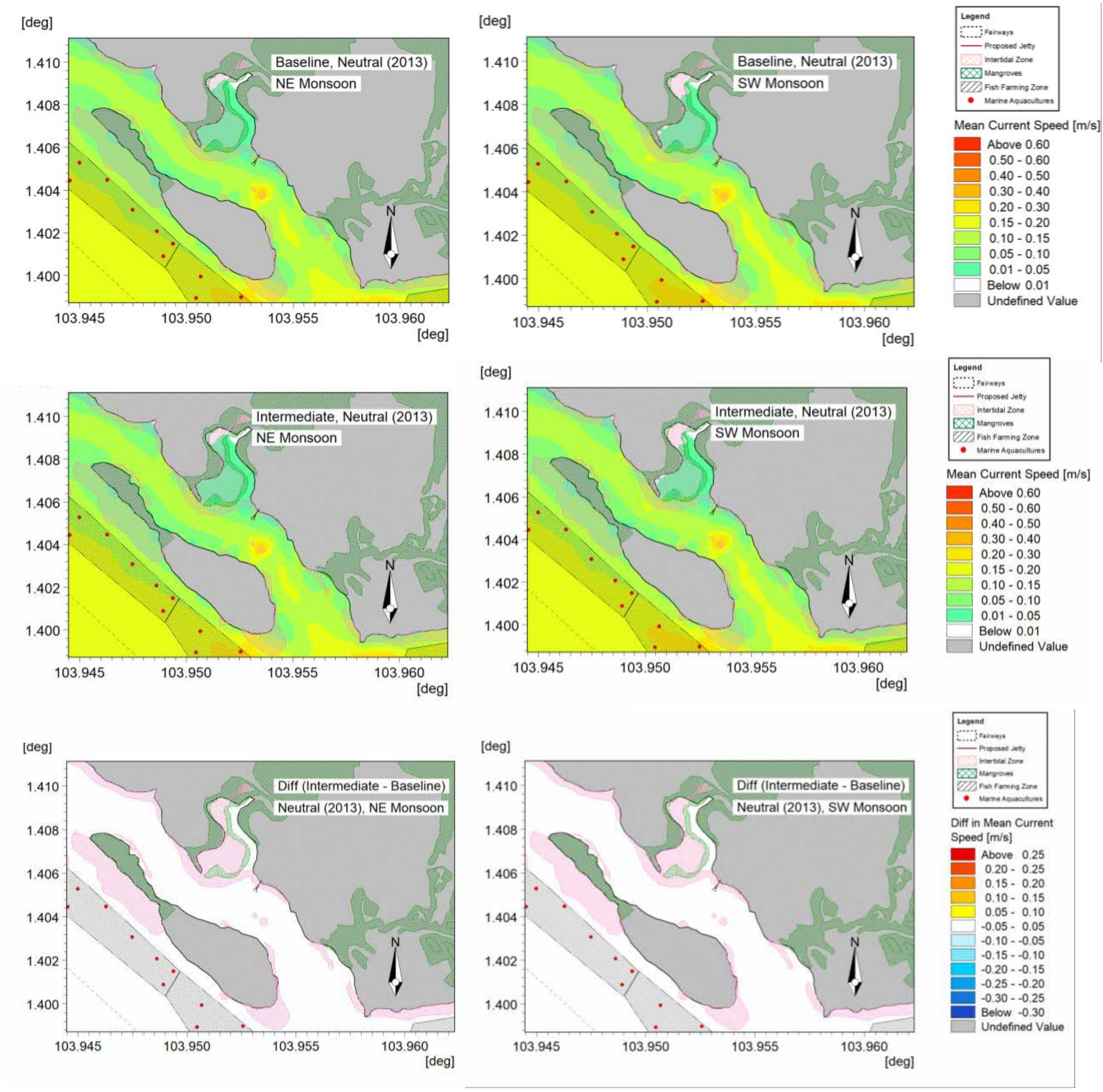


Figure A.15 Mean current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon.

Change in 95th Percentile Current Speeds

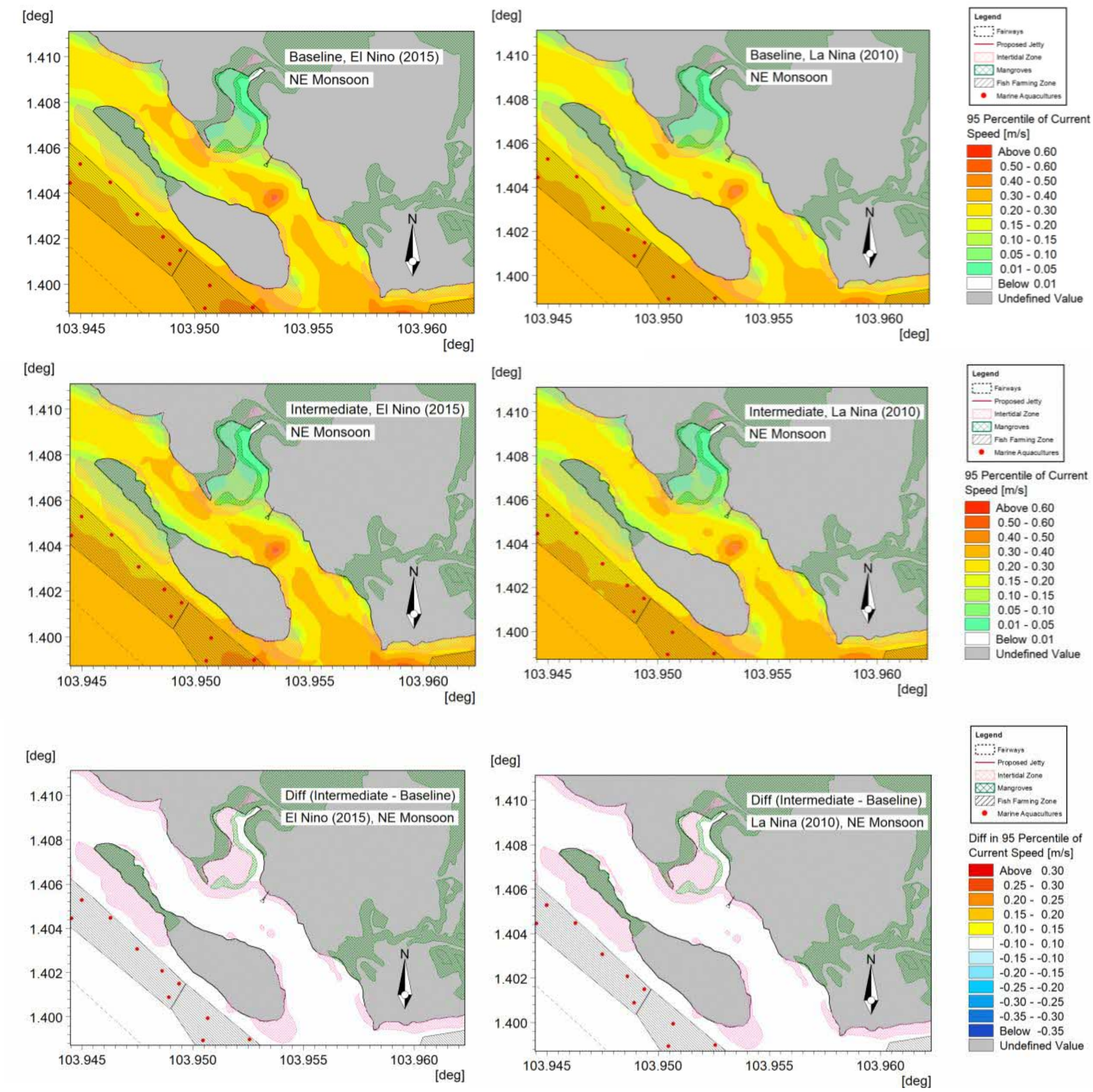


Figure A.16 95th percentile current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña.

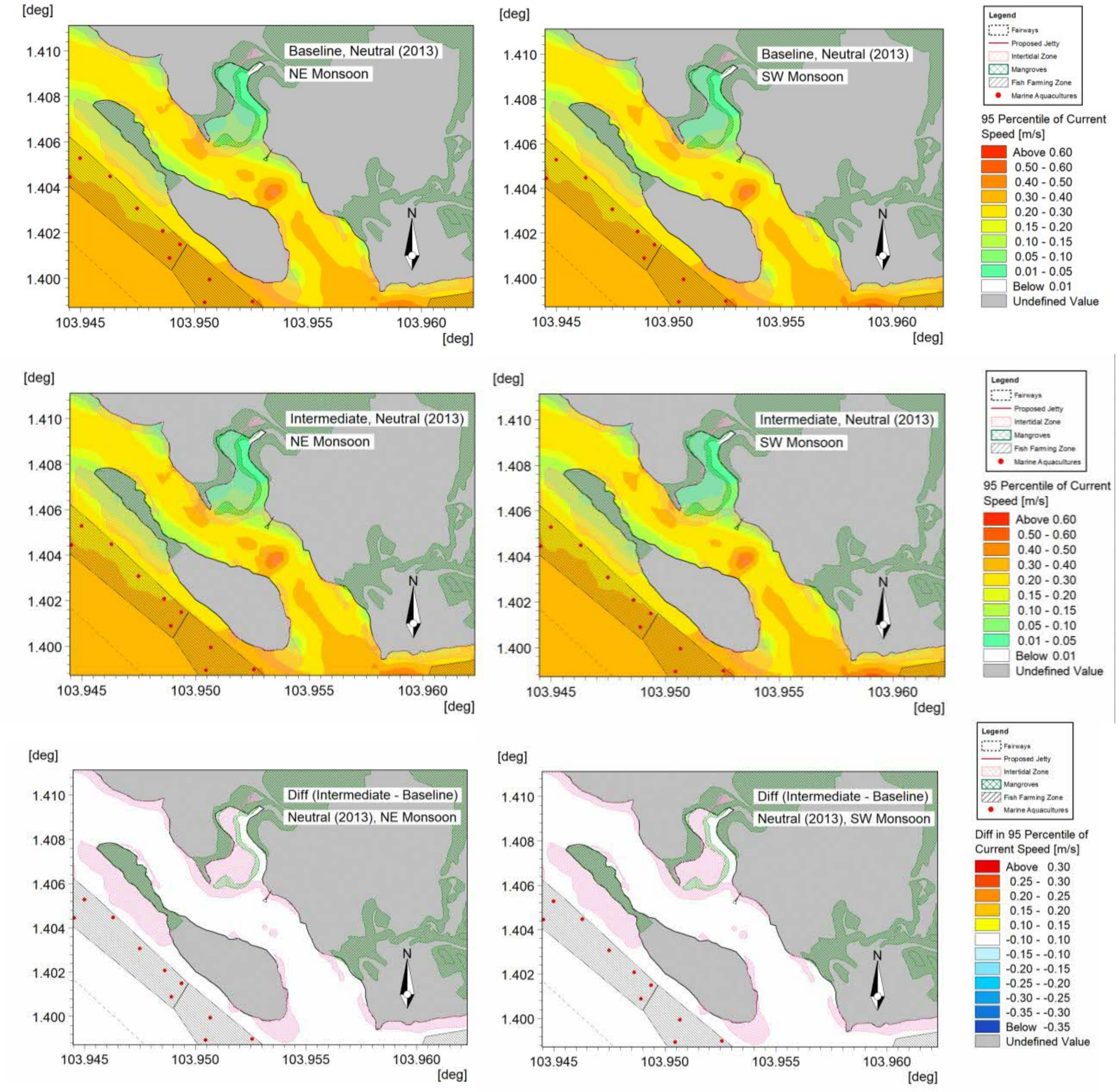


Figure A.17 95th percentile current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon.

Representative Current Speeds: Slackwater (<0.5 knots), exceedances of 2.0 knots and 3.5 knots

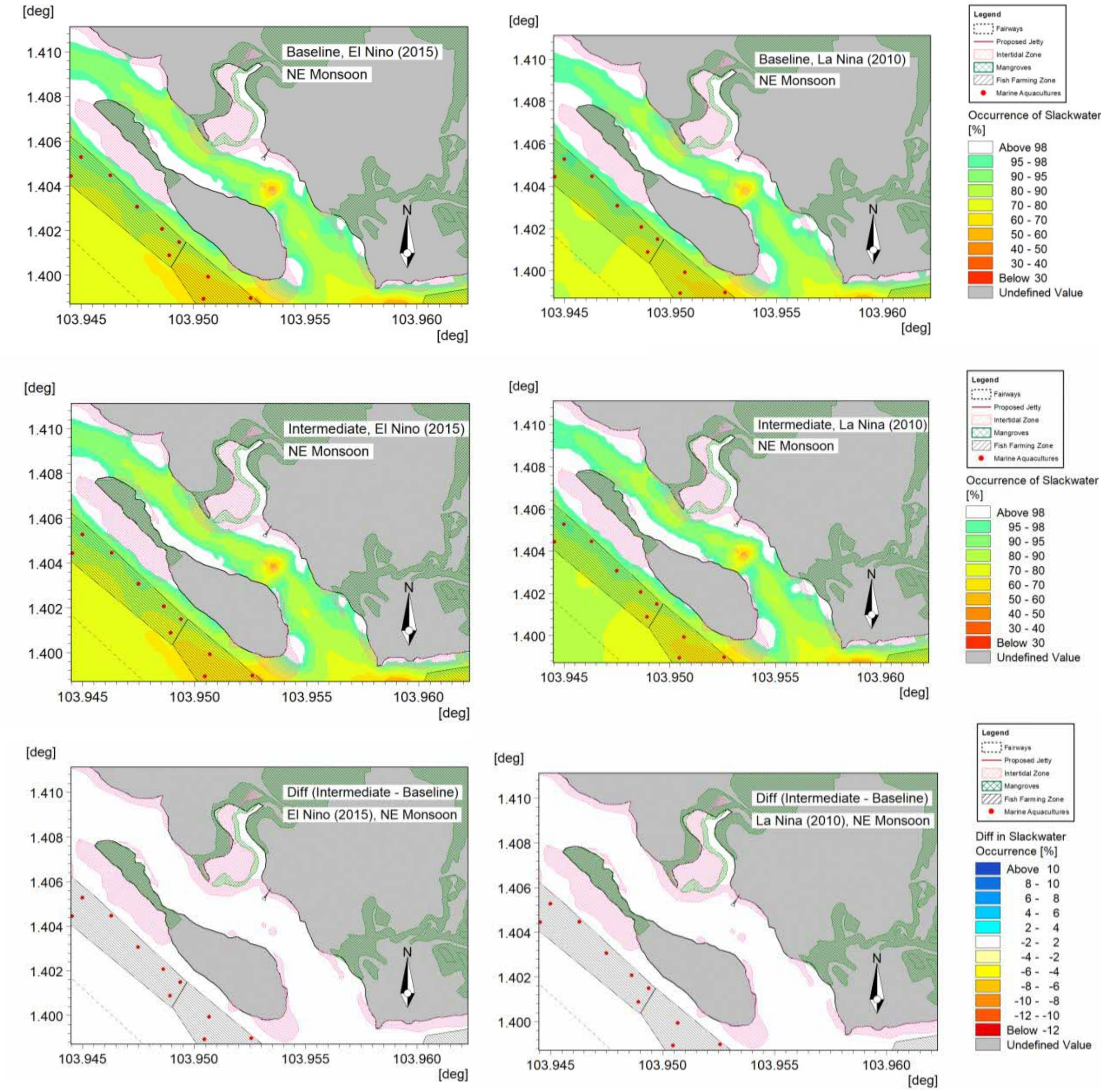


Figure A.18 Slackwater duration (Current speeds < 0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña.

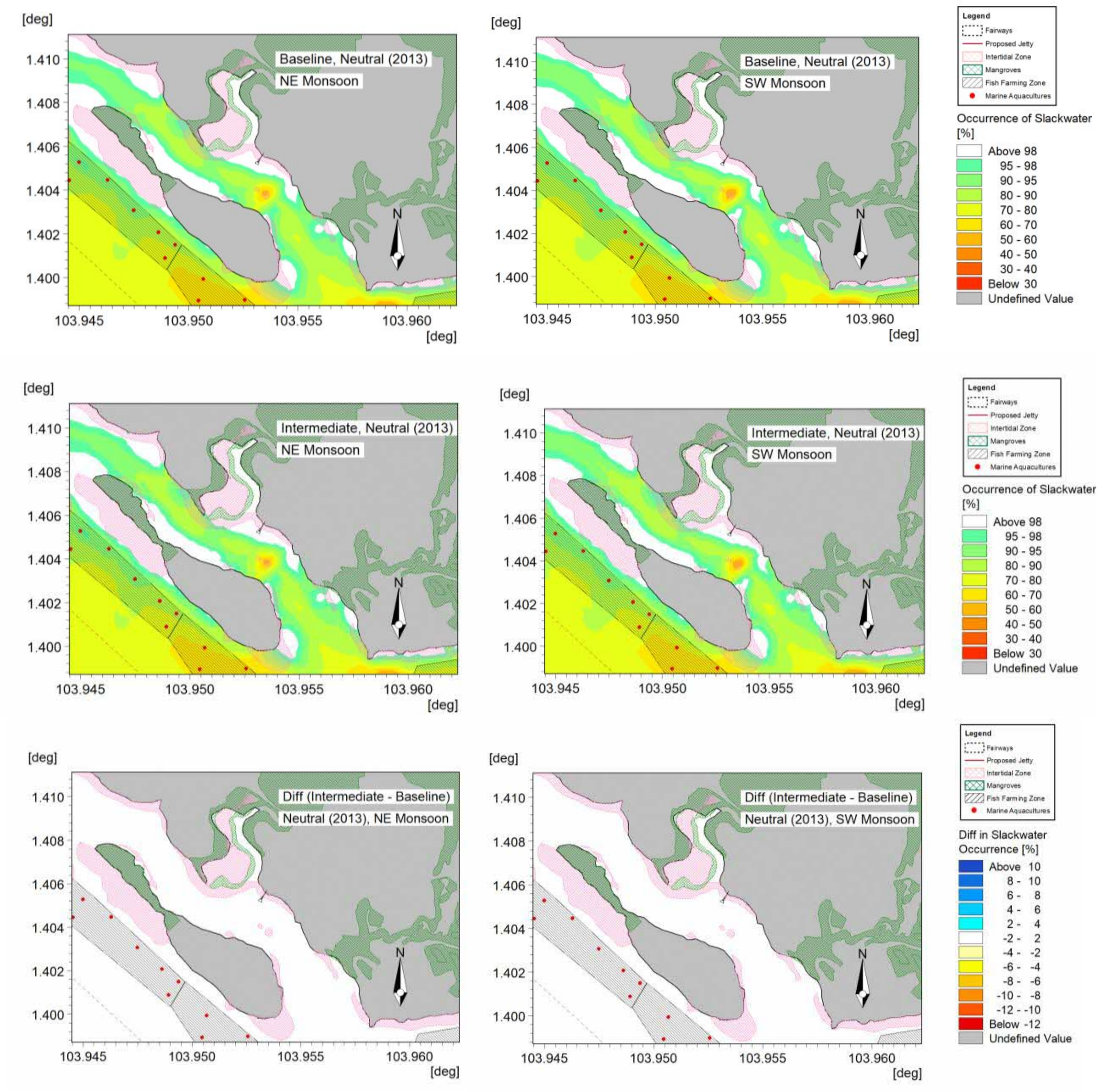


Figure A.19 Slackwater duration (currents < 0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon.

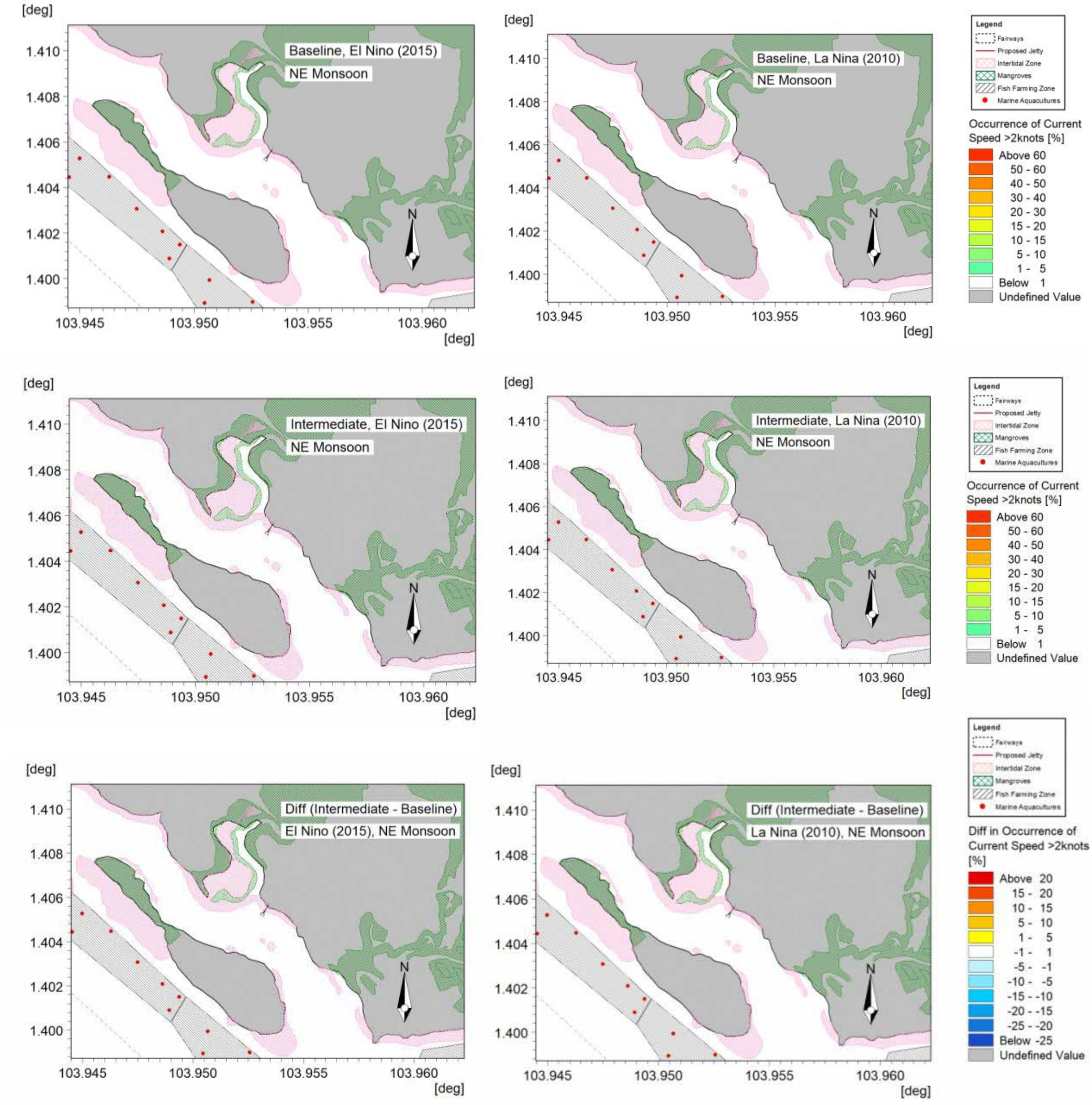


Figure A.20 Percentage of time when current speeds exceeded 2.0 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña.

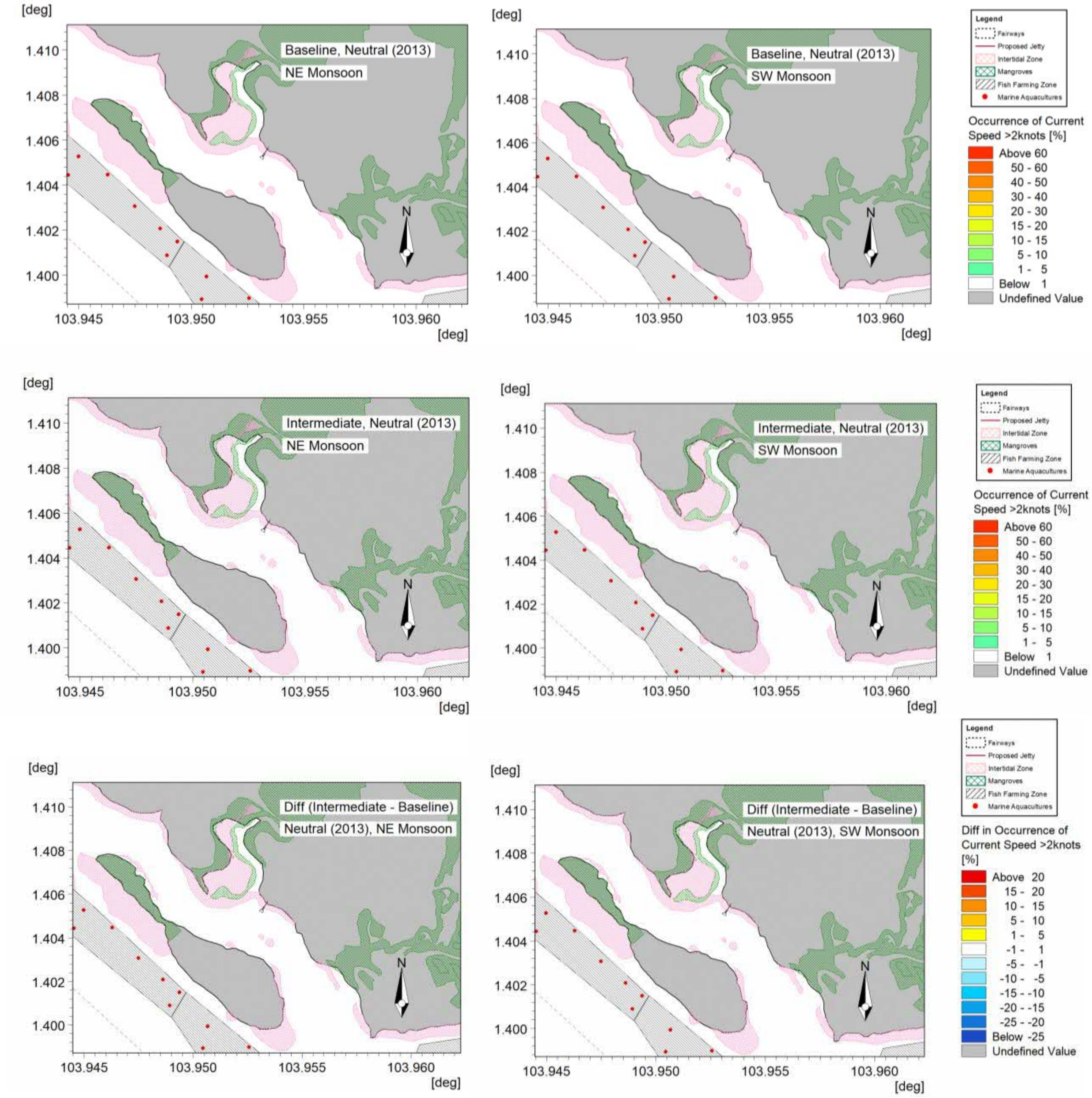


Figure A.21 Percentage of time when current speeds exceeded 2.0 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon.

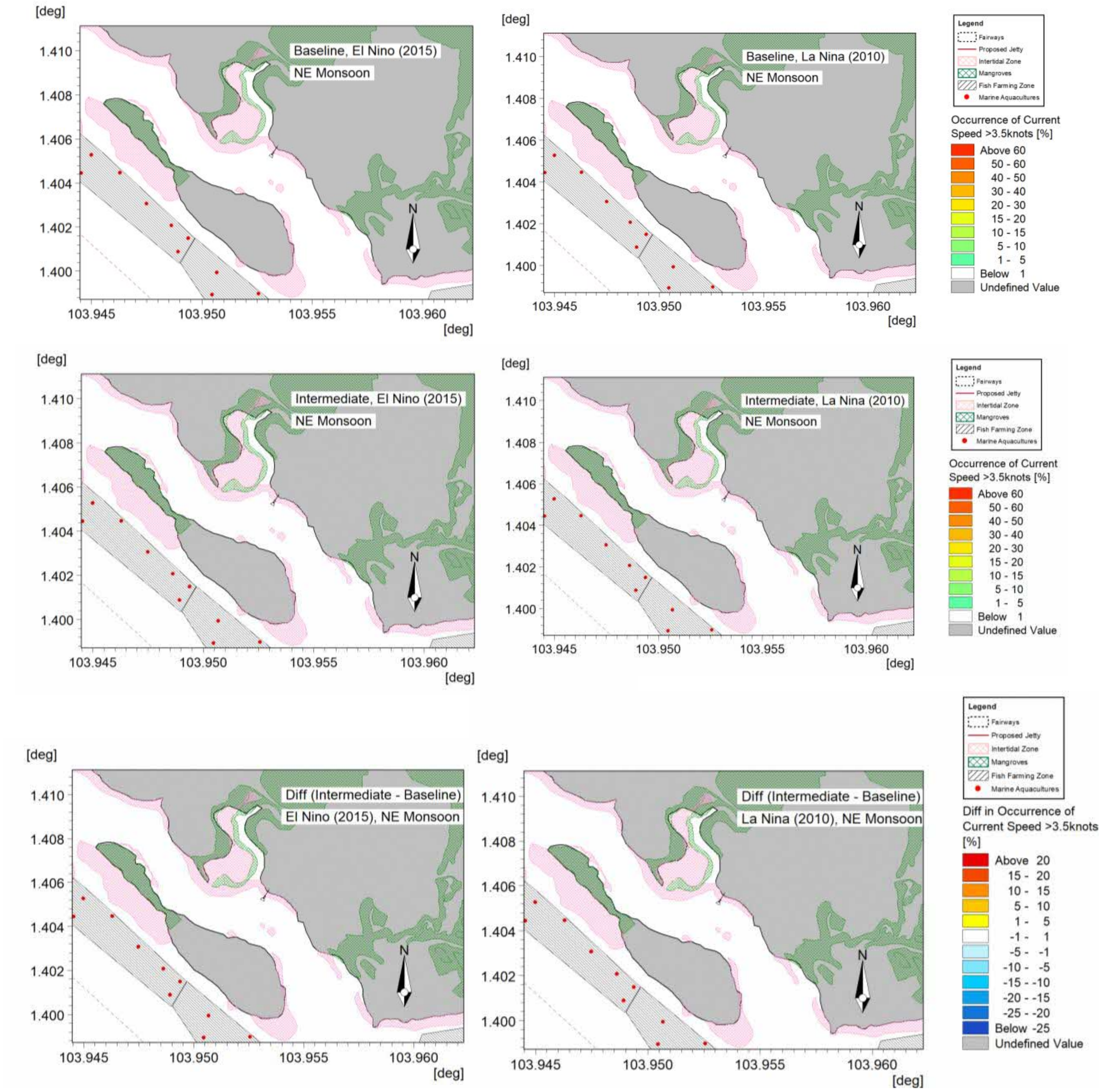


Figure A.22 Percentage of time when current speeds exceeded 3.5 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Construction Phase, El Niño. Bottom-left: Difference between Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Construction Phase, La Niña. Bottom-right: Difference between Construction Phase and Baseline, La Niña.

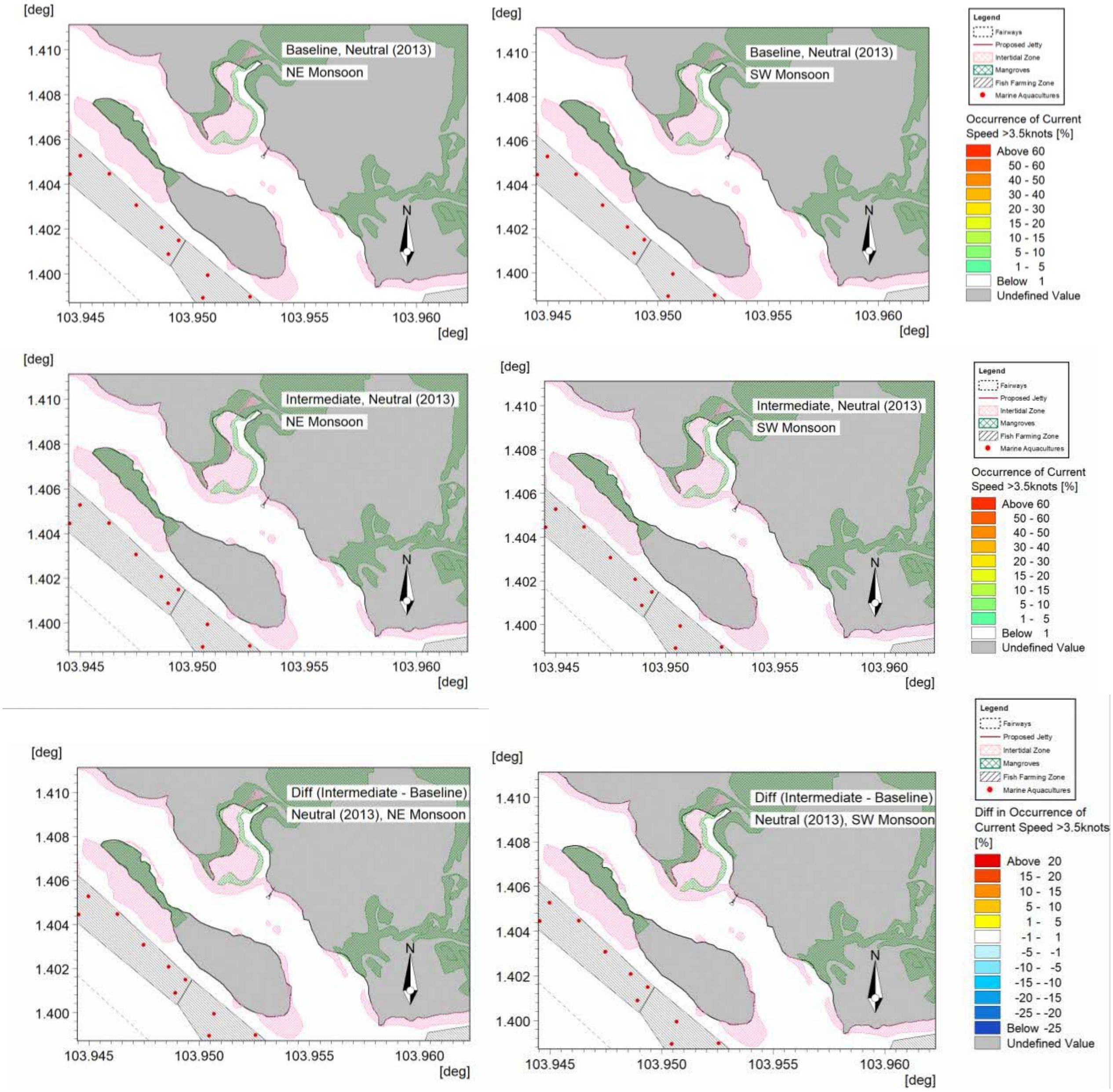


Figure A.23 Percentage of time when current speeds exceeded 3.5 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Construction Phase, NE monsoon. Bottom-left: Difference between Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Construction Phase, SW monsoon. Bottom-right: Difference between Construction Phase and Baseline, SW monsoon.

A.3.2 Model Results for Post-Construction Phase

Change in Mean Current Speeds

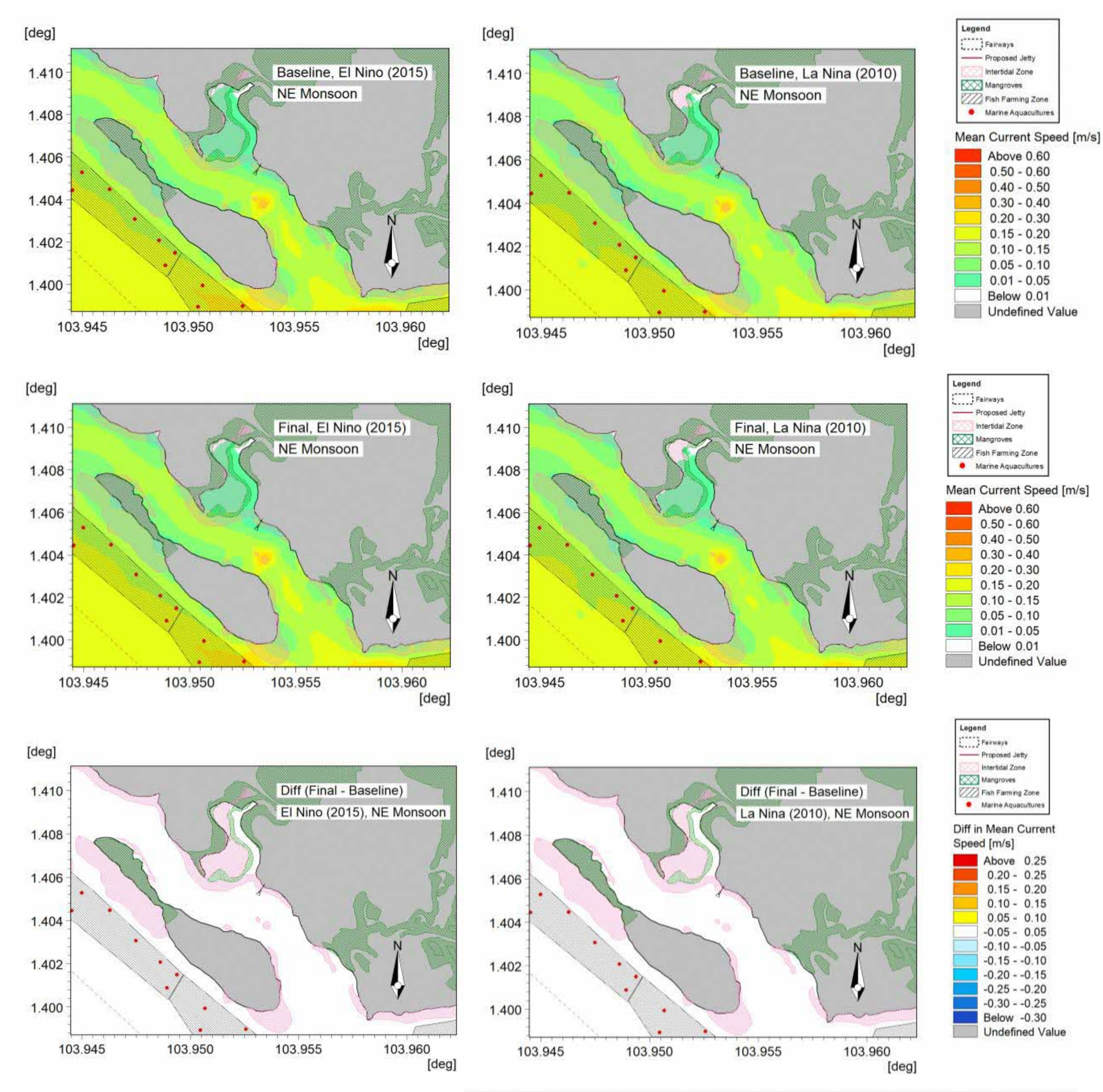


Figure A.24 Mean current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

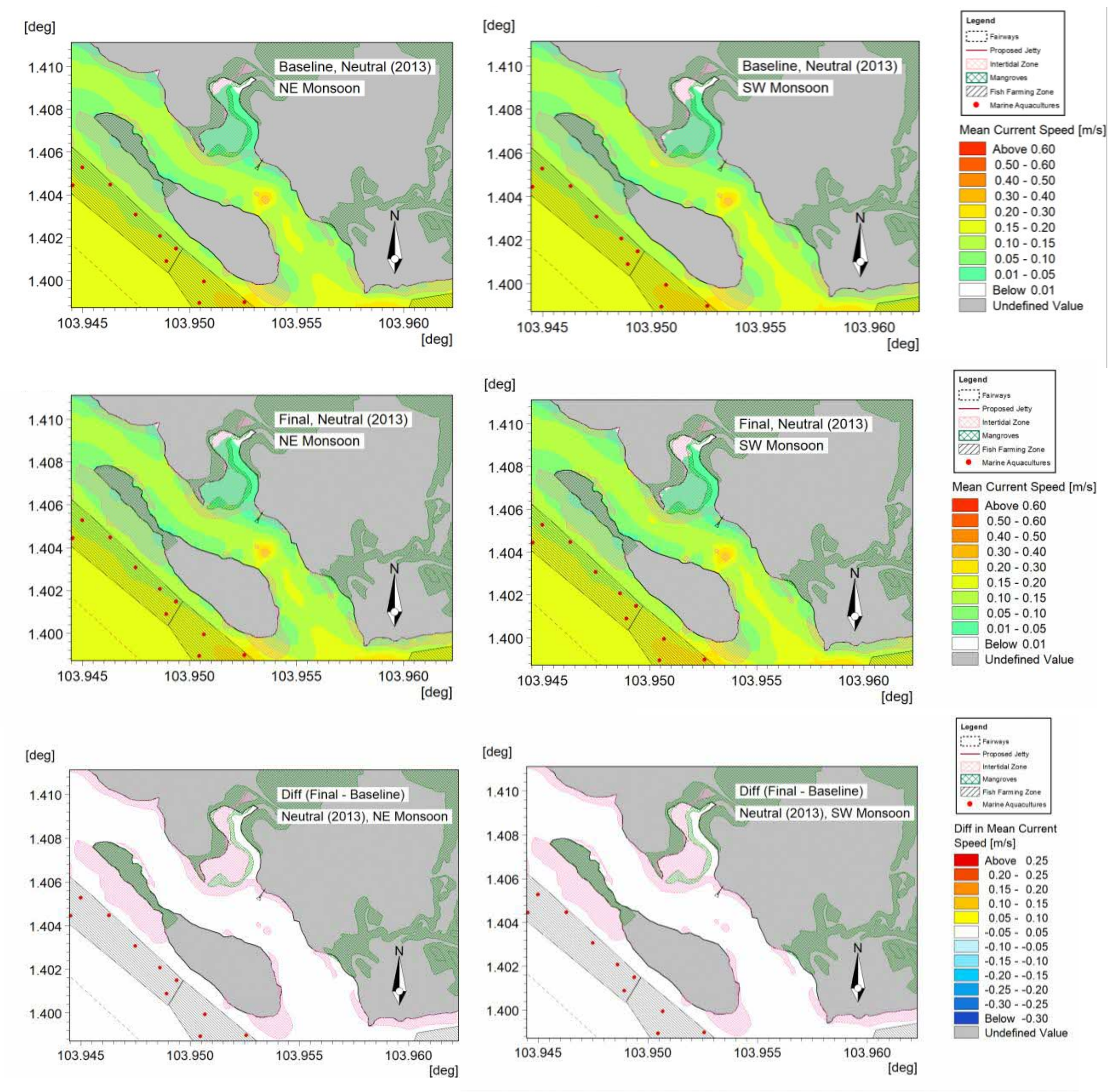


Figure A.25 Mean current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon.

Change in 95th Percentile Current Speeds

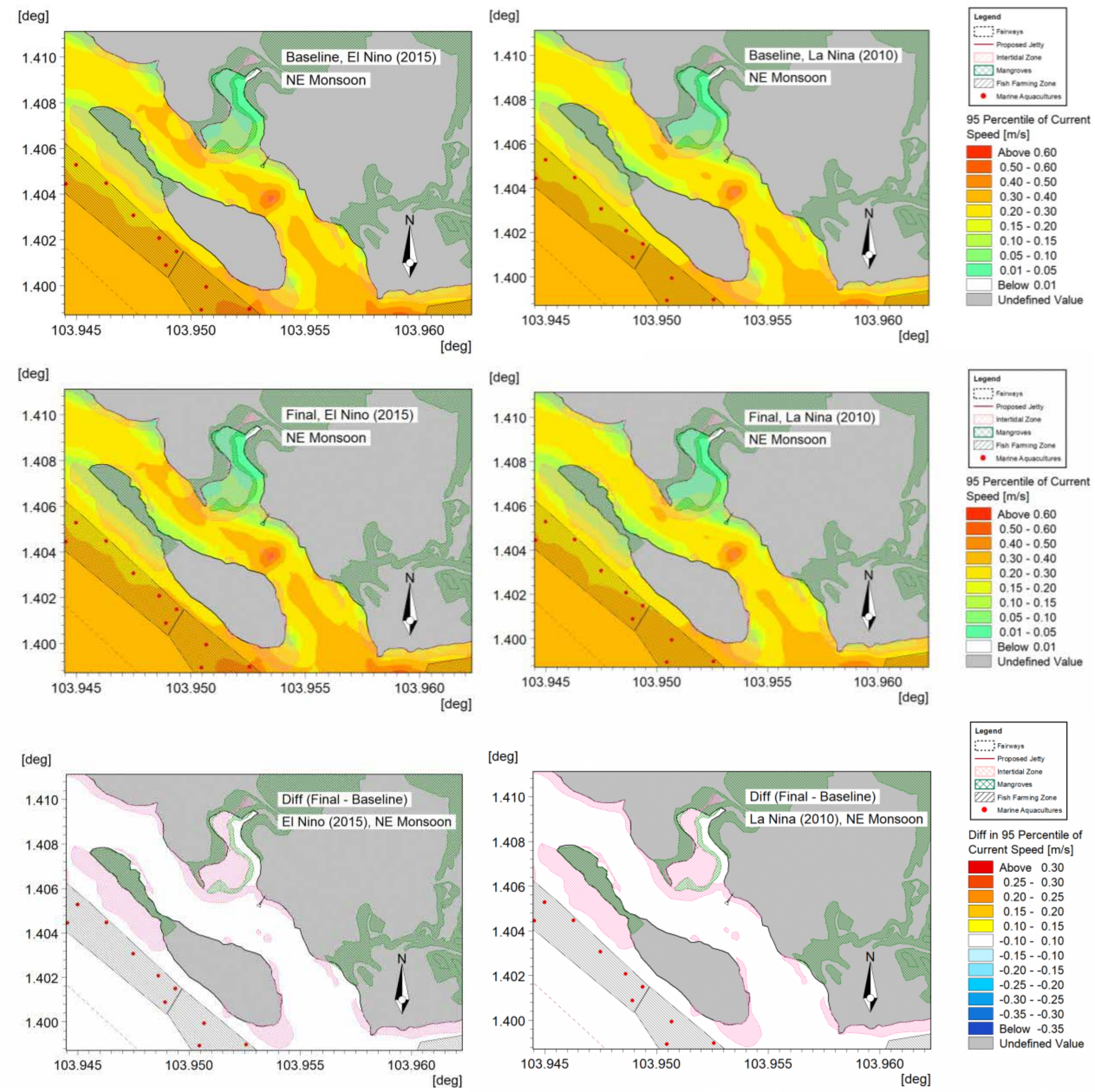


Figure A.26 95th percentile current speed during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

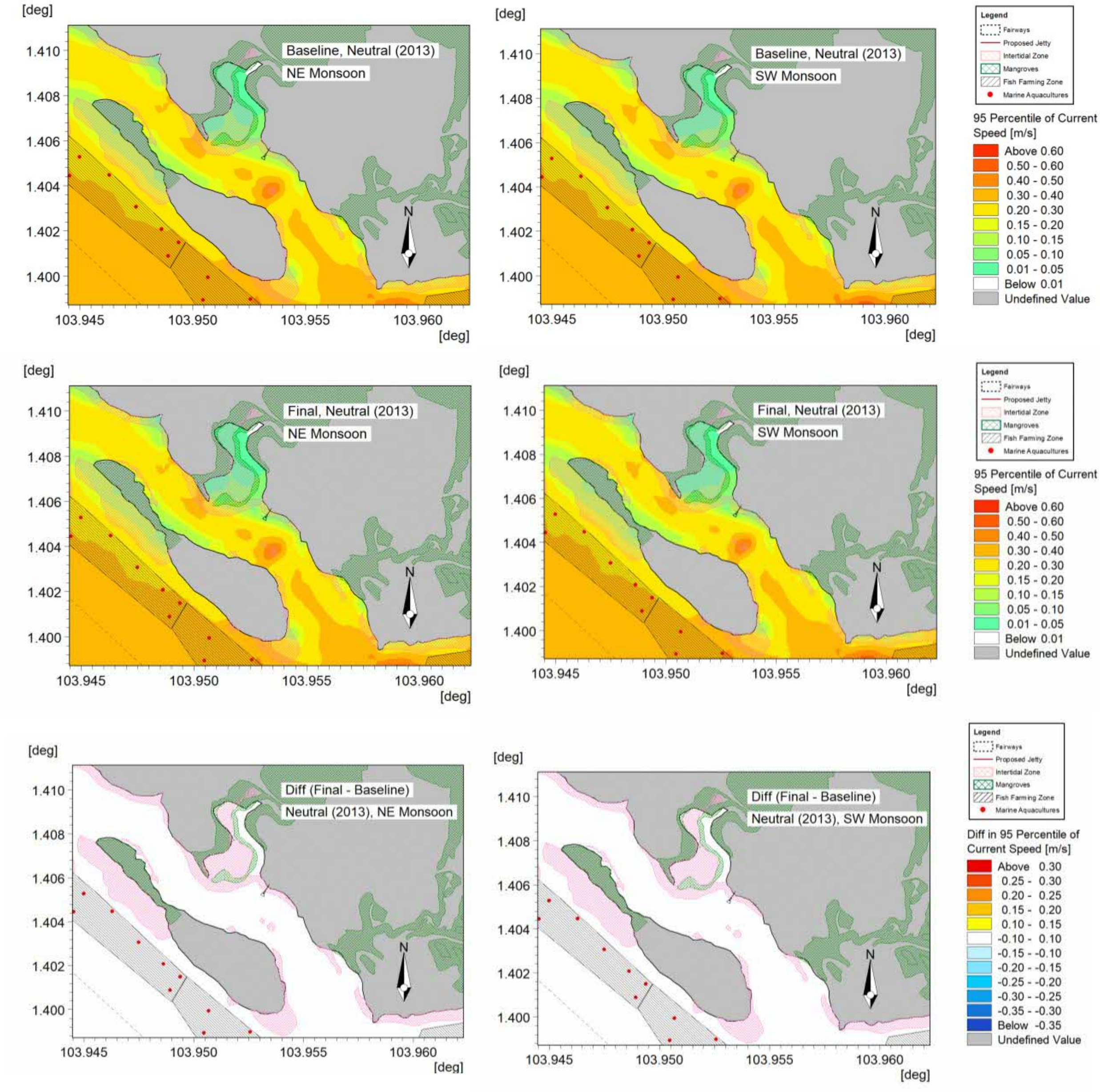


Figure A.27 95th percentile current speed during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon.

Representative Current Speeds: Slackwater (<0.5 knots), exceedances of 2.0 knots and 3.5 knots

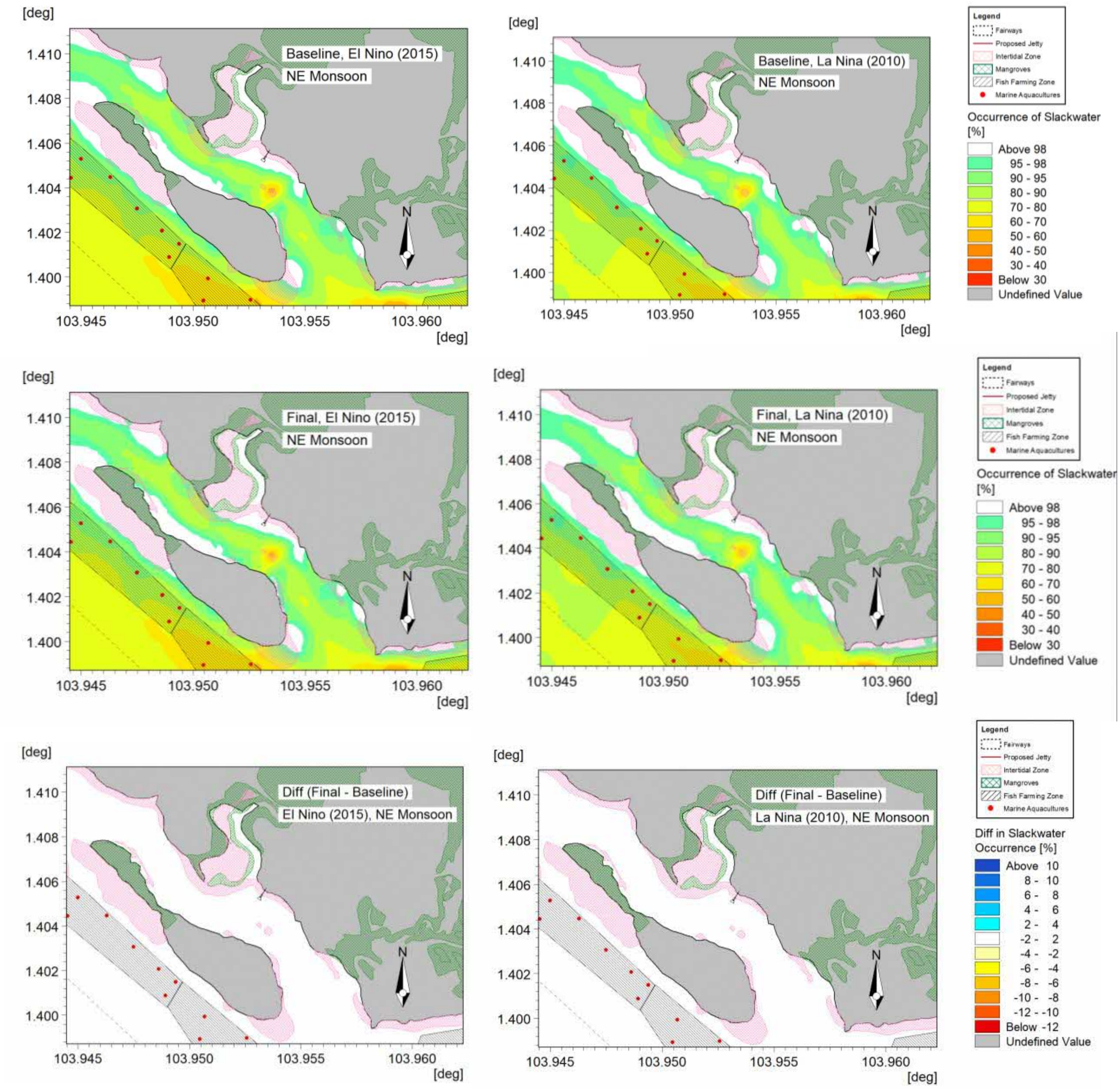


Figure A.28 Slackwater duration (Current speeds < 0.5 knots) during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

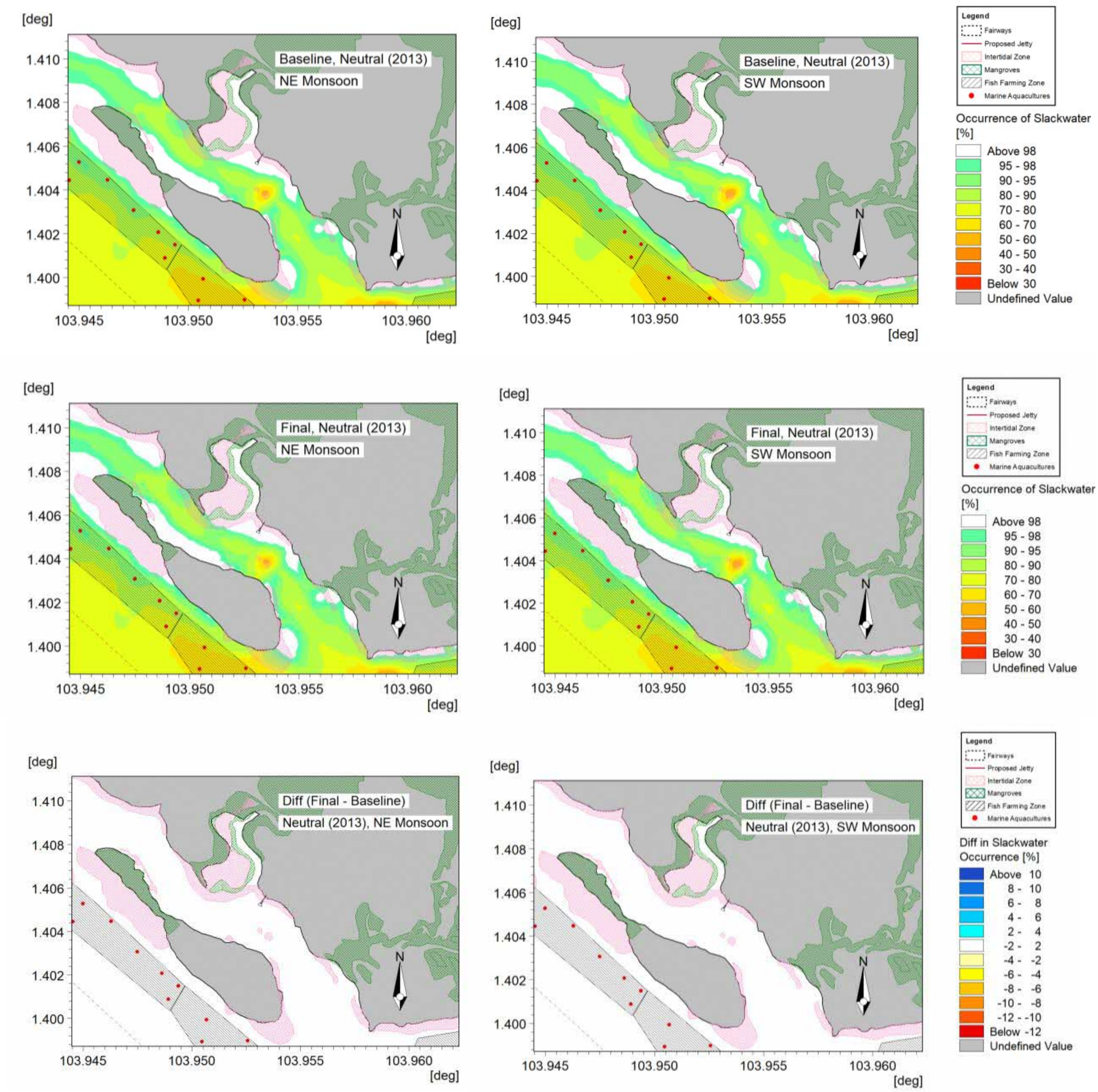


Figure A.29 Slackwater duration (currents < 0.5 knots) during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

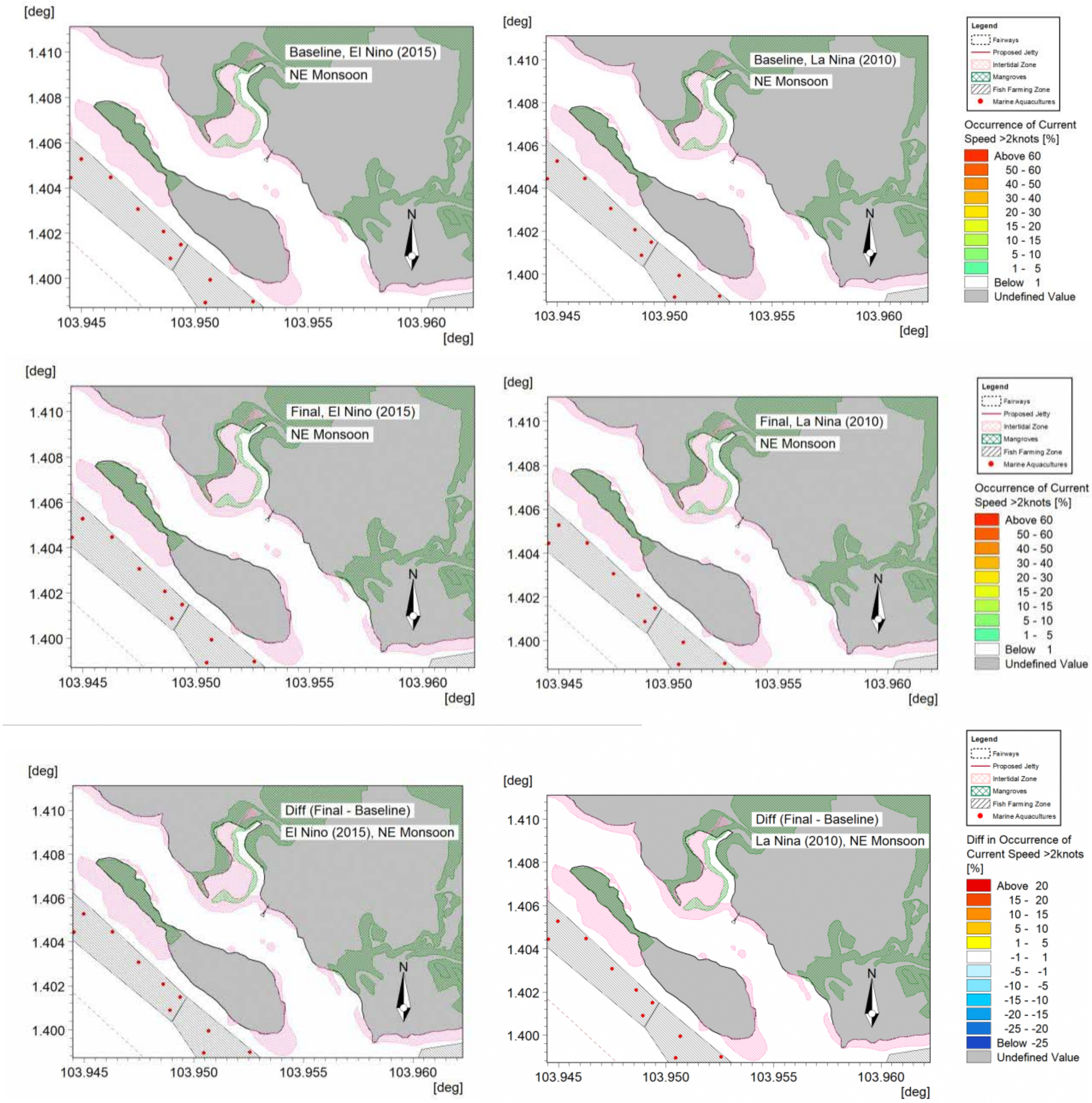


Figure A.30 Percentage of time when current speeds exceeded 2.0 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

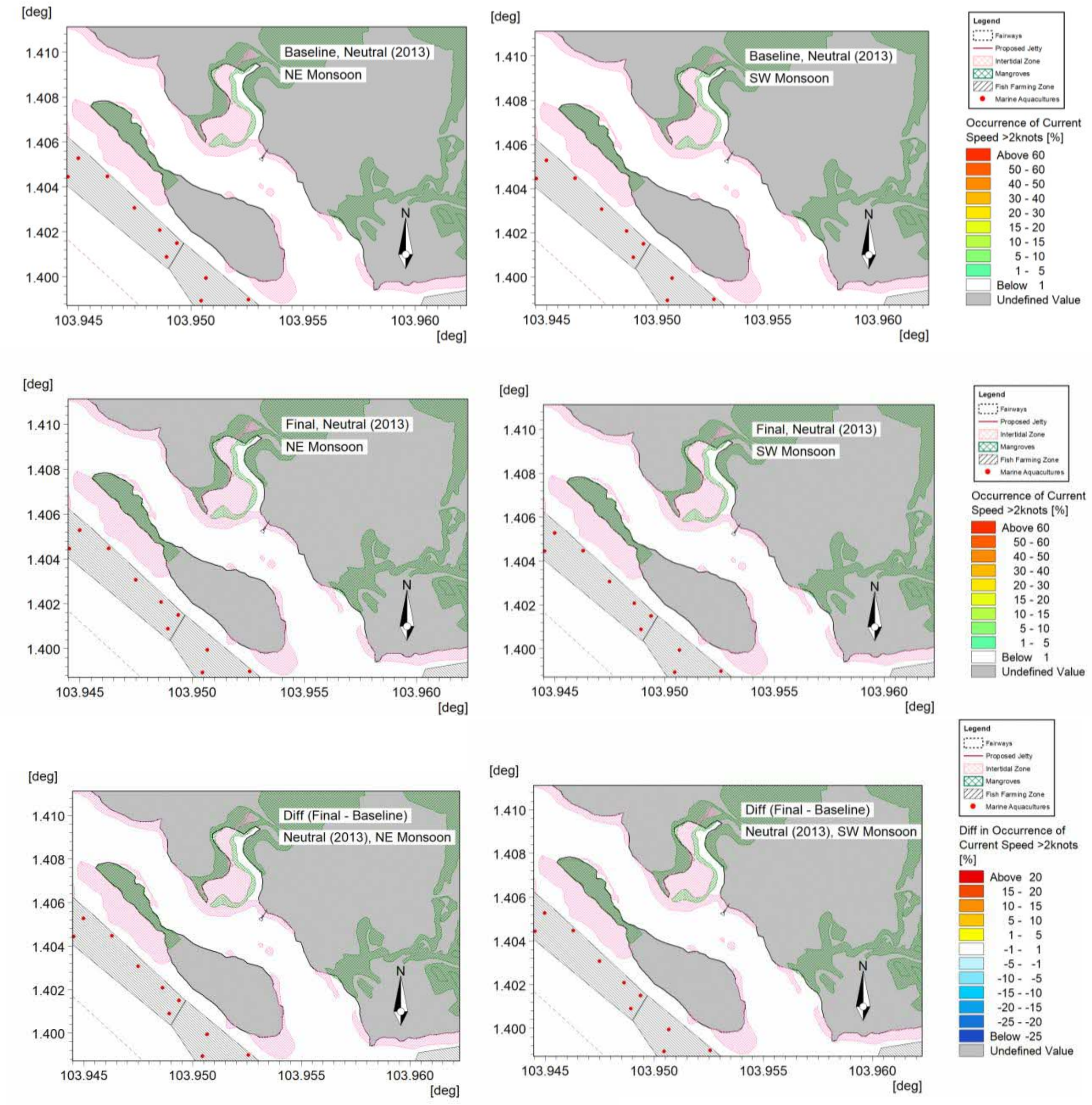


Figure A.31 Percentage of time when current speeds exceeded 2.0 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

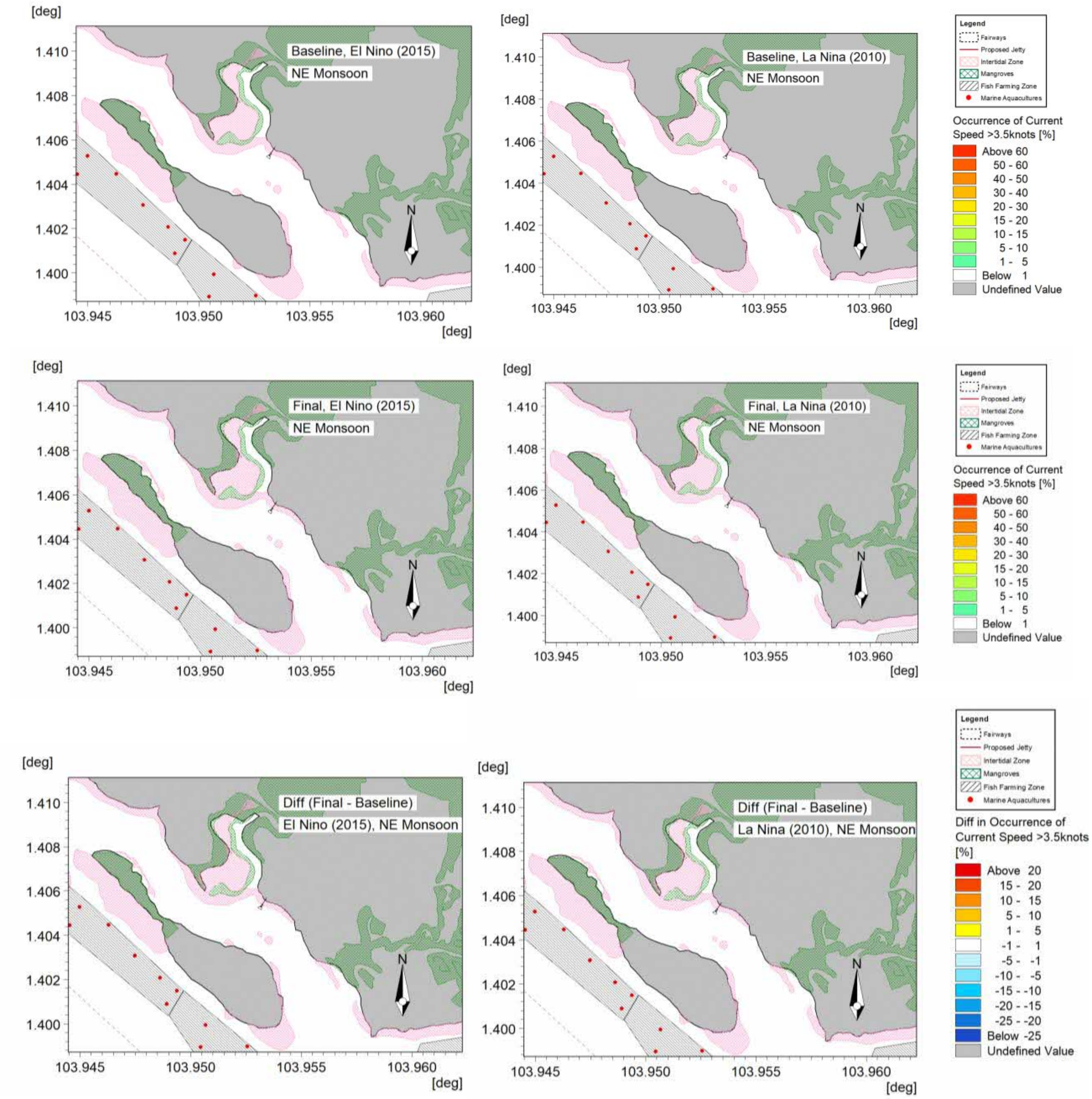


Figure A.32 Percentage of time when current speeds exceeded 3.5 knots during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

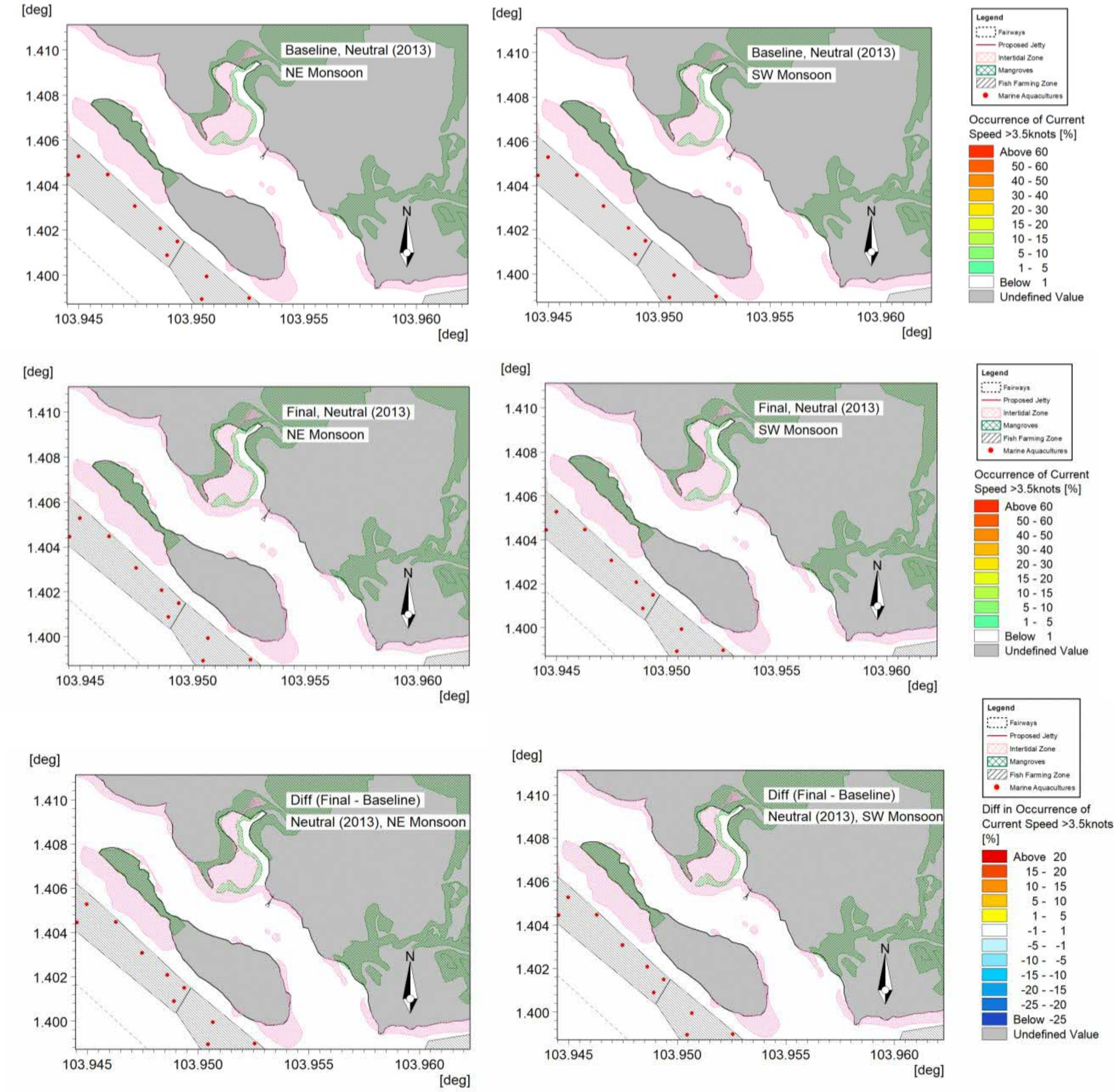


Figure A.33 Percentage of time when current speeds exceeded 3.5 knots during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Change in Mean Bed Shear Stress

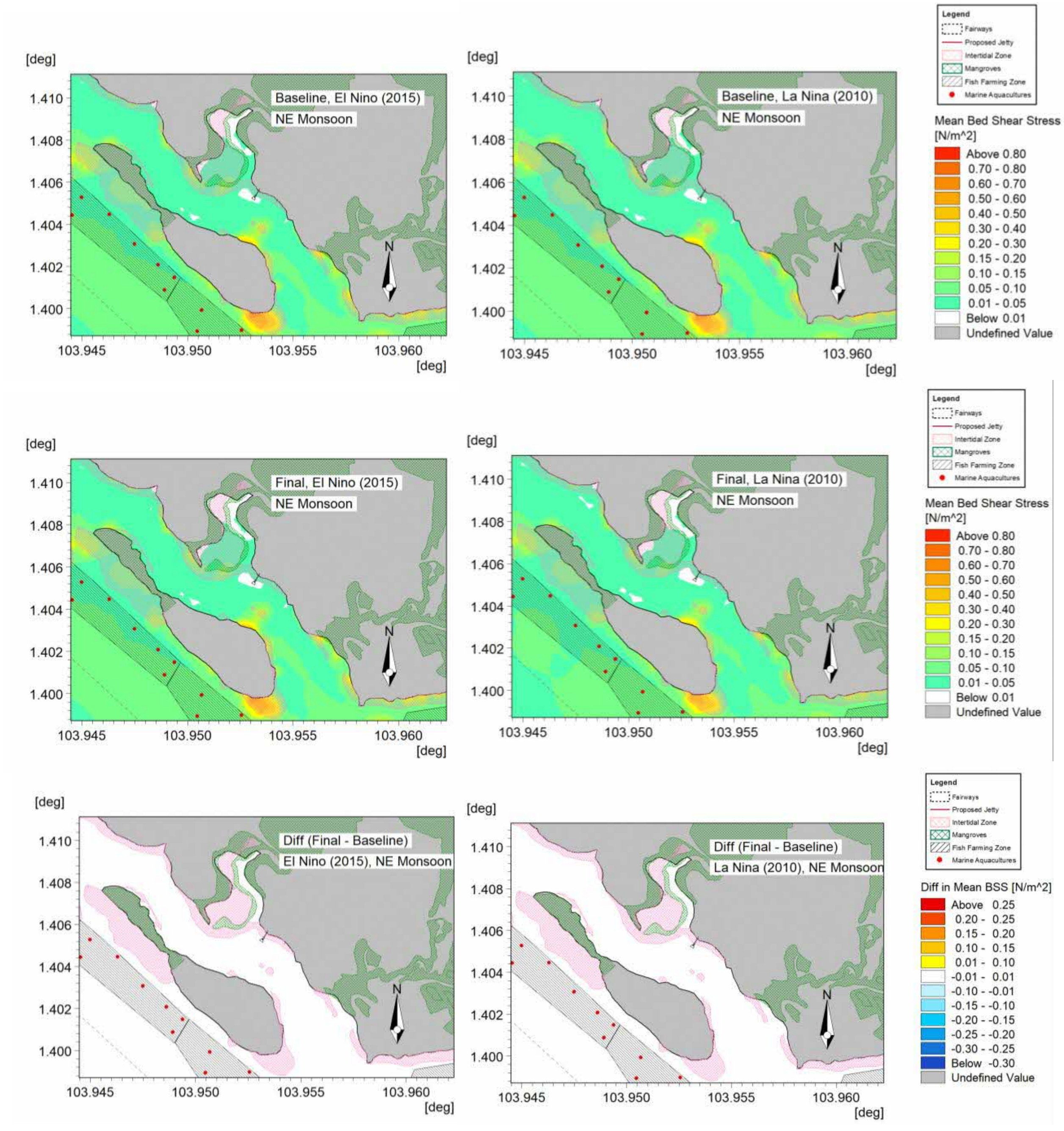


Figure A.34 Mean bed shear stress during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

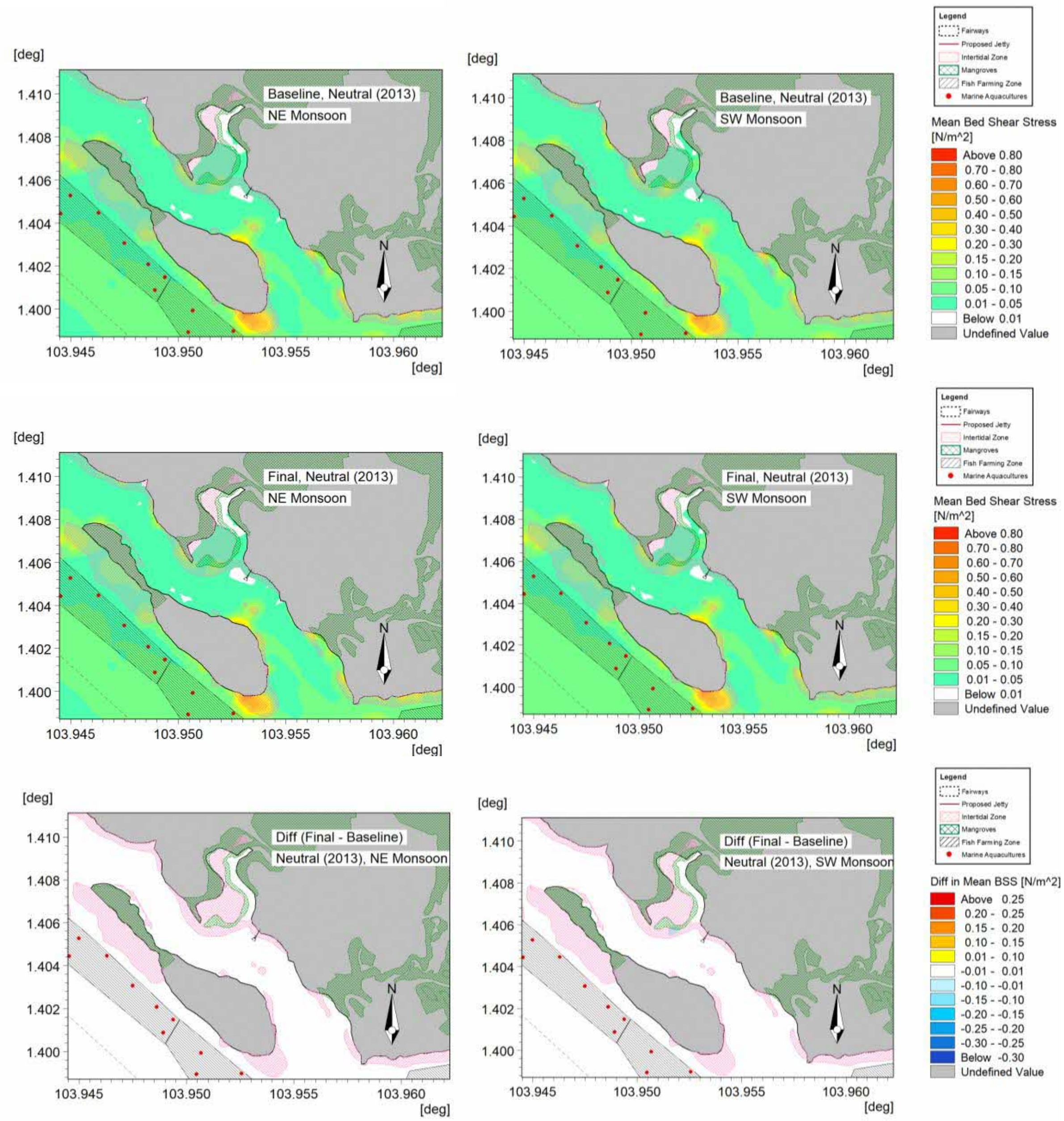


Figure A.35 Mean bed shear stress during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

Change in 95th Percentile Bed Shear Stress

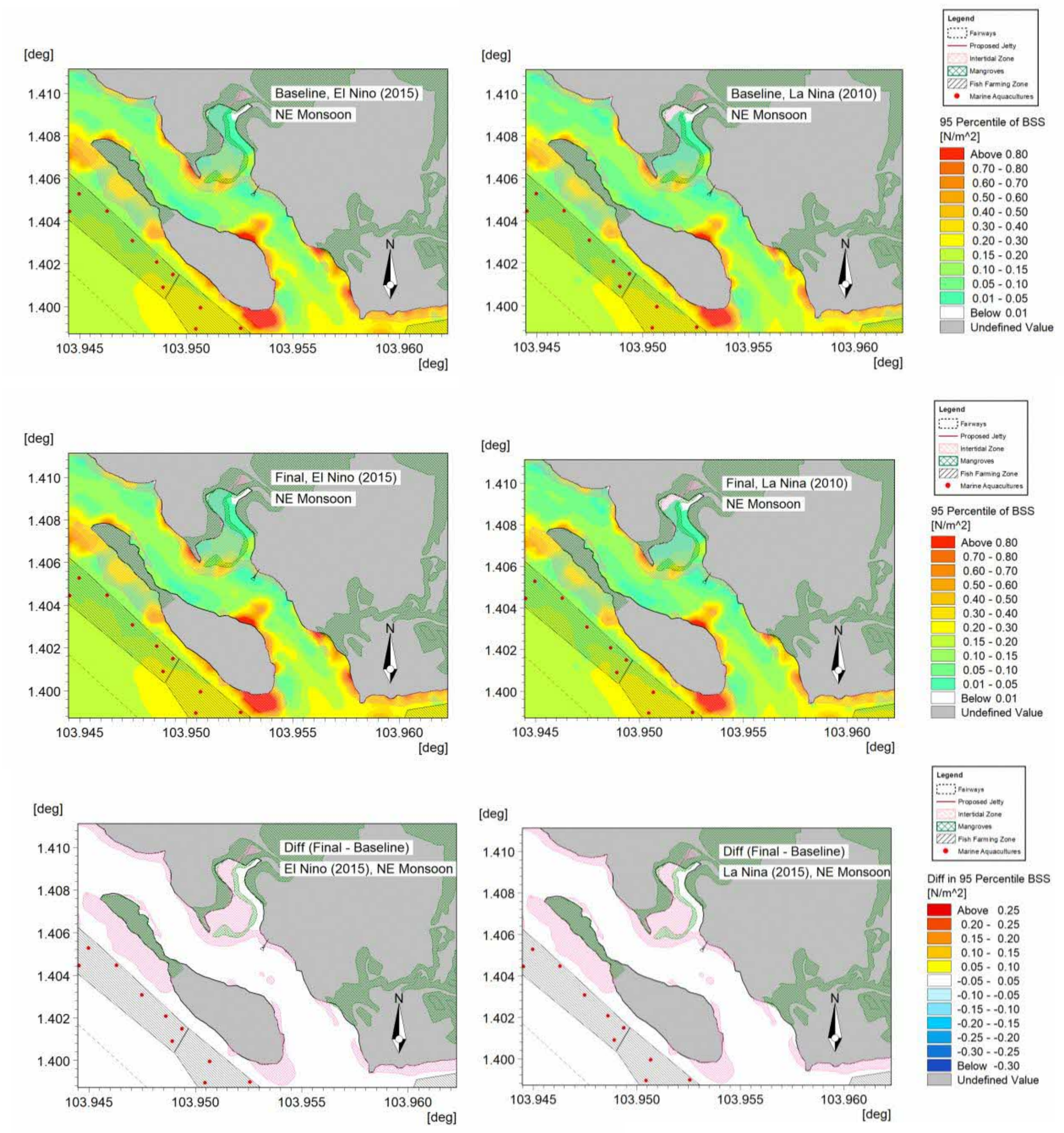


Figure A.36 95th percentile bed shear stress during NE monsoon: El Niño (left column) and La Niña (right column). Top-left: Baseline, El Niño. Middle-left: Post-Construction Phase, El Niño. Bottom-left: Difference between Post-Construction Phase and Baseline, El Niño. Top-right: Baseline, La Niña. Middle-right: Post-Construction Phase, La Niña. Bottom-right: Difference between Post-Construction Phase and Baseline, La Niña

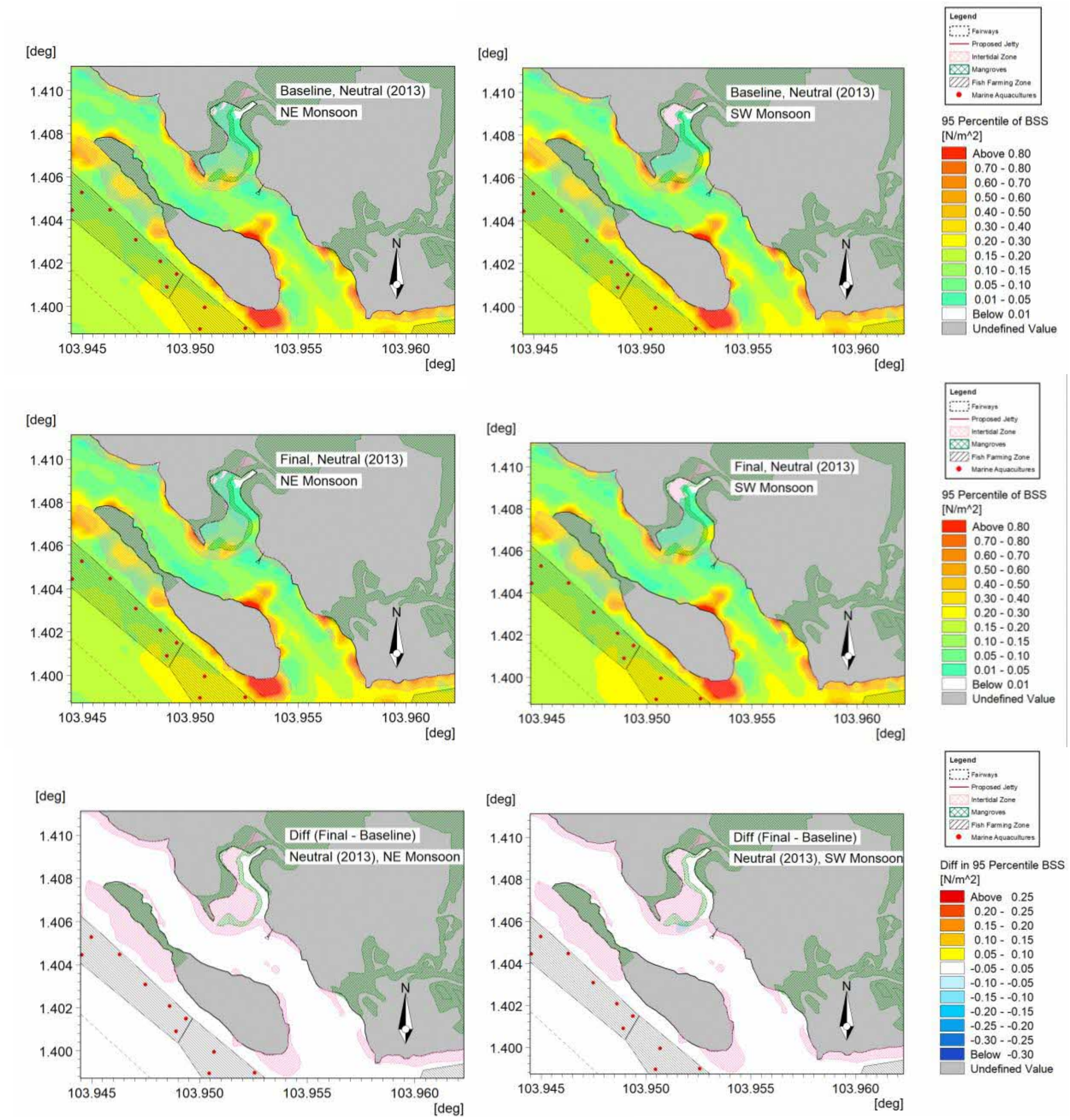


Figure A.37 95th percentile bed shear stress during Neutral year: NE monsoon (left column) and SW monsoon (right column). Top-left: Baseline, NE monsoon. Middle-left: Post-Construction Phase, NE monsoon. Bottom-left: Difference between Post-Construction Phase and Baseline, NE monsoon. Top-right: Baseline, SW monsoon. Middle-right: Post-Construction Phase, SW monsoon. Bottom-right: Difference between Post-Construction Phase and Baseline, SW monsoon

References

/1/ DHI. 2020. “MIKE 21 FLOW MODEL FM, Hydrodynamic Module User Guide.”

/2/ Lellouche, J.-M., Bourdalle-Badie, R., Greiner, E., Garric, G., Melet, A., Bricaud, C., Legalloudec, O., Hamon, M., Candela, T., Regnier, C., and Drevillon, M.: The Copernicus global 1/12° oceanic and sea ice reanalysis, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14961, https://doi.org/10.5194/egusphere-egu21-14961, 2021.

/3/ UK Foundation for Water Research publication Ref FR0374 “A framework for marine and estuarine model specification in the UK”.

APPENDIX B

Sediment Plume Model Setup and Results

B Sediment Plume Modelling

B.1 Model Description

Sediment plume model is based upon DHI's MIKE 21 MT (Mud Transport) multi-fraction cohesive sediment transport model (DHI, 2022), which is applied in a decoupled mode with the MIKE 21 Hydrodynamic Flow Model (DHI, 2020). The model simulates the spatial and temporal variation in suspended sediment concentrations subject to hydrodynamic transport and settling, deposition and re-suspension processes. In the present model, the sediment plume model is divided into two sections: (1) construction sediment plume modelling (resulting from the piling and trimming activities) and (2) propeller wash induced sediment plume modelling (resulting from future vessel traffic activities).

B.2 Construction Sediment Plume

B.2.1 Model Setup

In order to capture the spring-neap tidal cycles, simulations are made over a 14-day period during El Niño year and northeast (NE) monsoon to cover the worst peak ebb/flood in currents that may affect the model results.

B.2.2 Spill Properties

The sediment plume model has three fractions and a single bed layer. Fraction 1 to 3 represents the composition of the silt and clay seabed material. The spill is modelled as a point source with constant or time varying spill spread over a period of time.

Fraction 1	22.5 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 371 m/s Coarse fines: settles quickly outside the work area
Fraction 2	22.5 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 26.5 m/s Medium fines: can be transported large distances during spring tide, prime cause of remote sedimentation
Fraction 3	55 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 0.53 m/s Fine fines: Regularly transported large distances, generally will not settle out and is only contributing to suspended sediment impacts

B.2.3 Initial Conditions

The background concentration is considered to be zero and so the initial concentration is zero for all the fractions. Since the spill is modelled, initial bed layer thickness is set to zero.

B.2.4 Boundary Conditions

Suspended sediment concentrations along the boundaries are set to zero for all the fractions.

B.2.5 Bed Roughness

Constant bed roughness of 0.0687 m was assumed based on past experience.

B.2.6 Settling Characteristics

The settling velocity is a parameter that has a strong bearing on the model simulations. Flocculation is an important process which enhances the settling velocity of suspended matter by allowing the individual particles to stick together and form larger aggregates. Therefore, it is considered relevant to include flocculation as a parameter influencing the settling velocity of the suspended matter.

The formulation for settling velocity in MIKE 21 MT is as described below, whereby w_s is a settling velocity, w_0 is a settling velocity coefficient, C_{floc} is a concentration at which flocculation begins, $\rho_{sediment}$ is sediment density (2,650 kg/m^3) and γ is a constant equal to 1. $C_{hindered}$ is a minimum concentration at which hindered settling occurs. Hindered settling and consolidation are not included in the settling model. The settling velocity is assumed to be constant for $C<C_{floc}$ and $C> C_{hindered}$, and it is a function of concentration as long as $C_{floc} < C < C_{hindered}$, as shown below.

$$w_s = w_0 \left(\frac{C_{floc}}{\rho_{sediment}} \right)^{\gamma} \qquad C < C_{floc}$$

$$w_s = w_0 \left(\frac{C}{\rho_{sediment}} \right)^{\gamma} \qquad C_{floc} < C < C_{hindered}$$

$$w_s = w_0 \left(\frac{C_{hindered}}{\rho_{sediment}} \right)^{\gamma} \qquad C > C_{hindered}$$

Table B.1 summarizes the adopted coefficients for the settling velocity.

Table B.1 Settling characteristics

Parameter	F1	F2	F3
C_{floc} (kg/m^3)	0.01	0.01	0.01
$C_{hindered}$ (kg/m^3)	10	10	10
$\rho_{sediment}$ (kg/m^3)	2,650	2,650	2,650
w_0 (m/s)	371	26.5	0.53
γ (-)	1	1	1

B.2.7 Model Scenario

One (1) worst-case sediment plume modelling was simulated during the Construction Phase. The sediment plume model assumed that there will be two (2) trimming works, with a volume of 200 m^3 each, and four (4) piling locations. These activities will take place consecutively over a period of twelve (12) days, with each piling work lasting for three (3) days. Trimming will also be completed within this 12-day period and is assumed to be completed within a day. The detailed sediment plume assessment scenario is presented in Table B.2, while the location of piling and trimming works for simulation is displayed in Figure B.1.

Table B.2 Sediment plume assessment schedule

Construction Phase/ Model Period	Day 1 – 3	Day 4 – 6	Day 7 – 9	Day 10 – 12
Piling				
Trimming				

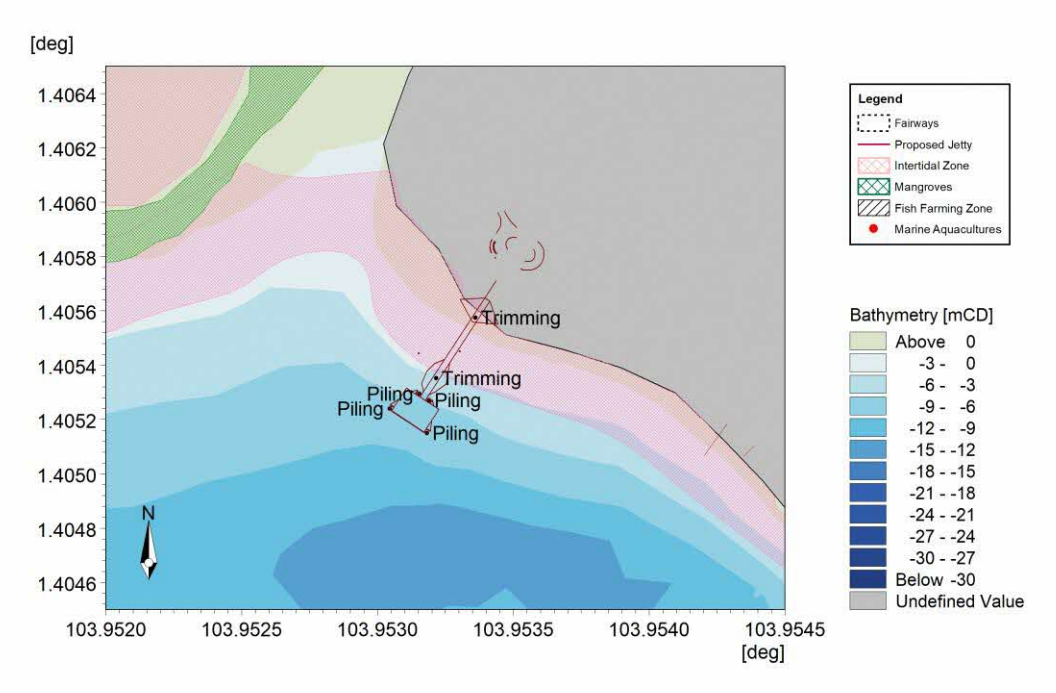


Figure B.1 Scenario for the sediment plume modelling, involving two (2) trimming areas and four (4) piling locations. Black points indicate the location of sediment release from the works

B.2.8 Spill Rate

Based on the information provided by the client and the results of earlier comprehensive studies carried out by DHI on reclamation and dredging works in Singapore waters, the spill rate from dredging activity, which is somewhat similar to the trimming operation, will be approximately 2% of fines (Zhao et. al., 2017) with typical sand contains fine material of 90%. Meanwhile, for piling activities, it is assumed that 15% of fine sediments will escape and will be transported to other areas, which is a fairly conservative assumption.

B.2.9 Example Spill Rate Calculation

B.2.9.1 Trimming Spill Rate

For the present assessment, trimming work was done by grab dredger with each dredger is modelled in terms of grab size, cycle time (i.e., time to complete one grab), spill time and location, with the material being introduced as a suspended sediment source distributed uniformly over depth (MIKE 21 MT being a depth-integrated model).

The spill strength is calculated based upon the following methodology:

Dredger	: Grab Dredger
Volume/day	: 200 m^3
Volume/grab	: 1 m^3
Spill Time	: 20 second spill per 90-second cycle
Number of cycles	: 200 m^3/1 m^3 = 200 cycles continuously per day
% Fines in grab	: 90% (from survey result)
% Spill	: 2% fines (assumption based on Zhao et. al., 2017)
Bulk density	: 1,900 kg/m^3

Total spill per day	= 200 m^3 x 90% fines x 2% spill over a day
	= 3.6 m^3 x 1,900 kg/m^3 total spill over a day
	= 6,840 kg over a day = 6,840 kg/day
Total spill per grab	= 1 m^3 x 90% fines x 2% spill over 20 seconds
	= 0.018 m^3 x 1,900 kg/m^3 total spill over 20 seconds
	= 34.20 kg over 20 seconds = 1.710 kg/s

The spill rate is served as model inputs for two (2) days based on the trimming work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3) in a ratio of 1:1:2 respectively.

B.2.9.2 Pilling Spill Rate

For the present assessment, cycle time (i.e., time to complete one pile), working hour and location were considered. The sediment source was assumed to be distributed uniformly over depth (MIKE 21 MT is a depth-integrated model).

The spill rate is calculated based upon the following methodology:

Pile diameter, D	0.813 m (assumed including casing)
Penetration depth, L	30 m (based in the example in the Method Statement)
Average drilling speed	1.25 m/hour (based on the example in the Method Statement)
Volume (cylindric)	$(\frac{\pi D^2}{4} \times L)$ = 15.57 m^3
Cycle time	1 pile per 2 days (assuming 8 hours of operation per day)
Percentage of fines	90% (from survey results)
Escape rate	15% (conservative assumption based on DHI expert judgment)
Dry bulk density	1,900 kg/m^3 (average measured)
Spill rate of fines	= Dry bulk density (kg/m^3) x pile area (m^2) x piling rate (m/hour) x % fines x % escape rate x (1 hour/ 3600 s)
	= 1,900 kg/m^3 x (π x 0.813^2/4 m^2) x 1.25 m/hour x 90% fines x 15% escape rate x (1 hour / 3600 s)
	= 0.05 kg/s
Spill rate of fines per day	= Spill rate of fines x 3600 s * 8 (assuming 8 hours per day)
	= 1,331.55 kg/day

The spill rate is served as model inputs for twelve (12) days based on the piling work assumption discussed in Section B.2.7. The source rate is subsequently distributed over the three representative sediment fractions (Fraction 1 to 3) in a ratio of 1:1:2 respectively.

B.2.10 Model Calibration and Validation

For obvious reasons, calibration or validation of a sediment plume model against data measured in the field cannot be carried out for a future spill situation. However, the robustness of the model has been proven for earlier studies carried out at other sites in Singapore and other regions, where specific validation against ongoing dredging and reclamation works has been possible. Figure B.2 shows the example of sediment plume validation for dredging operation in Singapore.

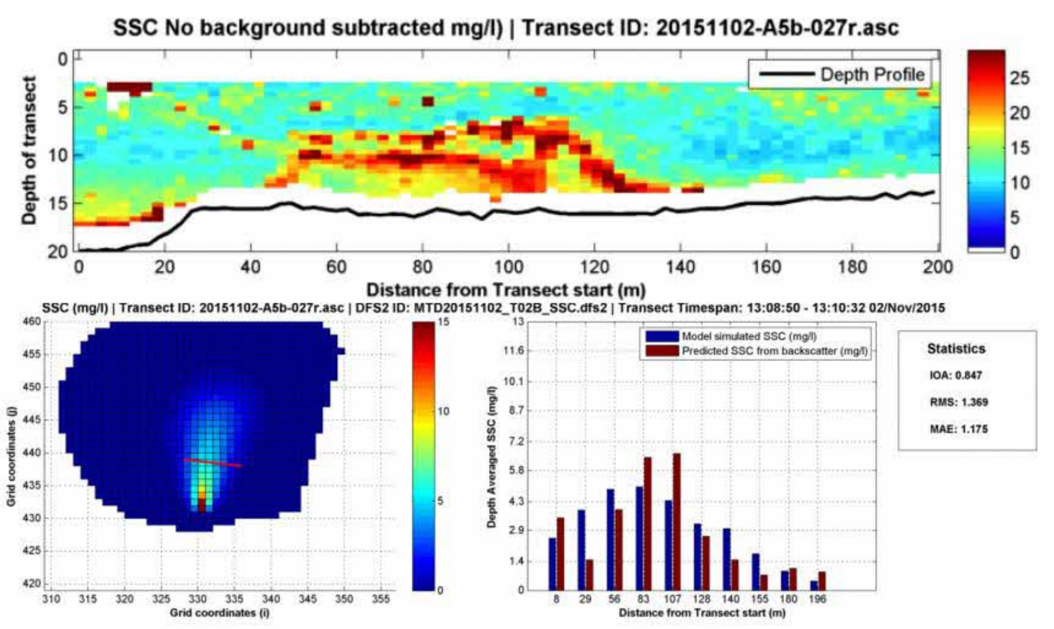


Figure B.2 Example of sediment plume validation in Singapore carried out by DHI. Top: measured SSC profile from ADCP; Bottom: comparison of depth averaged incremental SSC (blue bars represent simulation, and red bars represent measurement) (Zhao et. al., 2017)

Of particular relevance in the calibration exercise is the choice of dispersion coefficient, which is a critical parameter with respect to the spatial distribution of the sediment plume.

The critical shear stress for deposition and erosion are set as 0.1 N/m^2 and 0.3 N/m^2, respectively, over the entire domain.

B.2.11 Model Results

The results from the sediment plume model include:

- 2D maps for incremental mean SSC
- 2D maps of time percentage incremental SSC exceeds 5 mg/l, 10 mg/l and 25 mg/l

The model results are presented in the EIA report.

B.3 Propeller Wash Induced Sediment Plume

B.3.1 Model Setup

In order to capture the spring-neap tidal cycles, simulations are made over a 14-day period during El Niño year and northeast (NE) monsoon to cover the worst peak ebb/flood in currents that may affect the model results.

B.3.2 Spill Properties

The sediment plume model has three fractions and two bed layers. Fraction 1 to 3 represents the composition of the silt and clay seabed material. The spill is modelled as a point source with constant or time varying spill spread over a period of time.

Fraction 1	22.5 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 371 m/s Coarse fines: settles quickly outside the work area
Fraction 2	22.5 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 26.5 m/s Medium fines: can be transported large distances during spring tide, prime cause of remote sedimentation
Fraction 3	55 % contribution from spilled material from scouring around the piles Settling velocity coefficient = 0.53 m/s Fine fines: Regularly transported large distances, generally will not settle out and is only contributing to suspended sediment impacts

B.3.3 Initial Conditions

The background concentration is considered to be zero and so the initial concentration is zero for all the fractions. Initial bed layer thickness is set to 1 m along vessel track for layer 2 and set to zero in the entire domain for layer 1.

B.3.4 Boundary Conditions

Suspended sediment concentrations along the boundaries are set to zero for all the fractions.

B.3.5 Bed Parameters

Bed Layer 1	Density of bed layer = 400 kg/m^3
Bed Layer 2	Density of bed layer = 1900 kg/m^3

Constant bed roughness of 0.0687 m was assumed based on the past experience.

B.3.6 Settling Characteristics

The settling velocity is a parameter that has a strong bearing on the model simulations. Flocculation is an important process which enhances the settling velocity of suspended matter by allowing the individual particles to stick together and form larger aggregates. Therefore, it is considered relevant to include flocculation as a parameter influencing the settling velocity of the suspended matter.

The formulation for settling velocity in MIKE 21 MT is as described below, whereby w_s is a settling velocity, w_0 is a settling velocity coefficient, C_{floc} is a concentration at which flocculation begins, $\rho_{sediment}$ is sediment density (2,650 kg/m^3) and γ is a constant equal to 1. $C_{hindered}$ is a minimum concentration at which hindered settling occurs. Hindered settling and consolidation are not included in the settling model. The settling velocity is assumed to be constant for $C<C_{floc}$ and $C> C_{hindered}$, and it is a function of concentration as long as $C_{floc} < C < C_{hindered}$, as shown below.

$$w_s = w_0 \left(\frac{C_{floc}}{\rho_{sediment}} \right)^{\gamma} \qquad C < C_{floc}$$

$$w_s = w_0 \left(\frac{C}{\rho_{sediment}} \right)^{\gamma} \qquad C_{floc} < C < C_{hindered}$$

$$w_s = w_0 \left(\frac{C_{hindered}}{\rho_{sediment}} \right)^{\gamma} \qquad C > C_{hindered}$$

Table B.3 summarizes the adopted coefficients for the settling velocity.

Table B.3 Settling characteristics

Parameter	F1	F2	F3
C_{floc} (kg/m^3)	0.01	0.01	0.01
$C_{hindered}$ (kg/m^3)	10	10	10
$\rho_{sediment}$ (kg/m^3)	2,650	2,650	2,650
w_0 (m/s)	371	26.5	0.53
γ (-)	1	1	1

B.3.7 Model Scenario

One (1) worst-case scenario was simulated. The production period for the sediment propeller wash modelling covered a period of 14-day spring-neap tidal cycle. The simulated vessel trips were simulated based the routes shown in Figure B.3. The specific frequency, speed, and type of future vessel traffic assumption that will navigate along the boating channel corresponds to the scenario described in Table B.4. This future vessel traffic assumption is anticipated based on the information provided by Client.

Table B.4 Frequency, type, and speed of future vessel traffic assumption used as model input for the propeller wash assessment

Vessel	LOA (m)	Width (m)	Draft (m)	SOG (knot)	No. of Trip/day
Bumboat	13.0	3.0	1	10	6 (Weekdays) 18 (Weekend)
Ferry	18.7	5.2	2.2	12	2 (Weekdays) 6 (Weekend)

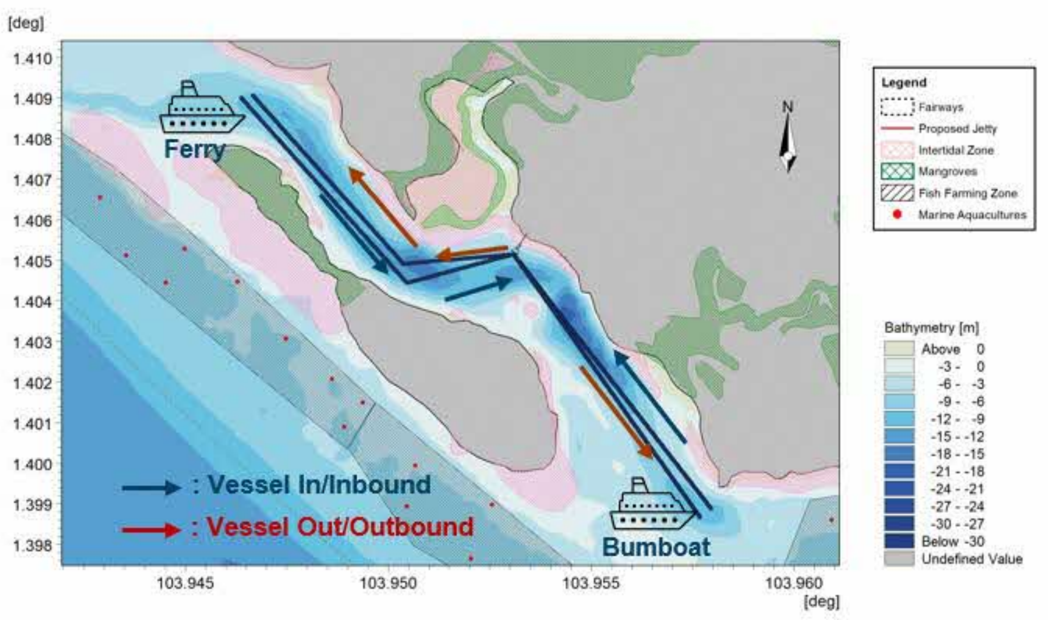


Figure B.3 Vessel track for propeller wash induced sediment modelling

B.3.8 Propeller Wash Model Parameter Setup

In order to simulate the impact of vessel propeller induced jet over seabed, some parameters are required to according to the characteristics of vessel type, which includes:

- Propeller diameter;
- Distance maximum: the distance where calculation of jet over seabed is set to cut off;
- RPS (Revolutions Per Second): refers to the number of times a propeller rotates around its axis in one second; and
- Thrust coefficient (K_T): dimensionless quantity used in fluid mechanics to describe the efficiency of a propeller in generating thrust. A typical value K_T of 0.35 is fairly conservative assumption (Prosser, 1986).

B.3.8.1 Bumboat Vessel

For the present assessment, the vessel input for bumboat is set to the following parameters described in Table B.5. RPS 6.7 Hz for typical conventional motor vessel is used for this assessment, which it is assumed to be similar with passenger vessel (Verhey, 1983).

Table B.5 Parameters setup for bumboat vessel input

Parameter	Value
Propeller diameter (m)	0.5
Distance maximum (m)	100
RPS (Hz)	6.7
K_T coefficient	0.35

B.3.8.2 Ferry Vessel

For the present assessment, the vessel input for bumboat is set to the following parameters described in Table B.6. RPS 6.7 Hz for typical conventional motor vessel is used for this assessment, which it is assumed to be similar with passenger vessel (Verhey, 1983).

Table B.6 Parameters setup for ferry vessel input

Parameter	Value
Propeller diameter (m)	1.0
Distance maximum (m)	100
RPS (Hz)	6.7
K_T coefficient	0.35

B.3.9 Model Result

The results from the propeller induced sediment plume model include:

- 2D maps for incremental maximum (95th percentile) SSC;
- 2D maps of time percentage incremental SSC exceeding 5 mg/l; and
- 2D maps for total bed thickness change over 14 days period

The model results are presented in the EIA report.

References

/1/ DHI. 2020. “MIKE 21 FLOW MODEL FM, Hydrodynamic Module User Guide.”

/2/ DHI. 2022. “MIKE 21 FLOW MODEL FM, Mud Transport Module User Guide.”

/3/ Prosser, M.J. 1986. Propeller-induced scour. *Coastal Engineering*, 9(5):423-437.

/4/ Verhey, H.J. 1983. The stability of bottom and banks subjected to the velocities in the propeller jet behind ship. 8th International Harbour Congress, Antwerp, Belgium, June 13-17.

/5/ Zhao, B., Jensen, J. H., Tan, L. H., Tan, C. A. 2017. Determination of settling velocities of cohesive sediments: from field measurements to numerical modelling. 36th IAHR World Congress, Kuala Lumpur, Malaysia, August 13-18, 2017.

APPENDIX C

Shipwake Model Setup and Results

C Ship Wake Modelling

Ship wakes are generated by the displacement of water induced by a passing vessel. Changes in propagation patterns of ship-generated wake in the area due to the nearshore development is also assessed. Wake heights depend on the displacement volume of the vessel (a function of the length, beam and draught), vessel speed and the amount of clearance between the vessel hull and channel bottom (Shi et. al., 2015). The ship-generated waves (i.e. ship wake) for all scenarios were calculated using empirical formulas by Kriebel and Seelig (2005) and Sorensen and Weggel (1984). This ship wake will then be propagated and transformed across the area of interest using DHI's MIKE 21 Spectral Wave (SW) model (DHI, 2020).

C.1 Wake Generation

When a vessel moves through the water, a system of waves will typically be generated from the vessel bow, from the foremost and sternmost, and from the vessel stern. Wake wash arises as a consequence of pressure differences along the ship hull. Figure C-1 shows a definition sketch for ship-generated waves caused by a moving vessel.

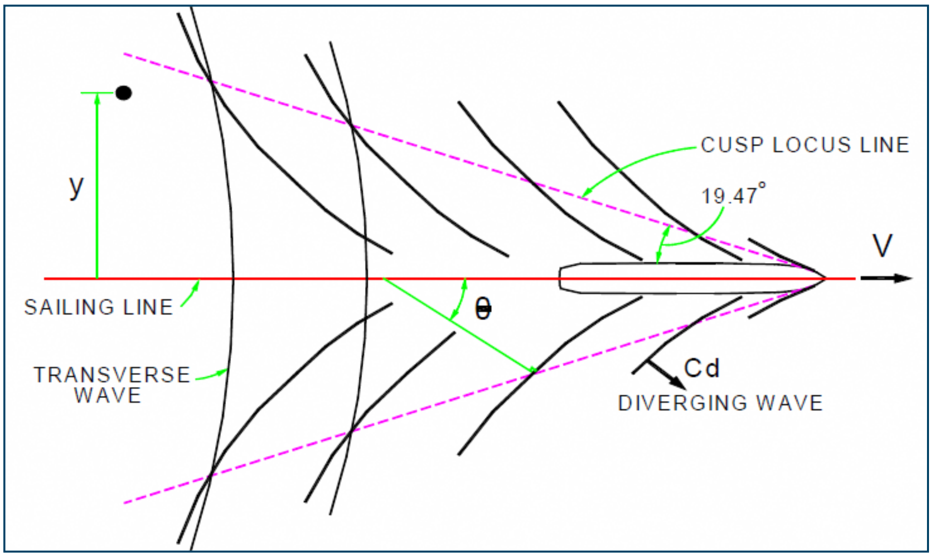


Figure C-1 Definition sketch showing plan-form of ship-generated waves (Source: Kriebel and Seelig, 2005)

C.1.1 Modelling Scenarios

Forty-eight (48) ship wake scenarios were simulated in this study along the Ketam Channel (Table C.2). For ease of understanding and better clarity when modelling, assessment of ship wake height was first divided into two (2) shorelines, Pulau Ubin and Pulau Ketam, and each shoreline was subsequently subdivided into three (3) areas (Figure C.2). Detailed shoreline areas and inbound/outbound vessel tracks for each shoreline are shown in Figure C.3 and Figure C.4. The simulated vessel dimensions were selected based on the proposed future vessel specifications as provided by the client (Table C.1). The assessment vessel speed was conducted for vessel speeds of 5 knots, 7 knots, 10 knots, and 12 knots so that the effects of a range of vessel speeds can be understood. The ship wake simulation is based on the single trip going back and forth from the proposed jetty at ULL at the respective vessel speed.

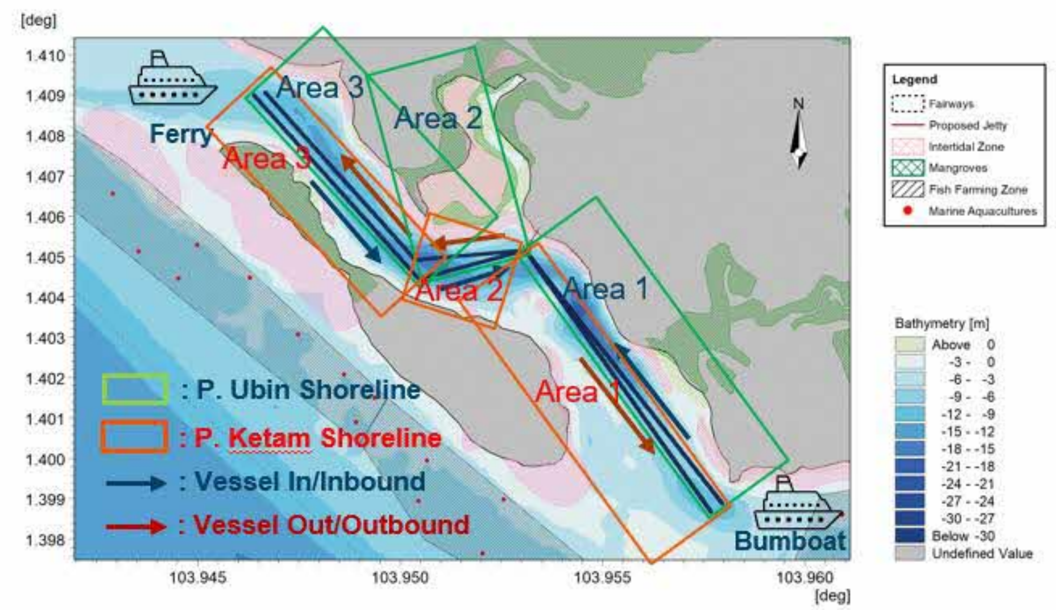


Figure C.2 Ship wake assessment areas for Pulau Ubin and Pulau Ketam shorelines

Table C.1 Properties of the vessels applied for ship wake assessment

Vessel	LOA (m)	Width (m)	Draft (m)
Bumboat	13.0	3.0	1
Ferry	18.7	5.2	2.2

Table C.2 Modelling scenarios for the ship wake assessment

<table>
<tr><th>Scenarios</th><th>Shoreline</th><th>Vessel Direction</th><th>Area</th><th>Vessel Type</th><th>SOG (knots)</th></tr>
<tr><td>1</td><td rowspan="11">Pulau Ubin</td><td rowspan="11">Vessel In</td><td rowspan="4">Area 1</td><td rowspan="4">Bumboat</td><td>12</td></tr>
<tr><td>2</td><td>10</td></tr>
<tr><td>3</td><td>7</td></tr>
<tr><td>4</td><td>5</td></tr>
<tr><td>5</td><td rowspan="4">Area 2</td><td rowspan="4">Ferry</td><td>12</td></tr>
<tr><td>6</td><td>10</td></tr>
<tr><td>7</td><td>7</td></tr>
<tr><td>8</td><td>5</td></tr>
<tr><td>9</td><td rowspan="3">Area 3</td><td rowspan="3">Ferry</td><td>12</td></tr>
<tr><td>10</td><td>10</td></tr>
<tr><td>11</td><td>7</td></tr>
</table>

12					5
13		Vessel Out	Area 1	Bumboat	12
14					10
15					7
16					5
17			Area 2	Ferry	12
18					10
19					7
20					5
21			Area 3	Ferry	12
22					10
23					7
24					5
25	Pulau Ketam	Vessel In	Area 1	Bumboat	12
26					10
27					7
28					5
29			Area 2	Ferry	12
30					10
31					7
32					5
33			Area 3	Ferry	12
34					10
35					7
36					5
37		Vessel Out	Area 1	Bumboat	12
38					10
39					7
40					5
41			Area 2	Ferry	12

42					10
43					7
44					5
45			Area 3	Ferry	12
46					10
47					7
48					5

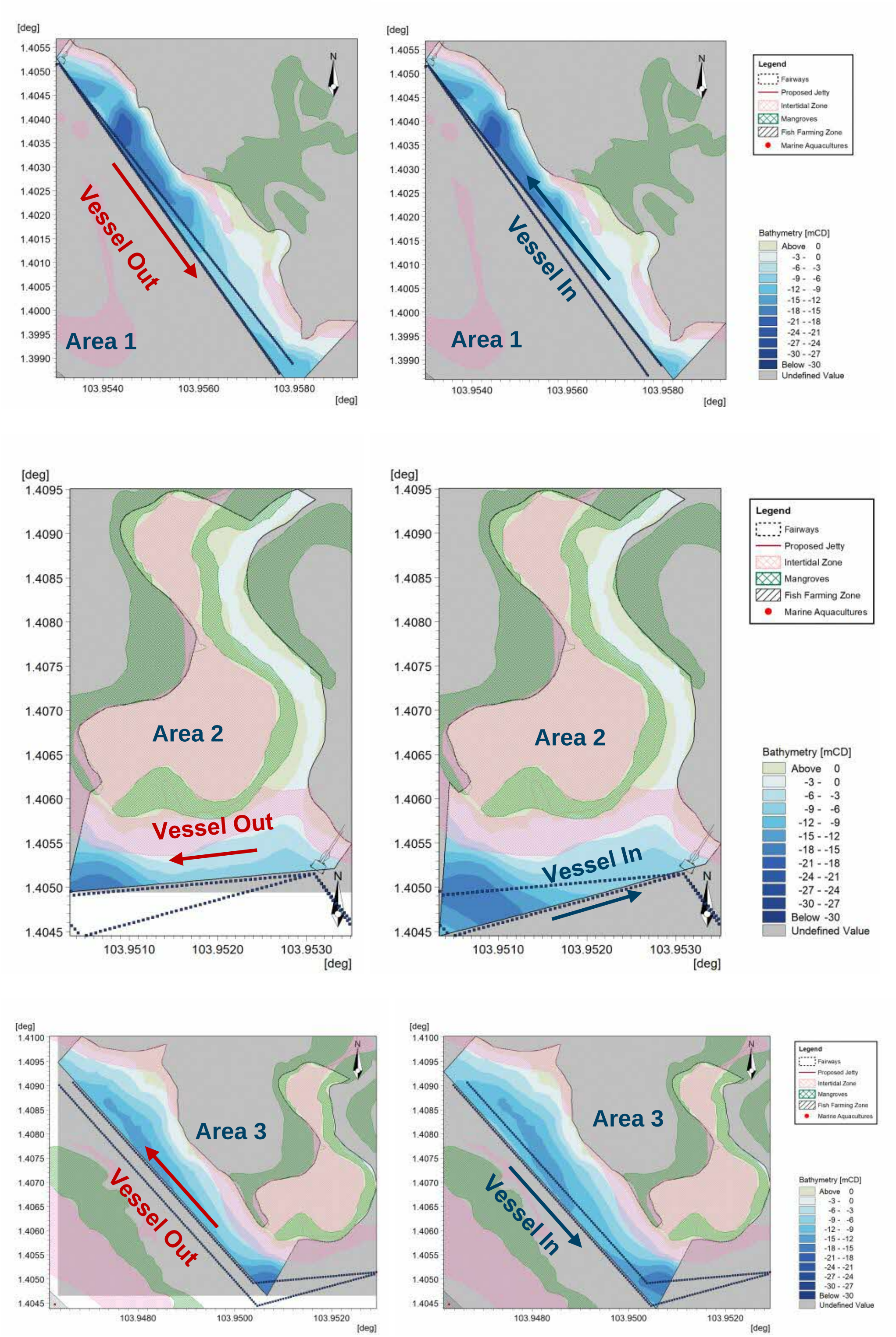


Figure C.3 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ubin shoreline

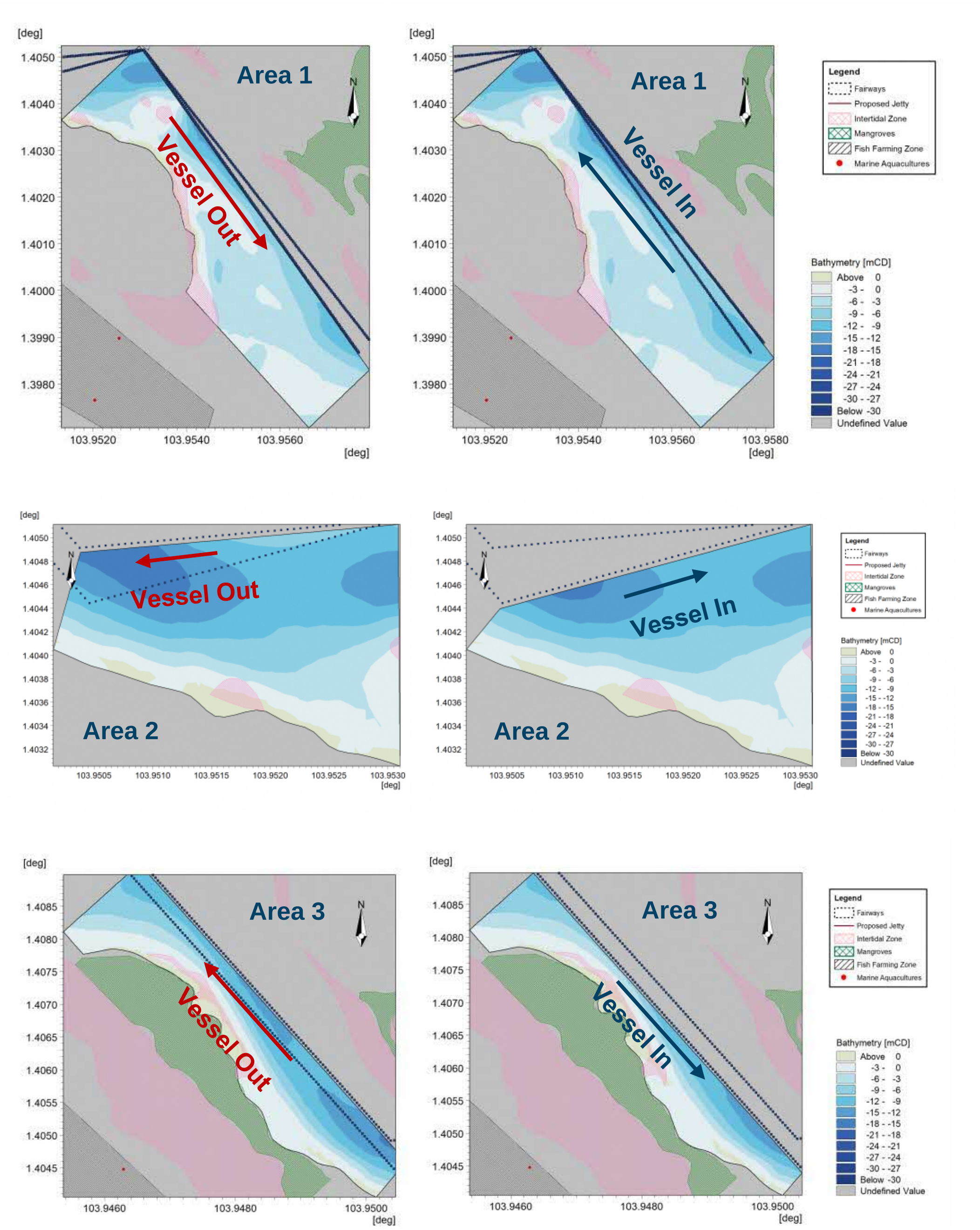


Figure C.4 Outbound (left column) and inbound (right column) directions of vessel tracks for ship wake assessment at the Pulau Ketam shoreline

C.1.2 Maximum Ship Wake Generation

Based on the selected vessel data, speed over ground (SOG), vessel directions, and shoreline area in the modelling scenarios (Table C.2), the maximum wave height along the track induced by the selected vessel is calculated based on the empirical formula by Kriebel and Seelig (2005) and Sorensen and Weggel (1984) shown below.

Kriebel and Seelig (2005)

The first step in calculating the ship-generated wave by Kriebel and Seelig (2005) is calculating the modified Froud number, Fr_*. Fr_* is a function of five parameters: vessel speed V [ms^{-1}], length L [m], draught D [m], water depth d [m] and hull form α [-]:

$$Fr_* = F_L \exp(\alpha D/d) = \frac{V}{\sqrt{gL}} \exp(\alpha D/d) \qquad (C.1)$$

where:
Fr_* - Froude number;
V - vessel speed (m/s);
g - gravitational constant (9.81 m/s^2);
L - vessel length (m);
α - empirical parameter depends on hull form (-);
D - vessel draught (m); and
d - water depth (m).

The hull form parameter α is a transformed version of the block coefficient (C_b) which describes the fullness of the hull:

$$\alpha = 2.35(1 - C_b) \qquad (C.2)$$

A lower coefficient would indicate a more streamlined hull. Hull fullness is characterised by the vessel's displacement volume in relation to its absolute (block) dimensions.

Fr^* is then used to calculate the maximum wake height H [m] induced by passing ships, which is a function of four additional parameters; vessel speed V [ms^{-1}], length L [m], hull form β [-] and distance from the point of interest to the sailing line y [m]:

$$\frac{gH}{V^2} = \beta(Fr^* - 0.1)^2 (\frac{y}{L})^{-1/3} \qquad (C.3)$$

where:
H - wave height (m);
y/L - normalized distance (m); and
β - empirical parameter depends on hull form (-).

The hull form parameter β is a transformed version of the bow entry length L_e [m], which is the distance from the bow to the widest part of the hull.

$$\beta = 1 + 8tanh^3(0.45\left(\frac{L}{L_e} - 2\right) \qquad (C.4)$$

This empirical formulation was validated with a limited set of parameters and should only be applied for ships with Fr^* in the range <$0.1 < Fr^* < 0.5$ and $\beta(Fr^* - 0.1)^2 < 0.4$.

Sorensen and Weggel (1984)

Theis model suggests a ship-generated wave height as a function of ship speed, displacement, water depth, and distance from the sailing line. Using the methods of Sorensen and Weggel (1984), the maximum wave height can be calculated using the relationship shown below.

$$\frac{H_m}{L} = \alpha \left(\frac{y_s}{L}\right)^n \left(\frac{L}{\nabla^{1/3}}\right)^{n-1} \quad (C.5)$$

Here, α can be calculated as:

$$\log \alpha = -\frac{0.6}{Fn_d} + 0.75 Fn_d^{-1.125} \log\left(\frac{d}{\nabla^{1/3}}\right) + (2.6531 Fn_d)\left[\log\left(\frac{d}{\nabla^{1/3}}\right)\right]^2 \quad (C.6)$$

The power n in equation C.5 is related to water depth and given as:

$$n = \beta \left(\frac{d}{\nabla^{1/3}}\right)^\delta \quad (C.7)$$

where,

$$\beta = -0.225 Fn_d^{-0.699},\ \delta = -0.118 Fn_d^{-0.356}, \text{ for } 0.20 \le Fn_d \le 0.55 \quad (C.8)$$

$$\beta = -0.342,\ \delta = -0.146, \text{ for } 0.55 \le Fn_d \le 0.80 \quad (C.9)$$

where:
H_m – maximum wave height (m);
y_s – distance from sailing line (m);
Fn_d – water depth Froud number;
∇ - volume displacement of ship (m^3);
L - waterline length (m);
β - empirical parameter depends on hull form (-);
d - water depth (m).

The two (2) formulas above were used to obtain a maximum wake height and associated peak wave period along the vessel route shown in Figure C.3 and Figure C.4 for each scenarios presented in Table C.2. This information was incorporated into a MIKE 21 SW model as boundary condition, where the wake would be propagated from the sailing route into the project site.

C.2 Wake Propagation

For the assessment of the propagation and transformation of the ship-generated waves towards the shore, the phase-averaged spectral wave model MIKE 21 SW was used. The model predicts the spatial variation of a characteristic wave height, period and direction within the defined domains and thereby describes the “strength” or severity of the wake wash in shallow waters.

MIKE 21 SW is a spectral wave model describing the most important physical processes which have an impact on the waves as they propagate from the ship route towards the coast (DHI, 2020). Processes such as refraction, shoaling, bottom friction and wave breaking are included. A short description of this software is given in the section below and further information is found in DHI’s SW Module’s scientific documentation (2020).

C.2.1 MIKE 21 Spectral Wave (SW)Model

MIKE 21 Spectral Wave (SW) model is developed, supported and maintained by DHI. Like the other modules included in the flexible mesh series of MIKE Powered by DHI, the spectral wave model is based on an unstructured, cell-centred finite volume method and uses an unstructured mesh in geographical space. This approach, which has been available from DHI now for more than a decade and which is thus fully matured, gives the maximum degree of flexibility, and allows the model resolution to be varied and optimised according to requirements in various parts of the model domain.

The MIKE 21 SW version 2020 was applied in this project. A summary of the model description and capabilities is given below. Note that some features were not included in this study.

MIKE 21 SW Spectral Waves FM

MIKE 21 SW is DHI's state-of-the-art third generation spectral wind-wave model. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas.

Due to its unique **unstructured flexible mesh** technique, MIKE 21 SW is particularly suited for simultaneous, i.e. in one single model domain, wave modelling at regional scale and at local scale. Coarse spatial resolution is used for the regional part of the mesh and a higher resolution is applied in more shallow water environment at the coastline, around structures, etc.

MIKE 21 SW includes the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction (quadruplet and triad-wave interactions)
- Dissipation due to white-capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations and currents
- Effect of time-varying water depth and currents
- Effect of ice coverage on the wave field (not included in the present study)
- Wave diffraction
- Wave reflection
- Influence of structures (like piers, wind turbine foundations, WEC, TEC)

Main computational features of MIKE 21 SW are:

- Source functions based on state-of-the-art 3rd generation formulations
- Fully spectral and directionally decoupled parameterised formulation
- In-stationary and quasi-stationary solutions
- Optimal degree of flexibility in describing bathymetry and ambient flow conditions using depth-adaptive and boundary-fitted unstructured mesh
- Coupling with hydrodynamic flow model for modelling of wave-current interaction and time-varying water depth
- Flooding and drying in connection with time-varying water depths
- Water-structure interaction module
- Parallelised using OpenMP and MPI techniques

For further details, see DHI's SW module's scientific documentation (2020).

C.2.2 Model Domain

The model domain is based on the area inbound and outbound vessel track presented in Section C.1.1 (see Figure C.3 and Figure C.4).

C.2.3 Model Specifications

The model setup parameters are summarised in Table C.3.

Table C.3 Summary of spectral wave model set-up parameters

Setting	Value	
Mesh resolution	5-m at the entire domain area	
Basic equations	Spectral Formulation	Directionally Decoupled Parametric Formulation
	Time Formulation	Quasi Stationary Formulation
Directional Discretisation	Discretization type: 360 degree rose Number of directions: 36	
Solution Technique	Quasi Stationary Formulation Geographical space discretization: Low order, fast algorithm Method: Newton-Raphson iteration Maximum number of iterations: 500 Tolerance (RMS-norm): 1e-06 Tolerance (Max-norm): 0.001 Relaxation factor: 0.1	
Wind forcing	No wind	
Wave breaking	Included, Specified Gamma (0.8), γ=1, α= 1	
Initial Condition	Spectra from empirical formula Type of formulas: JONSWAP fetch growth expression Maximum fetch length: 100000 Maximum peak frequency: 0.4 Maximum philips constant: 0.0081 Shape parameter, sigma a: 0.07 Shape parameter, sigma b: 0.09 Peakness parameter: 3.3	
Bottom friction	Nikuradse, k_n = 0.04 m	
Output specifications	2D spectral parameter (Wave Height – Period) along the wave domain model	

C.2.4 Output Specifications

The output of the model included integrated wave parameters at every mesh element in the entire model domain. The saved integrated wave parameters are listed in Table C.4.

Table C.4 Integral wave parameters available at every mesh element

Name	Abbrev.	Unit
Significant wave height	H_{m0}	m
Peak wave period	T_p	s

C.3 Ship Wake Results

The results from the ship wake model include:

- 2D maps for ship wake height at Pulau Ubin Shoreline;
- 2D maps for ship wake height at Pulau Ketam Shoreline.

The model results are presented in the EIA report.

C.4 Evaluation of Ship Wake Impact to Shoreline

The evaluation of potential ship wake impact to shoreline erosion was done by calculating the Bed Shear Stress (BSS) generated from the ship wake and combining it with the BSS from HD results (generated by currents). This gave the resultant BSS value, which was used to provide a preliminary assessment to document relative areas of potential morphological change (sedimentation or erosion).

Nine (9) analysis points at three different areas were selected to extract the BSS value for impact assessment (Figure C.5). The coordinates of the analysis point in each area are provided in Table C.5. A critical BSS threshold for erosion risk (τ_c) of 0.14 N/m^2 was used in this study to estimate occurrences of erosion from the time series BSS graphs (Shi *et al.*, 2015). The calculation of BSS generated by ship wake followed the formula by Nielsen (1992). A detail calculation of BSS generated from wave motion is presented in Section C.4.1. After the resultant BSS was obtained, assessment of ship wake induced erosion was through comparing this value with the critical BSS for erosion (τ_c). Exceedance of critical BSS indicates potential for shoreline erosion.

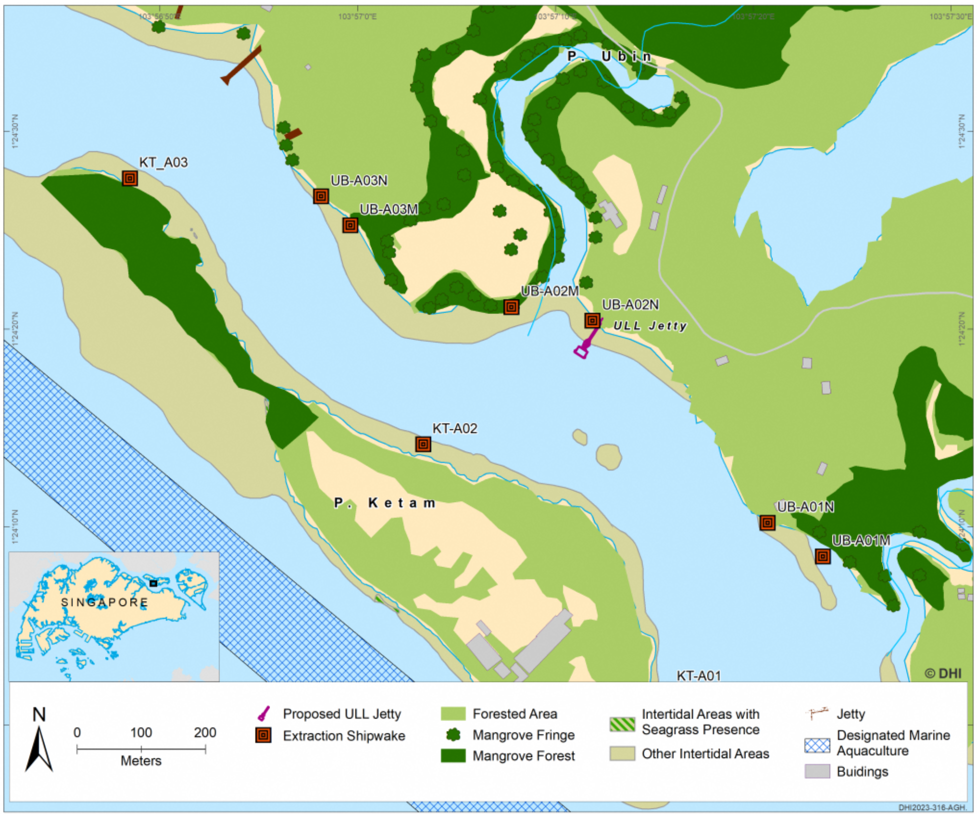


Figure C.5 Location of BSS extraction points for impact assessment of ship wake impacts on the shoreline

Table C.5 Coordinates of the nine (9) extraction points

Area	Extraction Point	Shoreline	Geographical Coordinates	
			Longitude (º)	Latitude (º)
1	UB-A01M	Pulau Ubin	103.956535	1.402367
	UB-A01N	Pulau Ubin	103.955760	1.402840
	KT-A01	Pulau Ketam	103.954355	1.400467
2	UB-A02M	Pulau Ubin	103.952160	1.405870
	UB-A02N	Pulau Ubin	103.953300	1.405680
	KT-A02	Pulau Ketam	103.950923	1.403942
3	UB-A03M	Pulau Ubin	103.949900	1.407020
	UB-A03N	Pulau Ubin	103.949490	1.407425
	KT-A03	Pulau Ketam	103.946803	1.407679

C.4.1 Bed Shear Stress Calculation

In the case of pure wave motion, the mean bed shear stress reads /5/:

$$\tau_w = \frac{1}{2} \rho \, f_w U_b^2 \qquad (C.10)$$

where:
τ_w – bed shear stress (N/m^2);
f_w – wave friction factor;
U_b – horizontal mean wave orbital velocity at the bed (m/s),
ρ – density of fluid (kg/m^3).

$$U_b = \frac{2H_s}{T_z} \frac{1}{\sinh\left(\frac{2\pi}{L} h\right)} \qquad (C.11)$$

where:
H_z – significant wave height (m);
T_z – zero-crossing wave period (s);
L – wave length (m),
h – water depth (m).

C.4.2 Bed Shear Stress Results

The results from the bed shear stress include:

- Time series graphs of BSS (generated by currents); and
- Time series graphs of resultant BSS (generated by current and shipwake).

The model results are presented below from Figure C.6 to Figure C.15.

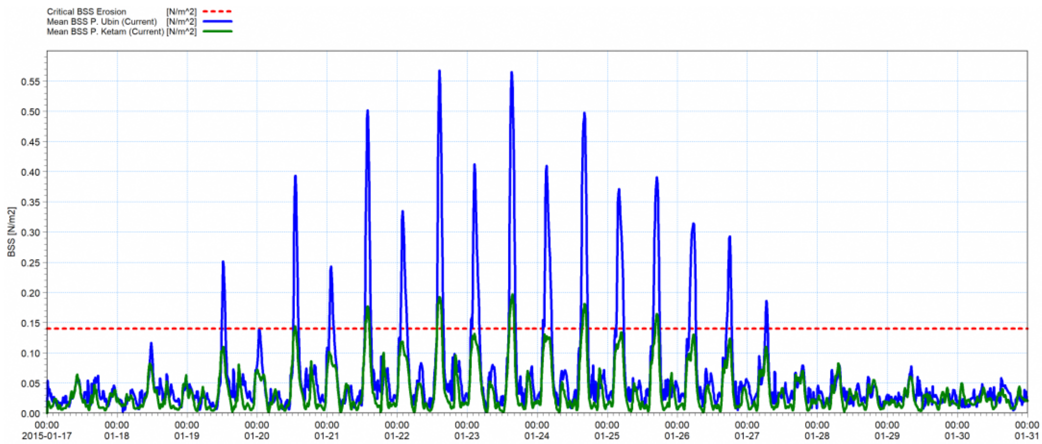


Figure C.6 Time series of mean BSS generated by currents (derived from HD) for Pulau Ubin and Pulau Ketam shorelines. Potential erosion occurs when BSS is >0.14 N/m²

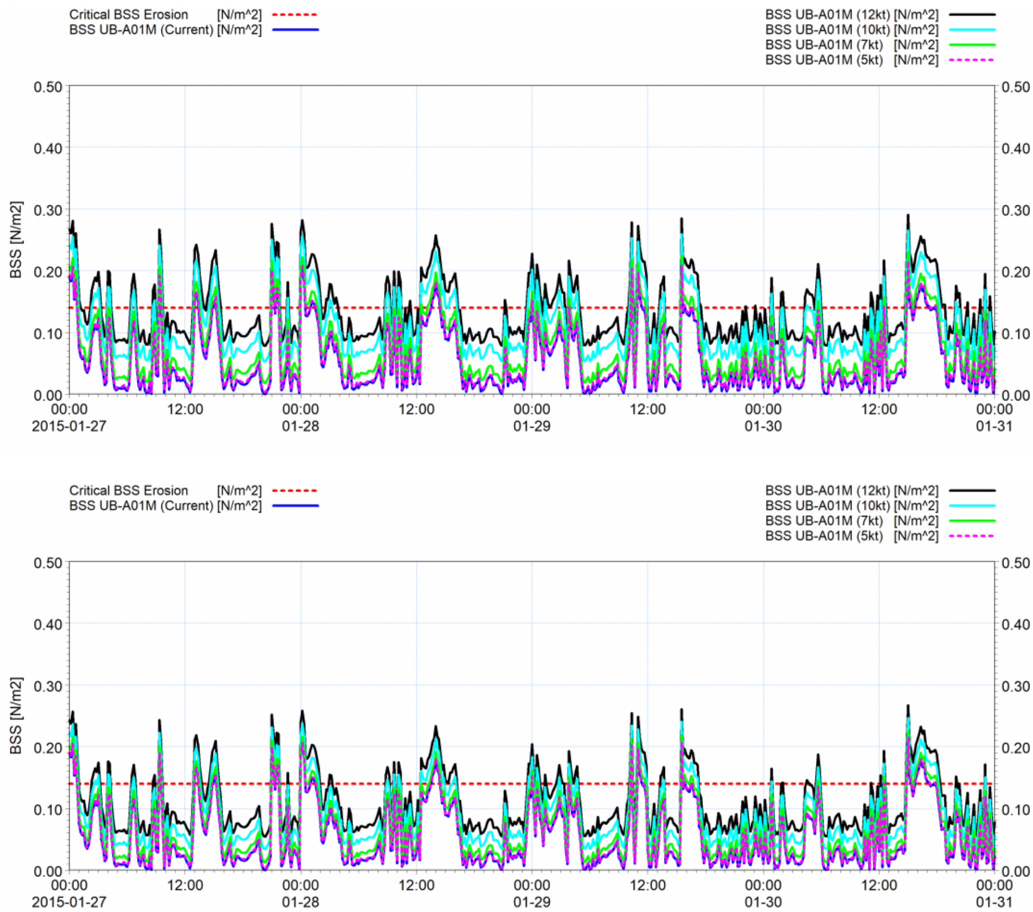


Figure C.7 Time series of BSS generated by current (HD) and ship wake at Area 1 mangrove for Pulau Ubin shoreline (UB-A01M). Each line represents the calculated BSS cause by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m²

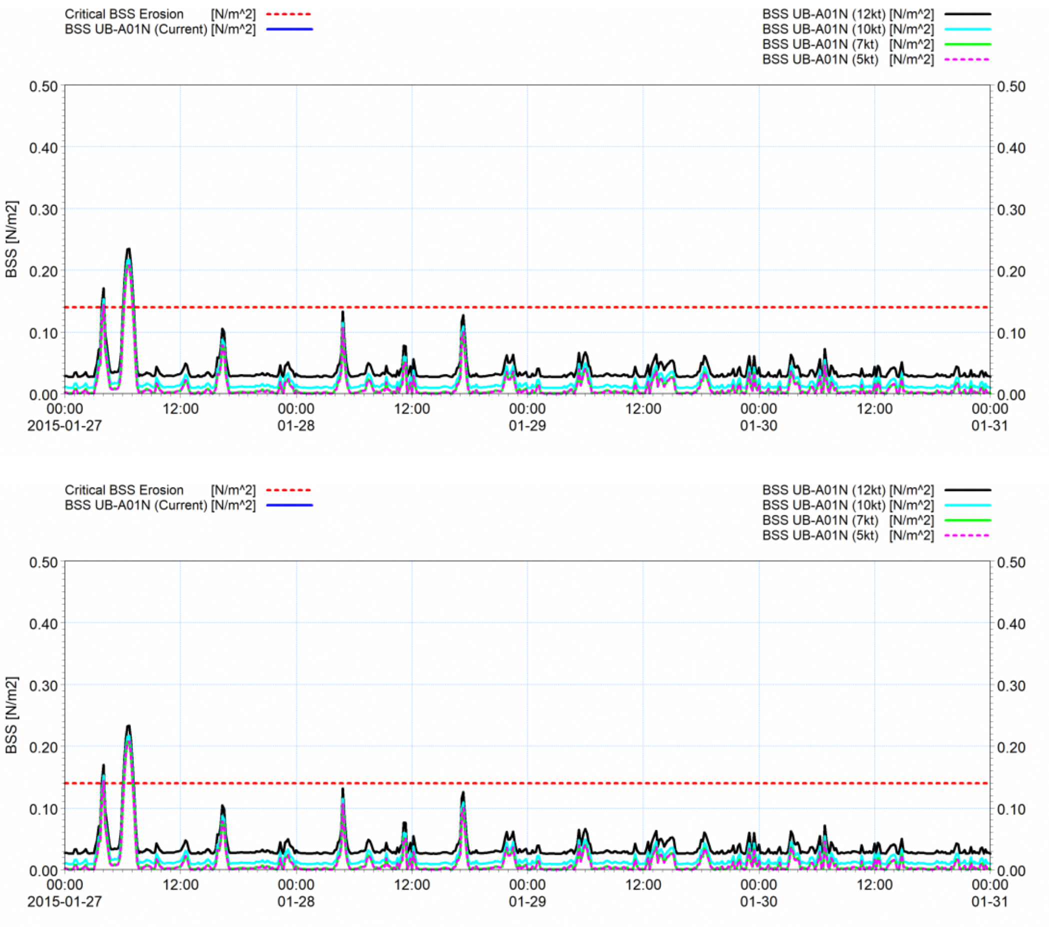


Figure C.8 Time series of BSS generated by current (HD) and ship wake at Area 1 intertidal zone for Pulau Ubin shoreline (UB-A01N). Each line represents the calculated BSS cause by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2

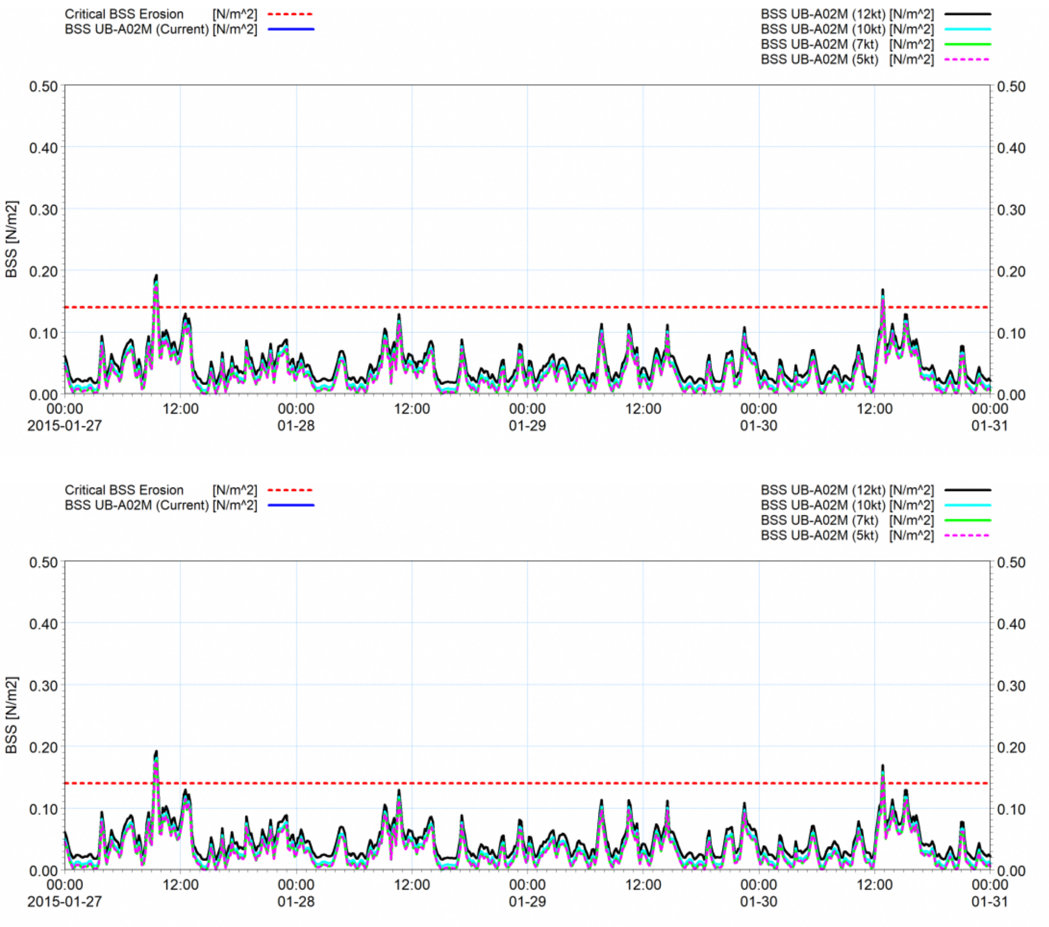


Figure C.9 Time series of BSS generated by current (HD) and ship wake at Area 2 mangrove for Pulau Ubin shoreline (UB-A02M). Each line represents the calculated BSS cause by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2

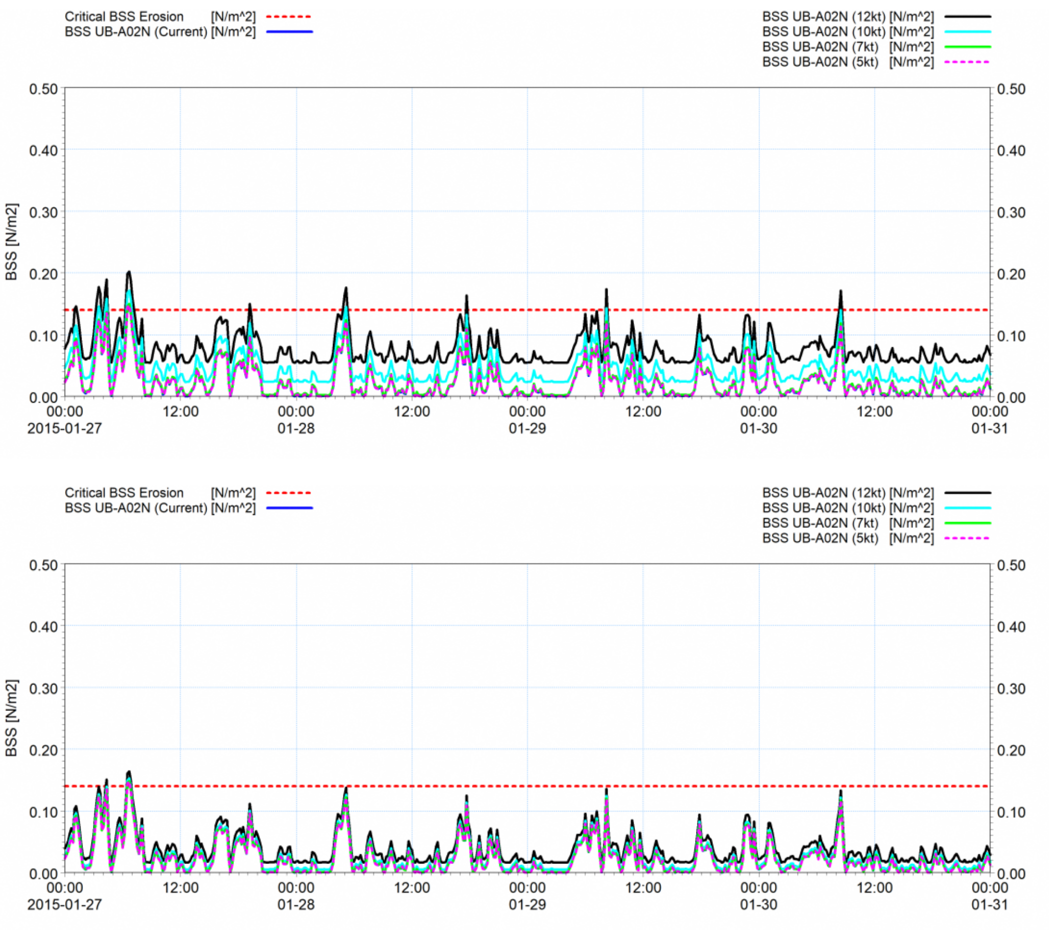


Figure C.10 Time series of BSS generated by current (HD) and ship wake at Area 2 intertidal zone for Pulau Ubin shoreline (UB-A02N). Each line represents the calculated BSS cause by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2

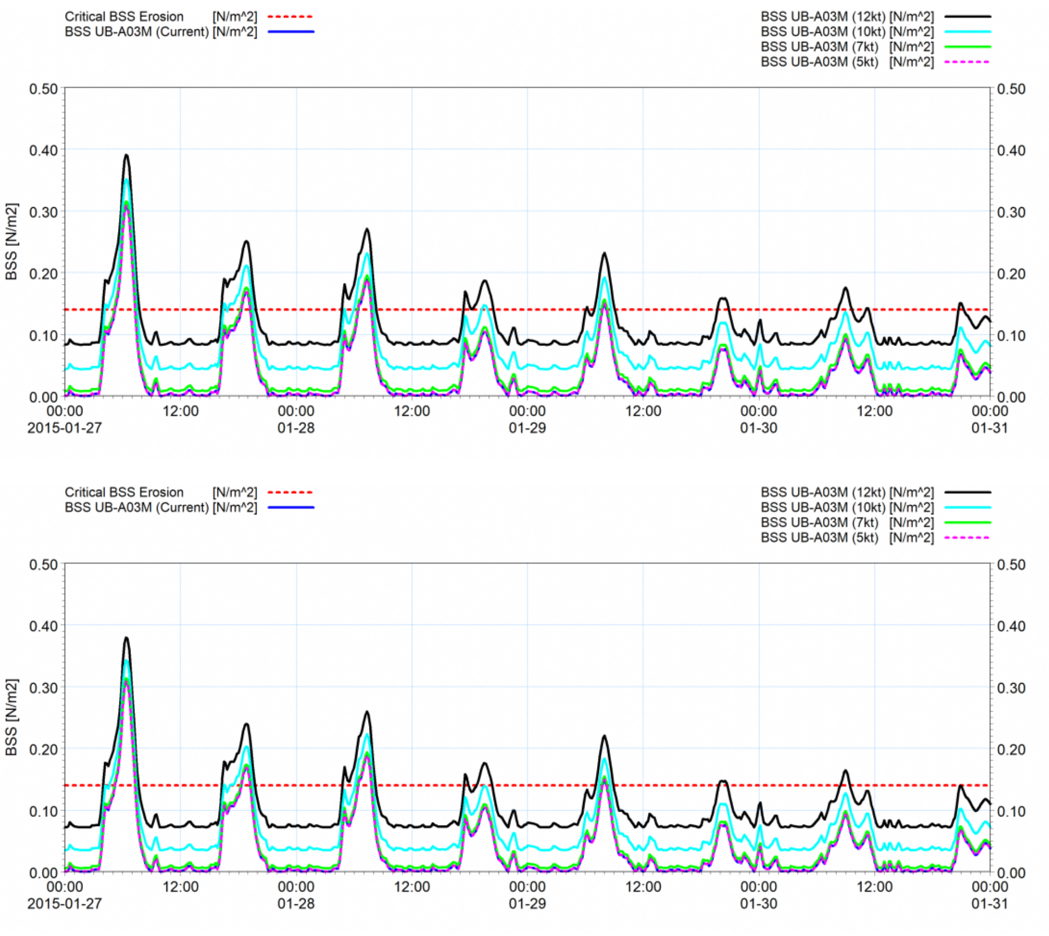
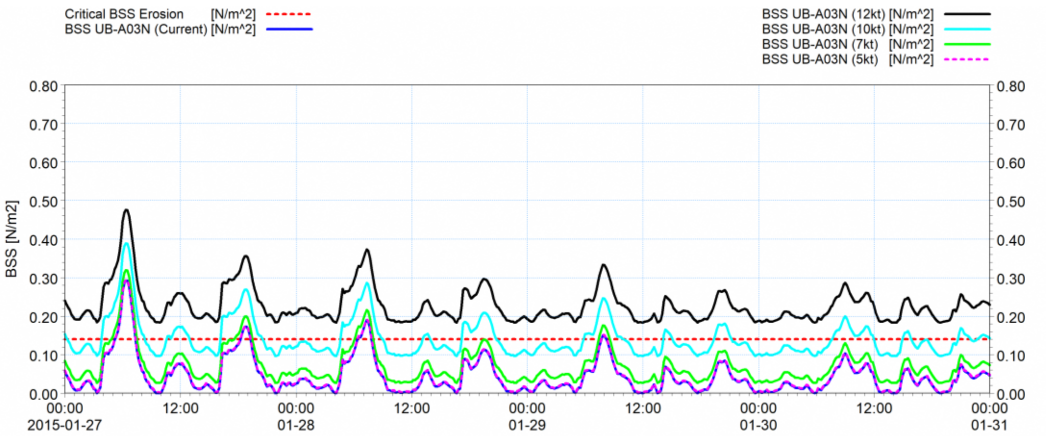


Figure C.11 Time series of BSS generated by current (HD) and ship wake at Area 3 mangrove for Pulau Ubin shoreline (UB-A03M). Each line represents the calculated BSS cause by vessels travelling at varying speeds (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2



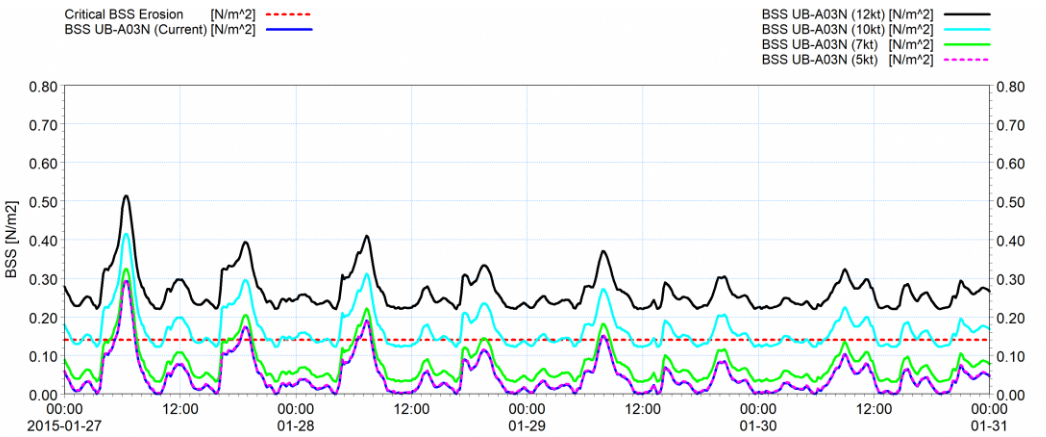
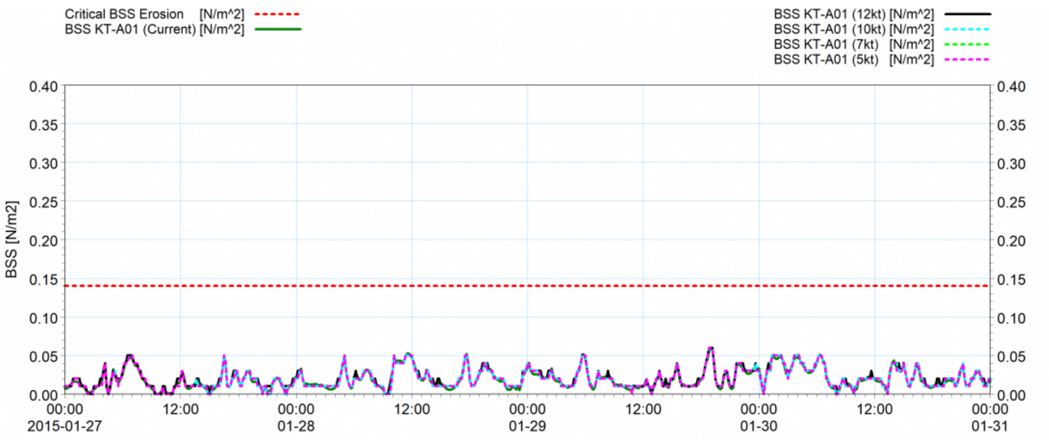


Figure C.12 Time series of BSS generated by current (HD) and ship wake at Area 3 intertidal zone for Pulau Ubin shoreline (UB-A03N). Each line represents BSS at different vessel speed (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2



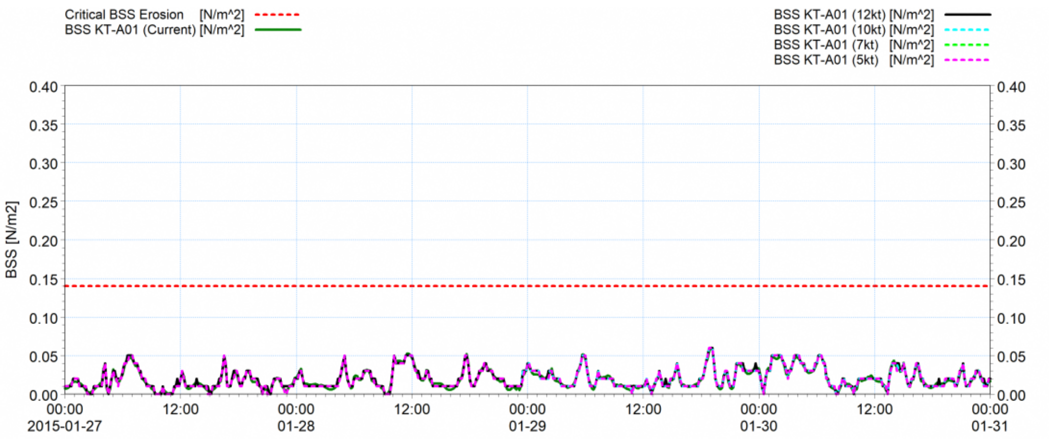
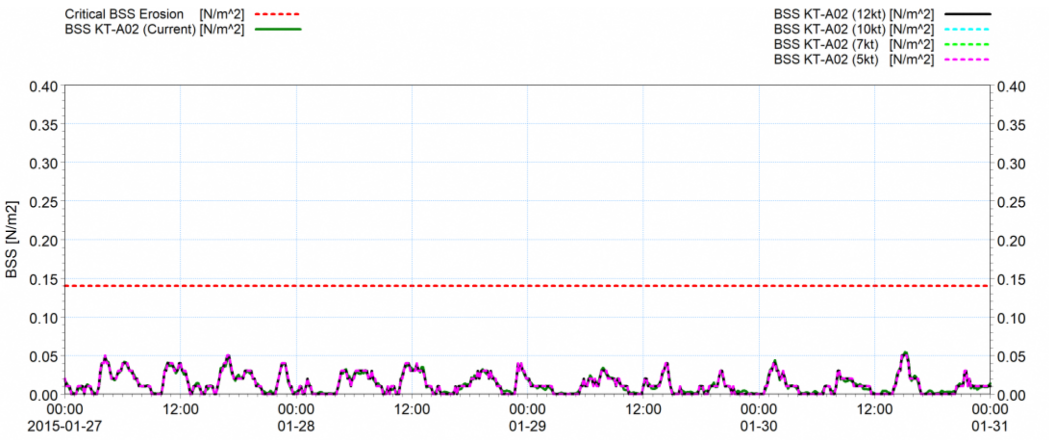


Figure C.13 Time series of BSS generated by current (HD) and ship wake at Area 1 Pulau Ketam shoreline (KT-A01). Each line represents BSS at different vessel speed (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2



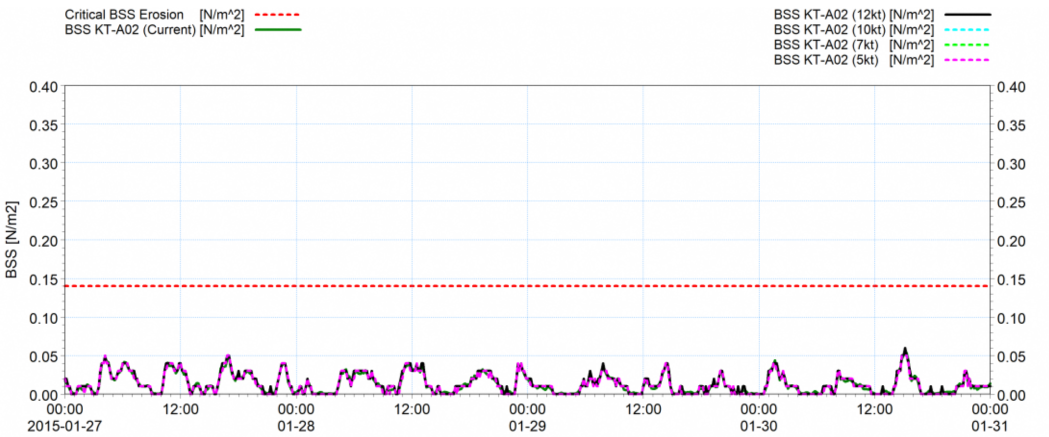


Figure C.14 Time series of BSS generated by current (HD) and ship wake at Area 2 Pulau Ketam shoreline (KT-A02). Each line represents BSS at different vessel speed (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2

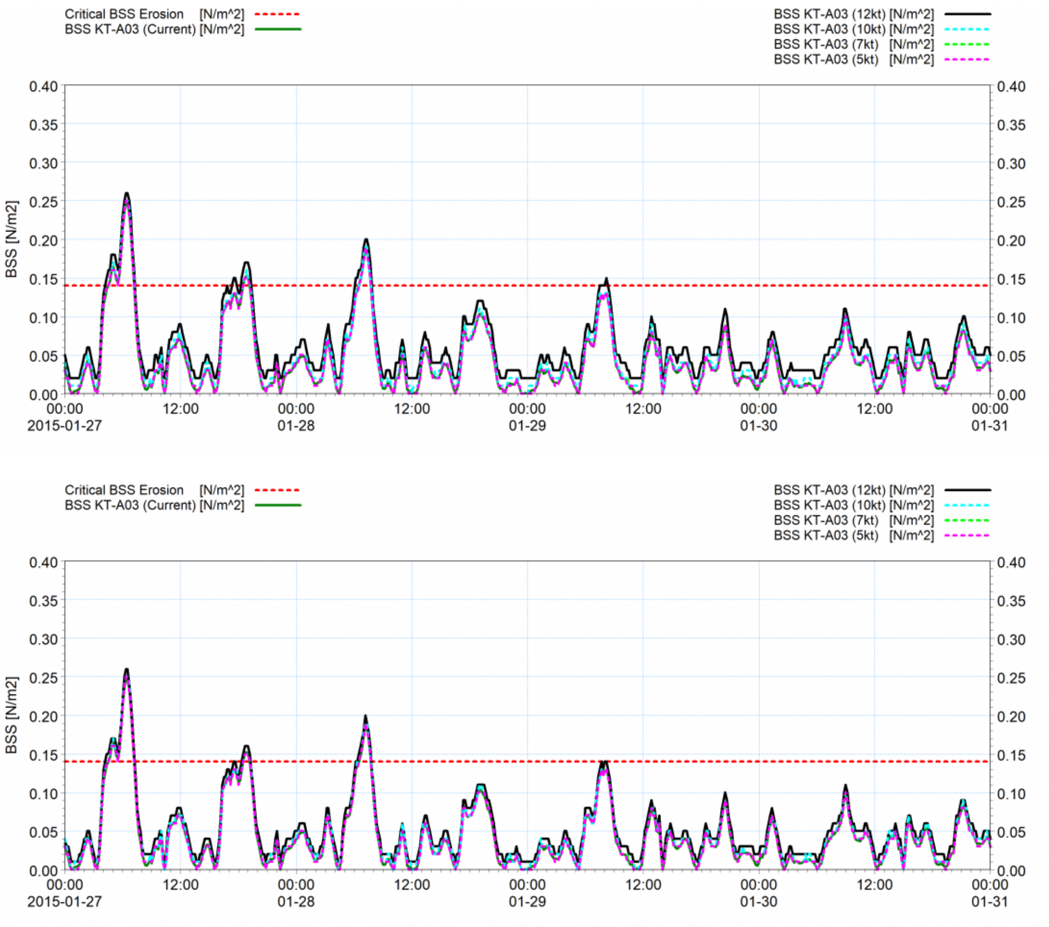


Figure C.15 Time series of BSS generated by current (HD) and ship wake at Area 3 Pulau Ketam shoreline (KT-A03). Each line represents BSS at different vessel speed (12 knots, 10 knots, 7 knots, 5 knots): vessel inbound (top) and vessel outbound (bottom). Potential erosion occurs when BSS > 0.14 N/m^2

References

/1/ Kriebel, D. L., Seelig, W. N. (2005). An empirical model for ship-generated waves. Ocean Waves Measurement and Analysis, Fifth International Symposium WAVES 2005, 3rd-7th, July, 2005. Madrid, Spain Paper number: 58

/2/ Shi, B., Wang, Y.P., Yang, Y., Li, M., Li, P., Ni, W., Gao, J. (2015). Determination of critical shear stresses for erosion and deposition based on in situ measurements of currents and waves over an intertidal mudflat. Journal of Coastal Research, 00(0), 000–000.

/3/ Sorensen, R. M., Weggel, J. R. (1984). Development of ship wave design information. Proceeding of the 19th International Conference on Coastal Engineering, Texas, USA. 3(216): 3227-3243.

/4/ DHI. 2020. “MIKE 21, Spectral Wave Module, Scientific Documentation.” Hørsholm.

/5/ Nielsen, P. (1992). Coastal bottom boundary layers and sediment transport. World Scientific Publishing Co.

APPENDIX D

Flora Baseline Report

DHI Water & Environment (S) Pte. Ltd

Pulau Ubin ULL Ecological Baseline Study

Flora Assessment for Proposed Jetty

Tony O'Dempsey
2/9/2023

Table of Contents

INTRODUCTION **3**

HISTORICAL LANDUSE ANALYSIS **3**

HABITAT MAPPING **6**

HABITAT CLASSIFICATION 6
HABITAT MAP 7
HABITAT DISCUSSION 9
Managed Vegetation *9*
Native Dominated Young Secondary Forest *11*
Native Dominated Coastal Edge Forest *16*

SURVEY METHODOLOGY AND RESULTS **19**

METHODOLOGY 19
Measured Plots/Transect *20*
Walking Transects *20*
Species Identification *20*
SAMPLING PLOTS & TRANSECT 21
Sampling Plot 1 .... *21*
Sampling Plot 2 .... *23*
Sampling Plot 3 .... *25*
Sampling Transect 1 .... *27*

SPECIES CHECKLIST **29**

DISCUSSION AND RECOMMENDATIONS **31**

SAMPLING TRANSECT AND PLOT RECORDS **32**

SAMPLING PLOT 1 32
SAMPLING PLOT 2 35
SAMPLING PLOT 3 38
SAMPLING TRANSECT 1 41

INTRODUCTION

Pulau Ubin is located to the north east of Singapore island Singapore. The study area of approximately 5.7 hectares is centred at geographic coordinates[1] E103° 57' 16" N1° 24' 21" and is situated over landfill and natural terrain areas on the island as illustrated in Figure 1 below. The baseline flora study is required in support of an Environmental Impact Assessment for a proposed jetty at the Ubin Living Labs (ULL) on the island.

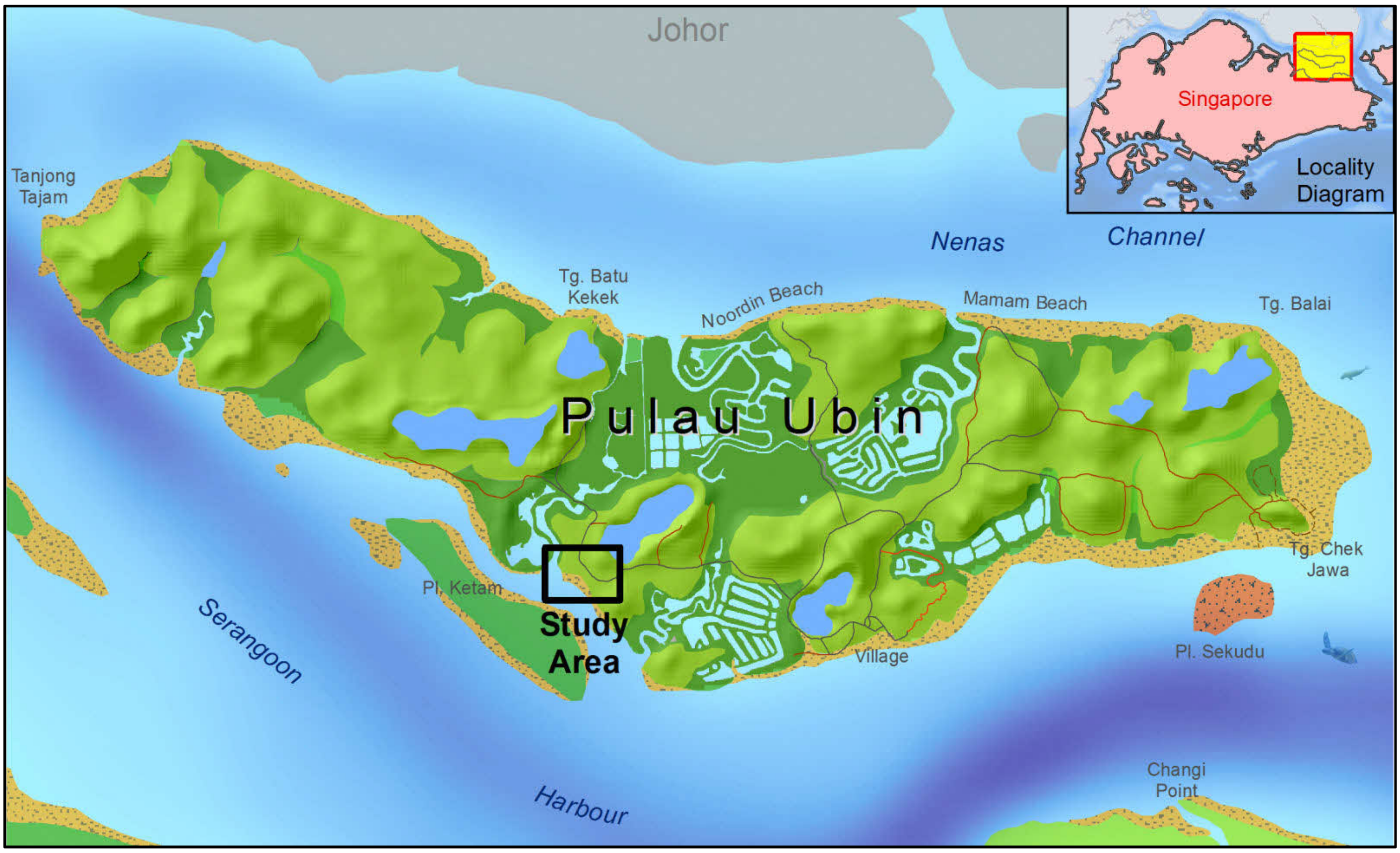


Figure 1: Pulau Ubin with baseline study area indicated.

HISTORICAL LANDUSE ANALYSIS

The flora study area is affected by two significant historical land uses, the first being the Ubin Quarry facilities for which the area was generally cleared for buildings, roads and railways as well as three jetties used for transport of quarried materials and machinery. Part of the mangrove area associated with Sungai Puaka was reclaimed for site of the former Celestial Resort which operated until 2012 after which the Ubin Living Labs was established on the site c. 2016.

[1] Geographic Coordinate datum is WGS84.

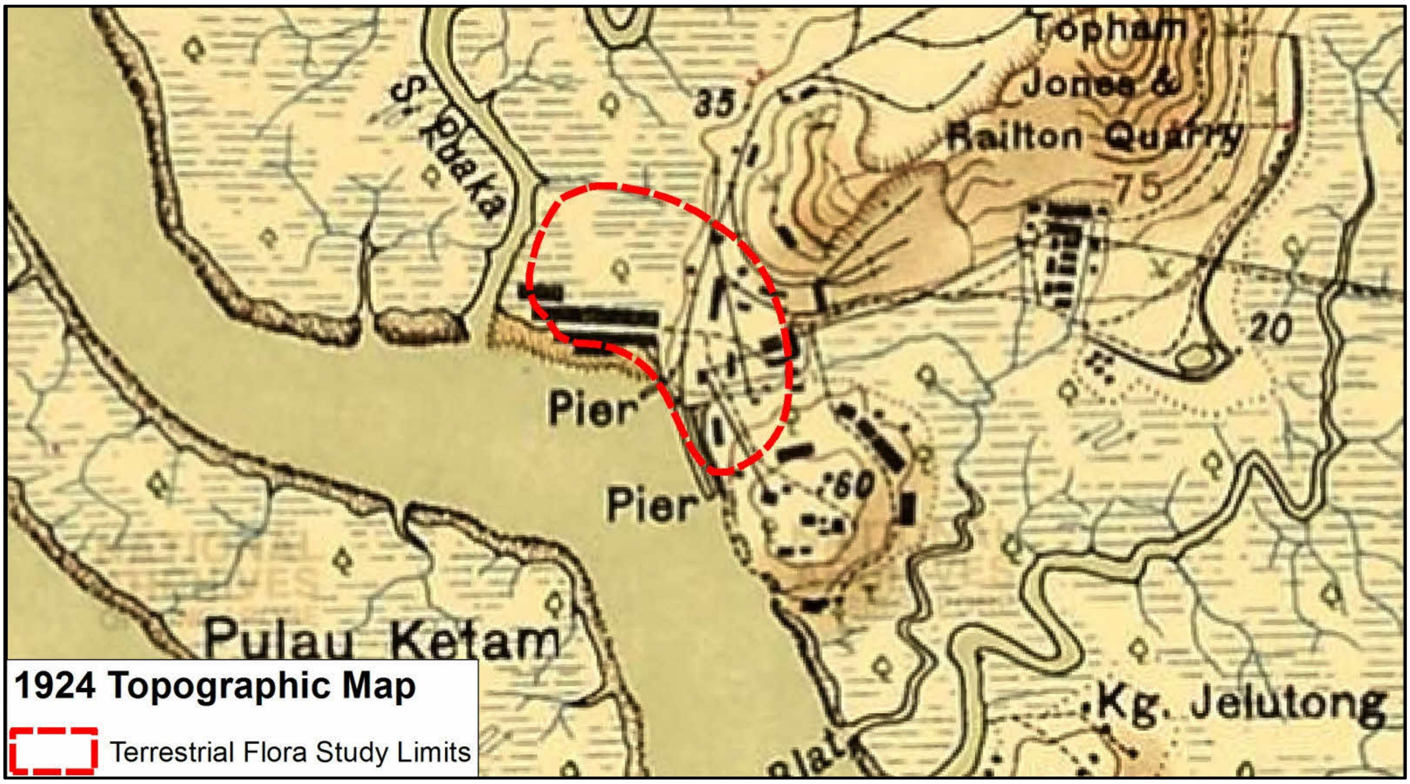


Figure 2: 1924 Topographic map showing quarry facilities over study site. (NAS Accession: D2019_000034_TNA)

The 1924 Topographic map shows quarry facilities including buildings, piers and industrial railway. The formation of the railway can still be found on the hillside behind the study site. The map also confirms that rubber trees were never planted in this area.

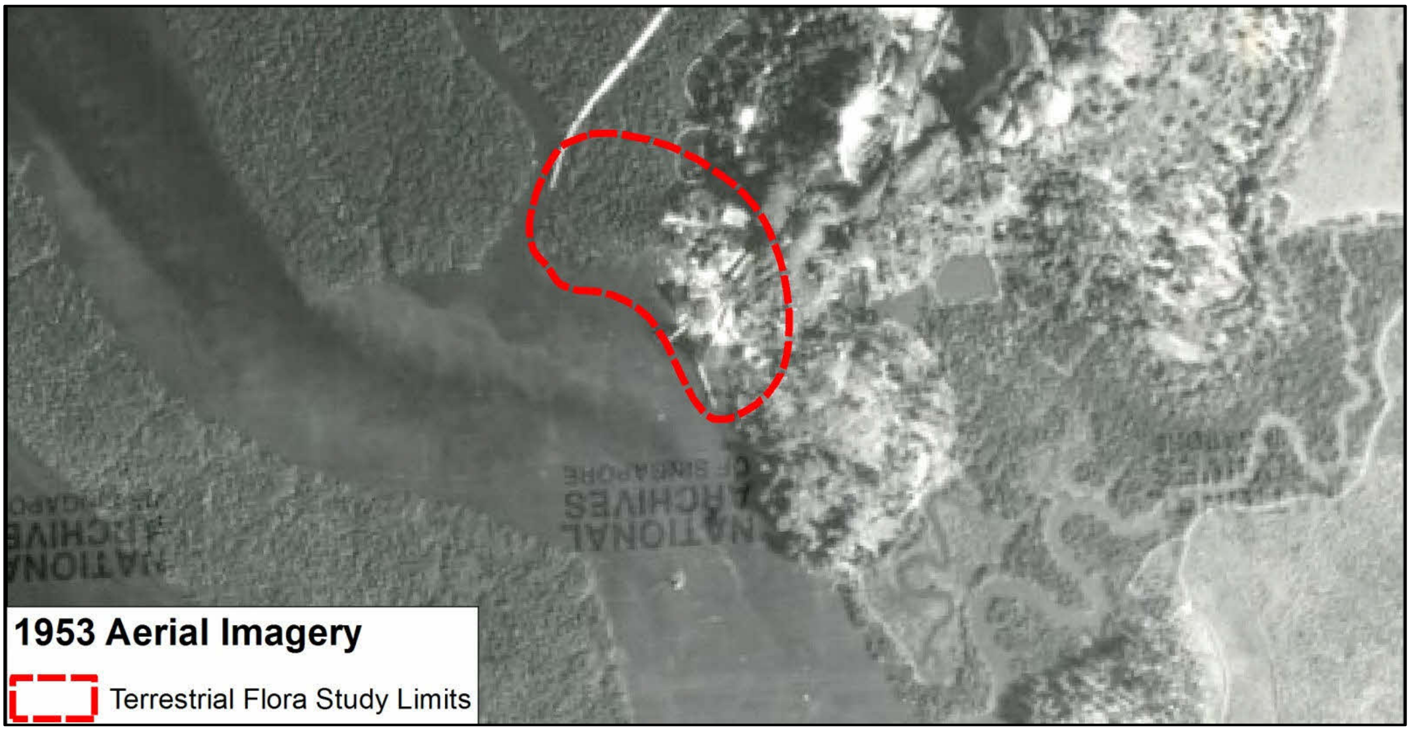


Figure 3: 1953 Aerial photo of the study area. (NAS Accession: 262406)

The 1953 Aerial photo shows quarry facilities including buildings, roads and railways, including a new railway and pier in Sungai Puaka. The aquaculture ponds are clearly visible along with mature forest between the ponds and the quarry facilities.

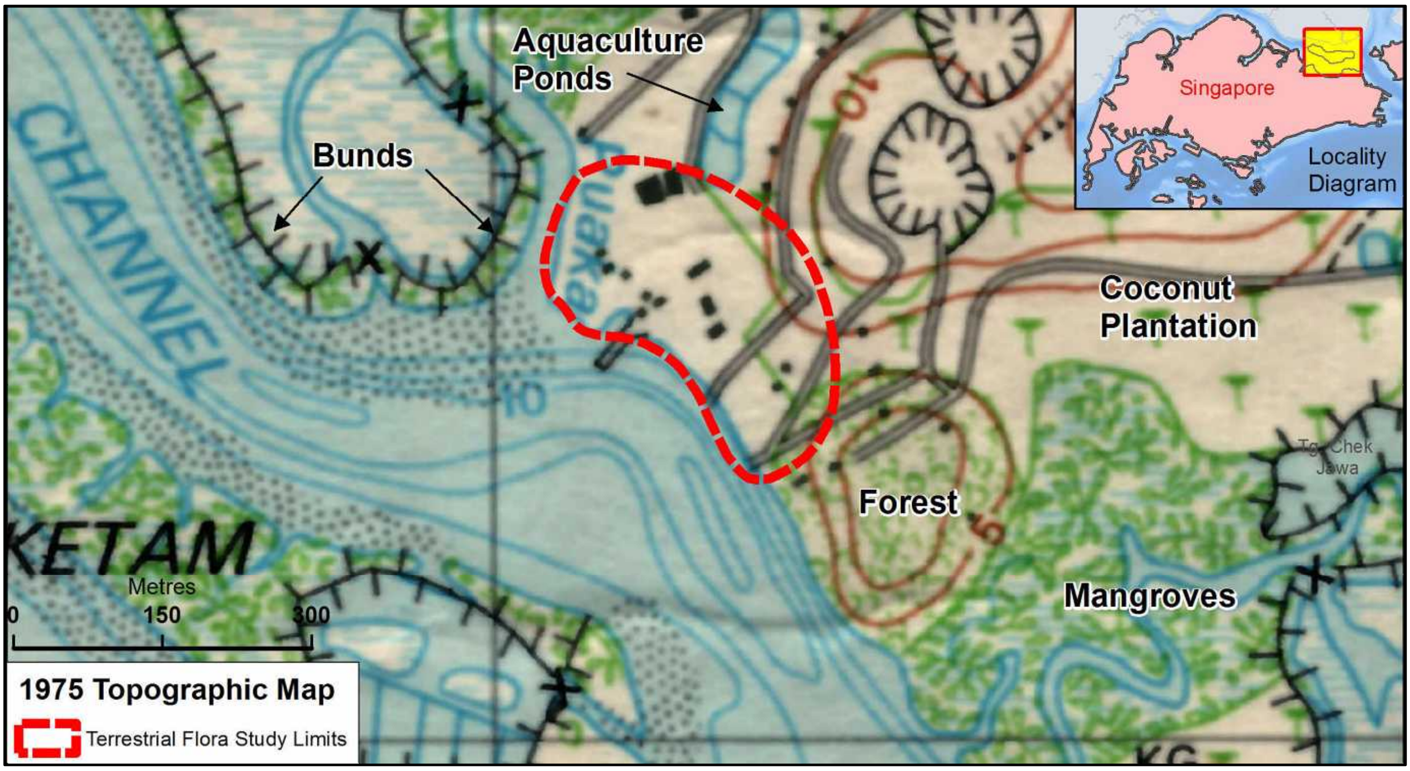


Figure 4: 1975 topographic map showing the study area and surrounding areas. (NUS online Map Library)

The 1975 topographic map shows changes in the surrounding areas including the development of large scale aquaculture ponds west of the study site as well as coconut plantation to the east. The site itself continues to support quarry operations. The mangroves within the study area are no longer shown.

Figure 5: 2016 Google Imagery showing the Ubin Living Labs and forested area to the north.

By 2016 the Ubin Living Labs had been established over the former site of the Celestial Resort. Native dominated forest has regenerated over cleared areas previously used for quarry operations.

HABITAT MAPPING

The habitat map is compiled with reference to formal flora sampling plots and walking transects utilised as ground truth basis for satellite image interpretation.

HABITAT CLASSIFICATION

The habitat classes have been chosen to coincide as much as possible with the Biodiversity Impact Assessment Guidelines published by the National Parks Board (NParks)[2].

Table 1: Flora Habitat Classes

Habitat Map Class	Description
Herbaceous	Areas of spontaneous herbaceous growth. This category occurs as a linear feature where forest and scrub were recently cleared for restoration of a pre-existing SLA fence-line.
Managed Vegetation	Areas of mowed grass and planted trees occurring within the ULL area. A part of this area is hoarded off for works.
Mangroves	Mangroves are recognised for the habitat map however they are assessed under the intertidal studies under separate report;
Native Dominated Young Secondary Forest	Areas covered by regenerating native tree species with closed canopy. The area was previously disturbed by Quarrying activities of the Ubin Quarry and had never been planted with rubber;
Native Dominated Coastal Edge Forest	A narrow strip of regenerating native Terrestrial and Mangrove Associate vegetation following the coastal edge of the ULL site. This area is dominated by Sea Hibiscus (*Hibiscus tiliaceus*);
Other intertidal areas	Tidal areas that are not covered by vegetation;
Urban Vegetation	A kampung area at the south-east corner of the study area features partly managed vegetation, fruit trees and some spontaneous native species regeneration.

Table 2: Land Cover classes

Land Cover Class	Description
Pond	Includes Quarry Ponds as well as the artificial pond located within the ULL area;
Swampy Ground	Includes low lying water logged areas and former aquaculture ponds;
Rocks	A sea wall of granite rocks is situated at the site of the proposed jetty;
Species Enrichment Areas	Areas that have been enhanced through enrichment planting.

[2] Biodiversity Impact Assessment (BIA) Guidelines, National Biodiversity Centre, NParks, 2020

HABITAT MAP

The habitat map below illustrates the interpreted habitat types as well as significant land cover classes. The locations of conservation status species encountered during execution of transects and sampling plots are illustrated.

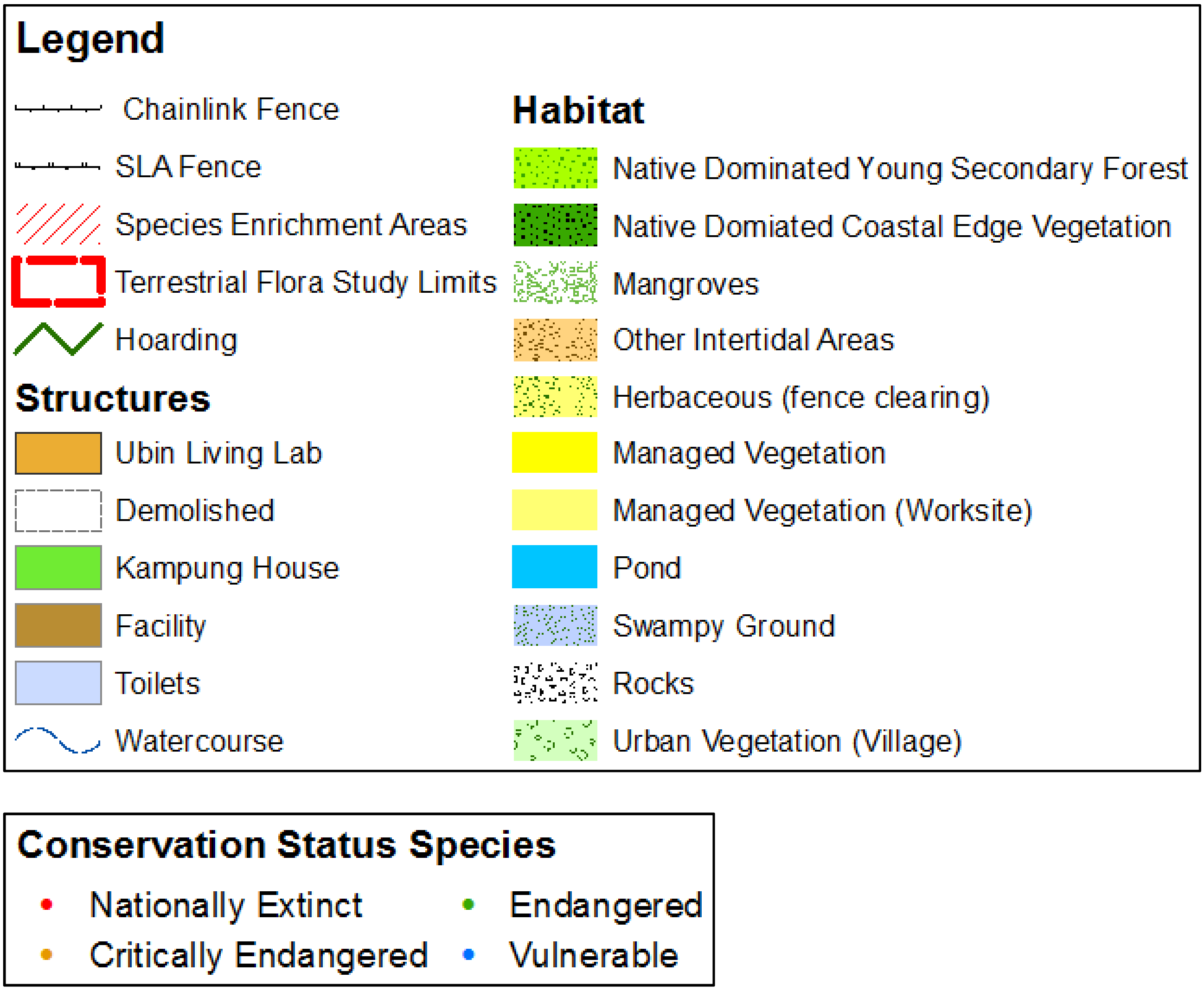


Figure 6: Habitat and Land cover map legends

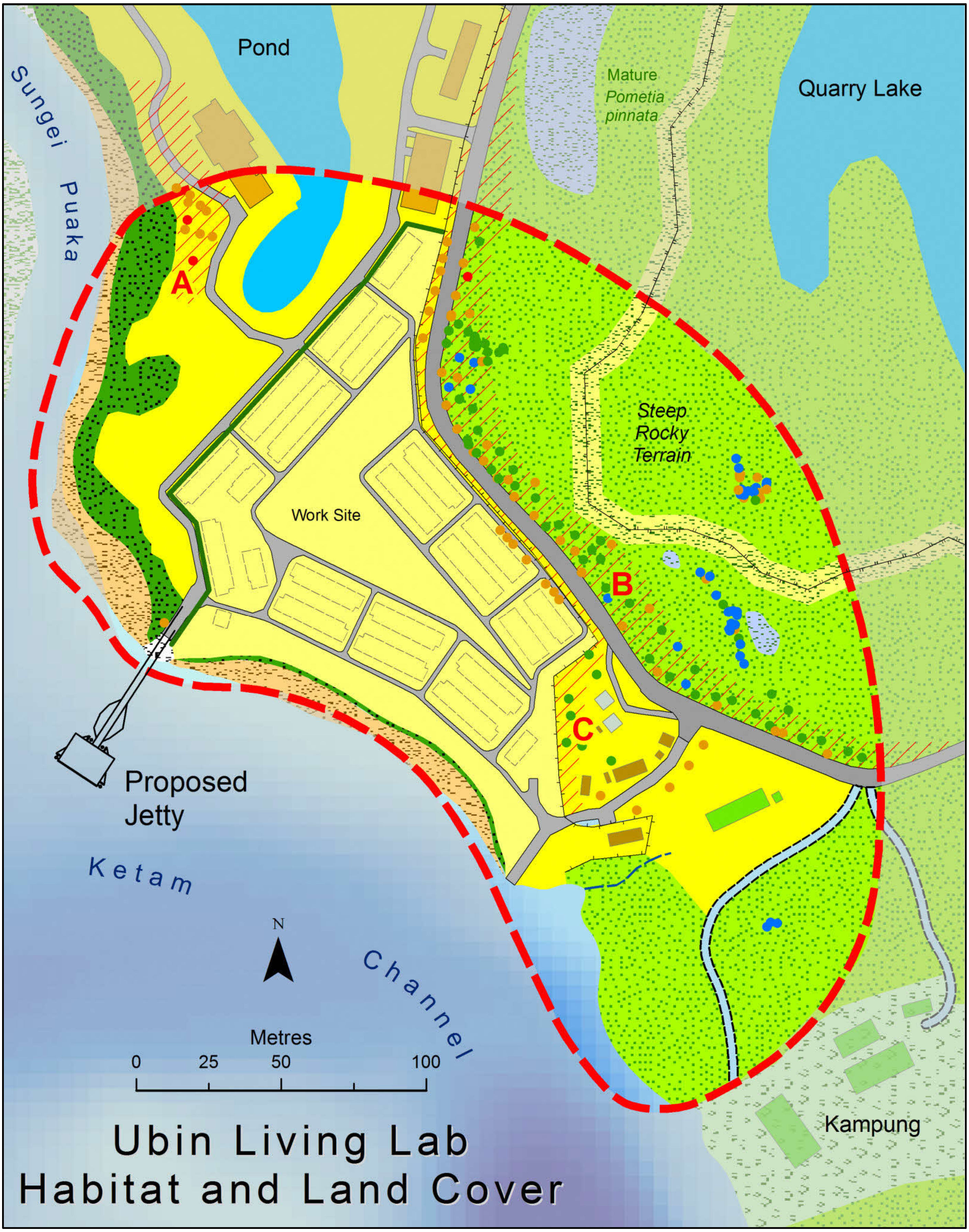


Figure 7: Flora baseline habitat and land cover map with conservation species.

HABITAT DISCUSSION

The study area is dominated by three distinct habitat types:

- Managed Vegetation
- Native Dominated Young Secondary Forest
- Native Dominated Coastal Edge Forest

The species assemblage of both Managed Vegetation and the Native Dominated Young Secondary forest is enhanced by parkland planting and enrichment planting of conservation status species respectively. In the case of Native Dominated young secondary forest progeny of planted species were found as seedlings and saplings. The areas of parkland and enrichment planting are illustrated as Enhancement areas A, B & C on the habitat map (Figure 7: Flora baseline habitat and land cover map with conservation species.).

Currently accepted latin names and conservation status used in this report are obtained from the Flora of Singapore: Checklist and Bibliography recently published[3] by NParks.

Managed Vegetation

The area immediately adjacent to the proposed Jetty as well as adjacent roadside planting is classified as Managed Vegetation and represents the bulk of Ubin Living Labs area. Parts of this area feature parkland planting of conservation status species (Table 3) which are actively maintained and usually feature signage indicating species and origin - refer to Species Enrichment Areas A & C in Habitat Map above (Figure 7) for planting locations. None of the bespoke plantings are in close proximity to the proposed jetty and there is no concern for impact due to the proposed works. One instance of *Crinum asiaticum* (Critically Endangered) was found immediately adjacent to the proposed jetty and will be affected by the proposed works. It should be noted that this species is extensively cultivated and is likely to be progeny of cultivated plants.

Table 3: Parkland planting species list

Species	Conservation Status	Context
Barringtonia racemosa	Critically Endangered	Roadside planting
Calophyllum inophyllum	Critically Endangered	Long established roadside planting
Cynometra ramiflora	Critically Endangered	Parkland planting
Garcinia celebica	Endangered	Parkland planting
Heritiera Littoralis	Endangered	Parkland planting
Memecylon edule	Endangered	Parkland planting
Ochrosia oppositifolia	Nationally Extinct	Parkland planting
Peltophorum pterocarpum	Critically Endangered	Long established roadside planting
Planchonella chartacea	Critically Endangered	Parkland planting
Planchonella obovata	Vulnerable	Parkland planting
Pteleocarpa lamponga	Nationally Extinct	Parkland planting
Serianthes grandiflora	Critically Endangered	Parkland planting
Tristaniopsis whteana	Endangered	Parkland and roadside planting

[3] Flora of Singapore: Checklist and Bibliography, *Gardens' Bulletin Singapore 74(Suppl. 1): 3–860. 2022*

Table 4: Managed Vegetation Photo Gallery

Figure 8: Managed Vegetation with parkland planting

Figure 9: Managed Vegetation with parkland planting

Figure 10: *Barringtonia asiatica* (CR) near ULL entrance.

Figure 11: Mature roadside *Calophyllum inophyllum* (CR)

Figure 12: *Terminalia catappa* (LC) in managed area

Figure 13: *Crinum asiaticum (CR) next to proposed jetty*

Native Dominated Young Secondary Forest

Native dominated young secondary forest occurs from the edge of Jalan Endut Senin towards the northeast hillside and quarry edge and is interrupted only by a new fence line clearing where spontaneous herbaceous growth occurs. In terms of naturally occurring conservation status species this area features *Litsea Umbellata* (Vulnerable), *Gnetum gnemon* (Critically Endangered) which are found as seedlings/saplings and small trees throughout the area as well as the climber *Scindapsus pictus* (Endangered) and *Sterculia coccinea* (Endangered) for which only one instance of each was found. It is possible that the *Gnetum gnemon* could have originated from cultivation in kampung areas. The naturally occurring species assemblage within the secondary forest is considered to be of moderate diversity and includes the following species:

Table 5: Naturally occurring secondary forest species

Species	**Type**	**Origin**	**Status**
Adenanthera pavonina	Tree	Exotic	Naturalised
Alstonia macrophylla	Tree	Exotic	Naturalised
Bridelia tomentosa	Tree	Native	Least Concern
Buchanania arborescens	Tree	Native	Least Concern
Caryota mitis	Tree	Native	Least Concern
Cinnamomum iners	Tree	Native	Least Concern
Christella subpubescens	Fern	Native	Least Concern
Claoxylon indicum	Tree	Native	Least Concern
Clausena excavata	Tree	Native	Least Concern
Elaeocarpus mastersii	Tree	Native	Least Concern
Ficus variegata	Tree	Native	Least Concern
Gironniera nervosa	Tree	Native	Least Concern
Gnetum gnemon	Tree	Native	Critically Endangered
Hevea brasilliensis	Tree	Exotic	Naturalised
Leea indica	Shrub	Native	Least Concern
Litsea umbellata	Tree	Native	Vulnerable
Mangifera odorata	Tree	Exotic	Casual
Nephelium lappaceum var. *lappaceum*	Tree	Cryptogenic	-
Pterocarpus indicus	Tree	Exotic	Casual
Ptychosperma macarthurii	Tree	Exotic	Naturalised
Pyrrosia piloselloides	Epiphyte	Native	Least Concern
Scindapsus pictus	Climber	Native	Endangered
Sterculia coccinea	Shrub	Native	Endangered
Syzygium grande	Tree	Native	Least Concern
Syzygium polyanthum	Tree	Native	Least Concern
Syzygium zeylanicum	Tree	Native	Least Concern
Terminalia catappa	Tree	Native	Least Concern
Tetrocera indica	Climber	Native	Least Concern
Tinospora crispa	Climber	Exotic	Casual
Vitex pinnata	Tree	Native	Least Concern

Table 6: Native Dominated Young Secondary Forest Photo Gallery

Figure 14: Secondary forest (BG), Herbaceous (FG)

Figure 15: Transect Line in Secondary Forest

Figure 16: *Ficus variegata* and *Tinospora crispa* (Climber)

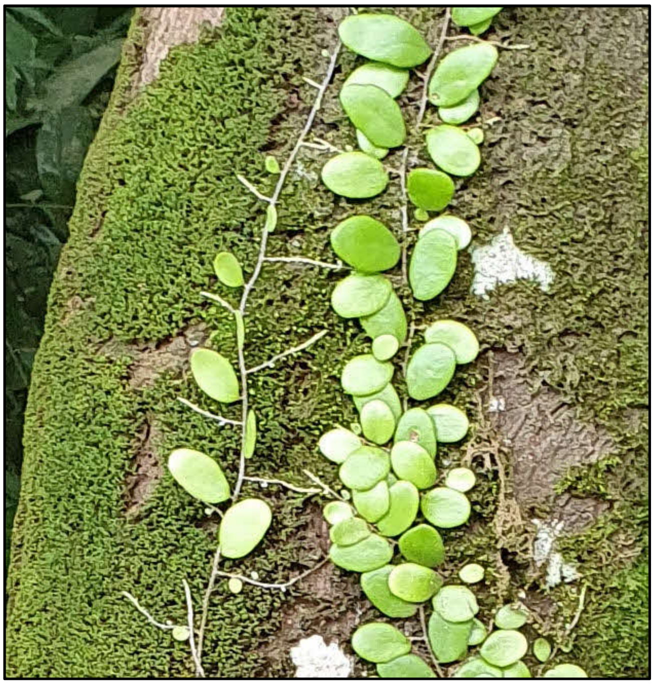


Figure 17: *Pyrrosia piloselloides*

Figure 18: *Gentum gnemon*

Figure 19: *Elaeocarpus mastersii*


Figure 20: *Gironniera nervosa*


Figure 21: *Cinnamomum iners*


Figure 22: *Buchanania arborescens*


Figure 23: *Alstonia macrophylla*


Figure 24: *Terminalia catappa*


Figure 25: *Scindapsus pictus*

Figure 26: *Litsea umbellata*

Figure 27: *Vitex pinnata* flowers

The strip of land immediately adjacent to Jalan Endut Senin also features enrichment planting of native and mostly rare species. The progeny of some of the enrichment species may also be found throughout the secondary forest, in particular *Adisia elliptica*, *Calophyllum inophyllum* and *Neolitsea cassia* seedlings/saplings are prominent. Enrichment species encountered include:

Table 7: Enrichment species occurring in forest area near Jalan Endut Senin.

Species	Type	Status	Comment
Ardisia elliptica	Tree	Endangered	Progeny spreading in forest
Calophyllum inophyllum	Tree	Critically Endangered	Progeny spreading in forest
Calophyllum soulattri	Tree	Critically Endangered	Progeny only (parent tree not found)
Cordia subcordata	Tree	Critically Endangered	Roadside planting
Cratoxylum formosum	Tree	Endangered	many trees next to road
Diospyros bauxifolia	Tree	Critically Endangered	One instance found
Ficus consociata	Tree	Critically Endangered	Several found along road edge
Grammatophyllum speciosum	Epiphyte	Nationally Extinct	Epiphyte - one instance found
Ixora congesta	Shrub	Least Concern	Near roadside
Knema carticosa	Tree	Vulnerable	One instance found
Memecylon ovatum	Tree	Endangered	One instance found on hillside
Neolitsea cassia	Tree	Vulnerable	Progeny spreading in forest
Pterospermum diversifolium	Tree	Critically Endangered	Several instances found
Terminalia phellocarpa	Tree	Nationally Extinct	One instance found
Melaleuca cajuputi	Tree	Nationally Extinct	One instance found

Table 8: Enrichment Species Photo Gallery

Figure 28: *Ardisia elliptica*

Figure 29: Calophyllum *soulattri*

Figure 30: *Cratoxylum formosum*

Figure 31: *Diospyros bauxifolia*

Figure 32: Ficus consociata

Figure 33: *Grammatophyllum speciosum*

Figure 34: *Knema corticosa*

Figure 35: *Ixora congesta*

Figure 36: *Neolitsea cassia*

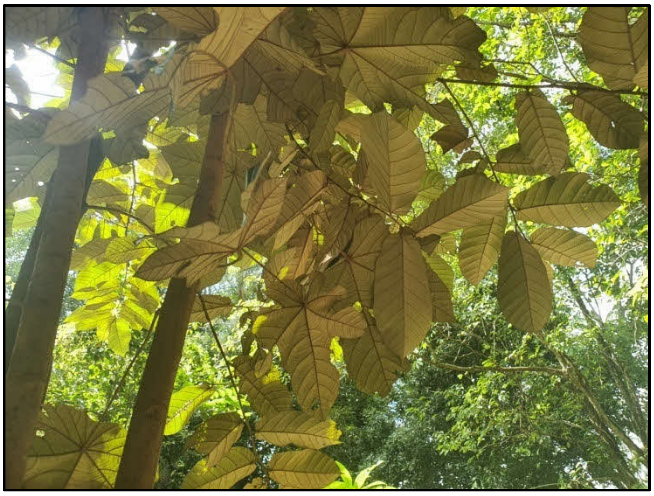


Figure 37: *Pterospermum diversifolium*

Native Dominated Coastal Edge Forest

The coastal edge of the ULL site features spontaneous and mostly native vegetation with limited species assemblage consisting of terrestrial and mangrove associate[4] species above high water level. Mangrove species occur below the high water mark and these are assessed under a separate report.

The coastal strip vegetation is dominated by *Hibiscus tiliaceus* which grows spontaneously over most of the costal edge. In terms of conservation status species one instance of the herb *Crinum asiaticum* (Critically Endangered) was found close to the proposed jetty area. *Crinum asiaticum* is extensively cultivated and this instance is likely to be progeny of cultivated material found in kampung areas of the island.

The species assemblage for the coastal strip is as follows:

[4] Refer to Tomlinson (2016), the Botany of Mangroves, Cambridge University Press

Table 9: Coast edge species

Species	Type	Status	Comment
Acacia auriculiformis	Tree	Naturalised	
Caryota mitis	Tree	Least Concern	Fish Tail Palm
Claoxylon indicum	Tree	Least Concern	
Clausena excavata	Tree	Least Concern	
Cocos nucifera	Tree	Naturalised	
Colubrina asiatica	Shrub	Least Concern	
Crinum asiaticum	Herb	Critically Endangered	Cultivated
Derris trifoliata	Climber	Least Concern	
Dillenia suffruticosa	Shrub	Least Concern	
Falcataria falcata	Tree	Naturalised	
Ficus microcarpa	Tree	Least Concern	
Hibiscus tiliaceus	Tree	Least Concern	Dominating species
Leea indica	Tree	Least Concern	
Morinda citrifolia	Tree	Least Concern	
Muntingia calabura	Tree	Naturalised	
Solanum torvum	Shrub	Naturalised	
Terminalia catappa	Tree	Least Concern	

Table 10: Coastal edge vegetation photo gallery

Figure 38: *Hibiscus tiliaceus (land side)*

Figure 39: *Hibiscus tiliaceus* with *Cocos nucifera*

Figure 40: *Colubrina asiatica*

Figure 41: *Crinum asiaticum*

Figure 42: *Hibiscus tiliaceus* (tidal side)

Figure 43: Coastal edge at worksite

SURVEY METHODOLOGY AND RESULTS

METHODOLOGY

The methodology adopted for this survey was to implement 3 measured plots (15 metre x 15 metre), 1 measured transect (50 metre x 5 metre) and obtain general coverage through walking transects. The coastal edge vegetation was specifically covered by a linear walking transect while the remainder of the transects were decided in the field with objective of obtaining comprehensive coverage of the species assemblage in each habitat.

Figure 44: Flora Transects and Sampling Plots (for general map symbology refer Figure 6)

Measured Plots/Transect

Measured plots and transects are located in the vicinity of pre-determined locations[5] with the objective of obtaining coverage across the whole study area. The final locations of these plots are adjusted based on local access limitations and ability to obtain representative coverage of species diversity. Each plot is temporarily marked in the field and initial point is recorded by GPS in point averaging mode. The plots are oriented on cardinal compass directions while the measured transect are oriented having regard to limitations such as the fence clearing, inundated areas, rock piles etc, such that a good representation of local species diversity may be obtained. A transect tape is laid out along a chosen cardinal direction and individual plants are recorded for chainage[6], offset, species and girth. For the sample plots three sub-transects are laid out at 5 metres intervals (refer Figure 45 below) such that the maximum offset measured in each sub-transect is no more than 2.5 metres (a convenient distance for measurement with offset tape). The measured transect involves a single deployment of the 50 metre transect tape from which offsets to plants up to 2.5 metres either side are obtained.

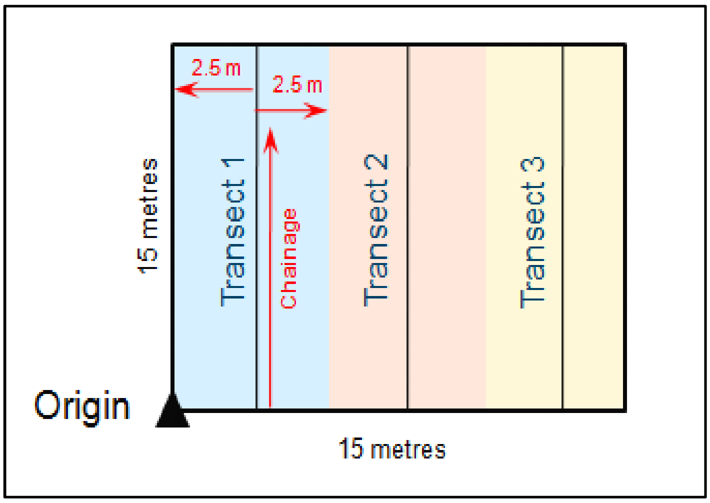


Figure 45: Sample Plot measurement strategy.

Walking Transects

Walking Transects involve walking along a pre-determined path while periodically recording location with a GPS device. Plants encountered are booked sequentially with reference to the most recent GPS position ID recorded.

Species Identification

Species are generally identified from vegetative characteristics due to non-availability of fertile specimens at time of survey. Some species are difficult to identify to species level when infertile, these are referred to the Singapore Herbarium for determination if an initial attempt at identification using online and text book resources fails to reveal a reliable identification. A good example of a herbarium reference in this project would be for *Litsea umbellata* which was encountered throughout the study area in infertile state[7].

[5] Predetermined locations are documented in the project inception report.

[6] Chainage is the recorded distance along the transect tape for each measured plant.

[7] *Litsea umbellata* could be identified to genus level in the field however since some *Litsea* species are known to have conservation status it was important to obtain a reliable species level identification by referring to the herbarium.

Sampling Plots & Transect

The following sub-sections provide individual sampling and transect summaries. Each section consists of a locality map, and graphs representing relative abundance by species and abundance by conservation status. The species plot and field collected data are provided in section Sampling Transect 1 below.

Sampling Plot 1

Sample Plot 1 is situated in former kampung area now overgrown with spontaneous vegetation. While native species dominate this area features the least species diversity for Native Dominated Young Secondary Forest.

Figure 46: Sampling Plot 1 Locality.

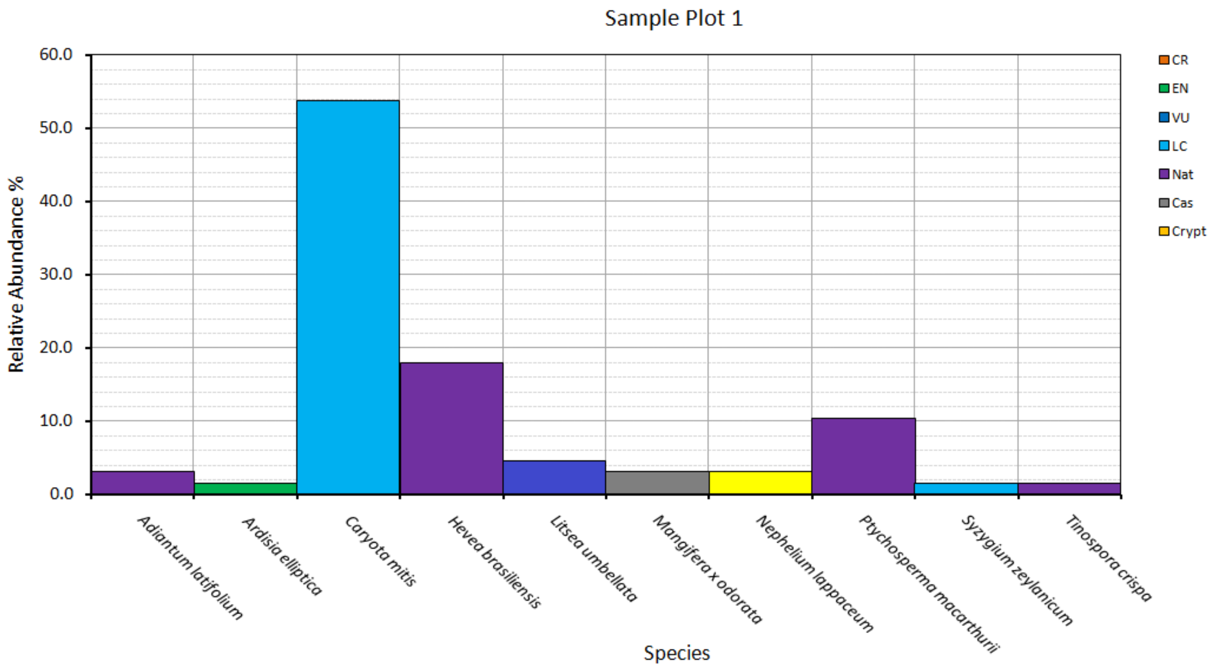


Figure 47: Sampling Plot 1 Relative Abundance by Species.

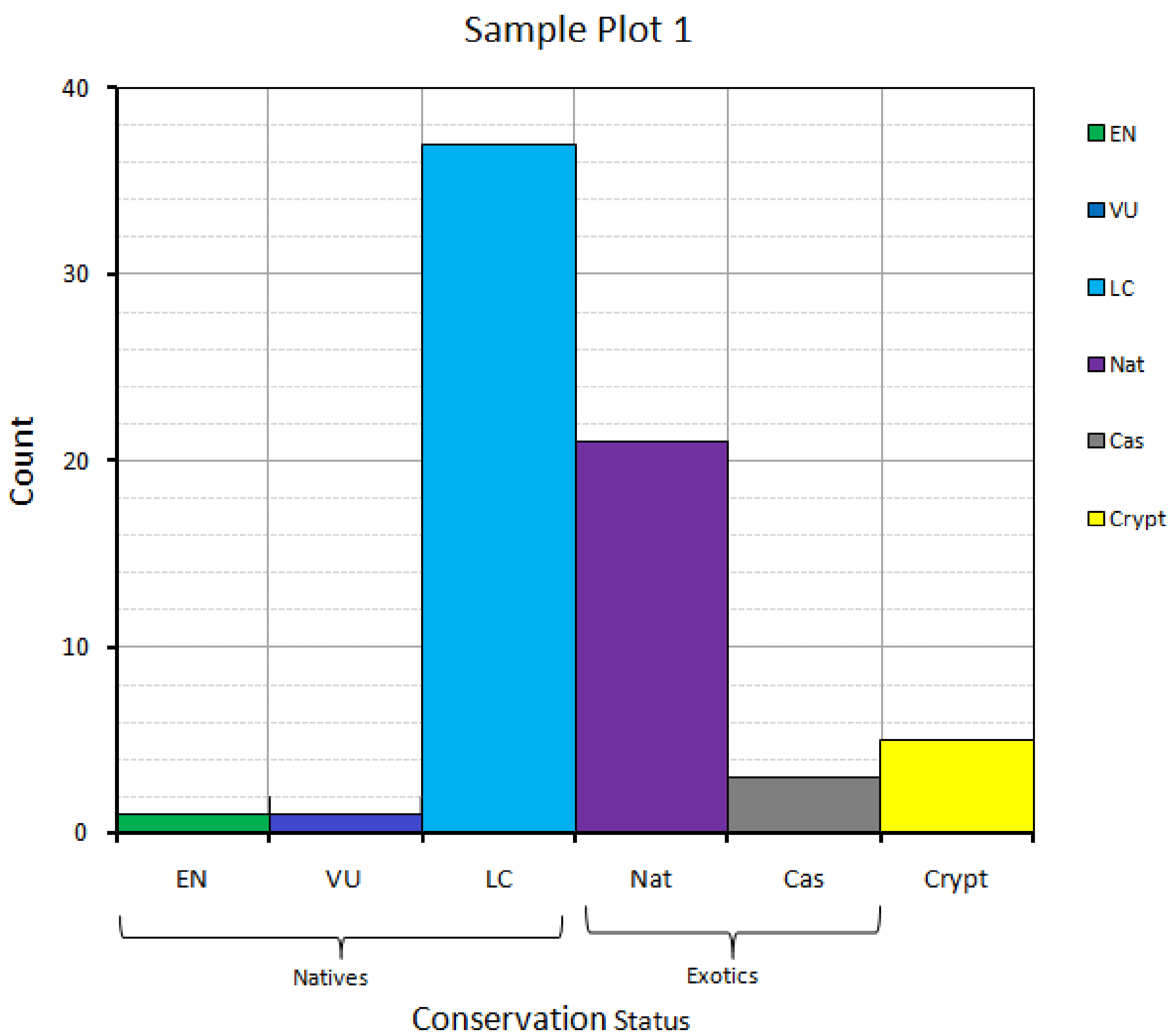


Figure 48: Sampling Plot 1 Abundance by Conservation Status.

Sampling Plot 2

Sample Plot 2 is located close to Jalan Endut Senin and features moderate diversity. The plot partially overlaps an area of enrichment planting and includes some progeny of the enrichment planting in seedling form. Therefore it is noted that there are an unusually high number of conservation status species considering the habitat is of young secondary forest type.

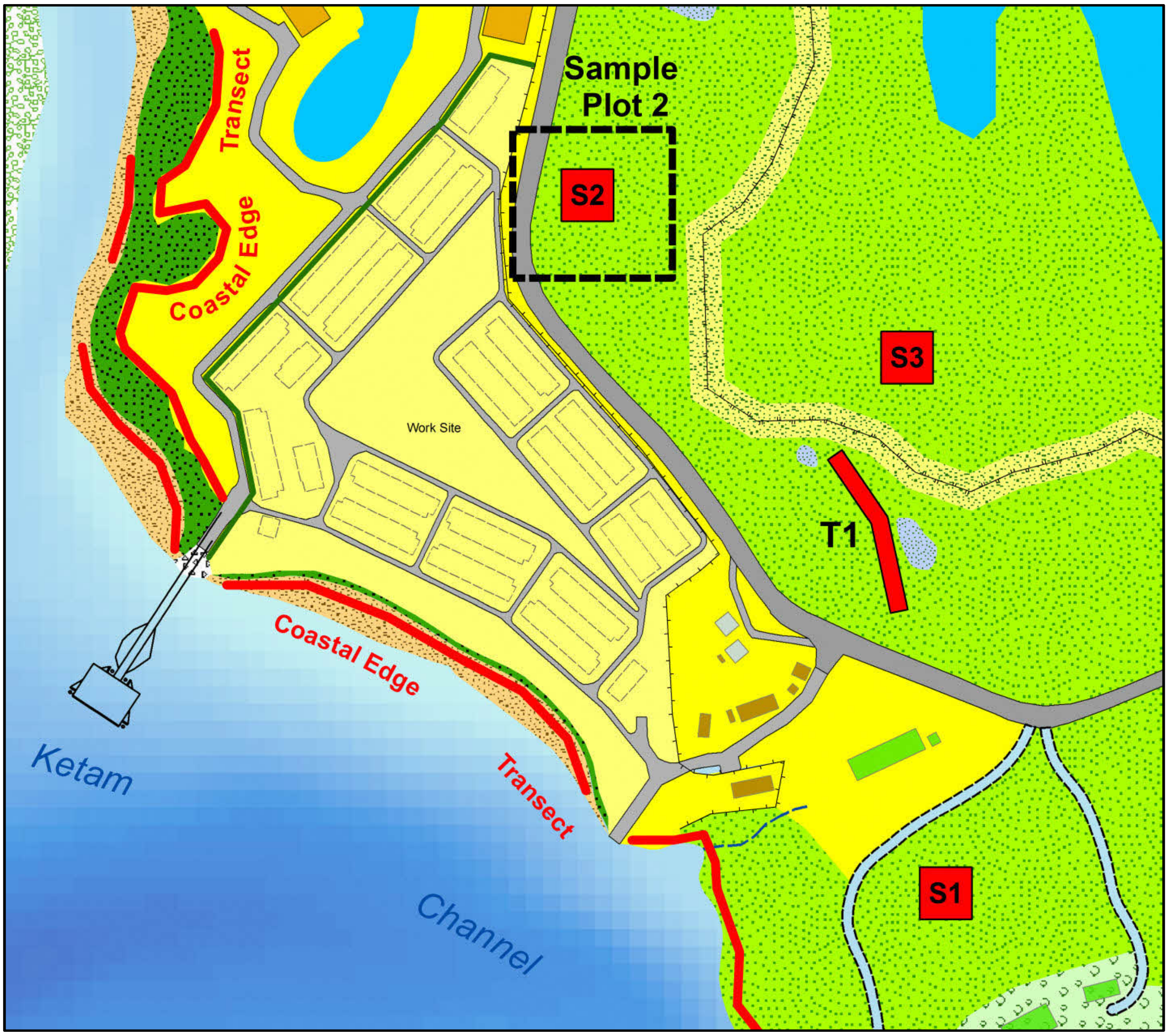


Figure 49: Sampling Plot 2 Locality Diagram.

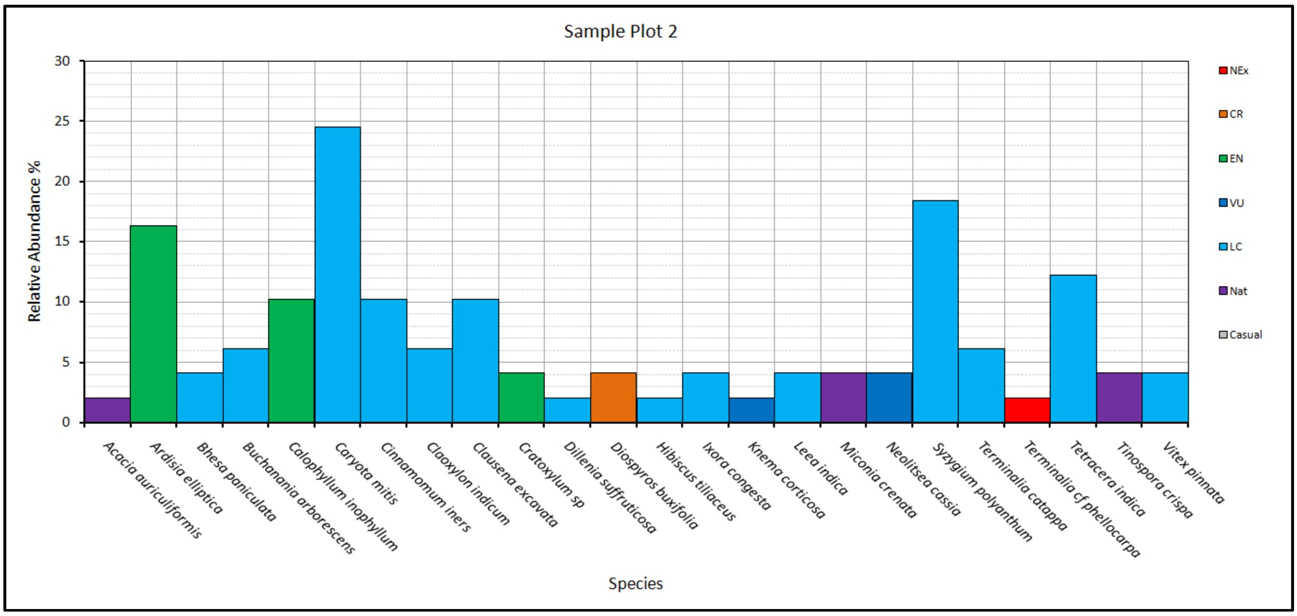


Figure 50: Sampling Plot 2 Relative Abundance by Species.

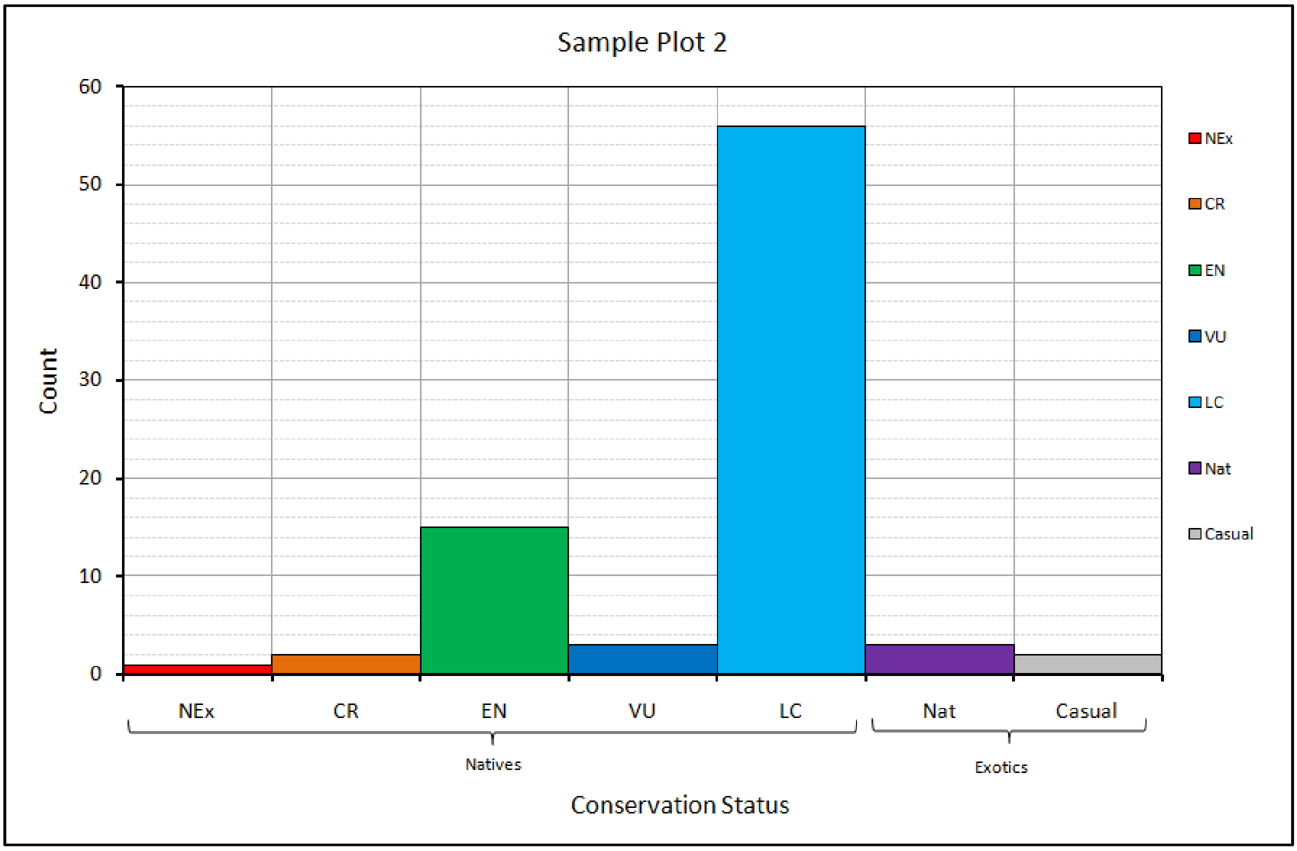


Figure 51: Sampling Plot 2 Abundance by Conservation Status.

Sampling Plot 3

Sample plot 3 is situated on the hillside beyond the SLA fence. The area features steep rock and broken terrain. The area also contains remnants of the former quarry infrastructure including dismantled industrial railway formation and concrete foundations of former structures. The species assemblage is of moderate species diversity and comparable to that of sampling Transect 1. One instance of *Memecylon ovatum* (EN) was identified at the edge of the plot and it is thought that this sapling could be progeny of planted species in the vicinity.

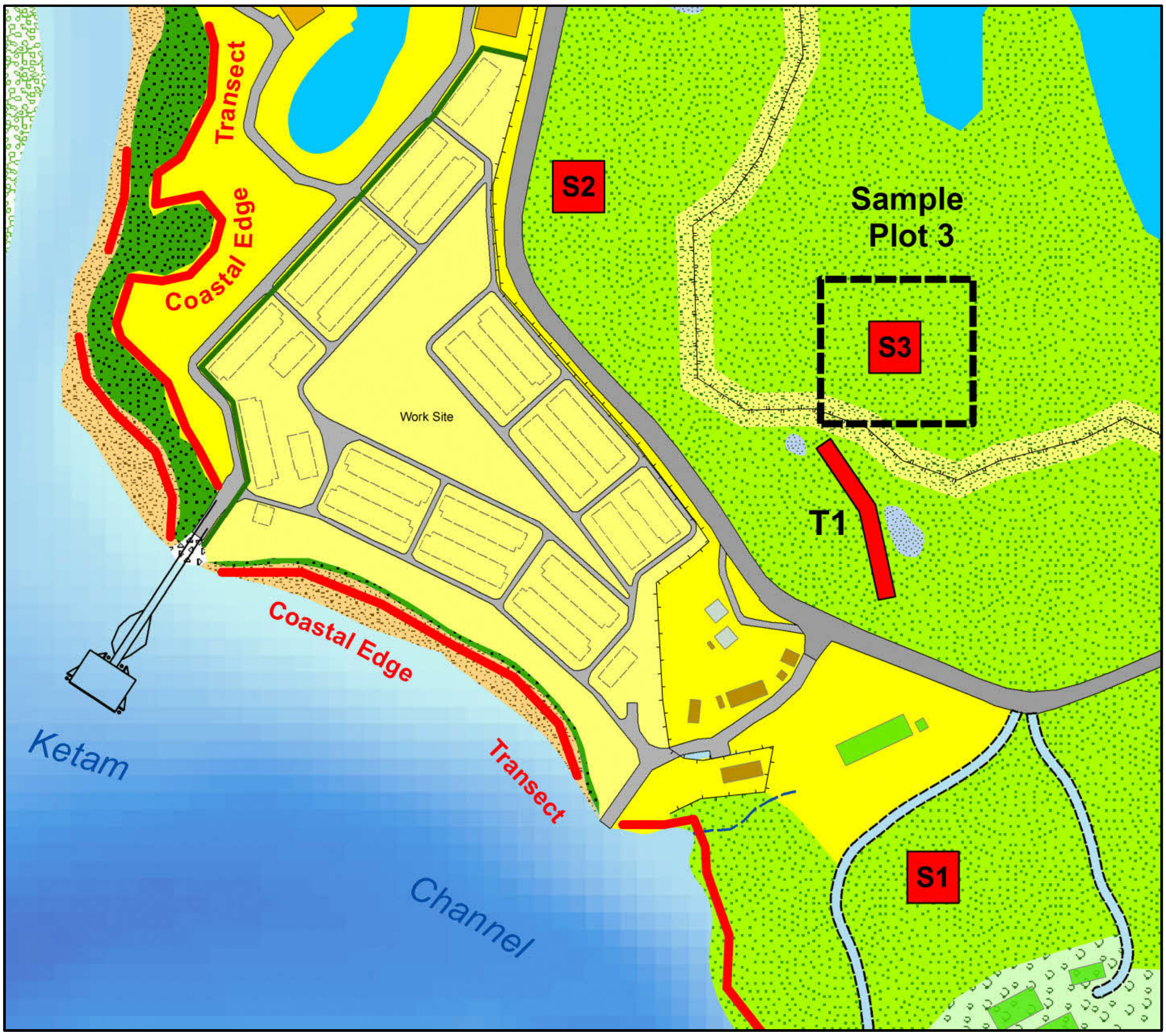


Figure 52: Sampling Plot 3 Locality Diagram.

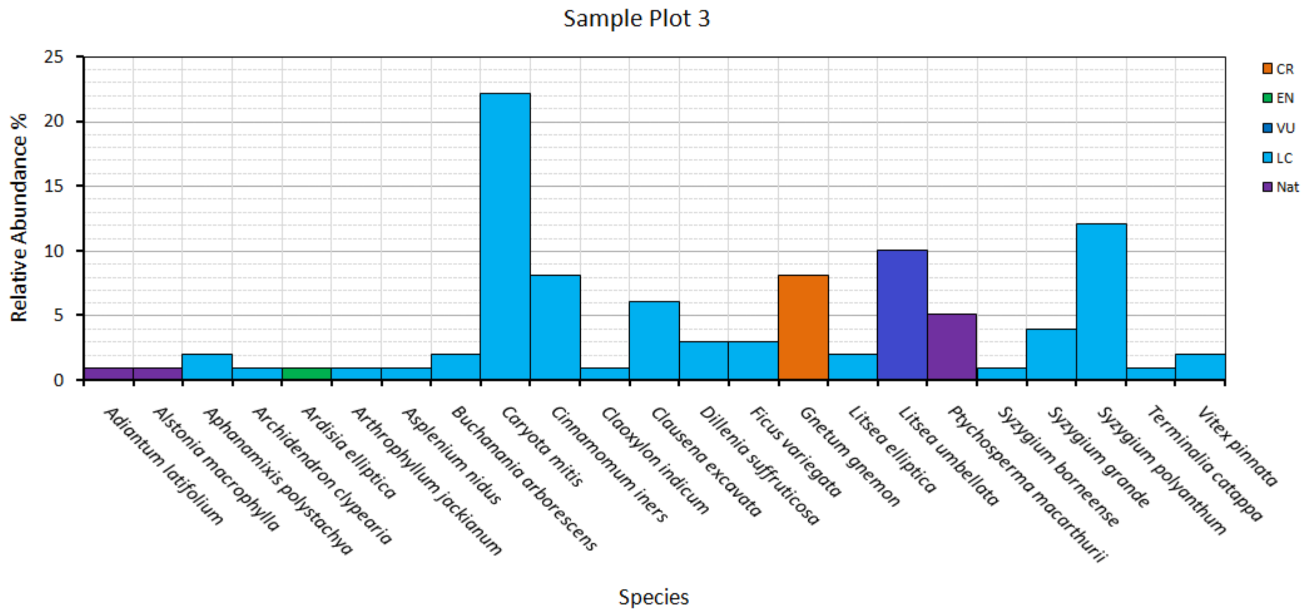


Figure 53: Sampling Plot 3 Relative Abundance by Species.

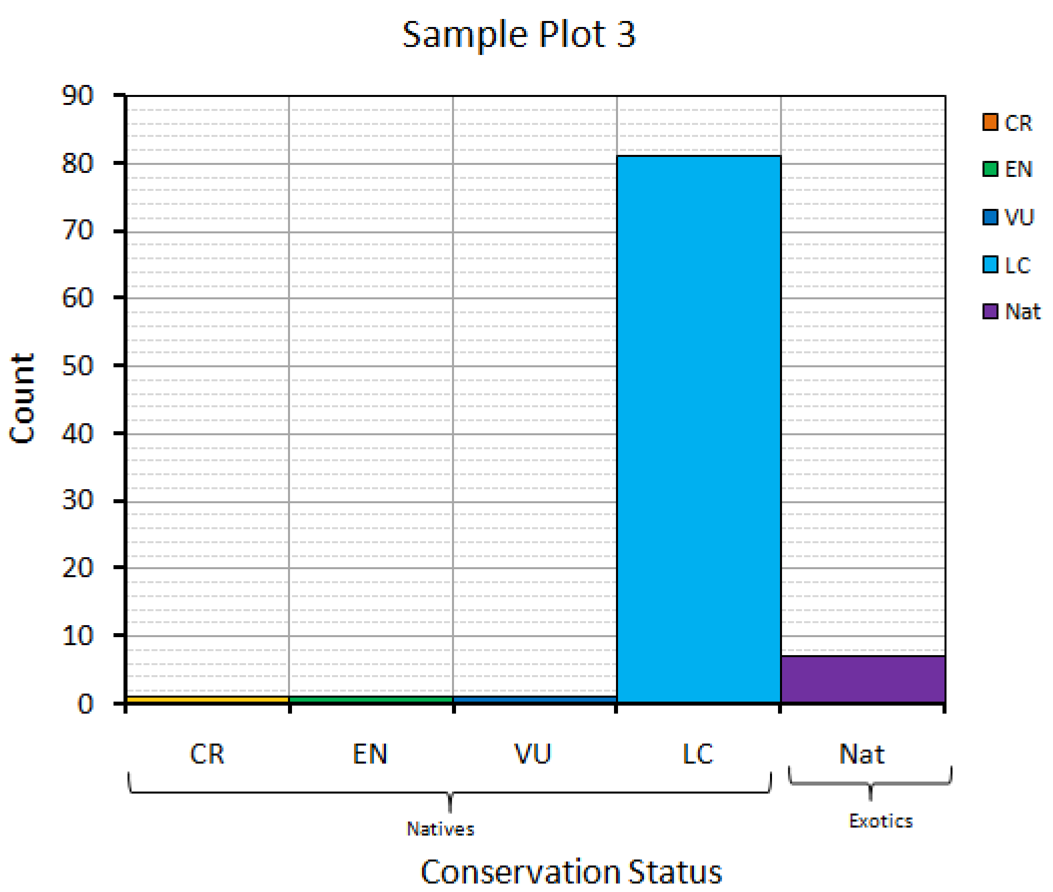
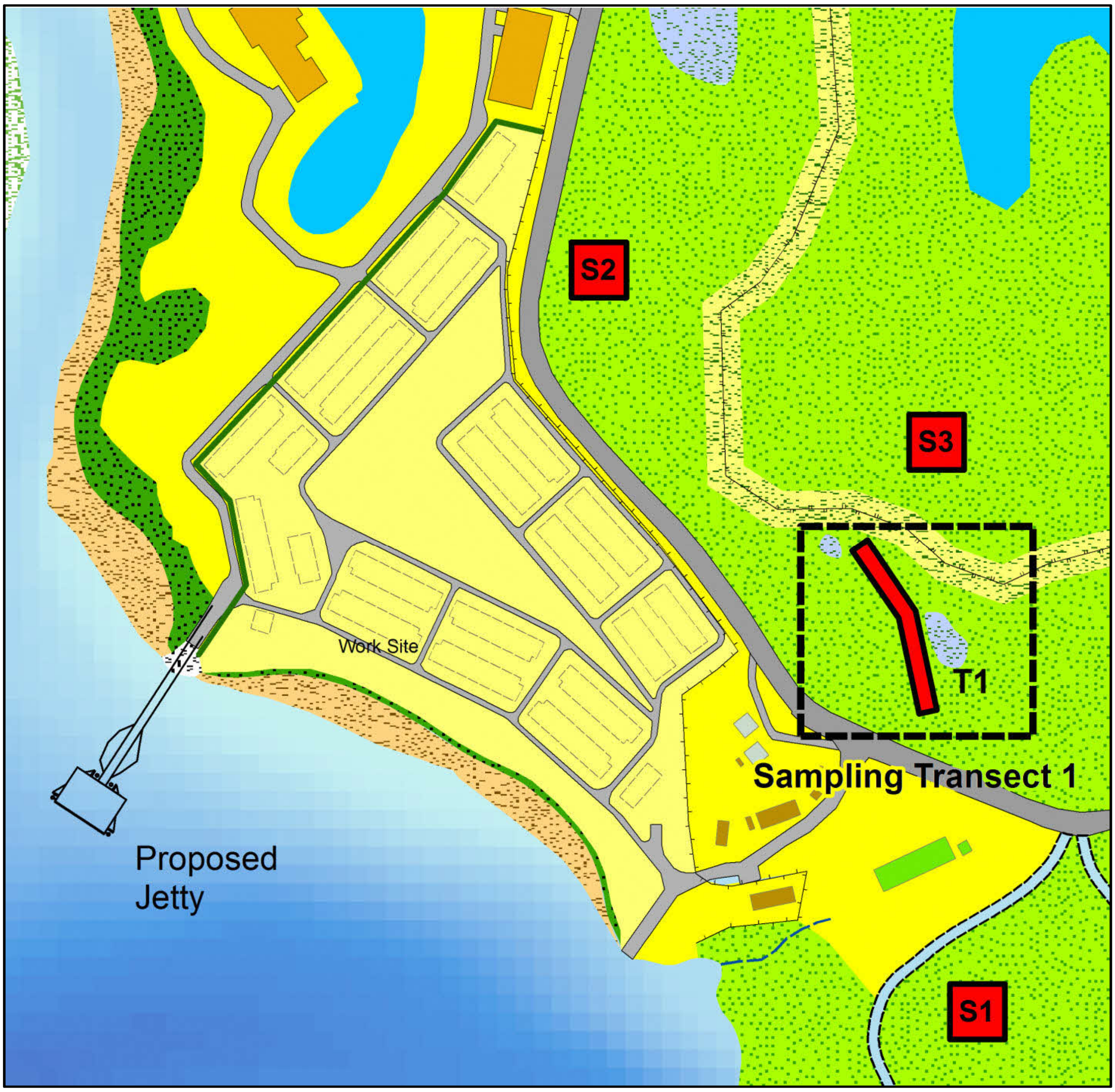


Figure 54: Sampling Plot 3 Abundance by Conservation Status.

Sampling Transect 1

Sampling Transect 1 is a 50 metre x 5 metre belt transect situated in Native Dominated Young Secondary Forest between the SLA fence and Jalan Endut Senin. This area consists mainly of common natives with four naturally occurring species with conservation status – *Gnetum Gnemon* (Critically Endangered) and *Litsea Umbellata* (Vulnerable), *Sterculia Coccinia* (Endangered) and *Scindapsus pictus* (Endangered). It is noted that *Gnetum gnemon* and *Litsea umbellate* are moderately abundant throughout the secondary forest areas in the vicinity.



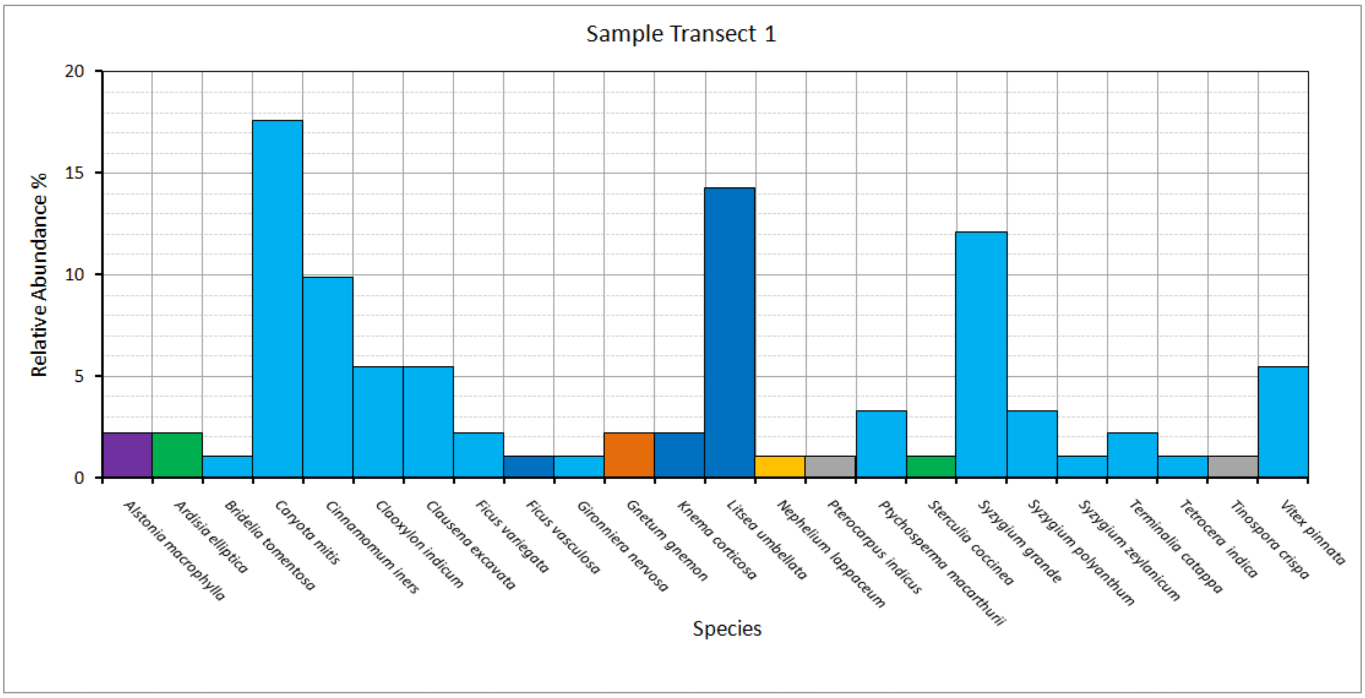


Figure 55: Sampling Transect 1 Relative Abundance by Species.

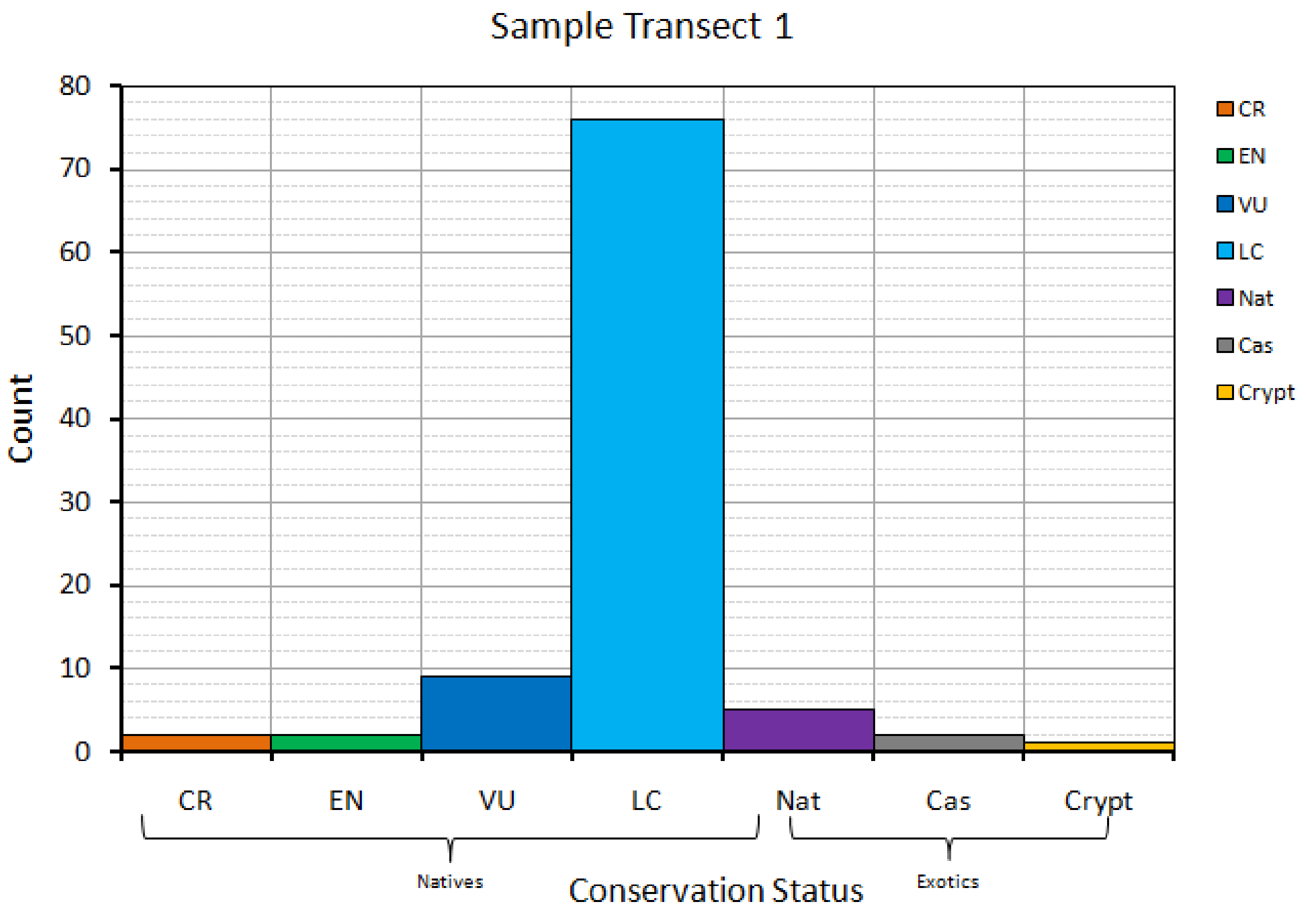


Figure 56: Sampleing Transect 1 Abundance by Conservation Status.

SPECIES CHECKLIST

The primary reference for species names and conservation status is the Flora of Singapore: Checklist and bibliography (Gardens' Bulletin Singapore 74(Suppl. 1): 3–860. 2022).

Family	Species	Type	Origin	Conservation Status
Adiantaceae	*Adiantum latifolium*	Herb	Native	Naturalised
Amaryllidaceae	*Crinum asiaticum*	Herb	Native	Critically Endangered
Anacardiaceae	*Buchanania arborescens*	Tree	Native	Least Concern
Anacardiaceae	*Mangifera × odorata*	Tree	Exotic	Casual
Apocynaceae	*Alstonia angustiloba*	Tree	Native	Least Concern
Apocynaceae	*Alstonia macrophylla*	Tree	Exotic	Naturalised
Apocynaceae	*Ochrosia oppositifolia*	Tree	Native	Nationally Extinct
Apocynaceae	*Ochrosia oppositifolia*	Tree	Native	Nationally Extinct
Araceae	*Epipremnum aureum*	Climber	Exotic	Casual
Araceae	*Epipremnum pinnatum*	Climber	Exotic	Naturalised
Araceae	*Scindapsus pictus*	Climber	Native	Endangered
Arecaceae	*Caryota mitis*	Tree	Native	Least Concern
Arecaceae	*Cocos nucifera*	Tree	Exotic	Naturalised
Arecaceae	*Cyrtostachys renda*	Shrub	Native	Critically Endangered
Arecaceae	*Elaeis guineensis*	Tree	Exotic	Casual
Arecaceae	*Licuala spinosa*	Tree	Native	Vulnerable
Arecaceae	*Ptychosperma macarthurii*	Tree	Exotic	Naturalised
Arilacee	*Arthrophyllum jackianum*	Tree	Native	Least Concern
Asparagaceae	*Dracaena fragrans*	Shrub	Exotic	Casual
Aspleniaceae	*Asplenium nidus*	Epiphyte	Native	Least Concern
Asteraceae	*Praxelis clematidea*	Herb	Exotic	Naturalised
Blechnaceae	*Stenochlaena palustris*	Climber	Native	Least Concern
Boraginaceae	*Cordia subcordata*	Tree	Native	Critically Endangered
Boraginaceae	*Pteleocarpa lamponga*	Tree	Native	Nationally Extinct
Calophyllaceae	*Calophyllum inophyllum*	Tree	Native	Endangered
Calophyllaceae	*Calophyllum soulattri*	Tree	Native	Critically Endangered
Cannabaceae	*Gironniera nervosa*	Tree	Native	Least Concern
Casuarinaceae	*Casuarina equisetifolia*	Tree	Native	Least Concern
Centroplacaceae	*Bhesa paniculata*	Tree	Native	Least Concern
Clusiaceae	*Garcinia celebica*	Tree	Native	Endangered
Clusiaceae	*Garcinia celebica*	Tree	Native	Endangered
Combretaceae	*Terminalia catappa*	Tree	Native	Least Concern
Combretaceae	*Terminalia cf phellocarpa*	Tree	Native	Nationally Extinct
Cucurbitaceae	*Coccinia grandis*	Climber	Exotic	Naturalised
Dilleniaceae	*Dillenia suffruticosa*	Tree	Native	Least Concern
Dilleniaceae	*Tetracera indica*	Climber	Native	Least Concern
Ebenaceae	*Diospyros buxifolia*	Tree	Native	Critically Endangered
Elaeocarpaceae	*Elaeocarpus mastersii*	Tree	Native	Least Concern
Euphorbiaceae	*Claoxylon indicum*	Tree	Native	Least Concern
Euphorbiaceae	*Hevea brasiliensis*	Tree	Exotic	Naturalised

Fabaceae	*Acacia auriculiformis*	Tree	Exotic	Naturalised
Fabaceae	*Adenanthera pavonina*	Tree	Exotic	Naturalised
Fabaceae	*Archidendron clypearia*	Tree	Native	Least Concern
Fabaceae	*Baphia nitida*	Shrub	Exotic	Casual
Fabaceae	*Cynometra ramiflora*	Tree	Native	Critically Endangered
Fabaceae	*Derris trifoliata*	Climber	Native	Least Concern
Fabaceae	*Falcataria falcata*	Tree	Exotic	Naturalised
Fabaceae	*Peltophorum pterocarpum*	Tree	Native	Critically Endangered
Fabaceae	*Pterocarpus indicus*	Tree	Exotic	Casual
Fabaceae	*Serianthes grandiflora*	Tree	Native	Critically Endangered
Gnetaceae	*Gnetum gnemon*	Tree	Native	Critically Endangered
Lamiaceae	*Vitex pinnata*	Tree	Native	Least Concern
Lauraceae	*Cinnamomum iners*	Tree	Native	Least Concern
Lauraceae	*Litsea elliptica*	Tree	Native	Least Concern
Lauraceae	*Litsea umbellata*	Tree	Native	Vulnerable
Lauraceae	*Neolitsea cassia*	Tree	Native	Vulnerable
Lecythidaceae	*Barringtonia asiatica*	Tree	Native	Critically Endangered
Lecythidaceae	*Barringtonia racemosa*	Tree	Native	Critically Endangered
Lythraceae	*Sonneratia alba*	Tree	Native	Least Concern
Malvaceae	*Durio zibethinus*	Tree	Exotic	Casual
Malvaceae	*Heritiera littoralis*	Tree	Native	Endangered
Malvaceae	*Hibiscus tiliaceus*	Tree	Native	Least Concern
Malvaceae	*Pterospermum diversifolium*	Tree	Native	Critically Endangered
Malvaceae	*Sterculia coccinea*	Tree	Native	Endangered
Melastomataceae	*Melastoma malabathricum*	Shrub	Native	Least Concern
Melastomataceae	*Memecylon edule*	Tree	Native	Endangered
Melastomataceae	*Memecylon ovatum*	Tree	Native	Endangered
Meliaceae	*Aphanamixis polystachya*	Tree	Native	Least Concern
Meliaceae	*Xylocarpus granatum*	Tree	Native	Least Concern
Menispermaceae	*Fibraurea tinctoria*	Climber	Native	Least Concern
Menispermaceae	*Tinospora crispa*	Climber	Exotic	Casual
Moraceae	*ficus benjamina*	Tree	Exotic	Cryptogenic
Moraceae	*Ficus consociata*	Strangler	Native	Critically Endangered
Moraceae	*Ficus microcarpa*	Strangler	Native	Least Concern
Moraceae	*Ficus variegata*	Tree	Native	Least Concern
Muntingiaceae	*Muntingia calabura*	Tree	Exotic	Naturalised
Musaceae	*Musa acuminata*	Herb	Exotic	Casual
Myristicaceae	*Knema corticosa*	Tree	Native	Vulnerable
Myrsinaceae	*Ardisia elliptica*	Tree	Native	Endangered
Myrtaceae	*Melaleuca cajuputi*	Tree	Native	Nationally Extinct
Myrtaceae	*Syzygium borneense*	Tree	Native	Least Concern
Myrtaceae	*Syzygium cerasiforme*	Tree	Native	Least Concern
Myrtaceae	*Syzygium grande*	Tree	Native	Least Concern
Myrtaceae	*Syzygium zeylanicum*	Tree	Native	Least Concern
Myrtaceae	*Tristaniopsis obovata*	Tree	Native	Critically Endangered

Myrtaceae	*Tristaniopsis whiteana*	Tree	Native	Endangered
Orchidaceae	*Grammatophyllum speciosum*	Epiphyte	Native	Nationally Extinct
Poaceae	*Cenchrus setosus*	Herb	Exotic	Naturalised
Poaceae	*Centotheca lappacea*	Herb	Native	Least Concern
Polygonaceae	*Antigonon leptopus*	Climber	Exotic	Casual
Polypodiaceae	*Pyrrosia longifolia*	Epiphyte	Native	Least Concern
Polypodiaceae	*Pyrrosia piloselloides*	Epiphyte	Native	Least Concern
Rhamnaceae	*Colubrina asiatica*	Shrub	Native	Least Concern
Rhizophoraceae	*Bruguiera cylindrica*	Tree	Native	Least Concern
Rhizophoraceae	*Bruguiera gymnorhiza*	Tree	Native	Least Concern
Rhutaceae	*Clausena excavata*	Tree	Native	Least Concern
Rubiaceae	*Ixora congesta*	shrub	Native	Least Concern
Rubiaceae	*Morinda citrifolia*	Tree	Native	Least Concern
Sapindaceae	*Nephelium lappaceum var. lapacium*	Tree	Cryptogenic	
Sapindaceae	*Pometia pinnata*	Tree	Native	Endangered
Sapotaceae	*Planchonella chartacea*	Tree	Native	Critically Endangered
Sapotaceae	*Planchonella obovata*	Tree	Native	Vulnerable
Solanaceae	*Solanum torvum*	Shrub	Exotic	Naturalised
Thelypteridaceae	*Christella subpubescens*	Herb	Native	Least Concern
Vitaceae	*Leea indica*	Tree	Native	Least Concern

DISCUSSION AND RECOMMENDATIONS

None of the Native Dominated Young Secondary Forest areas or enrichment plantings are in close proximity to the proposed Jetty and no impact is anticipated for this habitat type.

The parkland plantings within the managed vegetation area are not close enough to the proposed works to be impacted.

A small amount of Native Dominated Coastal Edge Forest will be impacted due to proximity to the proposed works. Only one instance of *Crinum asiatatica* (critically Endangered) occurs in this area however it is considered to be persistent from cultivation. It may be transplanted to a safe location if NParks wishes to retain the plant.

A heavy vehicle access is anticipated to be needed off Jalan Endut Senin and some road side planted trees may be impacted. The roadside trees (some of which have conservation status) in this area are small and may be transplanted to another location.

SAMPLING TRANSECT AND PLOT RECORDS

SAMPLING PLOT 1

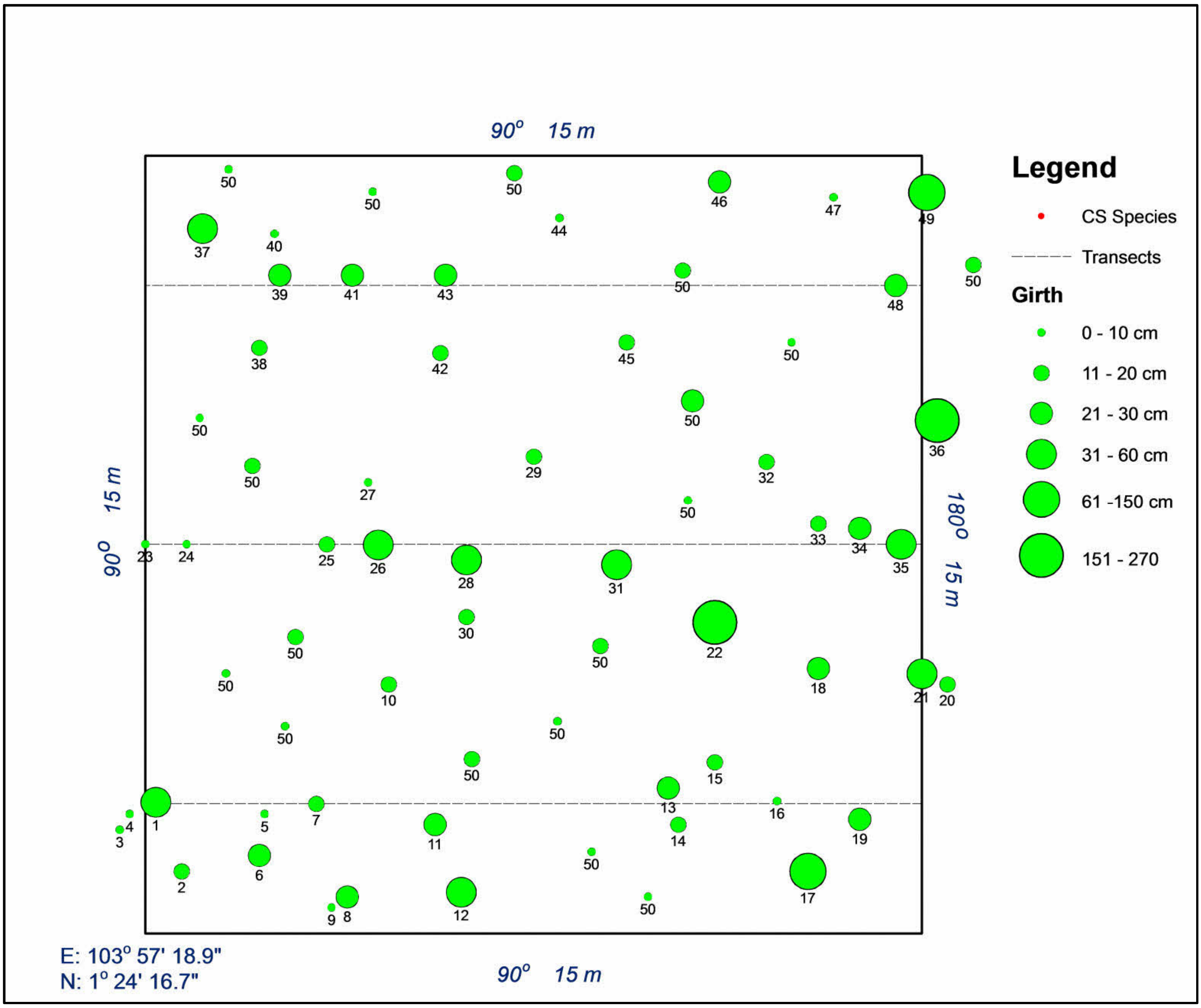


Figure 57: Sampling Plot 1 Species Layout Diagram.

Table 11: Sampling Plot 1 Field Data.

ID	Line	Chainage (m)	Offset (cm)	Girth (cm)	*Species*	Origin	Status
1	1	0.0	0	150	*Caryota mitis*	Native	LC
2	1	0.7	130	20	*Ptychosperma macarthurii*	Exotic	Nat
3	1	-0.5	50	3	*Ardisia elliptica*	Native	EN
4	1	-0.3	20	1	*Adiantum latifolium*	Exotic	Nat
5	1	2.3	20	1	*Adiantum latifolium*	Exotic	Nat
6	1	2.2	100	25	*Ptychosperma macarthurii*	Exotic	Nat
7	1	3.3	0	20	*Ptychosperma macarthurii*	Exotic	Nat
8	1	3.9	180	30	*Caryota mitis*	Native	LC

9	1	3.6	200	9	*Syzygium zeylanicum*	Native	LC
10	1	4.7	-230	16	*Caryota mitis*	Native	LC
11	1	5.6	40	30	*Caryota mitis*	Native	LC
12	1	6.1	170	52	*Caryota mitis*	Native	LC
13	1	10.1	-30	25	*Caryota mitis*	Native	LC
14	1	10.3	40	20	*Caryota mitis*	Native	LC
15	1	11.0	-80	13	*Hevea brasiliensis*	Exotic	Nat
16	1	12.2	-5	8	*Nephelium lappaceum*	Cryptogenic	Crypt
17	1	12.8	130	108	*Hevea brasiliensis*	Exotic	NAt
18	1	13.0	-260	30	*Caryota mitis*	Native	LC
19	1	13.8	30	30	*Caryota mitis*	Native	LC
20	1	15.5	-230	16	*Hevea brasiliensis*	Exotic	Nat
21	1	15.0	-250	53	*Hevea brasiliensis*	Exotic	Nat
22	1	11.0	-350	260	*Mangifera x odorata*	Exotic	Cas
23	2	0.0	0	3	*Nephelium lappaceum*	Cryptogenic	Crypt
24	2	0.8	0	10	*Litsea umbellata*	Native	VU
25	2	3.5	0	11	*Caryota mitis*	Native	LC
26	2	4.5	1.4	45	*Caryota mitis*	Native	LC
27	2	4.3	-120	1	*Litsea umbellata*	Native	VU
28	2	6.2	30	55	*Caryota mitis*	Native	LC
29	2	7.5	-170	15	*Caryota mitis*	Native	LC
30	2	6.2	140	18	*Caryota mitis*	Native	LC
31	2	9.1	40	40	*Caryota mitis*	Native	LC
32	2	12.0	-160	19	*Caryota mitis*	Native	LC
33	2	13.0	-40	15	*Caryota mitis*	Native	LC
34	2	13.8	-30	23	*Caryota mitis*	Native	LC
35	2	14.6	0	55	*Hevea brasiliensis*	Exotic	Nat
36	2	15.3	-240	270	*Mangifera x odorata*	Exotic	Cas
37	3	1.1	-110	40	*Caryota mitis*	Native	LC
38	3	2.2	120	20	*Ptychosperma macarthurii*	Exotic	Nat
39	3	2.6	-20	24	*Ptychosperma macarthurii*	Exotic	Nat
40	3	2.5	-100	2	*Tinospora crispa*	Exotic	Cas
41	3	4.0	-20	26	*Ptychosperma macarthurii*	Exotic	Nat
42	3	5.7	130	13	*Caryota mitis*	Native	LC
43	3	5.8	-20	30	*Caryota mitis*	Native	LC
44	3	8.0	-130	9	*Caryota mitis*	Native	LC
45	3	9.3	110	20	*Caryota mitis*	Native	LC
46	3	11.1	-200	30	*Caryota mitis*	Native	LC
47	3	13.3	-170	9	*Caryota mitis*	Native	LC
48	3	14.5	0	23	*Ptychosperma macarthurii*	Exotic	Nat
49	3	15.1	-180	124	*Hevea brasiliensis*	Exotic	Nat
50	3	16.0	-40	20	*Caryota mitis*	Native	LC
51	1	1.55	251	0	*Caryota mitis*	Native	LC
52	1	7.96	159	0	*Caryota mitis*	Native	LC
53	1	8.62	-93	0	*Caryota mitis*	Native	LC

54	1	9.71	-179	0	*Caryota mitis*	Native	LC
55	1	12.49	890	0	*Caryota mitis*	Native	LC
56	3	4.39	181	0	*Caryota mitis*	Native	LC
57	2	2.07	152	20	*Litsea umbellata*	Native	VU
58	2	1.05	244	0	*Hevea brasiliensis*	Exotic	Nat
59	1	2.7	149	3	*Hevea brasiliensis*	Exotic	Nat
60	2	10.48	85	0	*Hevea brasiliensis*	Exotic	Nat
61	3	7.13	217	12	*Hevea brasiliensis*	Exotic	Nat
62	3	1.61	224	0	*Caryota mitis*	Native	LC
63	1	2.9	321	13	*Hevea brasiliensis*	Exotic	Nat
64	1	6.31	86	20	*Caryota mitis*	Native	LC
65	2	10.57	277	23	*Caryota mitis*	Native	LC
66	3	10.38	29	11	*Hevea brasiliensis*	Exotic	Nat
67	1	8.79	-196	14	*Caryota mitis*	Native	LC

SAMPLING PLOT 2

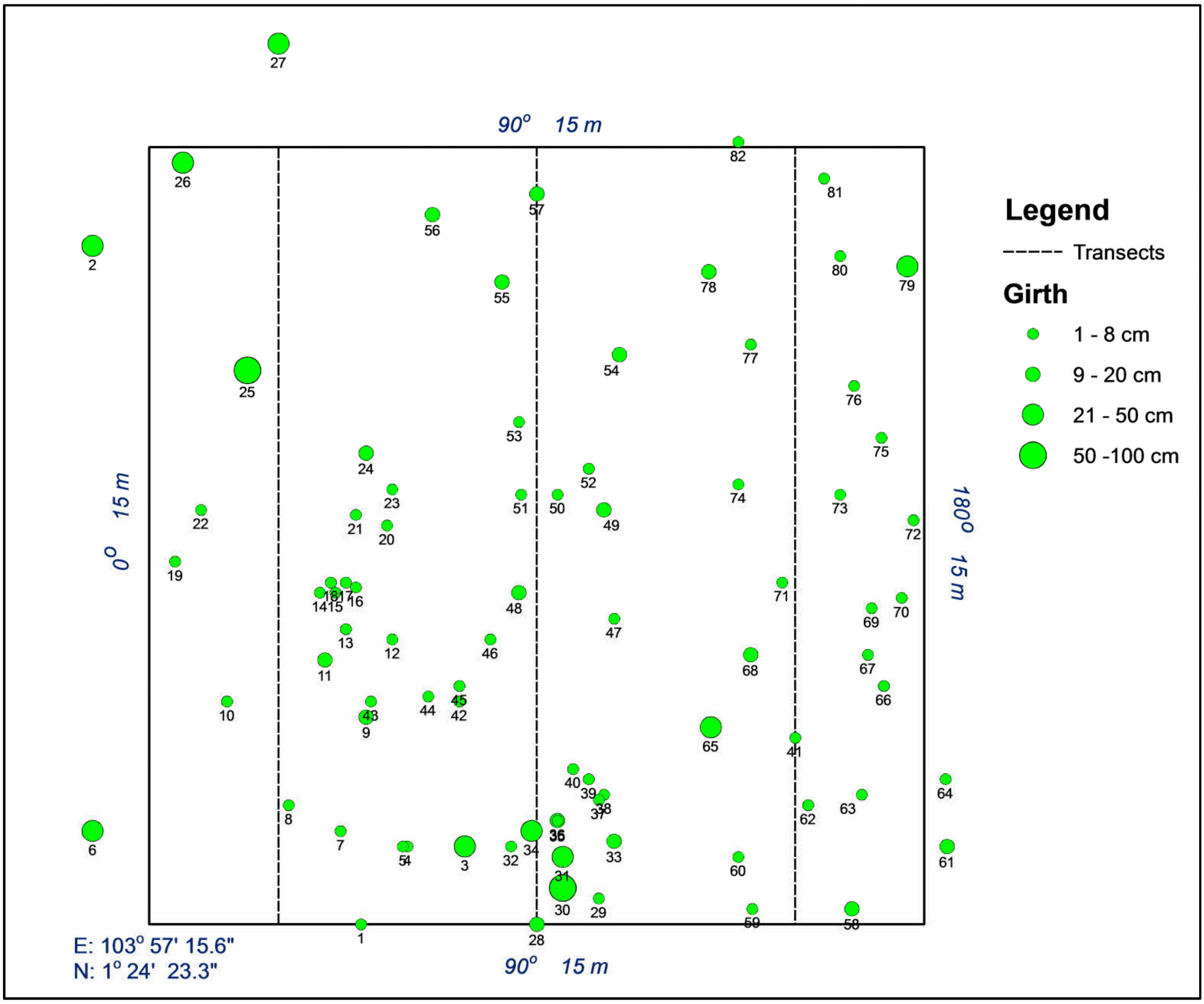


Figure 58: Sampling Plot 2 Species Layout Diagram.

Table 12: Sampling Plot 2 Field Data.

ID	Line	Chainage(m)	Offset (cm)	Girth (cm)	Species	Origin	Status
1	1	0.0	160	6	*Neolitsea cassia*	Native	VU
2	1	13.1	-360	50	*Calophyllum inophyllum*	Native	EN
3	1	1.5	361	25	*Diospyros buxifolia*	Native	CR
4	1	1.5	250	1	*Tinospora crispa*	Exotic	Casual
5	1	1.5	240	1	*Miconia crenata*	Exotic	Nat
6	1	1.8	-360	28	*Neolitsea cassia*	Native	VU
7	1	1.8	120	7	*Terminalia catappa*	Native	LC
8	1	2.3	20	2	*Syzygium polyanthum*	Native	LC
9	1	4.0	170	20	*Ixora congesta*	Native	LC
10	1	4.3	-100	6	*Ixora congesta*	Native	LC
11	1	5.1	90	9	*Acacia auriculiformis*	Exotic	Nat
12	1	5.5	220	6	*Calophyllum inophyllum*	Native	EN

13	1	5.7	130	3	*Calophyllum inophyllum*	Native	EN
14	1	6.4	80	3	*Syzygium polyanthum*	Native	LC
15	1	6.4	110	2	*Syzygium polyanthum*	Native	LC
16	1	6.5	150	3	*Calophyllum inophyllum*	Native	EN
17	1	6.6	130	2	*Caryota mitis*	Native	LC
18	1	6.6	101	1	*Tetracera indica*	Native	LC
19	1	7.0	-200	7	*Hibiscus tiliaceus*	Native	LC
20	1	7.7	210	1	*Calophyllum inophyllum*	Native	EN
21	1	7.9	150	3	*Ardisia elliptica*	Native	EN
22	1	8.0	-150	1	*Tetracera indica*	Native	LC
23	1	8.4	220	7	*Terminallia catapa*	Native	LC
24	1	9.1	170	9	*Cratoxylum sp*	Native	EN
25	1	10.7	-60	98	*Cratoxylum sp*	Native	EN
26	1	14.7	-185	-185	*Knema corticosa*	Native	VU
27	1	17.0	0	40	*Diospyros buxifolia*	Native	CR
28	2	0.0	0	12	*Leea indica*	Native	LC
29	2	0.5	120	2	*Ardisia elliptica*	Native	EN
30	2	0.7	50	60	*Vitex pinnata*	Native	LC
31	2	1.3	50	30	*Caryota mitis*	Native	LC
32	2	1.5	-50	3	*Buchanania arborescens*	Native	LC
33	2	1.6	150	13	*Bhesa paniculata*	Native	LC
34	2	1.8	-10	25	*Claoxylon indicum*	Native	LC
35	2	2.0	40	13	*Terminallia catapa*	Native	LC
36	2	2.0	40	1	*Tinospora crispa*	Exotic	Casual
37	2	2.4	120	1	*Tetracera indica*	Native	LC
38	2	2.5	130	2	*Ardisia elliptica*	Native	EN
39	2	2.8	100	1	*Clausena excavata*	Native	LC
40	2	3.0	70	2	*Caryota mitis*	Native	LC
41	2	3.6	500	3	*Ardisia elliptica*	Native	EN
42	2	4.3	-150	1	*Miconia crenata*	Native	Nat
43	2	4.3	179	3	*Cinnamomum iners*	Native	LC
44	2	4.4	-210	2	*Dillenia suffruticosa*	Native	LC
45	2	4.6	-150	1	*Tetracera indica*	Native	LC
46	2	5.5	-90	3	*Ardisia elliptica*	Native	EN
47	2	5.9	150	3	*Cinnamomum iners*	Native	LC
48	2	6.4	-35	12	*Bhesa paniculata*	Native	LC
49	2	8.0	130	13	*Buchanania arborescens*	Native	LC
50	2	8.3	40	3	*Vitex pinnata*	Native	LC
51	2	8.3	-30	3	*Syzygium polyanthum*	Native	LC
52	2	8.8	100	3	*Claoxylon indicum*	Native	LC
53	2	9.7	-35	3	*Buchanania arborescens*	Native	LC
54	2	11.0	160	18	*Terminalia cf phellocarpa*	Native	NEx
55	2	12.4	-67	12	*Caryota mitis*	Native	LC
56	2	13.7	-202	15	*Syzygium polyanthum*	Native	LC
57	2	14.1	0	10	*Cinnamomum iners*	Native	LC

58	3	0.3	110	20	*Caryota mitis*	Native	LC
59	3	0.3	-83	4	*Leea indica*	Native	LC
60	3	1.3	-110	5	*Cinnamomum iners*	Native	LC
61	3	1.5	294	12	*Caryota mitis*	Native	LC
62	3	2.3	25	2	*Clausena excavata*	Native	LC
63	3	2.5	129	4	*Ardisia elliptica*	Native	EN
64	3	2.8	291	2	*Clausena excavata*	Native	LC
65	3	3.8	-163	23	*Caryota mitis*	Native	LC
66	3	4.6	171	6	*Ardisia elliptica*	Native	EN
67	3	5.2	141	4	*Ardisia elliptica*	Native	EN
68	3	5.2	-86	14	*Caryota mitis*	Native	LC
69	3	6.1	148	1	*Tetracera indica*	Native	LC
70	3	6.3	206	2	*Clausena excavata*	Native	LC
71	3	6.6	-25	8	*Caryota mitis*	Native	LC
72	3	7.8	229	3	*Syzygium polyanthum*	Native	LC
73	3	8.3	87	1	*Clausena excavata*	Native	LC
74	3	8.5	-110	6	*Claoxylon indicum*	Native	LC
75	3	9.4	167	8	*Caryota mitis*	Native	LC
76	3	10.4	114	3	*Cinnamomum iners*	Native	LC
77	3	11.2	-86	3	*Syzygium polyamthum*	Native	LC
78	3	12.6	-167	12	*Caryota mitis*	Native	LC
79	3	12.7	217	25	*Caryata mitis*	Native	LC
80	3	12.9	87	1	*Tetracera indica*	Native	LC
81	3	14.4	56	3	*Syzygium polyanthum*	Native	LC
82	3	15.1	-110	3	*Syzygium polyanthum*	Native	LC

SAMPLING PLOT 3

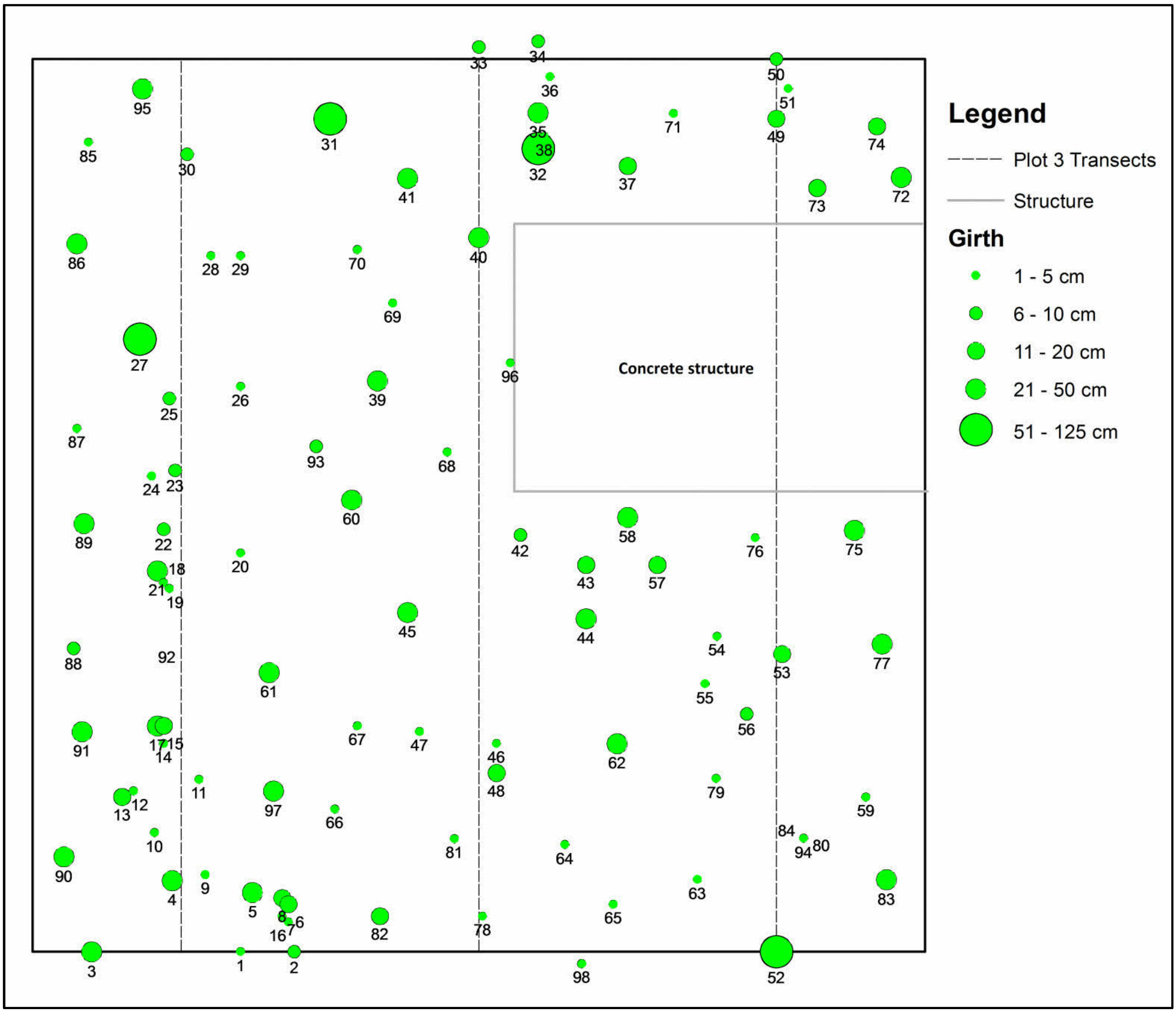


Figure 59: Sampling Plot 3 Species Layout Diagram.

Table 13: Sampling Plot 3 Field Data.

ID	Chainage (m)	Offset (cm)	Girth (cm)	Species	Origin	Status
1	0.0	-10	2	*Gnetum gnemon*	Native	CR
2	0.0	190	9	*Syzygium borneense*	Native	LC
3	0.0	-150	35	*Clausena excavata*	Native	LC
4	1.2	-15	30	*Litsea umbellata*	Native	LC
5	1.0	120	35	*Litsea umbellata*	Native	LC
6	0.8	180	12	*Archidendron clypearia*	Native	LC
7	0.6	170	3	*Dillenia suffruticosa*	Native	LC
8	0.9	170	15	*Asplenium nidus*	Native	LC
9	1.3	40	4	*Clausena excavata*	Native	LC
10	2.0	-45	4	*Clausena excavata*	Native	LC
11	2.9	30	3	*Litsea umbellata*	Native	LC

12	2.7	-80	4	*Gnetum gnemon*	Native	CR
13	2.6	-100	11	*Arthrophyllum jackianum*	Native	LC
14	3.5	-30	5	*Claoxylon indicum*	Native	LC
15	3.8	-30	12	*Caryota mitis*	Native	LC
16	0.5	180	3	*Clausena excavata*	Native	LC
17	3.8	-40	35	*Cinnamomum iners*	Native	LC
18	6.2	-30	3	*Cinnamomum iners*	Native	LC
19	6.1	-20	3	*Ardisia elliptica*	Native	LC
20	6.7	100	5	*Alstonia macrophylla*	Exotic	Nat
21	6.4	-40	27	*Ptychosperma macarthurii*	Exotic	Nat
22	7.1	-30	6	*Gnetum gnemon*	Native	CR
23	8.1	-10	7	*Gnetum gnemon*	Native	CR
24	8.0	-50	4	*Cinnamomum iners*	Native	CR
25	9.3	-20	8	*Ficus variegata*	Native	LC
26	9.5	100	1	*Adiantum latifolium*	Exotic	Nat
27	10.3	-70	70	*Litsea umbellata*	Native	LC
28	11.7	50	4	*Aphanamixis polystachya*	Native	LC
29	11.7	100	5	*Cinnamomum iners*	Native	LC
30	13.4	10	8	*Aphanamixis polystachya*	Native	LC
31	14.0	250	63	*Litsea elliptica*	Native	LC
32	13.5	100	125	*Ficus variegata*	Native	LC
33	15.2	0	8	*Buchanania arborescens*	Native	LC
34	15.3	100	7	*Buchanania arborescens*	Native	LC
35	14.1	100	25	*Caryota mitis*	Native	LC
36	14.7	120	4	*Clausena excavata*	Native	LC
37	13.2	250	20	*Vitex pinnata*	Native	LC
38	13.7	110	5	*Syzygium polyanthum*	Native	LC
39	9.6	-170	30	*Ptychosperma macarthurii*	Exotic	Nat
40	12.0	0	32	*Ptychosperma macarthurii*	Exotic	Nat
41	13.0	-120	29	*Ptychosperma macarthurii*	Exotic	Nat
42	7.0	70	8	*Gnetum gnemon*	Native	CR
43	6.5	180	12	*Vitex pinnata*	Native	LC
44	5.6	180	22	*Ptychosperma macarthurii*	Exotic	Nat
45	5.7	-120	35	*Caryota mitis*	Native	LC
46	3.5	30	3	*Litsea umbellata*	Native	LC
47	3.7	-100	3	*Terminalia catappa*	Native	LC
48	3.0	30	15	*Caryota mitis*	Native	LC
49	14.0	0	20	*Caryota mitis*	Native	LC
50	15.0	0	8	*Syzygium polyanthum*	Native	LC
51	14.5	20	3	*Clausena excavata*	Native	LC
52	0.0	0	63	*Cinnamomum iners*	Native	LC
53	5.0	10	15	*Litsea elliptica*	Native	LC
54	5.3	-100	5	*Litsea umbellata*	Native	LC
55	4.5	-120	4	*Litsea umbellata*	Native	LC
56	4.0	-50	7	*Syzygium polyanthum*	Native	LC

57	6.5	-200	15	*Caryota mitis*	Native	LC
58	7.3	-250	25	*Caryota mitis*	Native	LC
59	2.6	150	3	*Syzygium grande*	Native	LC
60	7.6	-213.51	30	*Caryota mitis*	Native	LC
61	4.7	148	25	*Caryota mitis*	Native	LC
62	3.5	232.35	24	*Caryota mitis*	Native	LC
63	1.2	-133	3	*Syzygium grande*	Native	LC
64	1.8	144.44	4	*Gentum gnemon*	Native	CR
65	0.8	226.07	5	*Dillenia suffruticosa*	Native	LC
66	2.4	-241.77	5	*Litsea umbellata*	Native	LC
67	3.8	-204.1	4	*Syzygium polyanthum*	Native	LC
68	8.4	-53.38	3	*Syzygium polyanthum*	Native	LC
69	10.9	-144.44	3	*Syzygium polyanthum*	Native	LC
70	11.8	-204.1	3	*Syzygium polyanthum*	Native	LC
71	14.1	-173	3	*Syzygium polyanthum*	Native	LC
72	13.0	210	25	*Caryota mitis*	Native	LC
73	12.8	68	12	*Ficus variegata*	Native	LC
74	13.9	169	16	*Caryota mitis*	Native	LC
75	7.1	131	25	*Caryota mitis*	Native	LC
76	7.0	-35	4	*Syzygium grande*	Native	LC
77	5.2	178	28	*Caryota mitis*	Native	LC
78	0.6	6.28	4	*Syzygium polyanthum*	Native	LC
79	2.9	-101	3	*Gentum gnemon*	Native	CR
80	1.9	71	0	*Dillenia suffruticosa*	Native	LC
81	1.9	-40.82	4	*Litsea umbellata*	Native	LC
82	0.6	-166.42	20	*Caryota mitis*	Native	LC
83	1.2	185	30	*Caryota mitis*	Native	LC
84	2.2	18	0	*Syzygium polyanthum*	Native	LC
85	13.6	-156	3	*Lauraceae ap*	Native	LC
86	11.9	-175	29	*Caryota mitis*	Native	LC
87	8.8	-175	4	*Cinnamomum iners*	Native	LC
88	5.1	-181	7	*Cinnamomum iners*	Native	LC
89	7.2	-163	32	*Caryota mitis*	Native	LC
90	1.6	-197	40	*Caryota mitis*	Native	LC
91	3.7	-166	45	*Caryota mitis*	Native	LC
92	5.1	-24	0	*Syzygium polyanthum*	Native	LC
93	8.5	227	7	*Cinnamomum iners*	Native	LC
94	1.9	46	5	*Syzygium polyanthum*	Native	LC
95	14.5	-65	36	*Caryota mitis*	Native	LC
96	9.9	53.38	2	*Syzygium grande*	Native	LC
97	2.7	155	33	*Caryota mitis*	Native	LC
98	-0.2	172.7	3	*Gnetum gnemon*	Native	CR

Sampling Transect 1

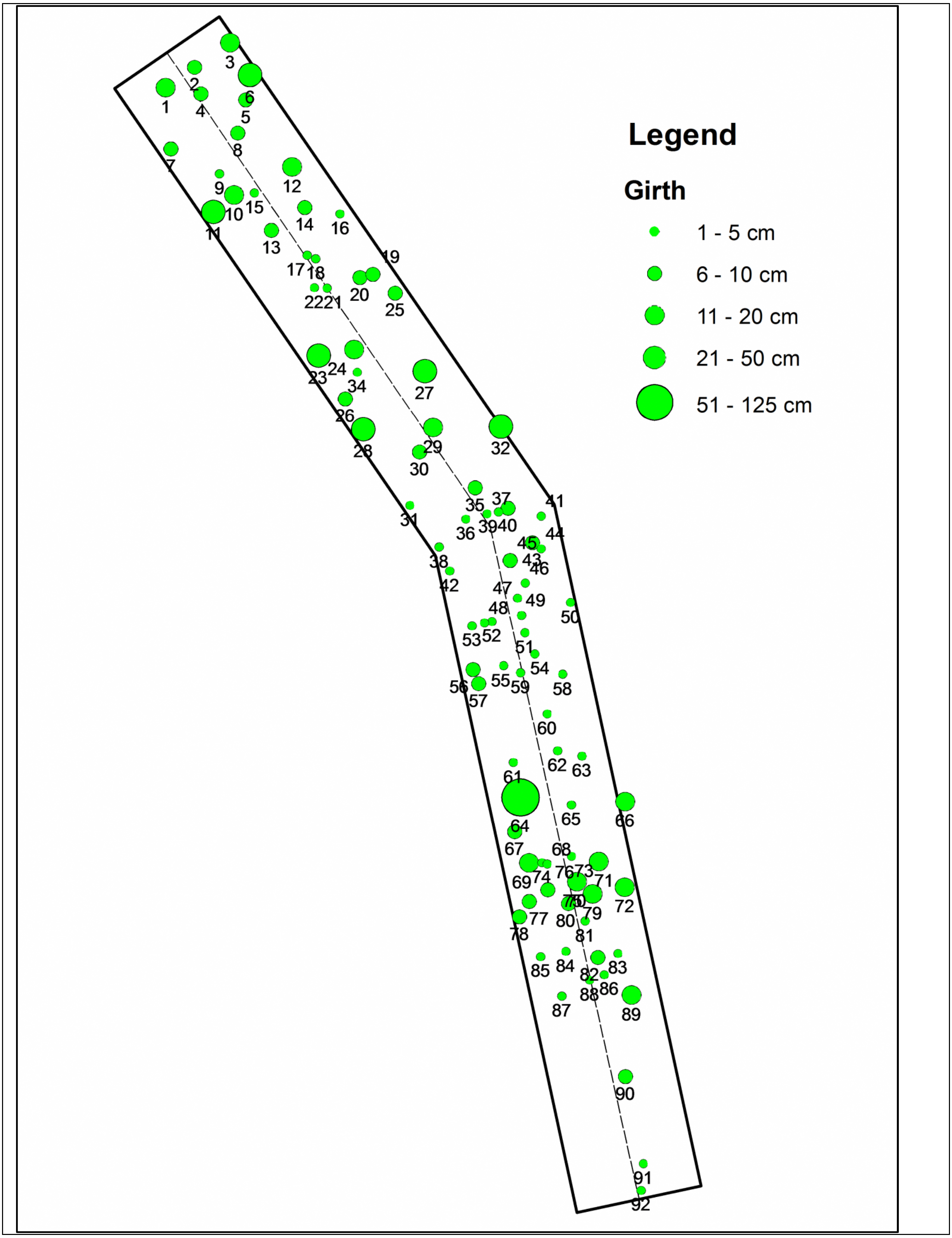


Table 14: Sampling Transect 1 Field Data

ID	Chainage (m)	Offset (cm)	Girth (cm)	Species	Origin	Status
1	0.0	100	30	*nephelium lappaceum*	Crypt	-
2	0.0	-40	20	*Syzygium grande*	Native	LC
3	0.0	-210	25	*Caryota mitis*	Native	LC
4	1.0	0	10	*Caryota mitis*	Native	LC
5	2.2	-130	20	*Caryota mitis*	Native	LC
6	1.5	-200	60	*Vitex pinnata*	Native	LC
7	2.1	221	9	*Ptychosperma macarthurii*	Exotic	Nat
8	3.1	-30	12	*Cinnamomum iners*	Native	LC
9	4.0	120		*Litsea umbellata*	Native	LC
10	5.0	120	39	*Vitex pinnata*	Native	LC
11	5.1	225	93	*Vitex pinnata*	Native	LC
12	5.4	-130	22	*Caryota mitis*	Native	LC
13	7.0	80	8	*Gnetum gnemon*	Native	CR
14	7.0	-80	6	*Knema corticosa*	Native	VU
15	5.4	50	3	*Cinnamomum iners*	Native	LC
16	8.0	-180	3	*Bridelia tomentosa*	Native	LC
17	8.6	20	3	*Clausena excavata*	Native	LC
18	8.9	0	2	*Ardisia elliptica*	Native	EN
19	10.7	-150	14	*Caryota mitis*	Native	LC
20	10.5	-100	15	*Ptychosperma macarthurii*	Exotic	Nat
21	10.1	30	4	*Cinnamomum iners*	Native	LC
22	9.8	70	3	*Syzygium grande*	Native	LC
23	12.1	210	97	*Ficus variegata*	Native	LC
24	12.7	80	39	*Vitex pinnata*	Native	LC
25	11.8	-180	17	*Caryota mitis*	Native	LC
26	14.1	220	18	*Caryota mitis*	Native	LC
27	15.0	-100	103	*Ficus variegata*	Native	LC
28	15.5	230	60	*Caryota mitis*	Native	LC
29	17.0	0	30	*Ptychosperma macarthurii*	Exotic	Nat
30	17.5	100	12	*Ardisia elliptica*	Native	EN
31	19.0	250	5	*Gironniera nervosa*	Native	LC
32	18.5	-220	69	*Caryota mitis*	Native	LC
33	14.0	-500	60	*Adenanthera pavonina*	Exotic	Nat
34	13.5	120	3	*Knema corticosa*	Native	VU
35	19.9	0	20	*Claoxylon indicum*	Native	LC
36	20.7	100	3	*Litsea umbellata*	Native	LC
37	21.0	20		*Litsea umbellata*	Native	LC
38	21.0	250	4	*Claoxylon indicum*	Native	LC
39	21.2	-20	2	*Clausena excavata*	Native	LC
40	21.3	-60	7	*Litsea umbellata*	Native	LC
41	22.3	-150	4	*Litsea umbellata*	Native	LC
42	22.0	270	2	*Claoxylon indicum*	Native	LC

43	23.0	-100	10	*Syzygium zeylanicum*	Native	LC
44	23.3	-130	3	*Litsea umbellata*	Native	LC
45	23.5	0	12	*Vitex pinnata*	Native	LC
46	24.5	-40	3	*Cinnamomum iners*	Native	LC
47	25.0	2	3	*Syzygium polyanthum*	Native	LC
48	25.7	150	2	*Tinospora crispa*	Exotic	Cas
49	25.7	0	4	*Terminalia catappa*	Native	LC
50	25.6	-200	2	*Tetrocera indica*	NAtive	LC
51	26.4	0	3	*Litsea umbellata*	Native	VU
52	25.7	120	3	*Litsea umbellata*	Native	VU
53	25.7	200	2	*Syzgium grande*	Native	LC
54	27.3	-20	3	*Syzgium polyanthum*	Native	LC
55	27.5	110	2	*Syzygium grande*	Native	LC
56	27.4	230	12	*Litsea umbellata*	Native	VU
57	28.0	220	8	*Litsea umbellata*	Native	VU
58	28.3	-110	3	*Claoxylon indicum*	Native	LC
59	27.9	50	3	*Gnetum gnemon*	Native	CR
60	29.7	-20	2	*Syzgium polyanthum*	Native	LC
61	31.3	150	2	*Clausena excavata*	Native	LC
62	31.2	-30	3	*Sterculia coccinea*	Native	EN
63	31.6	-120	3	*Syzygium grande*	Native	LC
64	32.7	150	320	*Pterocarpus indicus*	Exotic	Cas
65	33.4	-40	5	*Litsea umbellata*	Native	VU
66	33.7	-250	30	*Caryota mitis*	Native	LC
67	34.0	200	20	*Syzygium grande*	Native	LC
68	35.5	100	3	*Syzygium grande*	Native	LC
69	35.3	170	30	*Caryota mitis*	Native	LC
70	36.4	0	25	*Caryota mitis*	Native	LC
71	35.8	-100	35	*Cinnamomum iners*	Native	LC
72	37.0	-180	48	*Terminalia catappa*	Native	LC
73	35.4	0	2	*Clausena excavata*	Native	LC
74	35.4	120	5	*Clausena excavata*	Native	LC
75	36.4	0	25	*Caryota mitis*	Native	LC
76	36.5	120	13	*Cinnamomum iners*	Native	LC
77	36.8	200	10	*Cinnamomum iners*	Native	LC
78	37.3	250	12	*Cinnamomum iners*	Native	LC
79	37.0	-50	22	*Caryota mitis*	Native	LC
80	37.2	50	15	*Litsea umbellata*	Native	VU
81	38.0	0	3	*Cinnamomum iners*	Native	LC
82	39.5	-20	20	*Caryota mitis*	Native	LC
83	39.5	-100	3	*Syzygium grande*	Native	LC
84	39.0	100	4	*Syzygium grande*	Native	LC
85	39.0	200	3	*Syzygium grande*	Native	LC
86	40.2	-30	5	*Litsea umbellata*	Native	VU
87	40.7	150	4	*Syzygium grande*	Native	LC

88	40.3	30	3	*Ficus vasculosa*	Native	LC
89	41.2	-120	24	*Caryota mitis*	Native	LC
90	44.3	-30	9	*Claoxylon indicum*	Native	LC
91	47.8	-30	3	*Alstonia macrophylla*	Exotic	Nat
92	48.8	0	3	*Alstonia macrophylla*	Exotic	Nat