TOTAL E&P PNG LIMITED

PAPUA LNG PROJECT

UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1: MAIN REPORT

Chapter 8: Existing Environment - Marine

TOTAL E&P PNG LIMITED

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Table of Contents

Chapter

8. Existing Environment – Marine 8–1

8.1 General Setting 8–1

8.2 Seabed and Coastal Geomorphology 8–3

8.3 Physical Oceanography 8–11

8.4 Marine Water and Sediment Quality 8–19

8.5 Marine Biodiversity 8–37

8.6 Marine Fisheries and Resources 8–64

8.7 Underwater Noise 8–74

8.8 References 8–79

Tables

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area 8–54

Table 8.2 – Sensitivity Rating of Marine Habitats 8–61

Table 8.3 – Ambient Natural Underwater Noise Levels in the Marine Environment 8–77

Table 8.4 – Summary of Underwater Noise Levels and Key Noise Sources at Assessment Locations 8–79

Figures

Figure 8.1 – Regional Setting 8–2

Figure 8.2 – Conceptual Sediment Transport Patterns in the Gulf of Papua During the Southeast Trade Wind Season and Northwest Monsoon Season 8–4

Figure 8.3 – Landsat Satellite Imagery of Orokolo Bay 8–7

Figure 8.4 – Conceptual Sediment Transport Patterns in Orokolo Bay During the Southeast Trade Wind Season and Northwest Monsoon Season 8–8

Figure 8.5 – Marine Habitats of Caution Bay 8–10

Figure 8.6 – Bathymetry of Orokolo Bay 8–13

Figure 8.7 – Typical Wave Pattern in Orokolo Bay During the Southeast Trade Wind Season and Northwest Monsoon Season 8–15

Figure 8.8 – Modeled Net Currents for the Southeast Trade Wind Season and Northwest Monsoon Season 8–16

Figure 8.9 – Typical Wave Pattern along the Offshore Export Pipeline Corridor during the Southeast Trade Wind Season 8–18

Figure 8.10 – Typical Wave Pattern in Caution Bay During the Southeast Trade Wind Season and Northwest Monsoon Season 8–20

Figure 8.11 – Marine Survey Sites 8–22
Figure 8.12 – Temperature and Salinity Profiles in Orokolo Bay 8–23
Figure 8.13 – Turbidity and Dissolved Oxygen Profiles in Orokolo Bay 8–24
Figure 8.14 – Continuous Bottom Turbidity Measurements at Orokolo Bay 8–26
Figure 8.15 – Temperature and Salinity Profiles Along the Offshore Export Pipeline Corridor . 8–28
Figure 8.16 – Turbidity and Dissolved Oxygen Profiles Along the Offshore Export Pipeline Corridor 8–29
Figure 8.17 – Temperature and Salinity Profiles in Caution Bay 8–31
Figure 8.18 – Turbidity and Dissolved Oxygen Profiles in Caution Bay 8–32
Figure 8.19 – Sediment Particle Size, and Nutrient and Organic Matter Content 8–34
Figure 8.20 – Ecoregions of Southern New Guinea 8–38
Figure 8.21 – Nearshore Marine Habitats in Caution Bay 8–43
Figure 8.22 – Orokolo Bay Benthic Macroinvertebrate Community Metrics 8–49
Figure 8.23 – Number of Fish Species Recorded per Family in Caution Bay 8–52
Figure 8.24 – Sensitive Marine Areas 8–63
Figure 8.25 – Environmental Setting of Marine Fisheries 8–65
Figure 8.26 – Density of Prawn Trawler Positions in the GOPPF Reporting Areas 8–67
Figure 8.27 – Migration Route of the Ornate Rock Lobster 8–69
Figure 8.28 – Ambient Underwater Noise Spectra Levels in the Marine Environment 8–76
Figure 8.29 – Underwater Noise Desktop Assessment Locations 8–78

Plates

Plate 8.1 – Aerial View of the Purari River Mouth (Alele (left) and Aievi (right) Passages) Terminating in Orokolo Bay 8–5
Plate 8.2 – Beach Ridges and Tidal Creeks Along Orokolo Bay Coastline 8–6
Plate 8.3 – Example of Depositional Sediment Lobe at Orokolo Bay 8–9
Plate 8.4 – Mangrove-lined Coastline Near PNG LNG Facilities 8–11
Plate 8.5 – Turbid Plume from the Purari River in Orokolo Bay 8–19
Plate 8.6 – Typical Sediment of Orokolo Bay (Site M9) 8–33
Plate 8.7 – Example of Typical Sediment Along the Offshore Export Pipeline Corridor (Site M31) 8–35
Plate 8.8 – Example of Sandy Sediment in Caution Bay (Site M21) 8–36
Plate 8.9 – Example of Coral Rubble and Shell Debris in Caution Bay (Site M20) 8–36
Plate 8.10 – Example of a Dark Sandy Beach at Orokolo Bay 8–40
Plate 8.11 – Rocky Reef Benthos Examples (Site M6) 8–41

Plate 8.12 – Typical Flat and Featureless Seabed Substrate in Orokolo Bay (Site M12) 8–42

Plate 8.13 – *Acropora* Bombora with High Coral Cover and Long Apical-growing Tips (Site V26) 8–44

Plate 8.14 – *Pavona clavus* Bombora with High Coral Cover (Site V30) 8–45

Plate 8.15 – Rubble Reef Community with Low Live Coral Cover (Site M22) 8–45

Plate 8.16 – Patch Reef Community (Site V02) 8–45

Plate 8.17 – Deep Reef Community (Site V15) 8–46

Plate 8.18 – Reef Slope Community at Idihi Island (Site M24) 8–46

Plate 8.19 – Examples of Numerically Dominant Taxa 8–48

Plate 8.20 – Examples of Reef Fish 8–51

Plate 8.21 – Examples of Larger-bodied Fish (Bigtail Fusiliers, *Pterocaesio marri*) Observed in Caution Bay 8–53

Plate 8.22 – Saltwater Crocodile (*Crocodylus porosus*) in the Purari River 8–59

Plate 8.23 – Banana Prawn Catch 8–66

Plate 8.24 – Ornate Rock Lobster (*Panulirus ornatus*) 8–68

Plate 8.25 – Threadfin Salmon Caught in the Purari River Delta Estuary 8–72

Plate 8.26 – Species Observed in Subsistence Fish Catches from the Orokolo Bay Region ...8–73

Attachments

8.1 Underwater Noise Desktop Baseline Technical Paper

8. Existing Environment – Marine

This chapter has drawn on information from a series of interdependent marine studies that have involved detailed bibliographic reviews, numerical modeling and marine field surveys. Part 23 of Volume 2 has further information on the scope and methods of these field surveys. The field surveys were undertaken in the upstream Project study area between 20 June and 9 July 2016, during the southeast trade wind season, and between 12 and 31 January 2017, during the northwest monsoon season. Based on this information, descriptions are provided of the following components of the marine environment:

- Seabed and coastal geomorphology (Section 8.2) derived from the Seabed and Coastal Geomorphology Baseline Report (Part 9 of Volume 2).
- Physical oceanography (Section 8.3) derived from the Physical Oceanography Baseline Report (Part 10 of Volume 2).
- Marine water and sediment quality (Section 8.4) derived from the Marine Water and Sediment Quality Baseline Report (Part 11 of Volume 2).
- Marine biodiversity (Section 8.5) derived from the Marine Biodiversity Baseline Report (Part 12 of Volume 2).
- Marine fisheries and resources (Section 8.6) derived from the Marine Fisheries and Resources Baseline Report (Part 13 of Volume 2).

A desktop assessment of the existing underwater acoustic environment was also undertaken (Attachment 8.1) and is described in Section 8.7.

The baseline characterization of the marine setting primarily focused on three sectors of the export pipeline corridor:

- Orokolo Bay.
- Offshore export pipeline corridor through the Gulf of Papua.
- Caution Bay.

8.1 General Setting

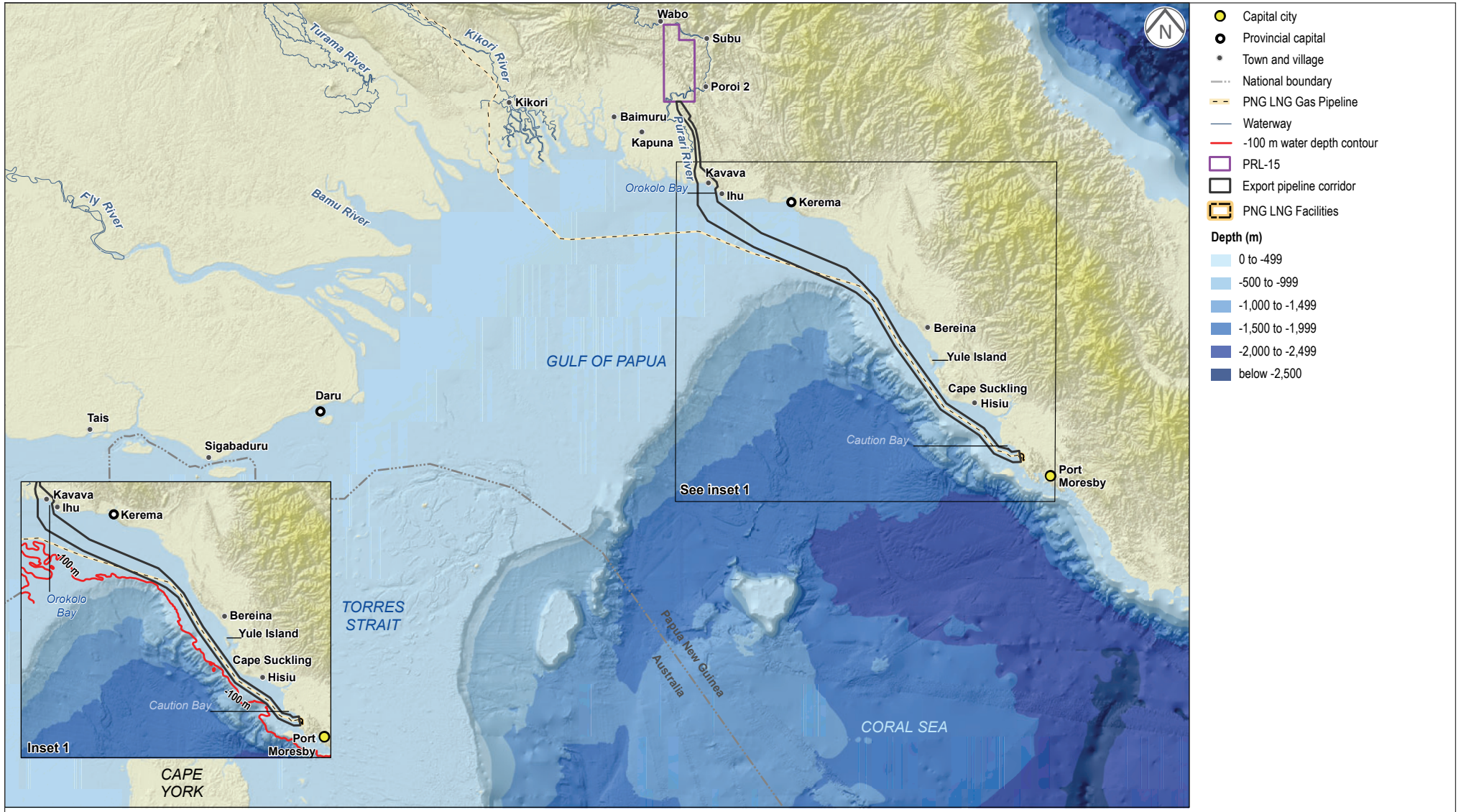
The proposed export pipeline corridor crosses the coastline at Orokolo Bay in the Gulf of Papua east of the Purari River delta. It then traverses the continental shelf along the eastern side of the gulf, adjacent to the existing PNG LNG Gas Pipeline, to Caution Bay (Figure 8.1).

The Gulf of Papua covers an area of approximately 50,000 km^2. It is open to the south adjacent to the Coral Sea and bordered by Torres Strait to the west and mainland Papua New Guinea to the northwest, north and east. Parts of the northern and western shorelines are low-lying swamps comprising the delta complexes of large rivers (including the Fly, Bamu, Turama, Kikori and Purari), which drain the mountainous highlands of central Papua New Guinea.

Large amounts of terrigenous sediments enter the northern and western parts of the gulf throughout the year, carried by flows from these large rivers. These riverine inflows have a large influence on conditions in the gulf, with freshwater sediment plumes sometimes extending to the boundary of the gulf (50 to 100 km from the coast) (Wolanski et al., 1995).

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FIGURE 8.1



The Gulf of Papua experiences two seasons, the southeast trade wind season (May to October) and the northwest monsoon season (December to March) with April and November considered transitional months with more variable conditions.

8.2 Seabed and Coastal Geomorphology

8.2.1 Regional Context

Much of the seafloor in the Gulf of Papua is located on the continental shelf at water depths less than 100 m. In particular, a large section of the western gulf, up to 200 km from land, has a depth no greater than 100 m. Beyond this section, the depth increases to 200 m over 30 to 50 km from land before reaching the edge of the continental shelf where the seafloor descends to a depth of 2,000 m over about 100 km (see Figure 8.1). By contrast, on the eastern side of the gulf, the edge of the continental shelf is within 30 to 50 km of the mainland, and the seafloor rapidly falls to 2,000 m deep within 50 km of the continental shelf.

Significant quantities of terrigenous sediment are contributed to the northern and western parts of the gulf throughout the year, carried by flows from several large rivers (including the Fly, Bamu, Turama, Kikori and Purari). A conceptual understanding of sediment transport processes for the Gulf of Papua is presented in Figure 8.2 and is based on existing literature and numerical modeling described in the Physical Oceanography Baseline Report (Part 10 of Volume 2) (Section 8.3).

Terrigenous sediment discharged by the rivers is initially deposited in shallower areas (less than 15 m deep) but is remobilized and transported by wave activity and increased currents (Walsh et al., 2004). During the southeast trade wind season, larger waves and currents remobilize finer sediments, and the clockwise current circulation pattern in the gulf transports sediment to the southeast. At the same time, waves coming predominantly from the southeast transport sediment in a northwesterly direction along the shoreline. During the northwest monsoon season, there is an anticlockwise circulation pattern on the continental shelf in the gulf. Lower-energy wave conditions cause more of the sediment delivered by the rivers to be deposited locally, and there is a much lower rate of shoreline sediment transport.

Off-shelf removal of terrigenous sediment occurs due to the Coral Sea Coastal Current, which flows northwards (entering the gulf along the eastern edge of the Torres Strait) and transports sediment in a northeasterly direction toward a narrow section of the continental shelf where it is removed by gravity currents (Harris et al., 1996).

8.2.2 Baseline Characterization

8.2.2.1 Study Overview

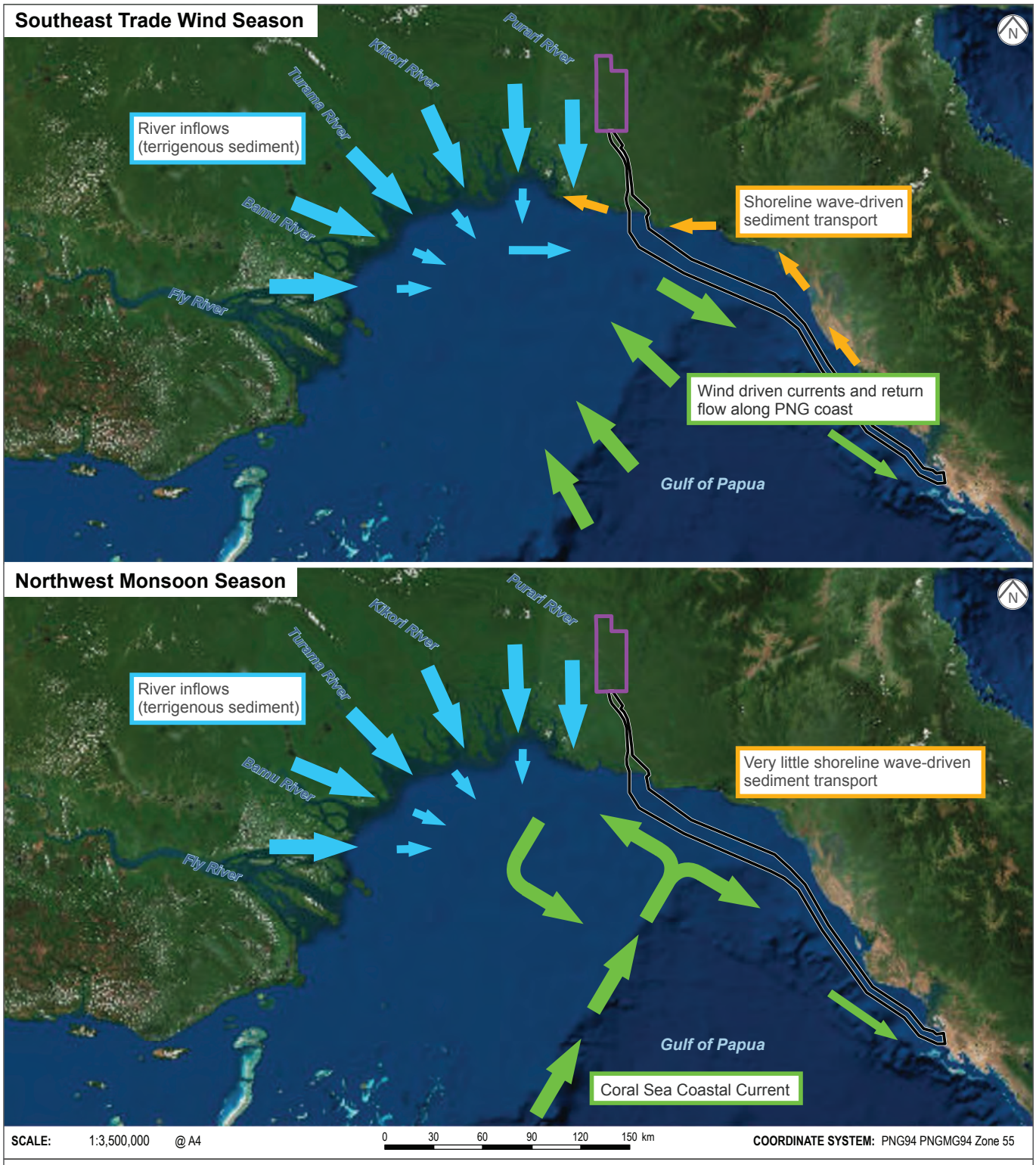
Description of the seabed and coastal geomorphology in the study area is based on existing information from previous studies, the scientific literature and the marine field surveys, which involved:

- Acoustic data collection to identify and map benthic features, including different substrate types.
- Sediment sampling to assess particle size distribution, and visual observation of benthic sediment (discussed in Section 8.4.3).
- Visual observation of coastal and seabed geomorphological features.

CONCEPTUAL SEDIMENT TRANSPORT PATTERNS IN THE GULF OF PAPUA DURING THE SOUTHEAST TRADE WIND SEASON AND NORTHWEST MONSOON SEASON

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FIGURE 8.2



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

8.2.2.2 Purari River Delta

The Purari River delta is a large low-lying deltaic complex that drains the Purari River catchment into the Gulf of Papua. It comprises three main distributary channels, namely the Wame-Varoi River, Urika-Ivo River and the Purari River (via Aievi and Alele passages; Plate 8.1), and smaller distributaries (see Figure 7.4). The Purari catchment discharges approximately 88.6 Mm^3/yr of sediment across the delta primarily through the three main river channels (Pickup, 1983; Thom & Wright, 1983). This sediment is predominantly silt and clay, with a small proportion of sand (Thom & Wright, 1983; Ruxton et al., 1969). As noted in Section 8.2.1, prevailing sediment transport along the shoreline is in a northwesterly direction, which is caused by the southeast trade winds.

Plate 8.1 – Aerial View of the Purari River Mouth (Alele (left) and Aievi (right) Passages) Terminating in Orokolo Bay



Photo: BMT WBM.

The Purari and Urika-Ivo channels discharge directly into the gulf and are exposed to substantial wave action, resulting in the formation of longshore bars and shoals. These two wave-dominated river mouths are subject to large ongoing changes in morphology (Thom & Wright, 1983). In contrast, the Wame-Varoi channel discharges into the sheltered environment of the Pie River estuary, where wave effects are small and tidal flows are more important. The Pie River estuary is considered to be tidally dominated, having a much deeper entrance channel than the Purari and Urika-Ivo channels due to greater tidal scour and lower fluvial sediment loads (Thom & Wright, 1983). This channel delivers only a small fraction of the total sediment discharged from the Purari River catchment.

The primary landform of the Purari River delta is saltwater tidal flats. Mangrove wetlands dominate much of the coastline of the Purari River delta, with sandy beaches found intermittently between tidal inlets and river mouths. The formation of these sandy beaches is partly the result of strong erosion pressures on vegetated areas caused by the shifting of river mouths (Thom & Wright, 1983). The Purari River delta is also slowly prograding, which has led to the generation of sandy spits and bars across the delta.

8.2.2.3 Orokolo Bay

The Orokolo Bay coastline is located east of the Purari River delta and extends southeast from the Alele Passage of the Purari River mouth for approximately 25 km to the mouth of the Vailala River (see Figure 7.4). The primary landform along this stretch of coast is classified in geomorphological maps as being beach ridges and beach plains (Ruxton et al., 1969).

Sediment supply to Orokolo Bay is predominantly from the Purari and Vailala rivers. A bathymetry survey in November 2009 found sediment accumulated in a very shallow zone extending approximately 2 km offshore from the Alele Passage, with water depths less than 3 m during high tide. Wind-generated littoral currents at Orokolo Bay move sediment westward along the coast as a result of stronger winds during the southeast trade wind season. This has led to the westward growth of trains of sandy spits and a pattern of broad composite beach ridges separated by tidal creeks (Plate 8.2), i.e., chenier plains (Ruxton et al., 1969; Thom & Wright, 1983). This sediment deposition is causing the movement of beach ridge barriers seaward, causing the degradation of inland margins by tidal scour and leading to the development of swamps in the swales of older dune systems. These beach ridges are characterized by strongly gleyed undifferentiated sandy soils containing heavy mineral sands that give sediment a dark color (i.e., black sand beaches). Inland of the beach ridges are the degraded remnants of historical ridges and beach plains, backing on low-relief hills.

Plate 8.2 – Beach Ridges and Tidal Creeks Along Orokolo Bay Coastline



Photo: Iain Woxvold.

Analysis of historical satellite imagery shows that the Orokolo Bay shoreline remains largely unchanged; however, some notable changes have occurred in the southeastern part of the bay, northwest of the Vailala River. An island has been increasing in size in this area over the past few decades, is currently around 7 km long and 1 km wide, and is now considered an extension of the mainland (Figure 8.3). This is likely attributable to the net northwesterly longshore transport of sediment from the Vailala River during the southeast trade wind season.

A conceptual understanding of sediment transport processes in the vicinity of Orokolo Bay is presented in Figure 8.4 and is based on existing literature and modeling of this area of the Gulf of Papua described in Part 10 of Volume 2 (Section 8.3).

This conceptual diagram shows large sediment inflows to the Orokolo Bay area from the Purari and Vailala rivers across the year (as evident from Figure 8.3). Sediment movement in Orokolo Bay follows the seasonal pattern outlined in Section 8.2.1 for the Gulf of Papua. Due to the weaker effect of currents during the northwest monsoon season, sediment deposition occurs in Orokolo Bay at this time of year. During the southeast trade wind season there is a clockwise circulation pattern in the Gulf of Papua due to wind-driven currents. This generates a return flow toward the southeast along the southern coast of Papua New Guinea. Under these conditions wave-related resuspension, together with the southeasterly-directed current, causes net sediment transport in a southeast direction offshore from Orokolo Bay. Closer to the shore, wave-driven

LANDSAT SATELLITE IMAGERY OF OROKOLO BAY

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FIGURE 8.3

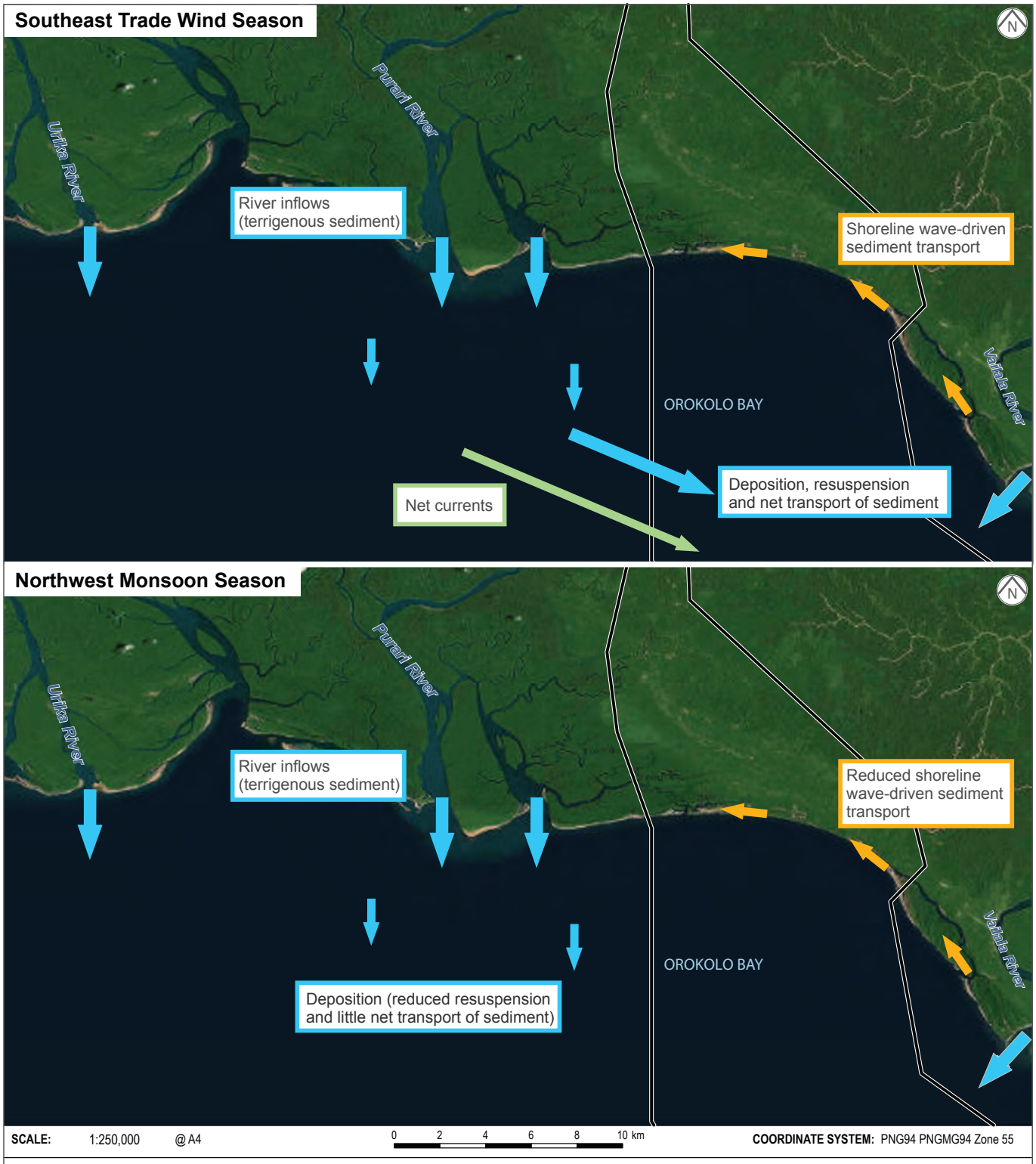


Source: Google Earth

CONCEPTUAL SEDIMENT TRANSPORT PATTERNS IN OROKOLO BAY DURING THE SOUTHEAST TRADE WIND SEASON AND NORTHWEST MONSOON SEASON

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FIGURE 8.4



transport generated by the strong southeast trade winds moves sediment northwest along the coastline. Plate 8.3 shows a depositional lobe of sediment at Orokolo Bay.

Plate 8.3 – Example of Depositional Sediment Lobe at Orokolo Bay



Photo: Iain Woxvold.

8.2.2.4 Offshore Export Pipeline Corridor

Sediment characteristics on the continental shelf in the Gulf of Papua transition from deltaic terrigenous muds in shallow waters to reef and non-reef shelf carbonates in deeper areas (Harris et al., 1996).

The offshore export pipeline corridor extends along the continental shelf, where water depths are between 50 and 100 m for most of the corridor's length. The seafloor is typically smooth, without notable trenches or canyons. Acoustic surveys indicate that the seafloor is featureless, with the exception of some reef platforms and shoals near Yule Island (see Figure 8.1) and the outer parts of Caution Bay.

As described in detail in Section 8.4.3, sediments along the offshore export pipeline corridor are predominantly silt and clay, except near Yule Island where there is a large volume of sand, which is attributed to the occurrence of shoals at Yule Island.

The sediment transport dynamics along the offshore export pipeline corridor are driven by the wave and current circulation patterns of the broader gulf, which are described in Section 8.2.1.

8.2.2.5 Caution Bay

The Caution Bay coastline has a wide strip of mangroves extending 7 km along the coast and up to 1 km wide in parts, in the vicinity of the PNG LNG Facilities (Figure 8.5 and Plate 8.4). A narrower mangrove strip also occurs between Boera and Porebada, with small patches between Papa and Lea Lea to the north. Mudflats back the major mangrove area around the PNG LNG Facilities. Small patches of sandy beach are found along the coast, notably to the south in areas where mangroves are absent (CNS, 2008a).

Fringing coral reefs are extensive in Caution Bay and parallel the eastern shoreline between 200 to 500 m offshore (CNS, 2008a). The large outer barrier reef in the southwest of Caution Bay includes the coral cay, Idihi Island, at its western extent (Figure 8.5). This reef system shelters the bay from ocean swells during the southeast trade wind season. Offshore reefs also exist around Vari Vari Island to the northwest, just outside of Caution Bay. Patch reefs, coral outcrops and low-relief rubble slopes are also present in the southern and central regions of Caution Bay. These reefs are further described in Section 8.5.

MARINE HABITATS OF CAUTION BAY

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FIGURE 8.5

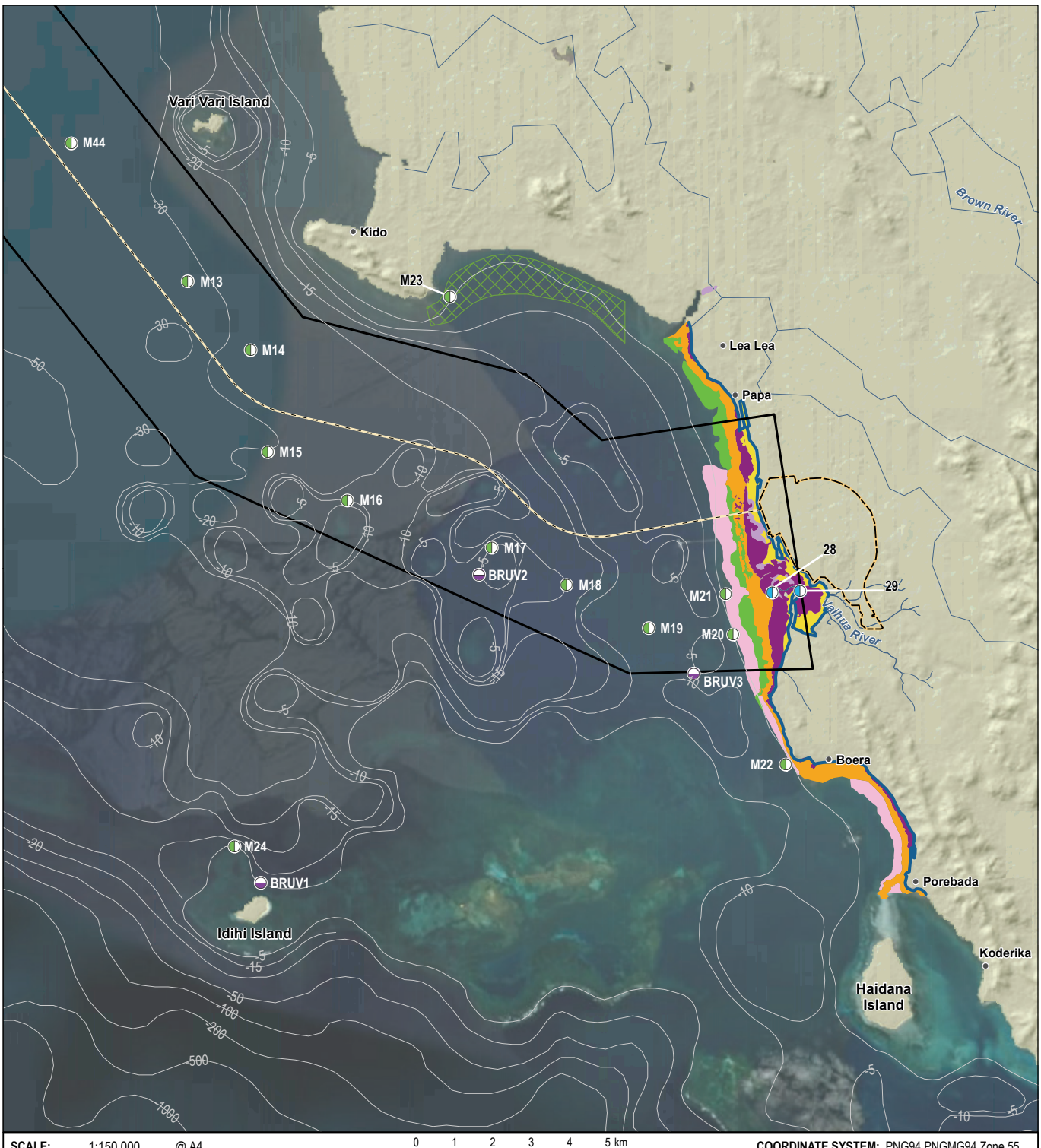


Plate 8.4 – Mangrove-lined Coastline Near PNG LNG Facilities



Photo: BMT WBM.

Sediments in shallow waters less than 30 m deep are predominantly sandy, with coral, rubble and shell debris close to coral reefs (CNS, 2008a). As indicated by acoustic surveys undertaken in 2017 (which are further described in Section 8.5), the deeper areas of Caution Bay (i.e., 30 to 50 m deep) have silty and clay sediments. Mudflats occur in intertidal areas.

The southern barrier reef system provides protection from waves during the southeast trade wind season, but it provides less protection in the northwest monsoon season when waves are predominantly from the west (Section 8.3). Unlike Orokolo Bay, no large rivers flow into Caution Bay to deliver substantial sediment loads. The short and seasonally ephemeral Vaihua River catchment delivers intermittent sediment into the bay (CNS, 2009). Sediment transport rates are therefore expected to be small in magnitude, and any associated morphology changes would be gradual.

There is little evidence that the shoreline in Caution Bay is undergoing active change. Comparison of Landsat satellite imagery from the 1980s and from 2015 shows little change in the extent of mangroves and no change in shoreline position (Part 9 of Volume 2).

8.3 Physical Oceanography

8.3.1 Regional Context

The physical oceanography of the Gulf of Papua is strongly influenced by the climate, which is characterized by the distinct northwest monsoon and southeast trade wind seasons (see Section 7.3).

Winds during the northwest monsoon season are calmer than winds during the southeast trade wind season, with January and February considered the calmest months. Wind strength then gradually increases throughout the year to a peak, with the strongest southeast trade winds in July, and then progressively decreases with the return of the monsoon season (Evesson, 1983; Saint-cast & Condie, 2006). Monsoon surges with strong northwest winds have been observed in the region (CNS, 2008b). These short-lived squalls of about one-hour duration, with wind speeds of 55 to 65 km/hr (15 to 18 m/s), are known locally as *gubas*.

The southeast trade wind–driven waves have a long fetch from across the Coral Sea, generating waves in the Gulf of Papua with seasonally averaged significant wave height (i.e., average height of the highest third of the waves) of 1.5 m (Hemer et al., 2004). These waves attenuate as water

becomes shallower. During the northwest monsoon season, wave heights are smaller due to the calmer winds and shorter fetch.

Tides in the gulf are semidiurnal (i.e., two high and two low tides per lunar day), with the largest tidal range of 5 m occurring in the western gulf near the mouth of the Fly River (Wolanski et al., 1995). Tidal range then attenuates heading eastward, with the maximum tidal range in the eastern gulf being approximately 3 m.

The Hiri Current forms a clockwise gyre in the Gulf of Papua (Saint-Cast & Condie, 2006). The strength of the Hiri Current is unlikely to be significantly altered by El Niño given a lack of response observed in the Coral Sea Current, which is thought to drive the Hiri Current (Saint-Cast & Condie, 2006).

Water inflows from the large rivers (including the Fly, Bamu, Turama, Kikori and Purari rivers) entering the Gulf of Papua also have a significant influence on hydrodynamics and sediment dynamics in the gulf (Wolanski et al., 1995).

The bathymetry of the Gulf of Papua is described in Section 8.2.1 (and shown in Figure 8.1).

8.3.2 Baseline Characterization

8.3.2.1 Study Overview

Description of the physical oceanographic processes in the study area is based on existing information from previous studies, scientific literature, marine field surveys (Part 23 of Volume 2) and numeric modeling specifically undertaken for the study area. The physical oceanographic modeling used several linked models, which included the following:

- Bathymetric digital elevation model (DEM).
- Three-dimensional (3D) hydrodynamic model and 3D advection-dispersion (i.e., water quality) TUFLOW-FV model.
- SWAN (Simulating Waves Nearshore) wave model.
- Sediment transport model, based on TUFLOW-FV and SWAN wave model outputs.

The numeric modeling was validated by comparing the model outputs to existing literature and data from previous studies. Detailed descriptions of the modeling and findings are presented in Part 10 of Volume 2.

Temperature and salinity in the study area are discussed in Section 8.4.

8.3.2.2 Orokolo Bay

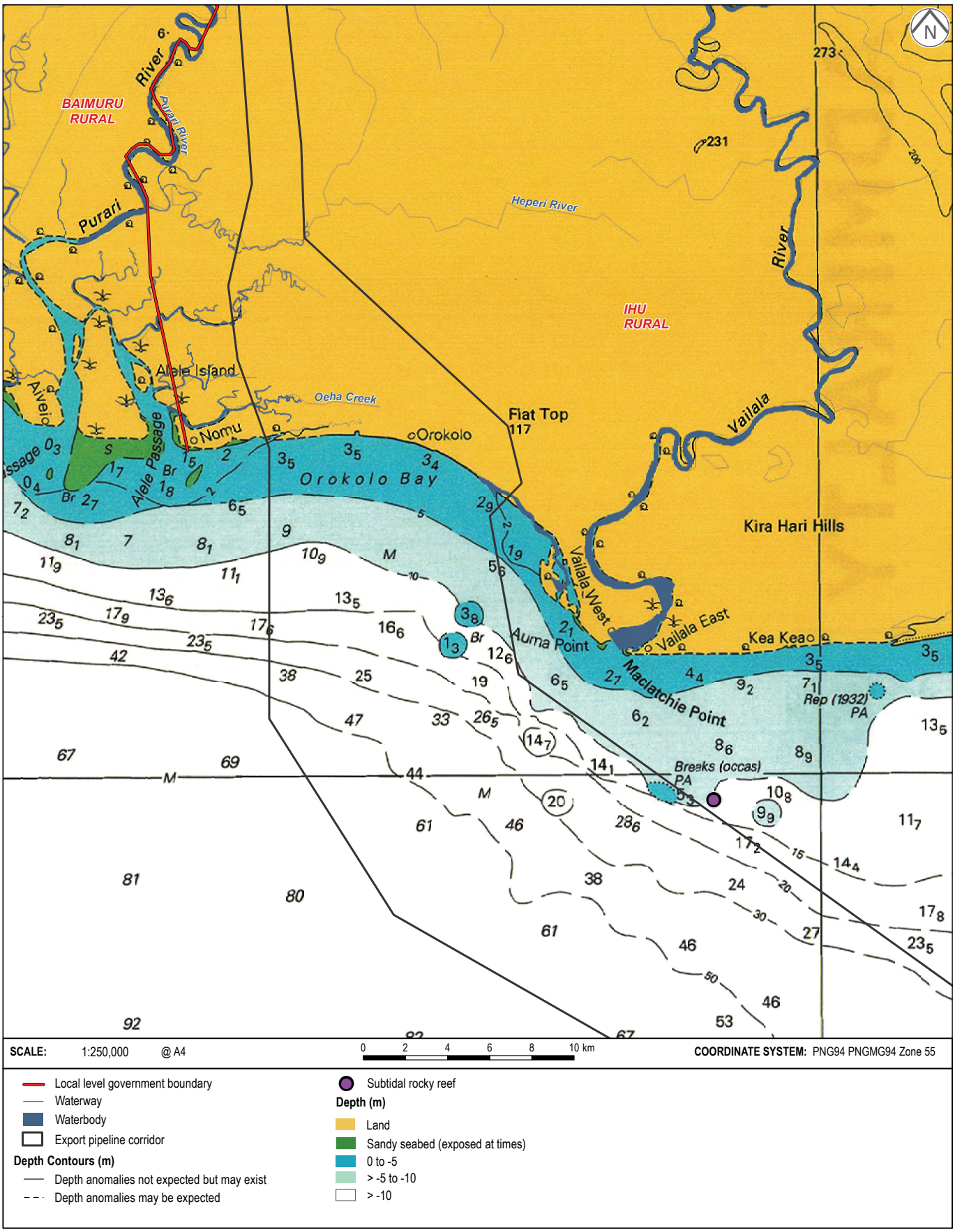
Bathymetry

Orokolo Bay is relatively shallow and flat, with a uniform slope throughout the bay (Figure 8.6). As described in Section 8.2.2.2, a very shallow zone extends approximately 2 km offshore from the mouth of the Purari River eastern channel, with water depths less than 3 m during high tide. The 15 m depth contour is approximately 8 km from the shoreline. Although some shallow shoals (e.g., naturally submerged ridges, banks or bars) are shown in Figure 8.6, including two locations west of Auma Point at the mouth of the Vailala River charted as being 3.8 m to 1.3 m deep, such features were not found to occur at these locations during the marine field surveys. One subtidal rocky reef was identified east of Orokolo Bay offshore from the Vailala River in approximately 15 m of water (shown in Figure 8.6 and described in more detail in Section 8.5.2.2).

BATHYMETRY OF OROKOLO BAY

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FIGURE 8.6



Source: Australian Hydrographic Service (2008) AUS 378

Tides

Tides are semidiurnal, with a tidal range in Orokolo Bay of approximately 3 m measured during the 2016 and 2017 marine field surveys. The TUFLOW-FV modeling shows the tidal range to be approximately 1 m during neap tides and 3 m during spring tides.

Currents

No measured current data is available in the vicinity of Orokolo Bay; therefore, current speed and direction were extracted from the TUFLOW-FV numerical model. The net current velocities beyond the 15 m contour are larger during the southeast trade wind season than during the northwest monsoon season, with maximum velocities of up to 0.5 m/s in the upper 10 m of the water column, and are directed toward the southeast. This is related to the Hiri Current, a large-scale clockwise current circulation pattern in the Gulf of Papua (more detail on currents in the gulf are provided in Section 8.3.2.3). During the northwest monsoon season, the current magnitude is generally small (i.e., less than 0.25 m/s in the upper 10 m of water) and is directed toward the northwest in the offshore part of Orokolo Bay (i.e., which is more than 15 m deep), which is part of an anticlockwise circulation pattern in the Gulf of Papua (Section 8.3.2.3).

Waves

Waves during the southeast trade wind season come predominantly from the south to southeast with significant wave heights up to 1.6 m. Waves during the northwest monsoon season are predominantly less than 1 m and, although variable, are mostly from the south-southwest (Figure 8.7). Wave height decreases closer to shore during both seasons.

8.3.2.3 Offshore Export Pipeline Corridor

Bathymetry

The offshore export pipeline corridor traverses the edge of the continental shelf along the eastern side of the gulf, with depths reaching up to 90 m.

Tides

Measurements of water level and the TUFLOW-FV modeling show that tides are semidiurnal along the offshore export pipeline corridor, with a tidal range of approximately 3 m, the same as occurs at Orokolo Bay.

Currents

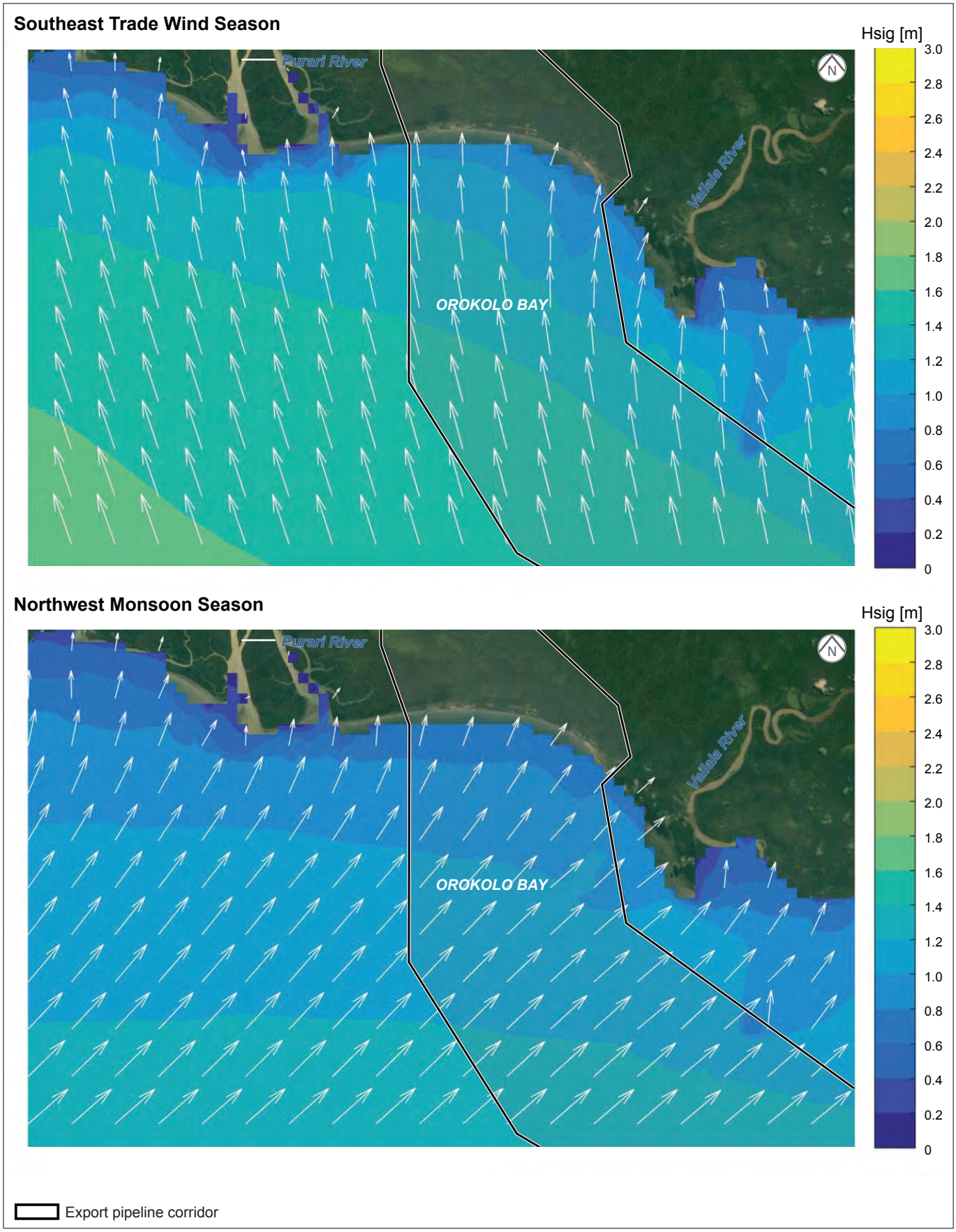
A maximum current speed of 0.6 m/s was previously recorded along the offshore export pipeline corridor, approximately 40 km south-southeast of Kerema, with a regular tidal variation of around 0.2 m/s (CNS, 2008b). The net current during the southeast trade wind season was usually directed toward the southeast with an average velocity of 0.2 m/s. The current direction in the opposite direction to the prevailing wind is due to the overall pattern of circulation in the gulf, with water further offshore driven by the wind into the gulf and returning via a coastal current along the southern PNG coastline. During the northwest monsoon season, currents were more variable but often moved in a westerly direction, with an average velocity of 0.1 m/s.

Figure 8.8 presents the net current patterns indicated by the TUFLOW-FV numerical model. The modeled current patterns are consistent with the measured currents described in CNS (2008b). The model results indicate that the currents along the offshore export pipeline corridor during the southeast trade wind season are generally directed toward the southeast. During the monsoon season, the currents are smaller in magnitude and are directed toward the northwest along the northern part of the pipeline corridor and to the southeast along the southern part of the pipeline

TYPICAL WAVE PATTERN IN OROKOLO BAY DURING THE SOUTHEAST TRADE WIND SEASON AND NORTHWEST MONSOON SEASON

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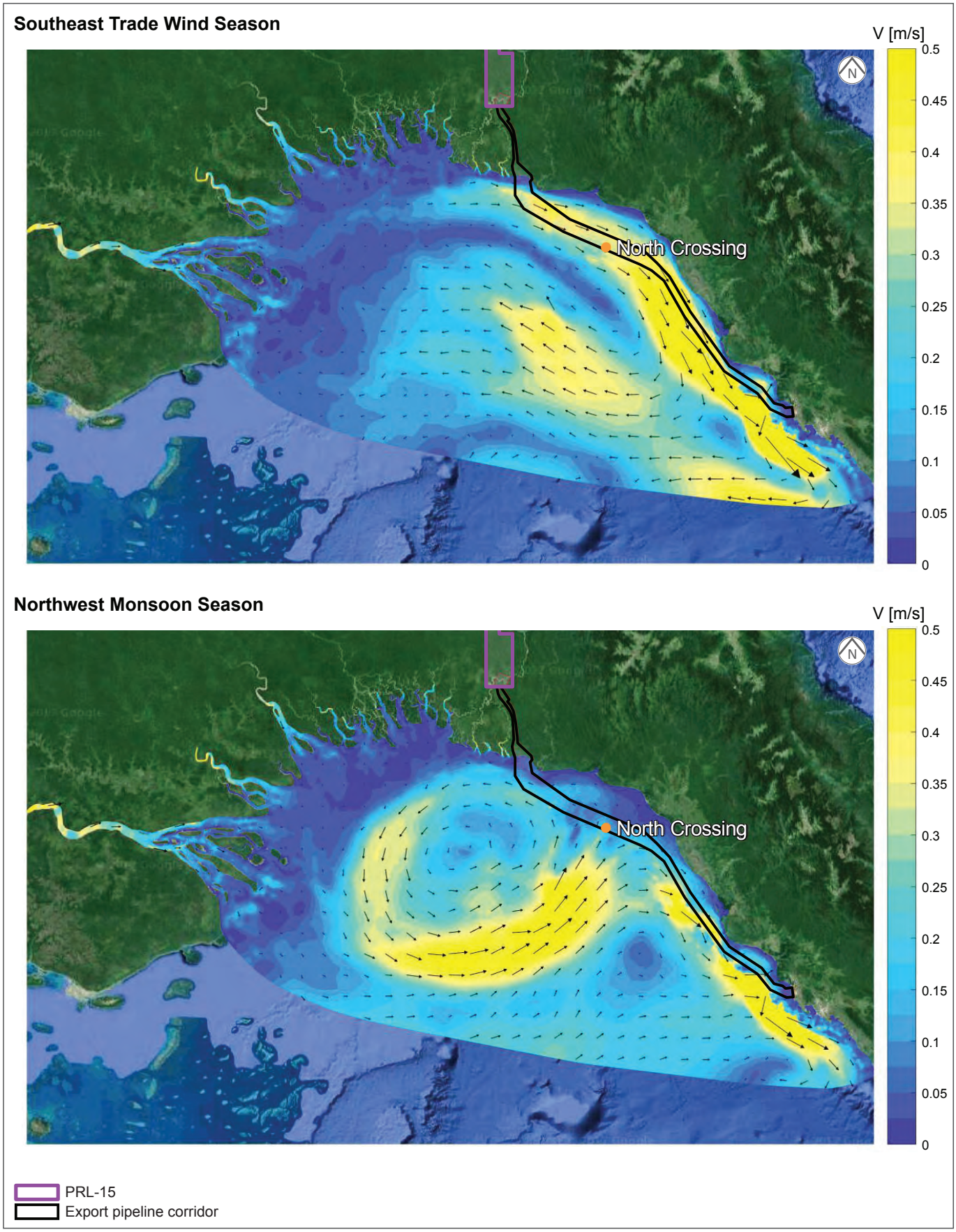
FIGURE 8.7



MODELED NET CURRENTS FOR THE SOUTHEAST TRADE WIND SEASON AND NORTHWEST MONSOON SEASON

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FIGURE 8.8



corridor. The model results indicate that the Hiri Current clockwise gyre operates further offshore in the northwest monsoon season off the continental shelf in concert with a separate anticlockwise gyre in the gulf, which is also referred to by Wolanski et al. (1995). In the southeast trade wind season, the model indicates that the prevailing winds from the southeast set up a larger clockwise gyre that encompasses the entire gulf.

The current patterns indicated by the numerical model are consistent with the results of previous studies, including Slingerland et al. (2008).

Waves

The SWAN wave model shows that waves during the southeast trade wind season are predominantly from the south due to the prevailing southeast wind direction and the pattern of wave refraction in the gulf (Figure 8.9). The significant wave height has an average of around 1.5 m and a maximum of 2 m. During the monsoon season, the wave direction is more variable, coming from the west to the south. The magnitude is also much lower, with a maximum significant wave height of around 1 m. Wave roses based on modeled data are provided for both seasons in Part 10 of Volume 2.

8.3.2.4 Caution Bay

Bathymetry

The bathymetry of Caution Bay is complex, with extensive coral reef formations and shoals, and deeper channels (see Figure 8.5). The average water depth in the bay is around 25 m. The bay is protected to the south by an outer barrier reef, which includes the coral cay, Idihi Island (see Figure 8.5). Beyond this outer barrier reef, the seafloor drops sharply to depths reaching over 1,000 m.

Tides

Water level measurements undertaken by bottom-mounted acoustic doppler current profilers for extended periods in 2007 to 2009 show that the tides in Caution Bay are semidiurnal with a maximum tidal range of approximately 3 m (CNS, 2008b).

Currents

Previous studies undertaken in Caution Bay have found that current speeds are generally low (i.e., less than 0.5 m/s) (CNS, 2008b). The direction tends to vary according to the tide during the northwest monsoon season but has a net northwesterly direction during the southeast trade wind season. In contrast, currents in Orokolo Bay and along the offshore export pipeline corridor move in a southeasterly direction in the southeast trade wind season. The difference in net current patterns in Caution Bay in the southeast trade wind season is likely due to a local current generated by the prevailing southeasterly winds. The TUFLOW-FV model also shows net currents in Caution Bay to be minimal and less than 0.1 m/s.

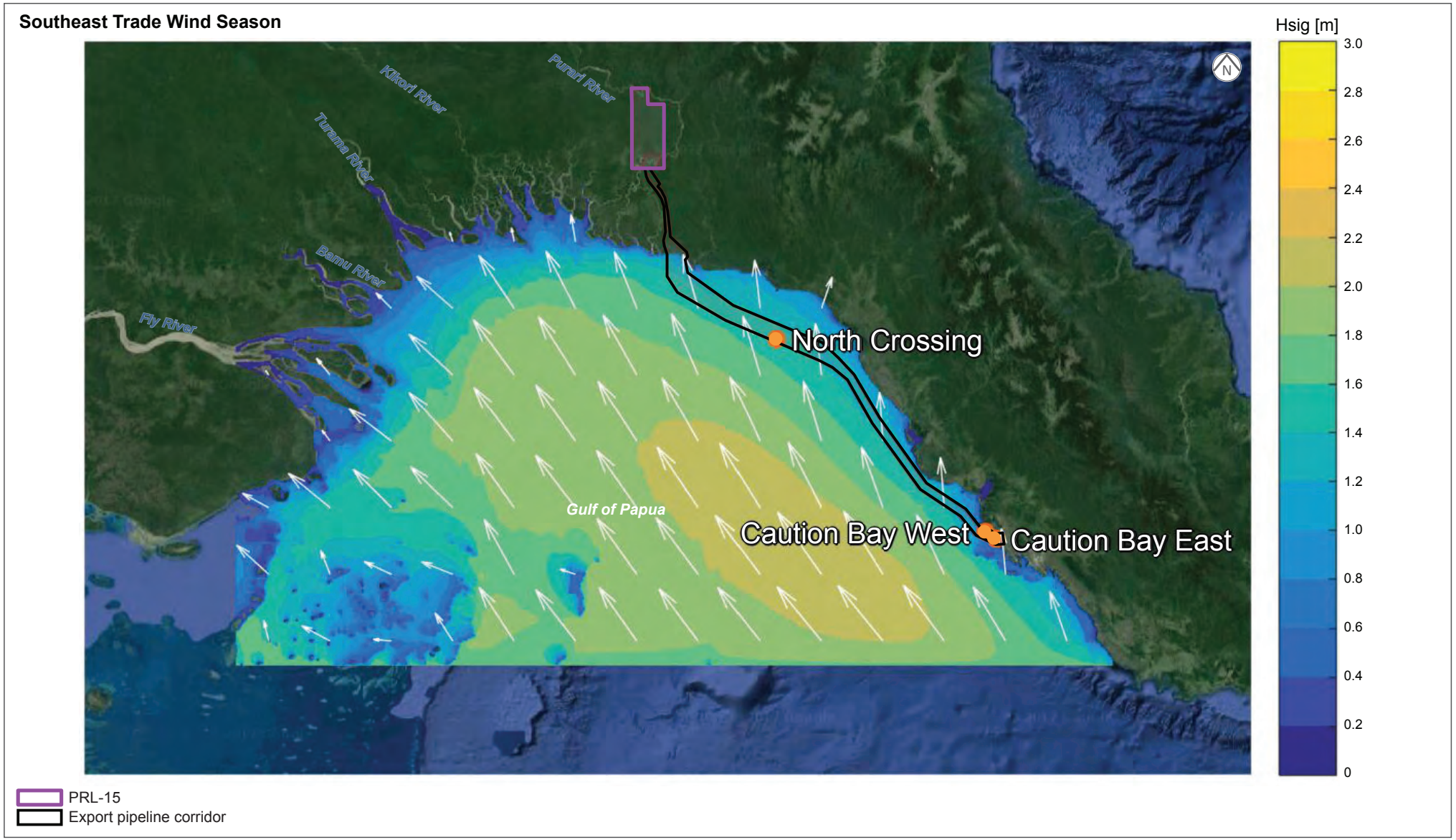
Waves

Measurements obtained from acoustic doppler current profilers deployed in Caution Bay during 2007 to 2009 found waves were predominantly from the south to southwest during the southeast trade wind season, with significant wave height predominantly less than 1 m. During the northwest monsoon season, the wave direction is from the west to southwest, with a significant wave height up to 1.5 m. The higher wave heights recorded during the northwest monsoon season are likely due to a higher incidence of waves from the less protected westerly direction. The outer barrier reef protects the bay from waves approaching from the south.

TYPICAL WAVE PATTERN ALONG THE OFFSHORE EXPORT PIPELINE CORRIDOR DURING THE SOUTHEAST TRADE WIND SEASON

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FIGURE 8.9



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The typical wave patterns (significant wave height and direction) in Caution Bay from TUFLOW-FV modeling of the southeasterly trade wind season and northwest monsoon season conditions are shown in Figure 8.10. Clearly, wave propagation into the bay can be much greater during the northwest monsoon season under westerly wind conditions.

8.4 Marine Water and Sediment Quality

8.4.1 Regional Context

The waters of the gulf are influenced by seasonal changes in wind and current patterns and by seasonal rainfall. Turbidity in the gulf is affected by inputs of terrigenous sediments delivered by some of the largest rivers in Papua New Guinea, which deliver over 365 million tonnes (Mt) of sediment per year into the river floodplains and deltas and the gulf (Milliman, 1995). Fluvial sediment loads are discharged into the gulf at a fairly consistent rate year-round but are highest during the northwest monsoon season (Slingerland et al., 2008). Turbid brackish plumes have been noted to extend up to 50 km from the mouth of some of the larger gulf rivers (CNS, 2008b). The 2015 Landsat imagery in Figure 8.3 shows a turbid plume extending approximately 10 km from the Purari River mouth. A turbid plume from the Purari River is also shown in Plate 8.5.

Plate 8.5 – Turbid Plume from the Purari River in Orokolo Bay



Photo: ERIAS Group.

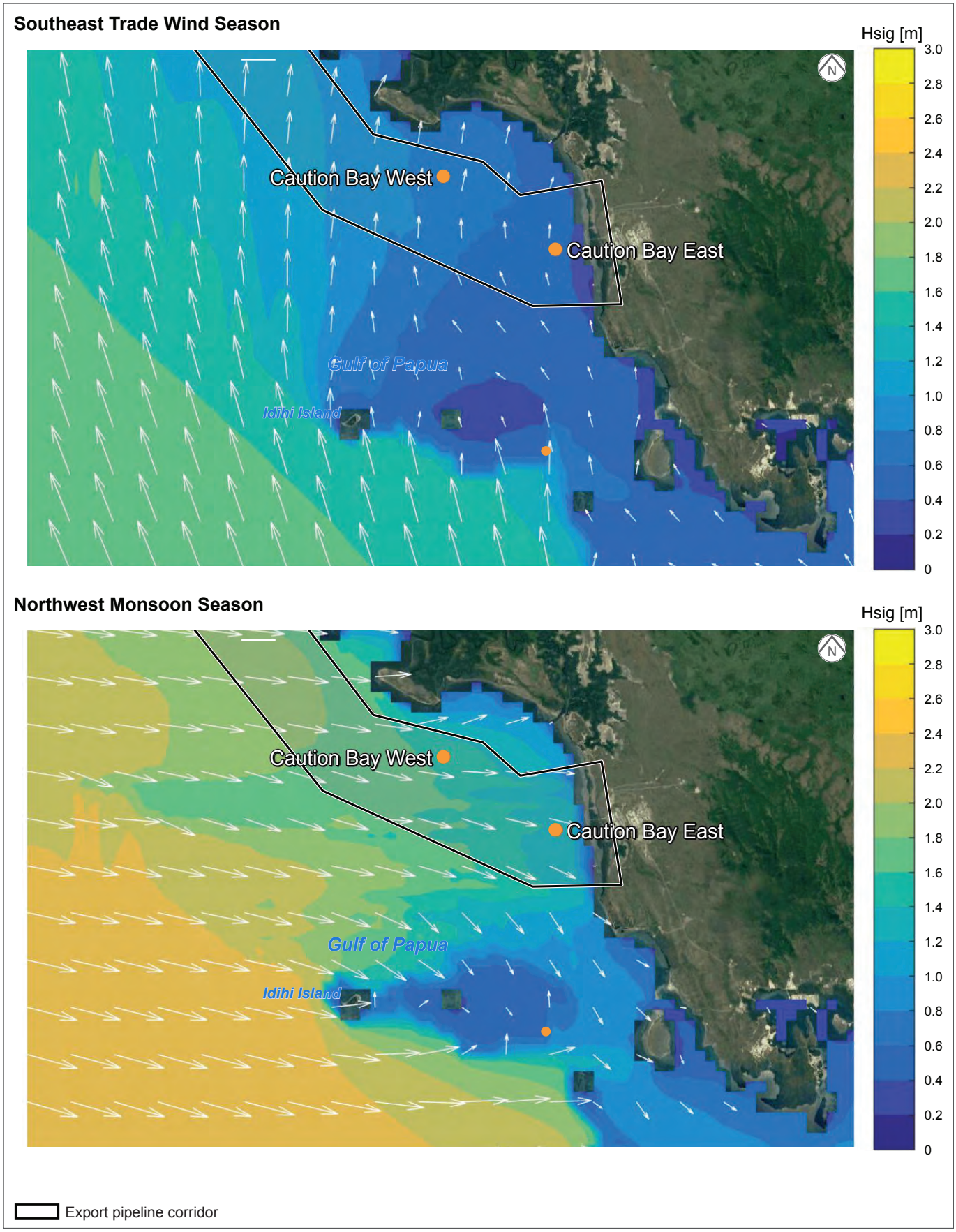
Salinity and temperature profile measurements undertaken by Robertson et al. (1998) have shown that a surface lens of low-salinity water extends across the inner gulf within 50 km of the coast, with a thickness of up to 40 m in the upper water column. Martins and Wolanski (2015) reported that this freshwater discharge produces a brackish water plume that covers most of the gulf, extending to 20 m deep and progressively thinning out with increasing distance from the coast.

Wind-driven waves resuspend sediments in the gulf, which results in increased turbidity (Saint-cast & Condie, 2006). Turbidity generated from wind-driven waves is generally highest during the southeast trade wind season when wind speeds are generally strong, reaching their peak in July then progressively weakening.

TYPICAL WAVE PATTERN IN CAUTION BAY DURING THE SOUTHEAST TRADE WIND SEASON AND NORTHWEST MONSOON SEASON

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FIGURE 8.10



8.4.2 Marine Water Quality Baseline Characterization

8.4.2.1 Study Overview

Two field surveys of marine waters were completed during the southeast trade wind season and the northwest monsoon season (Part 23 of Volume 2). The survey sites are shown in Figure 8.11.

The surveys involved in situ water column profiling of physicochemical parameters (i.e., turbidity, conductivity, salinity, temperature and dissolved oxygen) at 46 sites. Grab samples were obtained at 28 sites from various depths (i.e., surface, middle and bottom waters) for laboratory analysis of nutrients (i.e., ammonia, nitrate/nitrite, total nitrogen, filterable reactive phosphorus and total phosphorus), chlorophyll-a and contaminants (i.e., total and dissolved metals/metalloids, polyaromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), and benzene, toluene, ethylbenzene and xylenes (BTEX)). Water quality instruments were deployed at two sites in Orokolo Bay during both surveys. These instruments collected continuous bottom measurements of turbidity, conductivity, salinity, temperature and water depth.

This data was considered in conjunction with available information from previous studies to describe existing marine water quality in the study area, incorporating Orokolo Bay, the offshore export pipeline corridor and Caution Bay.

To provide a benchmark for the water quality results, data was compared to Schedule 1 of the *Environment (Water Quality Criteria) Regulation 2002* for marine waters, which provides legally enforceable water quality criteria in Papua New Guinea. The assessment also considered Australian and New Zealand guidelines for fresh and marine water quality (ANZECC/ARMCANZ, 2000), which provide good international industry practice guidance relevant to the region. Guidelines do not exist for all water quality parameters and analytes, including some nutrients and metals, such as aluminium and strontium; therefore, these are discussed in relative terms.

8.4.2.2 Orokolo Bay

Freshwater discharges from the Purari River and seasonal conditions strongly influence water quality in Orokolo Bay, e.g., sediment remobilization due to wind-driven waves during the southeast trade wind season.

Water quality profiling measurements of temperature, salinity, turbidity and dissolved oxygen were taken at each of the sampling sites during the southeast trade wind season and northwest monsoon season surveys (Figures 8.12 and 8.13). The temperature and salinity profiles show that the water column was significantly stratified at all measurement sites due to large freshwater inflows. This was particularly evident during the southeast trade wind season survey, when higher temperatures and lower salinities were observed in the upper 5 m of the water column compared to deeper waters.

Turbidity was low, being below 15 nephelometric turbidity units (NTU) throughout the water column at all sites in Orokolo Bay during the southeast trade wind season sampling event. Turbidity in the northwest monsoon season was generally lower and below 5 NTU at most sites. Two additional sites close to the Purari River mouth, sampled in the northwest monsoon season, recorded turbidity between 75 and 145 NTU nearest the river mouth (site M45), decreasing to less than 10 NTU about 5 km south of the river mouth at site M46 (Figure 8.11). Total suspended solid (TSS) levels were below 20 mg/L at all sites during the southeast trade wind season and generally less than 5 mg/L during the northwest monsoon season, correlating with turbidity. The highest TSS levels recorded were near the Purari River mouth, where concentrations were about 100 mg/L in surface and bottom waters during the northwest monsoon season.

MARINE SURVEY SITES

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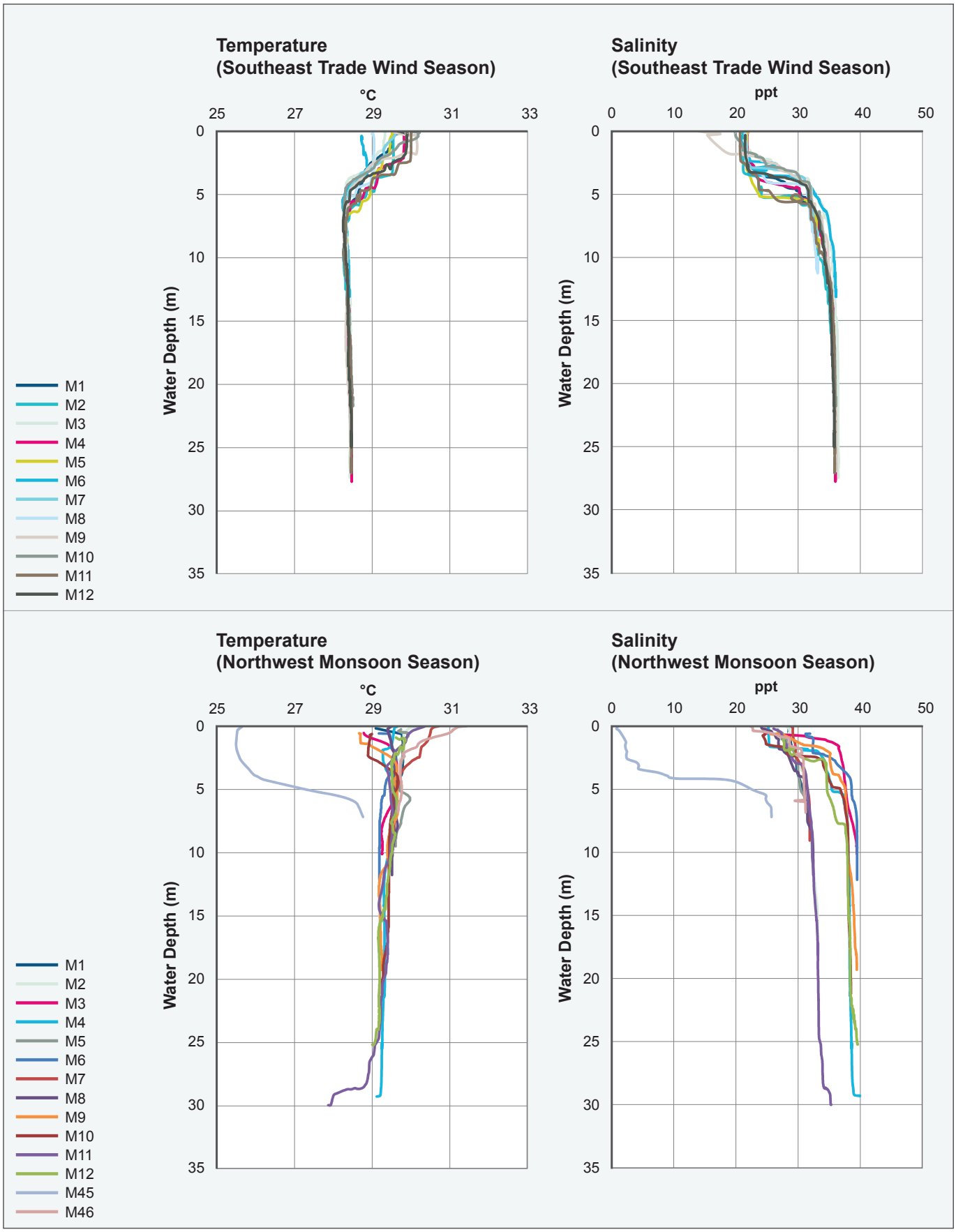
FIGURE 8.11



TEMPERATURE AND SALINITY PROFILES IN OROKOLO BAY

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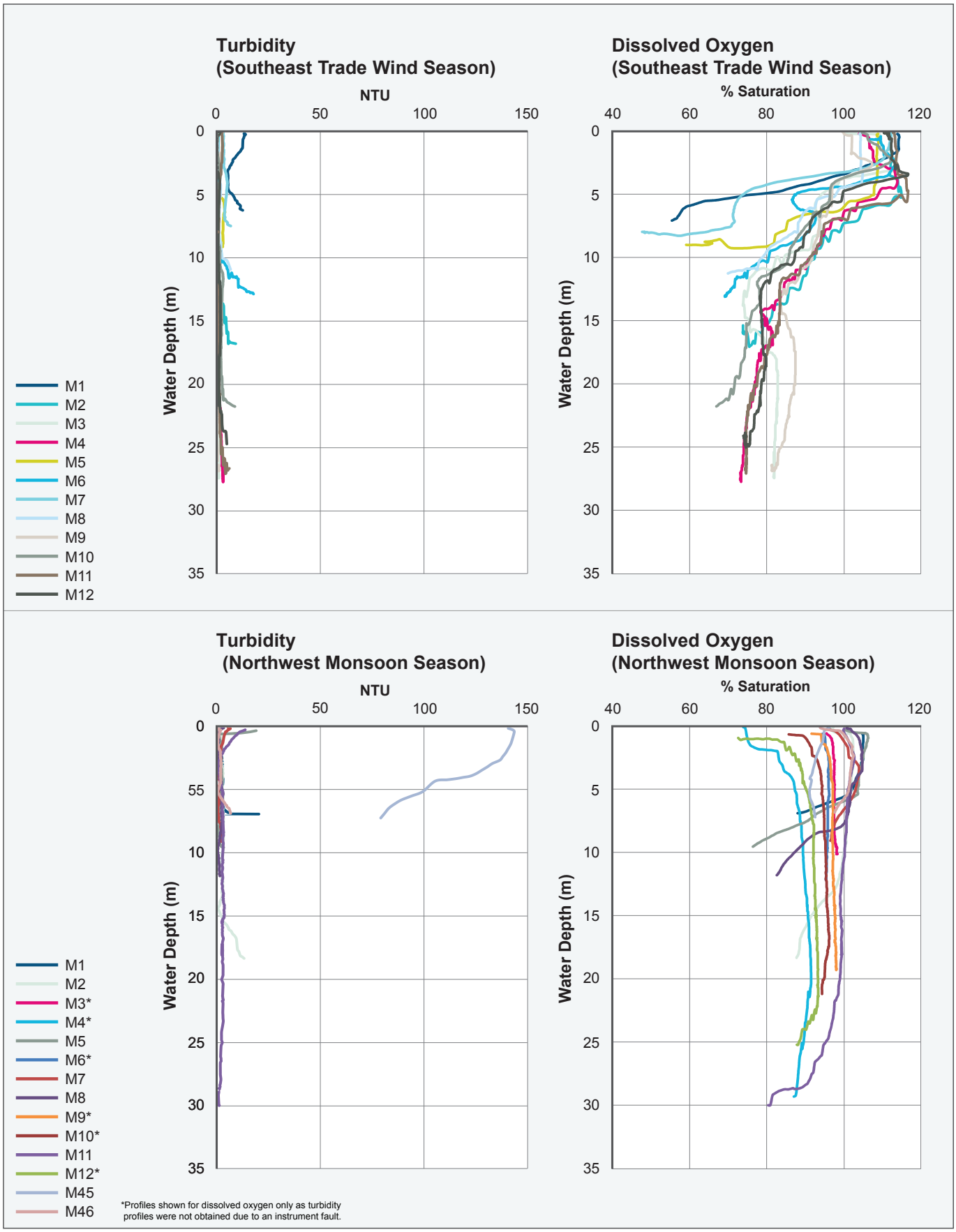
FIGURE 8.12



TURBIDITY AND DISSOLVED OXYGEN PROFILES IN OROKOLO BAY

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FIGURE 8.13



Continuous turbidity data collected from bottom-mounted instruments indicates that turbidity in Orokolo Bay is strongly linked to weather conditions. Higher winds and rougher seas resulted in increased turbidity levels to nearly 450 NTU in the southeast trade wind season during June to July 2016. During the northwest monsoon season, high flow events in the Purari River also increased turbidity levels close to the river mouth with values around 450 NTU recorded during one such event in January 2017 (Figure 8.14). The turbidity data collected from the bottom-mounted instruments is generally much higher than the water quality profiling data, which were below 15 NTU at most sites. This is due to the nature of profiling through the entire water column, and timing of profiling, i.e., undertaken during calmer periods when turbidity was lower. The bottom-mounted instruments are also exposed to resuspended bed sediments mobilized in water currents and wave action, and were located closer to river mouths than many of the profiling sites.

During the southeast trade wind season, dissolved oxygen levels in surface waters were greater than 100% saturation but decreased to 70 to 80% at around 5 to 10 m below the surface, which is below the ANZECC/ARMCANZ (2000) guideline value of 90% saturation. During the northwest monsoon season, dissolved oxygen levels varied less with depth and in some cases increased with depth, indicating greater mixing of waters during this sampling event.

Water pH at sampling sites in Orokolo Bay ranged from 7.8 to 8.3 and was generally similar between depths, sites and seasons. Freshwater inflows to Orokolo Bay have relatively little influence on pH, although the higher pH in the upper 5 m of the water column during the southeast trade wind season indicates that the riverine inflow is more alkaline than the receiving marine water.

All sites in Orokolo Bay had relatively low nutrient concentrations, with most results below laboratory limits of reporting during both surveys. Ammonia was an exception, with generally higher concentrations during the northwest monsoon season survey, when fluvial inputs would be expected to be higher. Ammonia concentrations in all samples were below the ANZECC/ ARMCANZ (2000) toxicity-based guideline value (0.91 mg/L) for the protection of aquatic ecosystems. Nitrate/nitrite concentrations were above laboratory reporting limits at some sites (i.e., ranging from 0.01 to 0.1 mg/L). The higher levels (i.e., up to 0.1 mg/L at site M3; see Figure 8.11) were measured in the southeast trade wind season in contrast to observations for ammonia. Total phosphorus concentrations during the southeast trade wind season survey were mostly below the limit of reporting (0.05 mg/L); however, higher concentrations (i.e., up to 0.26 mg/L) were measured at some sites during the northwest monsoon season survey.

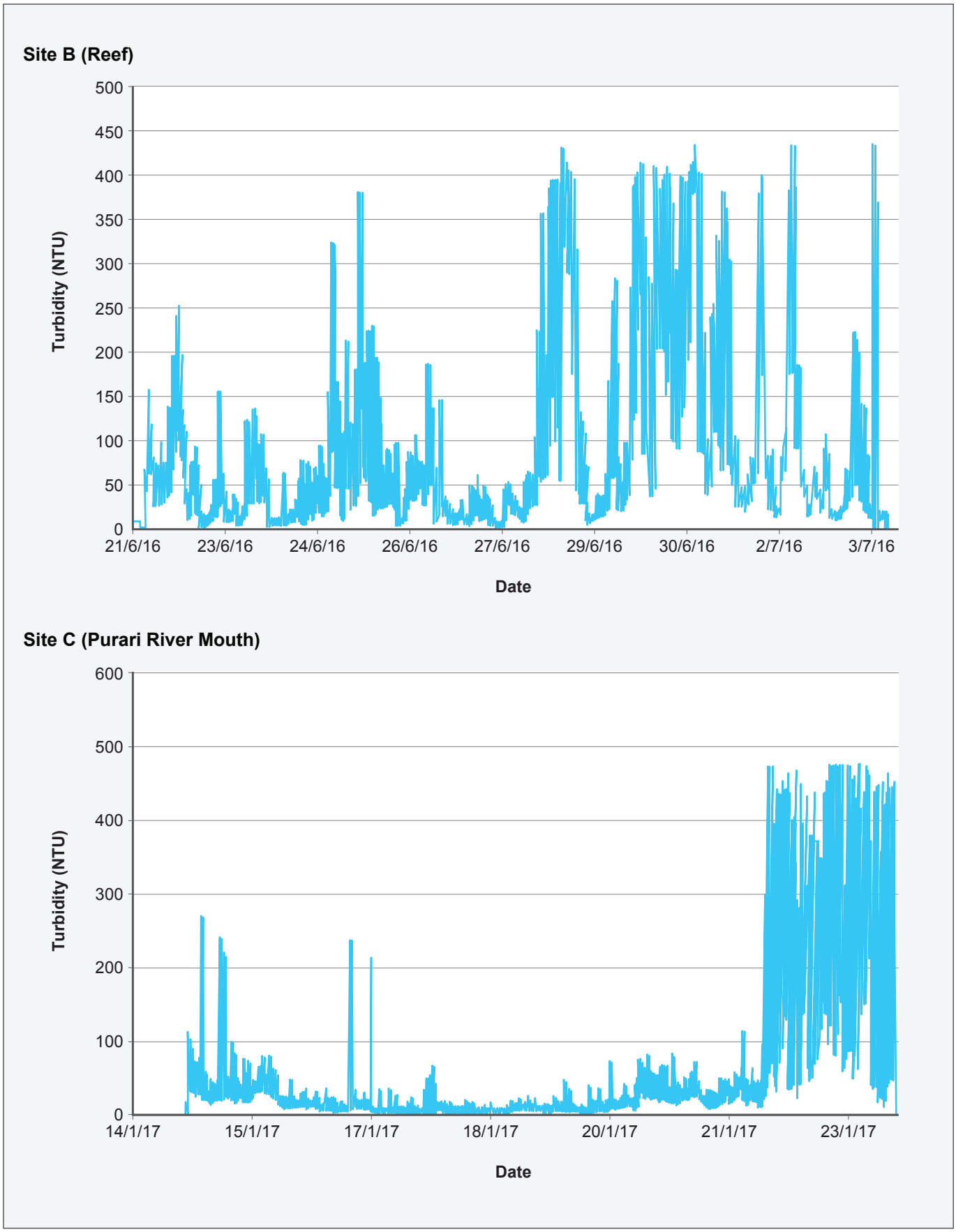
Elevated nutrient levels can result in nuisance algal growth depending on a number of factors; however, chlorophyll-a levels, which are indicative of phytoplankton growth, were low, with all results being below or close to the laboratory limit of reporting (1 µg/L). Fluvial discharges can typically lead to increased chlorophyll-a levels due to nutrient inputs; however, there was no evidence of this, with chlorophyll-a levels at sites most likely influenced by fluvial discharges (i.e., those closest to the Purari River mouth and sites M45, M46 and M7) less than 2 µg/L.

Concentrations of dissolved (i.e., filtered less than 0.45 µm) metals/metalloids in Orokolo Bay were generally similar between different sites, water depths and seasons. With the notable exception of strontium, levels were low, mostly less than laboratory reporting limits and below Schedule 1 of the *Environment (Water Quality Criteria) Regulation 2002* and ANZECC/ARMCANZ (2000) guideline values. Copper and mercury marginally exceeded the ANZECC/ARMCANZ (2000) guideline values in separate single samples from Orokolo Bay; however, these results were only marginally above the limit of reporting.

CONTINUOUS BOTTOM TURBIDITY MEASUREMENTS AT OROKOLO BAY

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FIGURE 8.14



Strontium is a constituent of seawater present in naturally high concentrations. During the southeast trade wind season, notably lower concentrations of this element were present in surface water compared to concentrations in deeper water and near the river mouth, indicating the presence of a freshwater lens across the bay. Total metal/metalloid concentrations were generally similar to dissolved concentrations except for aluminium and iron, which were higher, particularly in bottom waters during the southeast trade wind season and at the site nearest the Purari River mouth. This can be attributed to the higher suspended sediment levels in these samples. Aluminium and iron are major soil constituents, hence are present at naturally high concentrations in suspended sediment.

Concentrations of all hydrocarbon contaminants (i.e., PAHs, TPHs and BTEX) at all sites during both seasons were below the laboratory limits of reporting and relevant ANZECC/ARMCANZ (2000) guideline values.

8.4.2.3 Offshore Export Pipeline Corridor

Water quality profiling measurements of temperature, salinity, turbidity and dissolved oxygen were taken at each of the sampling sites during the southeast trade wind season and northwest monsoon season surveys (Figures 8.15 and 8.16).

Stratification of the water column was not noticeable during the southeast trade wind season; but during the northwest monsoon season survey, surface water temperatures were up to 3ºC higher, and there was lower salinity in the surface waters, extending to a depth of about 30 m.

Turbidity levels along the offshore export pipeline corridor are generally low and mostly less than 5 NTU throughout the water column in both seasons. Total suspended solids levels were less than 10 mg/L during the southeast trade wind season survey except for one bottom water sample (14 mg/L). Lower TSS levels were measured during the northwest monsoon season survey with most results less than 1 mg/L.

The upper 20 m of the water column was well oxygenated during both seasons, with dissolved oxygen levels being greater than 95% saturation. Levels progressively decreased below this depth to as low as 80% saturation in bottom waters, less than the ANZECC/ARMCANZ (2000) guideline value of 90%.

Nutrient concentrations along the offshore export pipeline corridor were low and below the limit of reporting at all sites, except for ammonia, which was present at levels similar to Orokolo Bay. Low levels of total phosphorus (0.07 mg/L to 0.13 mg/L) were also detected at some sites during the northwest monsoon season. Chlorophyll-a was not detected at any site, indicating that there was no nuisance algal growth.

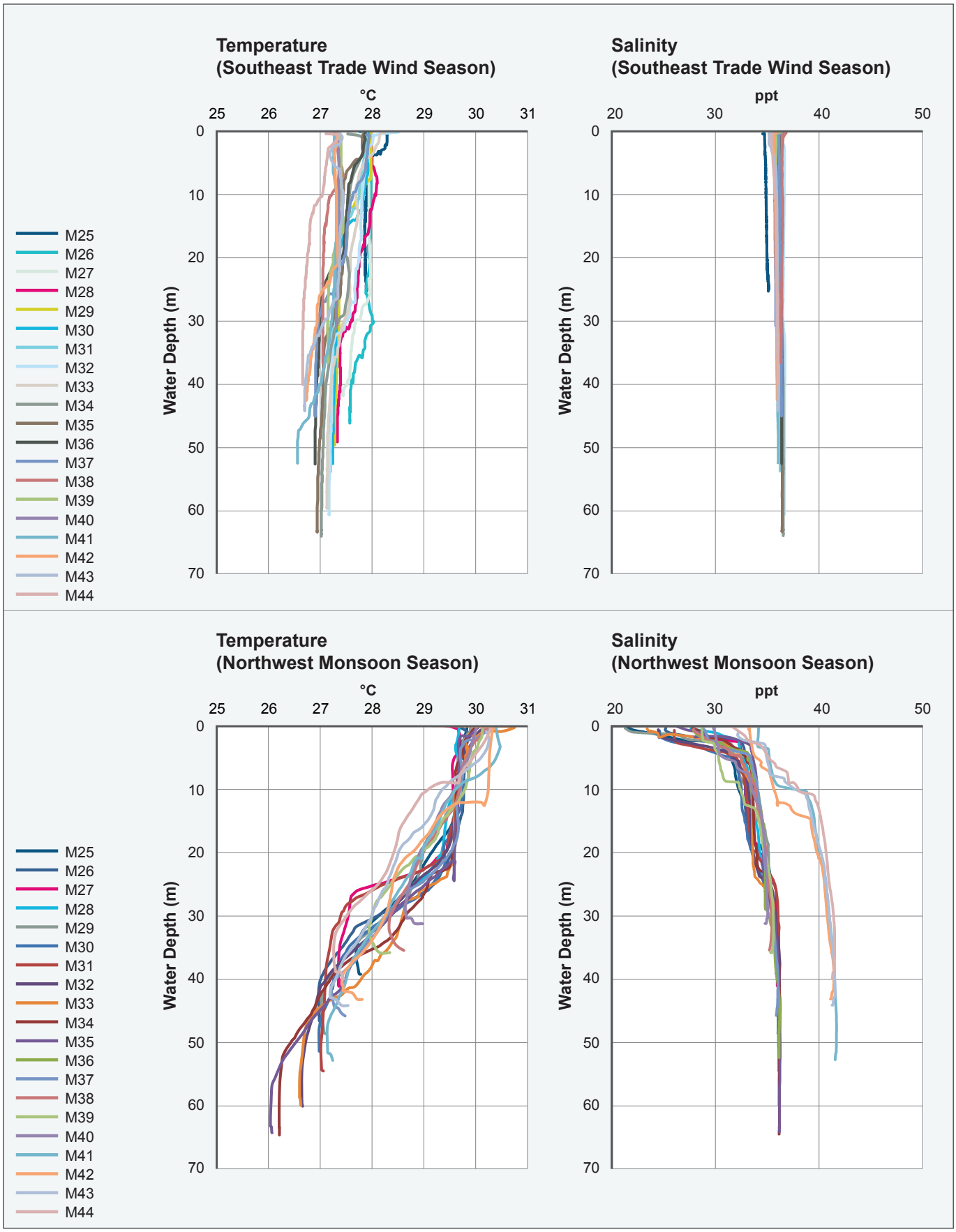
Metal and metalloid concentrations along the corridor were generally similar between sites, depths and seasons. Results were below water quality guideline values at all sites during both seasons. Total metal/metalloid concentrations were generally similar to dissolved concentrations, and concentrations were generally similar throughout the water column. Similar to Orokolo Bay, the exceptions were aluminium and iron, which had higher total concentrations in some bottom samples during the southeast trade wind season survey, reflecting the higher level of suspended sediment present in these samples due to sediment remobilization from the seabed.

Strontium concentrations were similar throughout the water column during the southeast trade wind season survey but lower in the surface water samples during the northwest monsoon season survey, which is the converse of the seasonal conditions observed in Orokolo Bay. This indicates the presence of a surface fresher water lens along the corridor during the monsoon

TEMPERATURE AND SALINITY PROFILES ALONG THE OFFSHORE EXPORT PIPELINE CORRIDOR

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FIGURE 8.15

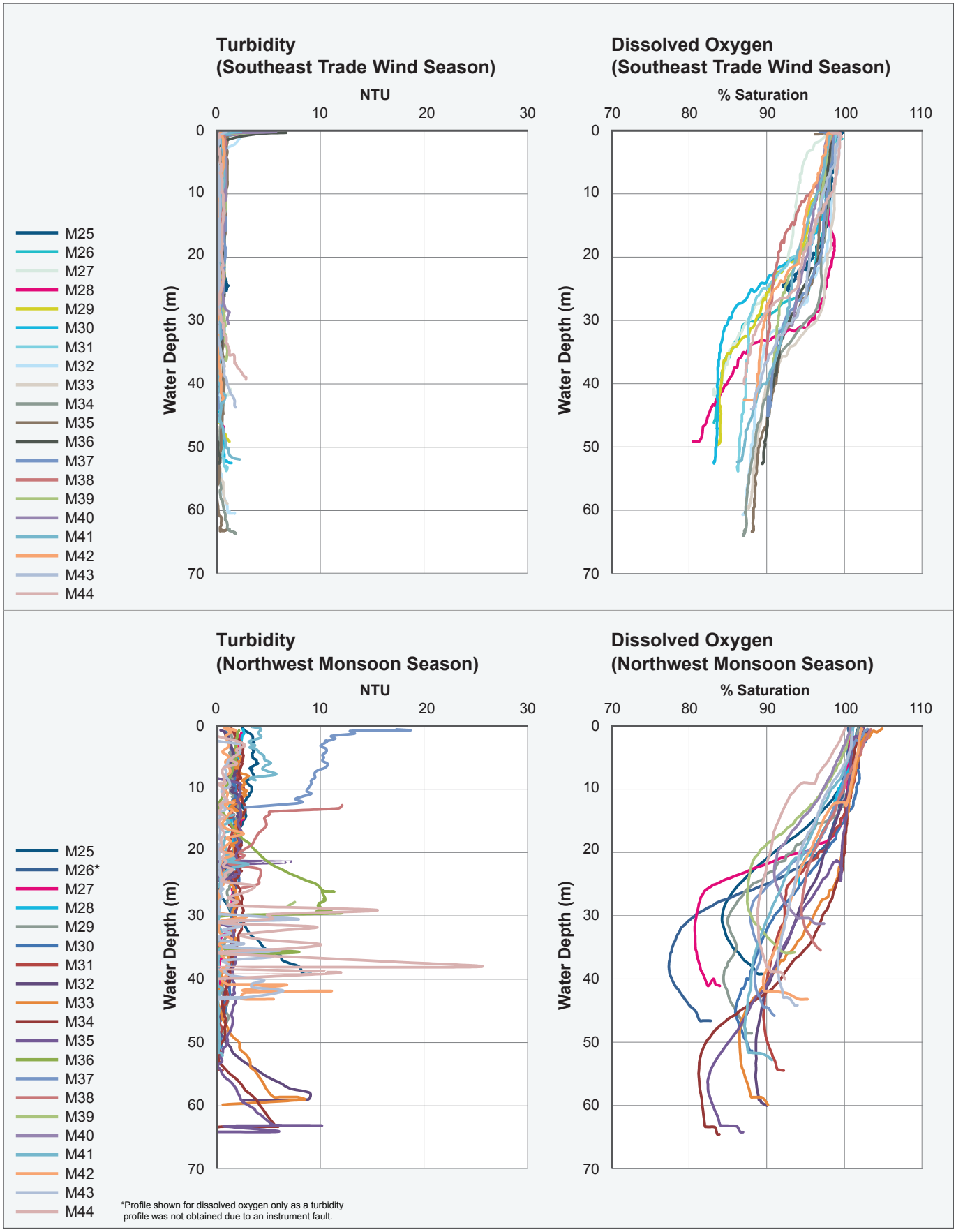


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TURBIDITY AND DISSOLVED OXYGEN PROFILES ALONG THE OFFSHORE EXPORT PIPELINE CORRIDOR

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FIGURE 8.16



season. This riverine influence on surface water is also indicated by the higher total aluminium and iron concentration in the surface water samples during the monsoon season.

Concentrations of PAHs, TPHs and BTEX were below the laboratory limits of reporting and relevant ANZECC/ARMCANZ (2000) guideline values at all sites during both seasons.

8.4.2.4 Caution Bay

Water quality profiling measurements of temperature, salinity, turbidity and dissolved oxygen were taken at each of the sampling sites during the southeast trade wind season and northwest monsoon season surveys (Figures 8.17 and 8.18).

Water quality properties in Caution Bay were relatively uniform throughout the water column during the 2016 southeast trade wind season survey and typical of conditions expected for marine waters.

During the 2017 northwest monsoon season survey, some stratification was evident, with water temperature about 2ºC warmer and salinity around 5 ppt lower in the upper 20 m of the water column. The pH was 0.1 units higher in surface waters, at around pH 8.2.

During the southeast trade wind season, turbidity levels were low (less than 2 NTU). In the northwest monsoon season, turbidity was higher but mostly less than 5 NTU although with some higher levels measured in deeper waters (i.e., sites M16, M17 and M20). This suggests that turbidity is increased due to remobilization of bed sediment by wind-driven waves. As described in Section 8.3, higher wave heights occur during the northwest monsoon season due to a higher incidence of waves from the less protected westerly direction. Shoals and a coral cay protect the bay from waves approaching from the south during the southeast trade wind season. This is consistent with previous studies conducted for the PNG LNG Project EIS, which reported higher water turbidity in Caution Bay during the northwest monsoon season than observed during the southeast trade wind season (CNS, 2008a).

Dissolved oxygen concentrations were greater than 90% saturation throughout the water column in the southeast trade wind season. Dissolved oxygen levels decreased from over 100% saturation near the surface to about 90% saturation in bottom waters in the northwest monsoon season.

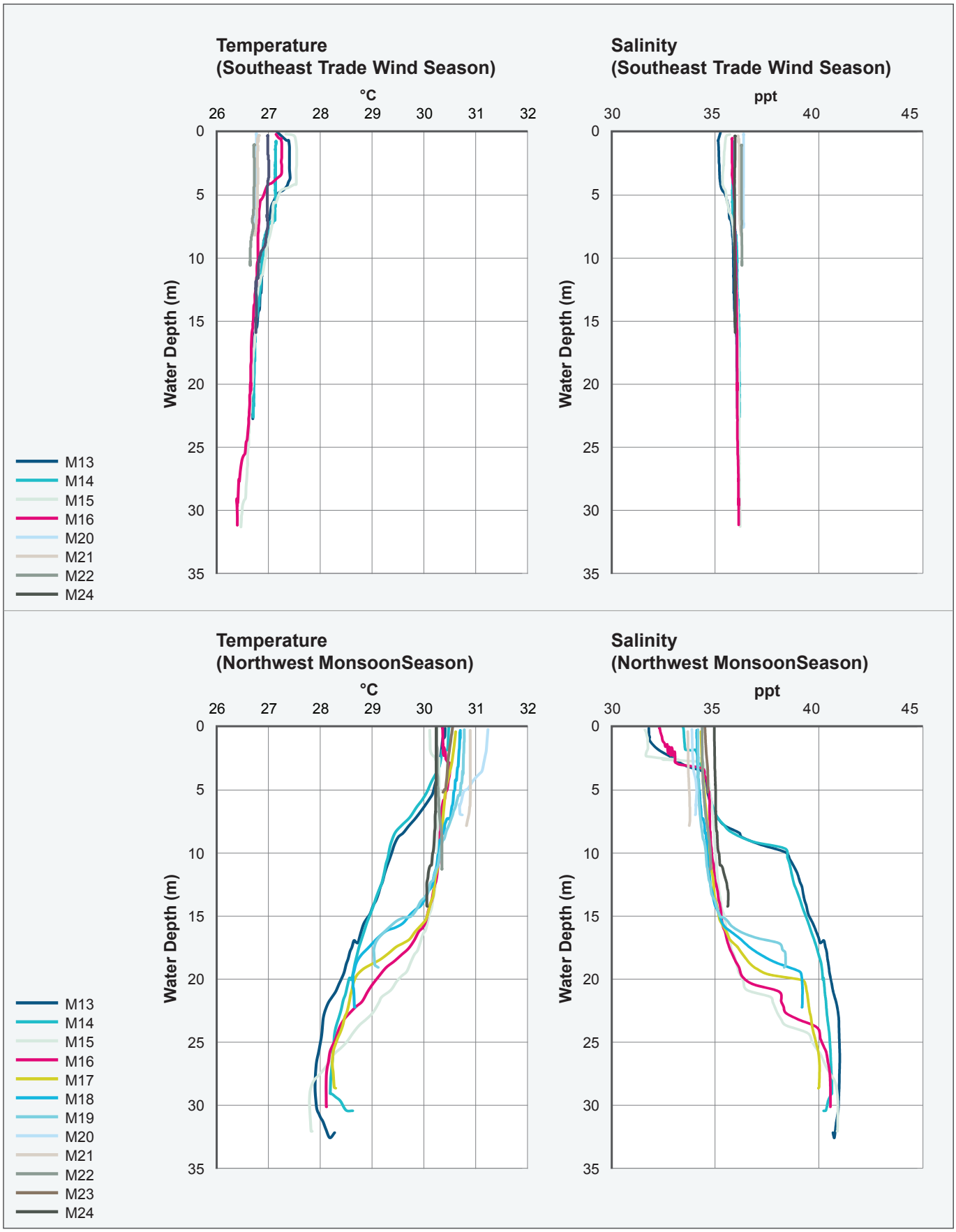
Total suspended solids were less than 8 mg/L at all sites in Caution Bay in both the 2016 southeast trade wind season survey and the 2017 northwest monsoon season survey. Previous studies in Caution Bay reported TSS levels between 2 and 17 mg/L in December 2007 during the northwest monsoon season and 26 to 68 mg/L in April 2008 during the southeast trade wind season. The higher TSS results in April were considered to be contrary to the higher visibility noted by divers and lower turbidity results compared with December (CNS, 2008a).

Previous studies in Caution Bay found nutrient levels varied seasonally, with higher levels in the southeast trade wind season, when ammonia ranged from 0.01 to 0.055 mg/L and was below the ANZECC/ARMCANZ (2000) guideline value of 0.91 mg/L (CNS, 2008a). In the current study, ammonia levels were found to be higher (i.e., 0.09 to 0.83 mg/L at most sites) but were still below the ANZECC/ARMCANZ (2000) guideline value. An ammonia concentration of 0.96 mg/L was recorded at site M13 (see Figure 8.5), which was above the guideline value (0.91 mg/L). Total phosphorus concentrations were also found to be higher in the current study, from less than 0.05 to 0.49 mg/L compared with 0.01 to 0.13 mg/L reported in CNS (2008a). In contrast to the previous studies, the current study found nutrient concentrations to be higher during the northwest monsoon season survey. Concentrations of all other nutrients in the current study were

TEMPERATURE AND SALINITY PROFILES IN CAUTION BAY

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FIGURE 8.17

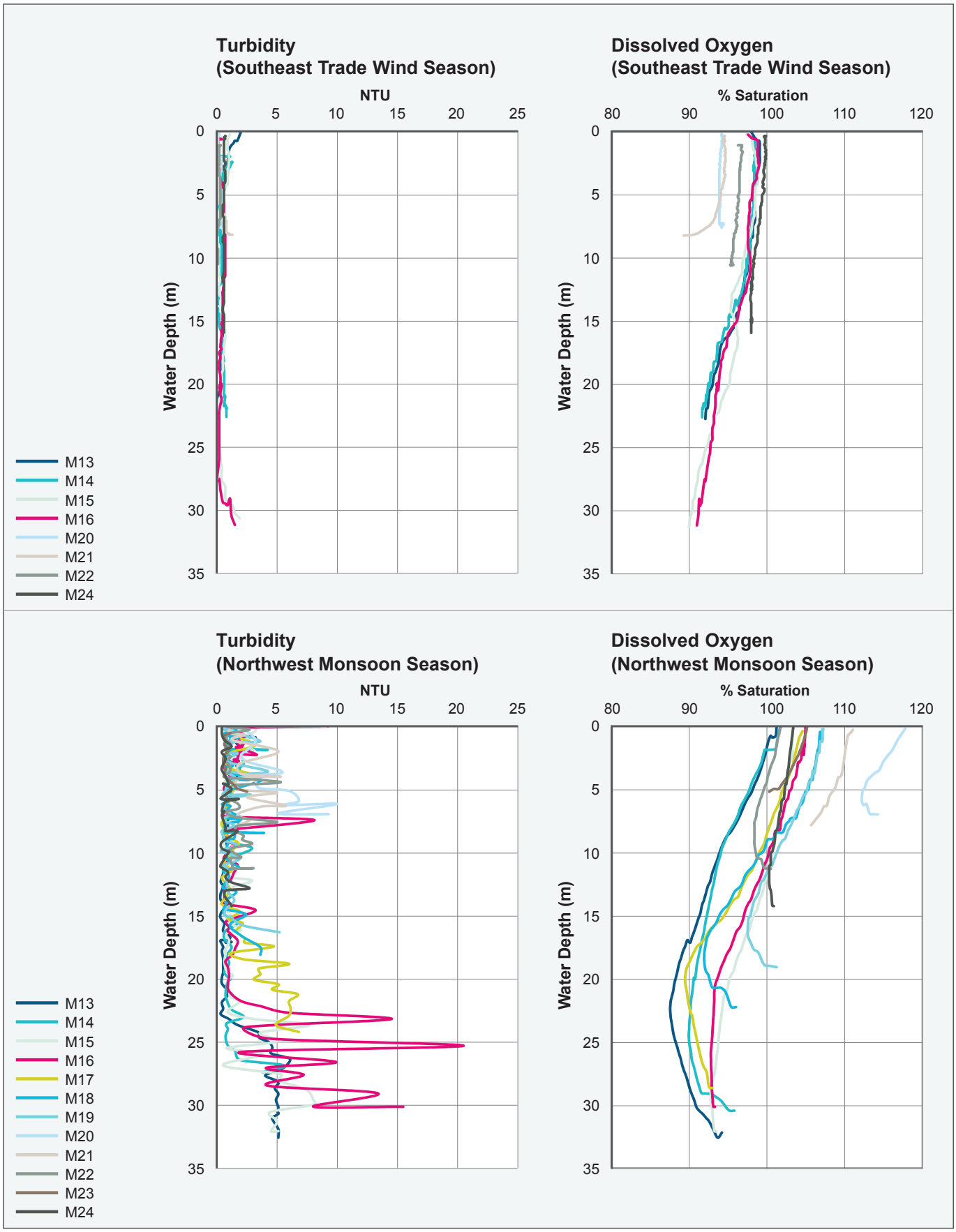


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TURBIDITY AND DISSOLVED OXYGEN PROFILES IN CAUTION BAY

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FIGURE 8.18



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below the limit of reporting at all sites during both seasons. Chlorophyll-a was not detected above the reporting limit at any site during both surveys, indicating that there was no nuisance algal growth.

Metal and metalloid concentrations were generally similar between sites, depths and seasons; and all samples were below relevant water quality guidelines. Previous studies also found metal and metalloid concentrations to be below PNG water quality criteria and ANZECC/ARMCANZ (2000) guidelines (CNS, 2008a).

Concentrations of PAHs, TPHs and BTEX were below the laboratory limits of reporting and relevant ANZECC/ARMCANZ (2000) guideline values at all sites during both seasons.

8.4.3 Marine Sediment Baseline Characterization

8.4.3.1 Study Overview

Sediment sampling in the study area was completed during the 2016 and 2017 marine surveys with samples collected from 18 sites. Sampling sites are shown in Figure 8.11.

Results from laboratory analyses of these samples were considered, in conjunction with available information from previous studies, to describe existing marine sediment characteristics in the study area, incorporating Orokolo Bay, the offshore export pipeline corridor and Caution Bay. To provide a benchmark for assessment of sediment quality, contaminant levels are compared to sediment quality guidelines contained in Schedule 2 of the *PNG Marine Pollution (Sea Dumping) Regulation 2013* and Simpson et al. (2013), which respectively provide Papua New Guinean and good international industry practice for assessing sediment contamination.

8.4.3.2 Orokolo Bay

Particle size analyses show that silts and clays comprise more than 90% of surface sediments in Orokolo Bay (Figure 8.19). This can be attributed to the influence of the Purari and Vailala rivers, which deliver large volumes of fine sediment to the gulf. Sediment is coarser in higher energy areas nearer the river mouth, with a site in the Purari River mouth (M45) having 90% sand and an inshore site nearest to the river mouth (M7) having 55% sand. Plate 8.6 shows an example of the typical, predominantly silty sediment found in Orokolo Bay.

Plate 8.6 – Typical Sediment of Orokolo Bay (Site M9)

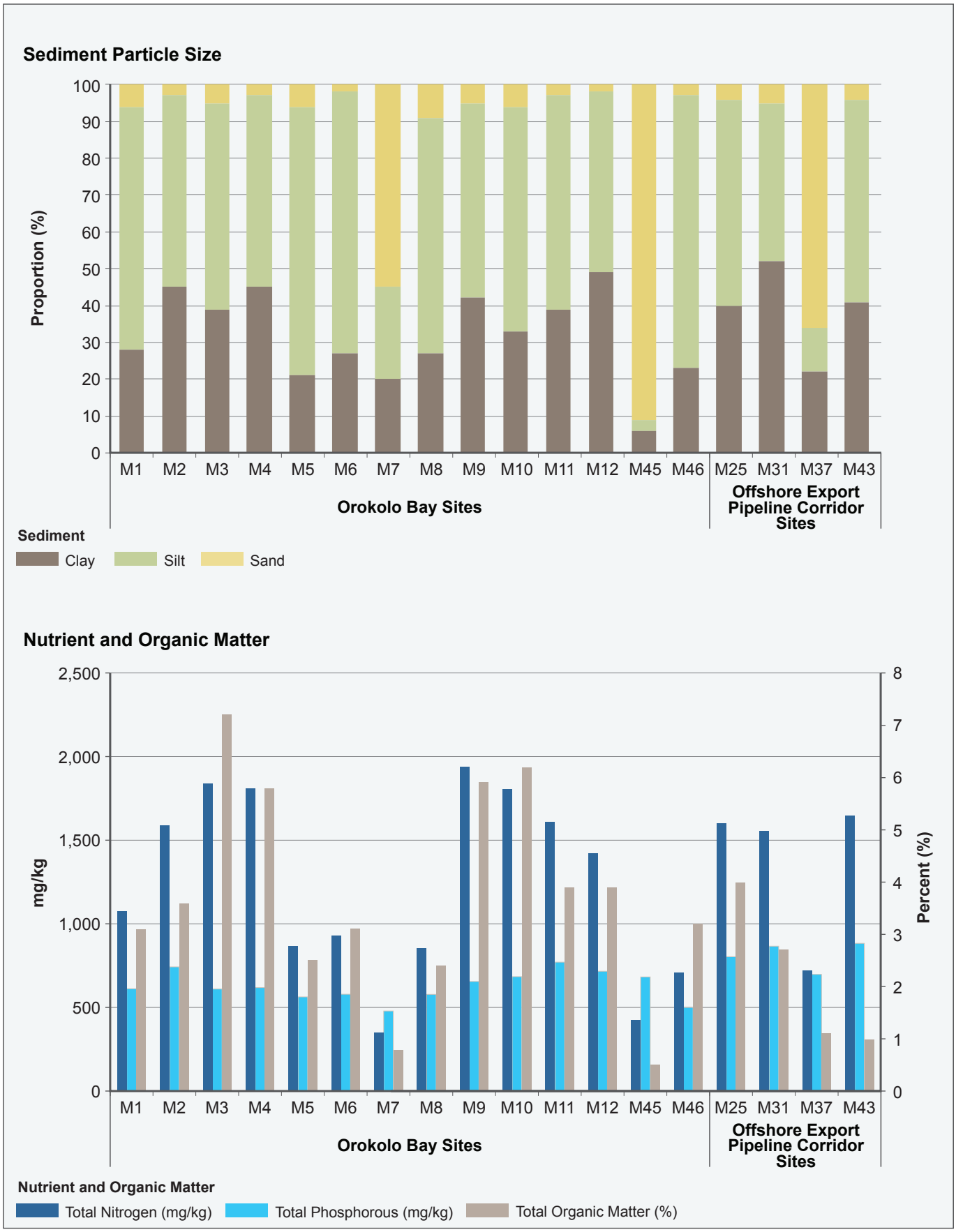


Photo: BMT WBM.

SEDIMENT PARTICLE SIZE DISTRIBUTION AND NUTRIENT AND ORGANIC MATTER CONTENT OF SEDIMENT

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FIGURE 8.19



Nutrient and organic content in sediments varies between sites according to the proportion of sand, silt and clay. Sediments with a higher clay proportion (e.g., sites M2, M3, M4, M9, M11 and M12) have higher total nitrogen and phosphorus concentrations ranging from 1,420 to 1,940 mg/kg and 608 to 773 mg/kg, respectively (see Figure 8.19). Total organic matter and total organic carbon concentrations are also higher at sites with greater amounts of silts and clay and are much lower at sites predominantly comprising sand (sites M7 and M45) with less than 0.8% total organic matter and less than 0.5% total organic carbon found at these sites.

Metal and metalloid concentrations are generally similar between sites and below sediment quality guidelines, with the exception of nickel. Nickel concentrations are similar at all sites (around 40 to 50 mg/kg), compared to the sediment guideline value of 21 mg/kg. Background nickel concentrations in sediments in Papua New Guinea are often found to be above this guideline value, reflecting the geology of the region (i.e., naturally high background nickel levels).

Metal (e.g., aluminium, copper, iron and nickel) concentrations are also notably lower at sites that contained higher amounts of sand (e.g., sites M7 and M45). This reflects the tendency for metals to be associated with finer sediment fractions due to the greater surface area available for adsorption, compared with coarser grained sands.

All hydrocarbon contaminant (i.e., PAHs, TPHs and BTEX) concentrations were below the laboratory limits of reporting and relevant sediment guideline values at all sites.

8.4.3.3 Offshore Export Pipeline Corridor

Similar to Orokolo Bay, sediments along the offshore export pipeline corridor are also predominantly silts and clays, which accounted for over 90% of sediment at most sites (see Figure 8.19). The exception was due west of Yule Island (site M37), where there is a high amount of sand-sized sediment (66%), which is likely attributable to the presence of shoals at Yule Island. An example of the typical silty clay sediment along the offshore export pipeline corridor is shown in Plate 8.7.

Plate 8.7 – Example of Typical Sediment Along the Offshore Export Pipeline Corridor (Site M31)



Photo: BMT WBM.

Sediment nutrient and organic content was similar between most sites and comparable to levels measured at Orokolo Bay (see Figure 8.19). Lower concentrations were present in sediment offshore from Yule Island, where sediment had a higher proportion of sand, and less silts and clays.

Metal and metalloid concentrations along the corridor were generally similar between sites. Concentrations were below sediment quality guidelines, except nickel concentrations, which were similar to those at Orokolo Bay from 38 to 50 mg/kg.

Concentrations of PAHs, TPHs and BTEX were below the laboratory limits of reporting and relevant sediment guideline values at all sites.

8.4.3.4 Caution Bay

No sediment samples were collected in Caution Bay during the 2016 and 2017 surveys, due to the safety risk from unexploded ordnances from a World War II battery at Boera that are possibly present in the study area. Surveys undertaken in Caution Bay for the PNG LNG Project (CNS, 2008a) indicate that, while the substrate predominantly comprises sandy sediments (Plate 8.8), there is a range of sediment types. In coral-dominated areas, sediments are characterized by larger particle size fractions associated with coral rubble and shell debris (Plate 8.9).

Plate 8.8 – Example of Sandy Sediment in Caution Bay (Site M21)



Photo: BMT WBM.

Plate 8.9 – Example of Coral Rubble and Shell Debris in Caution Bay (Site M20)



Photo: BMT WBM.

The deeper areas of Caution Bay are characterized by muddy terrigenous silt and clay sediments. The shallowest nearshore and intertidal areas, particularly in the vicinity of the Vaihua River estuary, are predominantly mudflats (CNS, 2008a).

The proportion of organic carbon in sediments in Caution Bay has previously been reported to be between 2.2 and 10%, while the total inorganic carbon was from 1.17 to 10.7% (CNS, 2008a). Nutrients were not analyzed in sediment samples collected in Caution Bay for the PNG LNG Project.

The 16 sites sampled in Caution Bay for the PNG LNG Project showed a considerable range in metal concentrations. This reflects the range of sediment particle sizes at different locations, with much higher concentrations at sites having higher amounts of silts and clays. The survey found that metal and metalloid concentrations were less than sediment quality guidelines, except nickel concentrations, which were close to or exceeded the guideline value of 21 mg/kg at some sites with results of up to 47 mg/kg (CNS, 2008a). This is consistent with the finding of high nickel concentrations in the 2016 and 2017 surveys at Orokolo Bay and the offshore export pipeline corridor, where nickel exceeded the sediment quality guideline at all sites.

Hydrocarbon contaminants were not analyzed in sediment samples collected in Caution Bay for the PNG LNG Project.

8.4.4 Summary of Water and Sediment Quality

Overall, water and sediment quality is high in the study area, and does not show evidence of anthropogenic contamination, although there are some naturally elevated nickel concentrations in sediment. Turbidity and physicochemical water properties vary across seasons and the water column due to changes in sea state conditions and fluvial inflows, and also vary based on proximity to the Purari, Vailala and Vaihua river mouths in the study area.

8.5 Marine Biodiversity

8.5.1 Regional Context

Papua New Guinea forms part of the Coral Triangle, a region that is home to the highest coral diversity in the world and is the center of marine biodiversity worldwide (Allen, 2006). Based on the Spalding et al. (2001) classification of marine ecoregions of the world, the study area encompasses the Gulf of Papua ecoregion, which covers Orokolo Bay and the western extent of the offshore export pipeline corridor, and the Southeast Papua New Guinea ecoregion, which covers Caution Bay and the eastern extent of the offshore export pipeline corridor (Figure 8.20). The Gulf of Papua and Australia share a strong biogeographic affinity due to their close proximity and recent geographic affinity; consequently, few endemic marine species are found in southern Papua New Guinea (Sekhran & Miller, 1996).

The study area contains no marine protected areas. The closest protected area is Paga Hill National Park Scenic Reserve, which covers part of Port Moresby harbor but is not considered relevant to the study area. This site is approximately 13 km southeast of Caution Bay.

8.5.2 Marine Habitat Baseline Characterization

8.5.2.1 Study Overview

Field surveys for the marine biodiversity study were completed during the 2016 southeast trade wind season and the 2017 northwest monsoon season.

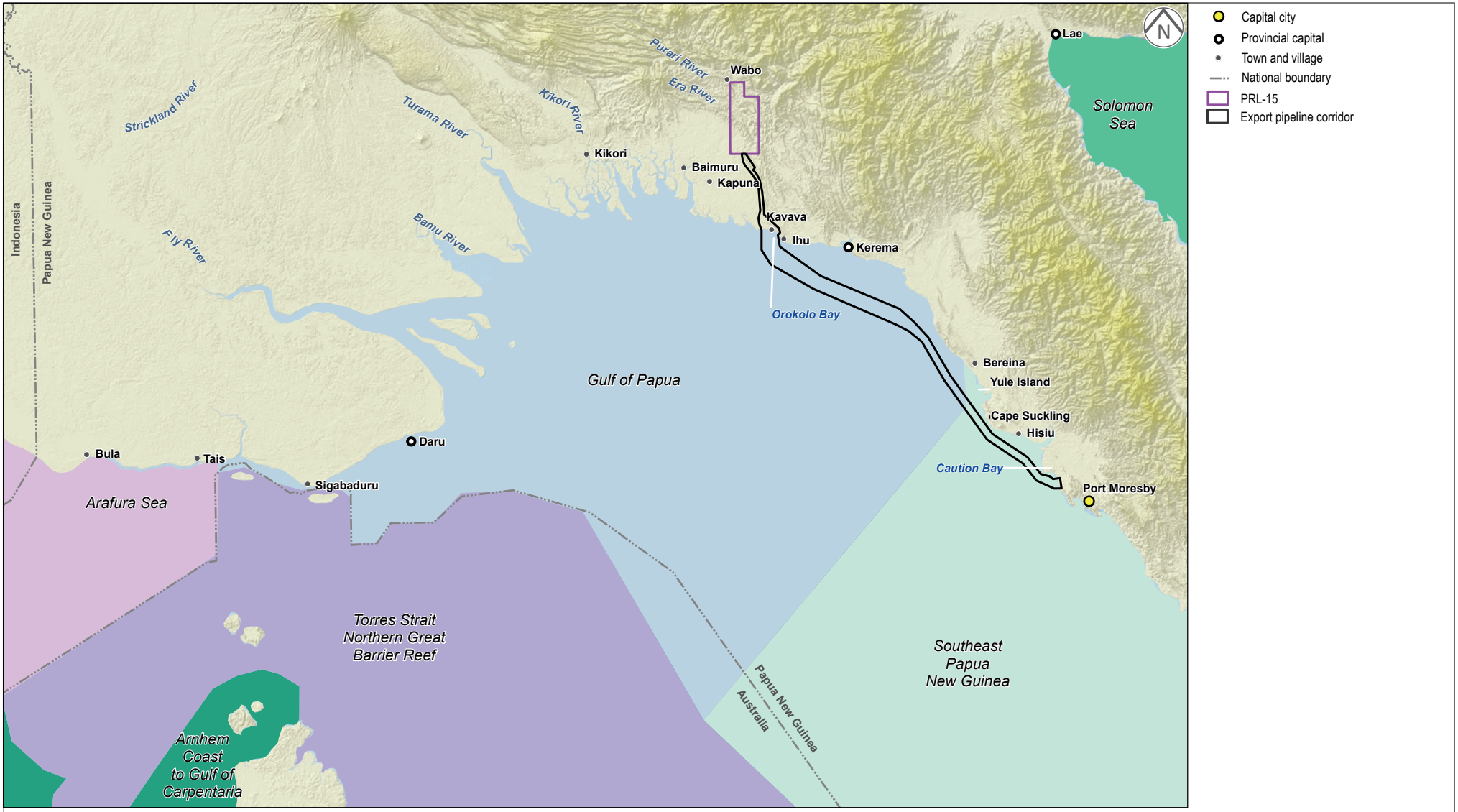
The surveys involved (Part 23 of Volume 2):

- Mapping benthic habitats, including sensitive receptors such as coral reefs, rocky reefs and seagrasses.
- Sampling benthic macroinvertebrates in different substrate types.
- Surveying reef fish assemblages in Caution Bay by baited remote underwater video.
- Assessing the occurrence of threatened or protected marine species or potential sensitive habitat in the study area.

ECOREGIONS OF SOUTHERN NEW GUINEA

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FIGURE 8.20



Survey sites are shown in Figure 8.11. The field survey data was used, in conjunction with existing information from previous studies in the area, scientific literature and databases, to provide a description of marine habitat types in the study area and to identify potential sensitive marine habitat and threatened, rare, or otherwise noteworthy species likely to be present.

Four major marine benthic habitat types were identified in the study area, including beach and intertidal flats, seagrass meadows, subtidal coral and rocky reefs, and soft sediments. The relevance of each of these benthic habitat types in the three sectors of the study area is described in the following sections. Mangrove communities, which dominate the coastline throughout the Purari River delta and the eastern coast of Caution Bay, are considered as part of estuarine communities in Section 7.6. The pelagic environment (i.e., the water column) of the study area is discussed in Section 8.5.2.5.

Beaches and intertidal flats are generally unvegetated habitats and are predominantly found along the north and east coastlines of the Gulf of Papua. Invertebrates, such as crustaceans and mollusks, can be found as permanent inhabitants, while birds can be found feeding opportunistically during low tides on intertidal flats and along the beaches.

Seagrass meadows are typically found in shallow, soft-bottomed marine coastlines and estuaries with the availability of light, tidal exposure, salinity, temperature and turbidity being some of the factors that determine their distribution (Seagrass Watch, 2015a). Seagrass meadows are found in Papua New Guinea growing on fringing reefs, in protected bays and inlets, and on the protected side of barrier reefs and islands (Seagrass Watch, 2015b).

All major coral reef types are found in Papua New Guinea, including fringing, patch and barrier reefs. Extensive barrier reefs are found southeast of Port Moresby along the south coast, around to East Cape on the eastern coast and around the Louisidae Archipelago located about 200 km southeast of East Cape. In the Gulf of Papua, no coral reefs are found to the west and north due to high sediment loads discharged from rivers to this part of the gulf. Coral reefs are found along parts of the eastern coastline, where there are fewer major river mouths and water clarity is higher. Soft sediment habitats are the major marine habitat type found throughout the Gulf of Papua due to the presence of the continental shelf and the delivery of large amounts of sediment from the rivers to the north and west of the gulf.

The occurrence of marine fauna, including benthic macroinvertebrates, fishes, macrocrustaceans, marine mammals and marine reptiles, in the study area is described in Section 8.5.3.

8.5.2.2 Orokolo Bay

Beaches and Intertidal Flats

Sandy beaches occur intermittently between tidal inlets and river mouths along the Purari River delta but are more continuous east of the delta in Orokolo Bay (Plate 8.10). These beaches comprise dark sandy material, with fine sand near the Purari River mouth grading to coarser sands and gravel toward the Vailala River.

Plate 8.10 – Example of a Dark Sandy Beach at Orokolo Bay



Photo: Iain Woxvold.

Seagrass Meadows

No seagrass meadows were identified in the shallow tidal waters of Orokolo Bay or close to the Purari River mouth. This is attributable to unsuitable environmental conditions, including:

- Bed mobilization by wave disturbance and fluvial discharges.
- High sediment loads and associated low light that reduces photosynthesis, and high sediment deposition associated with fluvial discharges and bed remobilization.
- Low salinity in nearshore waters due to fluvial discharges.

Subtidal Reefs

No coral reefs or intertidal rocky shores were recorded in the nearshore environments at Orokolo Bay near the Purari River mouth nor have they been previously noted.

A subtidal rocky reef was identified at site M6, approximately 10 km southeast of the Vailala River mouth, just outside of the offshore export pipeline corridor (see Figure 8.6). This reef supports an assemblage of filter feeding soft corals, sponges, colonial ascidians, crinoids, hydroids and other encrusting organisms (Plate 8.11). These species are known to tolerate the fluctuating salinity and turbidity associated with fluvial discharges and remobilization of bed sediment.

West of this location in the offshore export pipeline corridor and Orokolo Bay, the seabed was found to be flat and featureless with no subtidal reefs present.

Plate 8.11 – Rocky Reef Benthos Examples (Site M6)

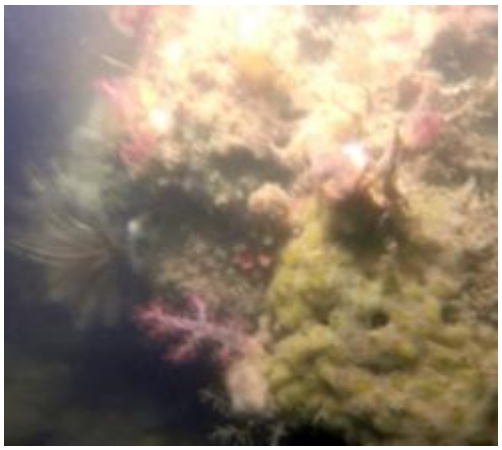
Crinoids



Polychaete tube worms, crinoids and *Dendronephthya* sp.



Mixed community with crinoid, *Dendronephthya* sp. and colonial ascidian



Hydroids



Photos: BMT WBM.

Soft Sediments

Substrates in subtidal areas of Orokolo Bay mostly comprise clay and silt, with less than 10% sand. Plates 8.6 and 8.12 show examples of the typical sediment and substrate, respectively. Fluvial sediment inputs from nearby rivers represent a major source of fine material to these nearshore environments, and overlying waters can be highly turbid. This was indicated by a suspended fluid mud layer observed above the seabed in Orokolo Bay in water 10 to 15 m deep during the survey undertaken during the southeast trade wind season.

Habitat mapping found featureless soft sediments to be the dominant habitat type in Orokolo Bay, with no sensitive features, such as seagrass meadows or coral reefs, present. Mangroves found along the Orokolo Bay coastline around the mouth of the Purari River are discussed in Section 7.

Plate 8.12 – Typical Flat and Featureless Seabed Substrate in Orokolo Bay (Site M12)



Photo: BMT WBM.

8.5.2.3 Offshore Export Pipeline Corridor

Seagrass Meadows

Similar to Orokolo Bay, no seagrass meadows were identified along the offshore export pipeline corridor, consistent with the findings of surveys conducted along the PNG LNG Gas Pipeline in 2008 (CNS, 2008b). Water depths along the corridor are considered too deep to support the growth of seagrasses, which are generally found in less than 20 m of water, although some *Halophila* species can be found at depths greater than 50 m (Waycott et al., 2004).

Subtidal Reefs

No subtidal reefs were identified along the offshore export pipeline corridor during the present or historical surveys. Outside of the study area, subtidal reefs have been recorded between the pipeline corridor and the coastline, particularly near Kerema and Yule Island (CNS, 2008b).

Soft Sediments

As described in Section 8.4.3, sediments sampled along the offshore export pipeline corridor predominantly comprise silt and clay, except near Yule Island, where the sediment was found to be predominantly sand.

Similar to Orokolo Bay, featureless soft sediments are the dominant habitat type along the offshore export pipeline corridor, with no sensitive features such as seagrass meadows or coral reefs present.

8.5.2.4 Caution Bay

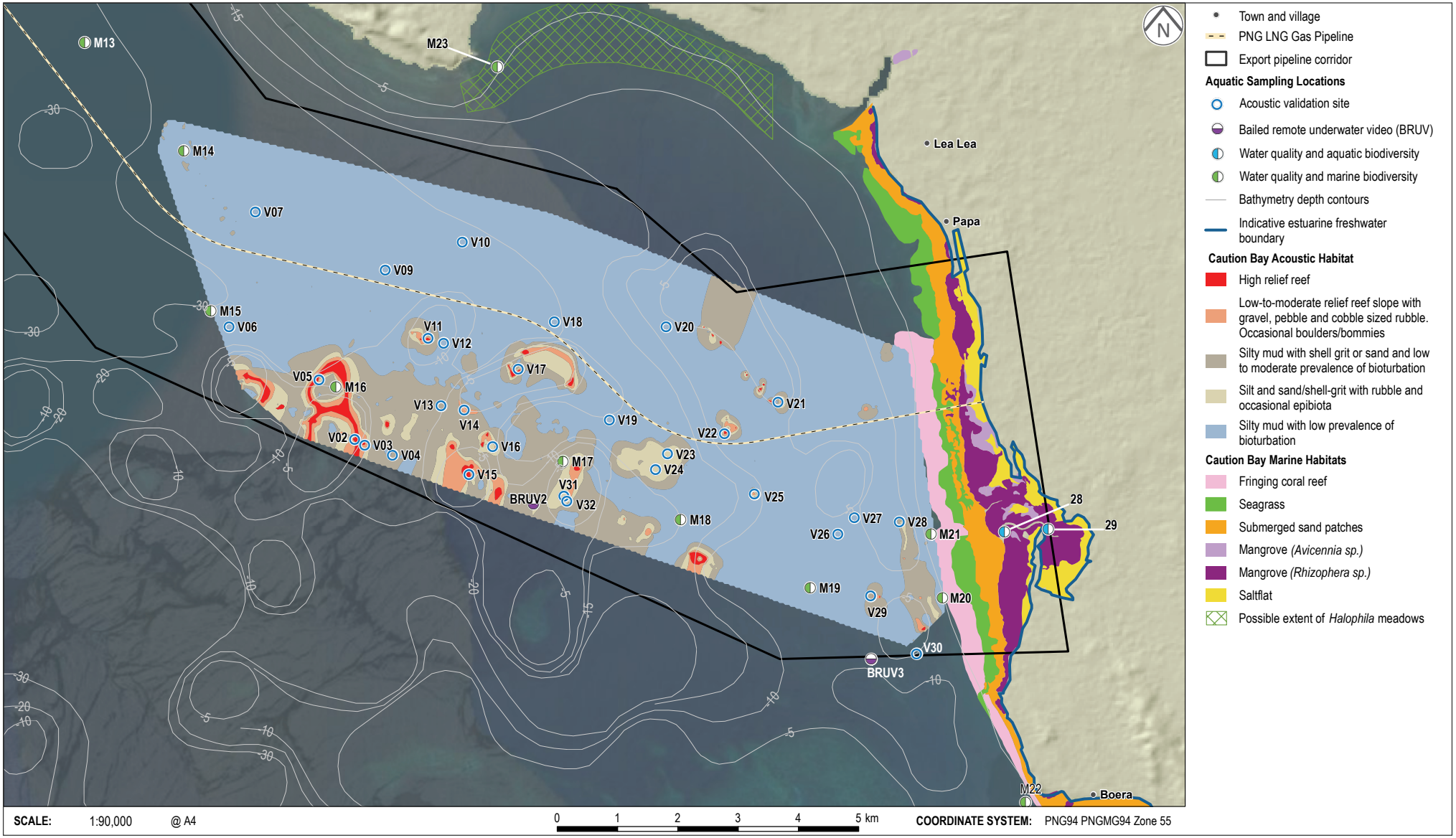
Beaches and Intertidal Flats

In Caution Bay, sandy beaches occurring particularly to the north, and small pockets of intertidal mudflats associated with mangroves around the Vaihua River estuary (Figure 8.21) both provide habitat, including feeding grounds, for fish, birds and invertebrates. Saltpan mudflats are found behind the mangroves (Figure 8.21) beyond the high tide level and also provide habitat, including feeding grounds for birds and invertebrates.

NEARSHORE MARINE HABITATS IN CAUTION BAY

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FIGURE 8.21



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

Seagrass Meadows

Dense seagrass meadows have been previously mapped in Caution Bay and occur on the flat, sandy seafloor between the mangrove-lined shore and the fringing reefs (CNS, 2008a). Seagrass meadows were not observed seaward of the fringing reefs and, although dense where they were found, seagrass meadows are not extensive. *Enhalus acroides*, *Syringodium isoetifolium* and *Cymodocea* spp. have been recorded in Caution Bay (CNS, 2008a). The present study confirmed these seagrass meadows are still present (see Figure 8.21). This study also identified additional, sparse seagrass meadows comprising *Halophila* species, with cover less than 5%, in the northern part of Caution Bay. Seagrass meadows in Caution Bay are considered to have a high ecological significance, as they stabilize the substrate and provide nursery and feeding habitats for a range of marine organisms, including prawns, lobsters, fish and turtles (CNS, 2008a).

No seagrass species known or likely to occur in the study area is listed as threatened or protected under the IUCN Red List or the *Fauna (Protection and Control) Act 1966*; however, the seagrass meadows of Caution Bay represent a high-value biotope since they may provide potential foraging habitat for threatened fauna species such as sea turtles (Section 8.5.3).

Subtidal Reefs

Fringing coral reefs are extensive in Caution Bay and are found parallel to the eastern shoreline, 200 to 500 m offshore (see Figure 8.21). A large outer barrier reef approximately 15 km wide is present in the south of Caution Bay and includes the coral cay, Idihi Island, at its western extent (see Figure 8.5). This barrier reef shelters the bay from ocean swells during the southeast trade wind season. Offshore reefs also exist around Vari Vari Island to the northwest just outside of Caution Bay (see Figure 8.5). Patch reefs, coral outcrops and low-relief rubble slopes are also present in the southern and central regions of Caution Bay.

Fringing and nearshore reefs have been previously noted to be in poor condition, most likely linked to high intensity fishing including dynamite fishing and the suspension of sediment from strong winds and waves (CNS, 2008a). The current survey found coral cover varied, with some areas having up to 100% live cover of *Acropora* species and *Pavona clavus* on some coral bomboras (Plates 8.13 and 8.14). Other areas had less than 5% live coral cover and were predominantly rubble with a sparse cover of soft corals, zoanthids, hydroids, sponges, ascidians and algae (Plate 8.15). There were also patches of cover where assemblages appeared to be recovering, with evidence of recent rapid growth rates (Plate 8.13).

Plate 8.13 – *Acropora* Bombora with High Coral Cover and Long Apical-growing Tips (Site V26)

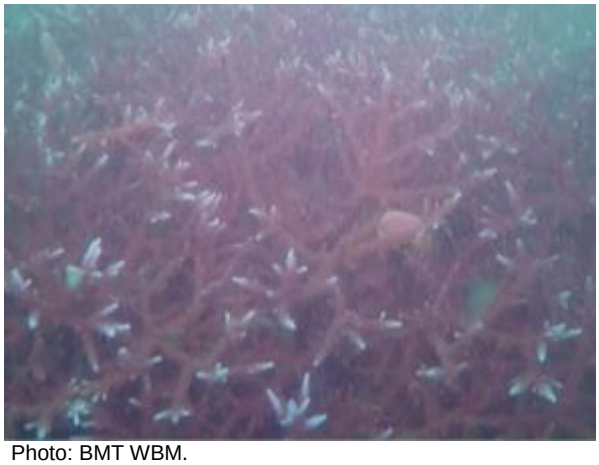


Photo: BMT WBM.

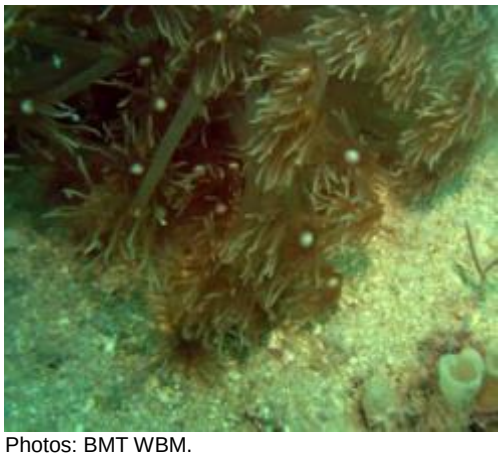
Plate 8.14 – *Pavona clavus* Bombora with High Coral Cover (Site V30)

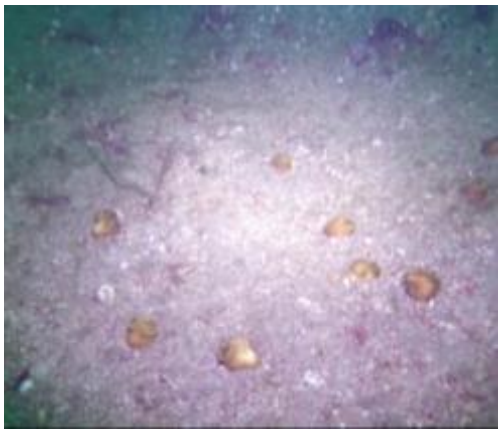


Photo: BMT WBM.

Plate 8.15 – Rubble Reef Community with Low Live Coral Cover (Site M22)

***Alveopora* sp. (stony coral)** **Free-living *Heteropsammia* sp. coral polyps**





Photos: BMT WBM.

Patch reefs found in Caution Bay occur in water 5 to 25 m deep. One patch reef was found approximately 10 km west of the PNG LNG Facilities (site V02) with moderate live coral cover of 30% observed on the reef crest, which included branching and digitate *Acropora* species (Plate 8.16). Closer to shore, shallow patch reefs were also recorded 1 to 7 km northwest and southwest of the PNG LNG Facilities.

Plate 8.16 – Patch Reef Community (Site V02)



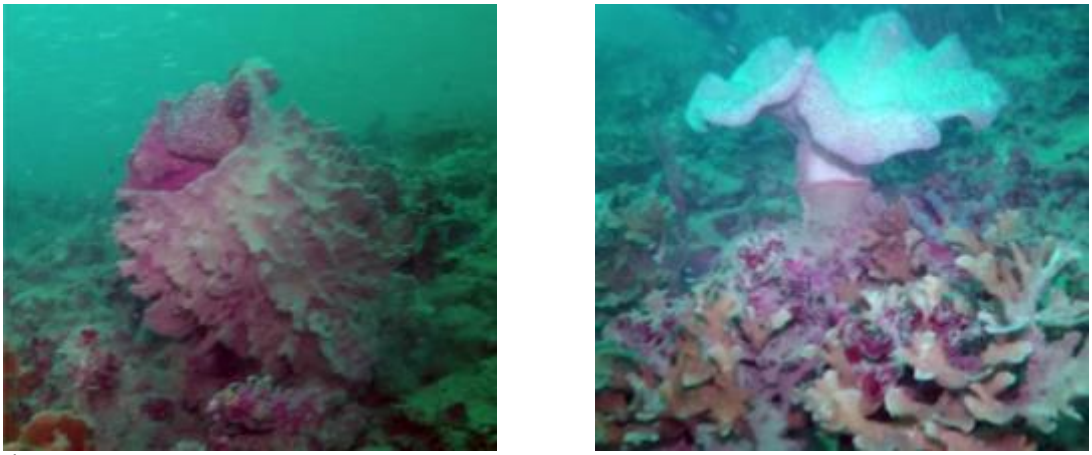


Photos: BMT WBM.

At depths greater than 25 m, reef assemblages were identified at sites V15, V16 and adjacent to site M16 (see Figure 8.21 and Plate 8.17), and were covered by octocorals (e.g., soft corals,

gorgonians and sea whips), including *Sarcophyton, Sinularia, Ellisella, Viminella* and *Ctenocella* species. Hard corals were also abundant, including species of *Goniopora*, *Alveopora, Fungia, Leptoseris*, *Pavona*, and *Acropora.* Crinoids and sponges were also observed on these reefs.

Plate 8.17 – Deep Reef Community (Site V15)

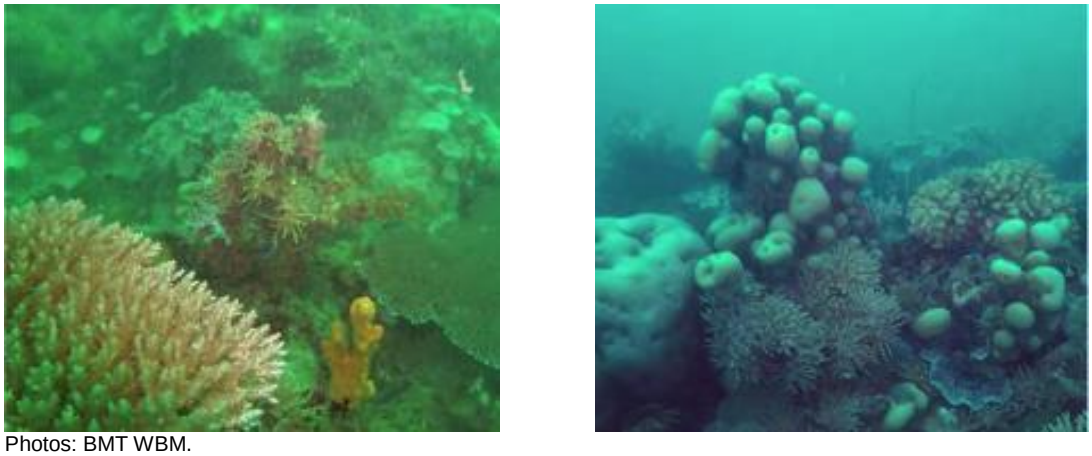


Photos: BMT WBM

The outer barrier reef and coral cay (Idihi Island), which are more extensive than the nearshore and fringing reefs, have up to 70% coral cover (Plate 8.18). These reefs, with less deposited sediment and anthropogenic disturbance, support a wider range of species. Coral at Vari Vari Island north of Caution Bay was also reported in CNS (2008a) to be in good condition with high coral cover supporting a range of species.

Coral reefs are not listed under Papua New Guinean legislation or the IUCN Red List; however, the coral reefs of Caution Bay represent a high-value biotope since they may provide habitat for threatened species, such as sea turtles and certain fish species (Section 8.5.3).

Plate 8.18 – Reef Slope Community at Idihi Island (Site M24[1])



Photos: BMT WBM.

Soft Sediments

The dominant subtidal soft substrate types in Caution Bay are muds and sands, as described in CNS (2008a) and verified during the present surveys. These soft sediments occur seaward of the fringing reef and between coral outcrops and shoals.

Based on validated acoustic habitat mapping undertaken in January 2017 (see Figure 8.21), two main types of substrate are present:

1 See Figure 5-3 in Part 12 of Volume 2.

- Substrate mostly comprising silty muds.
- Substrate between reef structures and in shallower environments in the eastern section of Caution Bay, mostly comprising silty muds with variable quantities of coarse sands, shell grit or coral rubble (see Plates 8.8 and 8.9 in Section 8.4.3.4).

8.5.2.5 Pelagic Environment

The pelagic zone, i.e., the water column of the open sea, provides habitat to marine fauna, including fish, reptiles and marine mammals, and represents the largest marine habitat in the study area by area. Conditions of the pelagic environment are controlled by fluvial runoff and coastal processes, which are described in Sections 8.2 and 8.3. Fluvial influences are also reflected in water quality conditions, which are described in Section 8.4.

Primary production in pelagic environments of the Gulf of Papua is generated from a combination of autotrophic (photosynthetic, i.e., phytoplankton) and heterotrophic (non-photosynthetic, i.e., microbial) sources. While the relative contributions from autotrophic and heterotrophic producers are thought to shift with seasonal changes and other variables, both groups form important base levels of food webs in the gulf (Robertson et al., 1998; McKinnon et al., 2007). Autotrophic production and chlorophyll-a, a surrogate for phytoplankton biomass, levels are typically greater in waters more heavily influenced by fluvial discharges, primarily due to nutrient inputs from the rivers (Davies, 2004; McKinnon et al., 2007). As discussed in Section 8.4.2.2, the survey produced no evidence of higher chlorophyll-a levels at sites closest to the Purari River mouth and therefore most influenced by fluvial discharges, with chlorophyll-a levels below or close to the limit of reporting of 1 µg/L. This likely reflects the low nutrient levels and turbid waters, which limit light penetration and together limit phytoplankton production.

The benthic-pelagic coupling in the Gulf of Papua is strong, with detrital inputs from rivers driving nearshore primary productivity (Robertson et al., 1998). The present study also recorded abundant empty planktonic skeletons in benthic samples along the offshore export pipeline corridor. This detrital material represents an energy source for benthic suspension-feeders and detrivores, which in turn support demersal fish and shellfish (e.g., prawns) of commercial fisheries significance.

8.5.3 Marine Fauna Baseline Characterization

Mobile marine fauna use different habitats during their life cycle, which, for some species, may include demersal and pelagic life stages, using freshwater, estuarine and marine environments or migrating over large distances and a variety of marine habitats. Fish, marine mammals, reptiles and crustaceans are therefore characterized in terms of the study area rather than by Project sector, as many species are expected to occur across multiple sectors. Benthic macroinvertebrates are considered in separate sectors of the study area, since they are considered to be more sedentary.

8.5.3.1 Benthic Macroinvertebrates

Orokolo Bay

A total of 3,742 individuals from 216 morphospecies were identified in sediment samples from Orokolo Bay. Benthic assemblages were numerically dominated by:

- Polychaete worms (82 taxa, 1,295 individuals).
- Decapod crustaceans (24 taxa, 1,390 individuals).
- Amphipod crustaceans (13 taxa, 255 individuals).

Plate 8.19 shows examples of these taxa.

Common and widespread groups included decapod crustaceans (the yabby (*Callianassa* sp.) and crab (*Xenophthalmus* sp.)), polychaete worms (from the genera *Sternaspis*, *Terebellides* and

Paraprionospio and the species *Prionospio ehlersi*), and Ampeliscidae amphipods. One crab species (*Xenophthalmus* sp.) accounted for 31% of all benthic fauna. Only single individuals were recorded for 67 of the 216 morphospecies observed. As shown in Figure 8.22, site M45, which was closest to the Purari River mouth and had the highest proportion of sand (see Figure 8.19), had the lowest species richness and lowest abundance of benthic fauna. The depauperate benthic assemblages in this area are likely due to multiple natural stressors, including low and temporally variable salinity, and the physical disturbance and remobilization of bed sediments by waves and fluvial discharges.

Plate 8.19 – Examples of Numerically Dominant Taxa

Polychaete Worm



Decapod (free swimming larval stage)



Amphipod



Photos: BMT WBM.

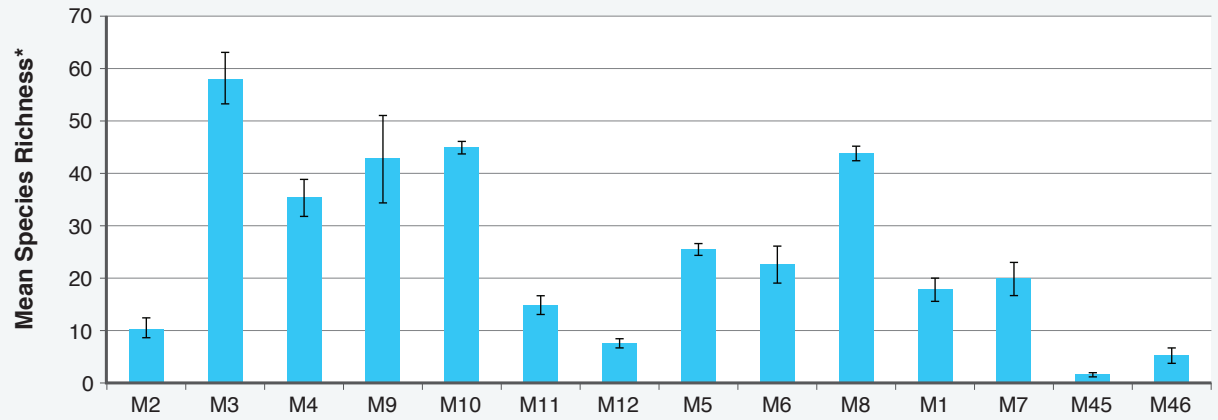
Offshore Export Pipeline Corridor

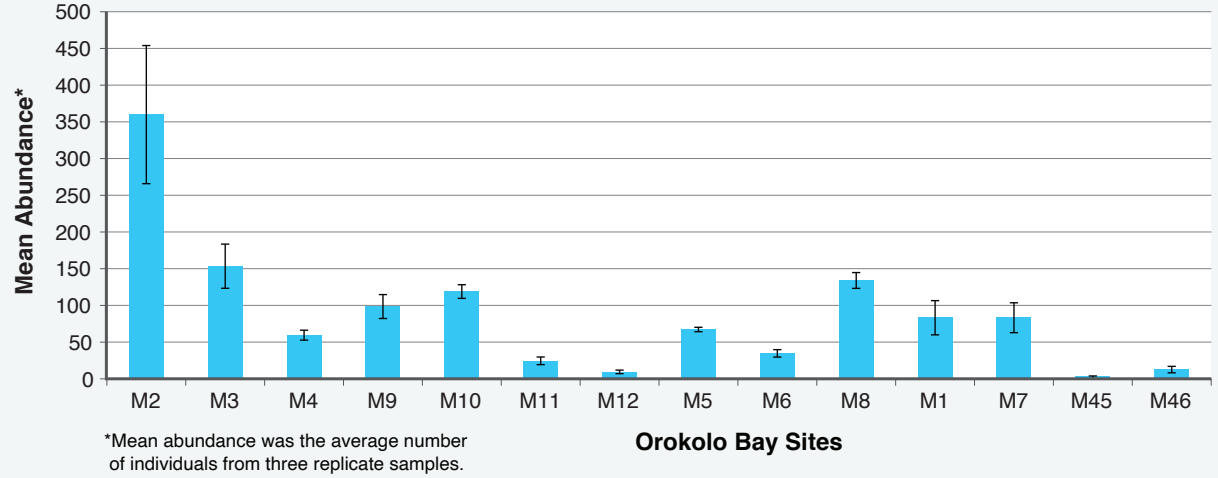
A total of 181 morphospecies of benthic infauna was identified, with polychaete worms and crustaceans (i.e., isopods, amphipods, shrimps and crabs) being the most abundant species. Previous surveys identified 137 species along the PNG LNG Gas Pipeline (CNS, 2008b).

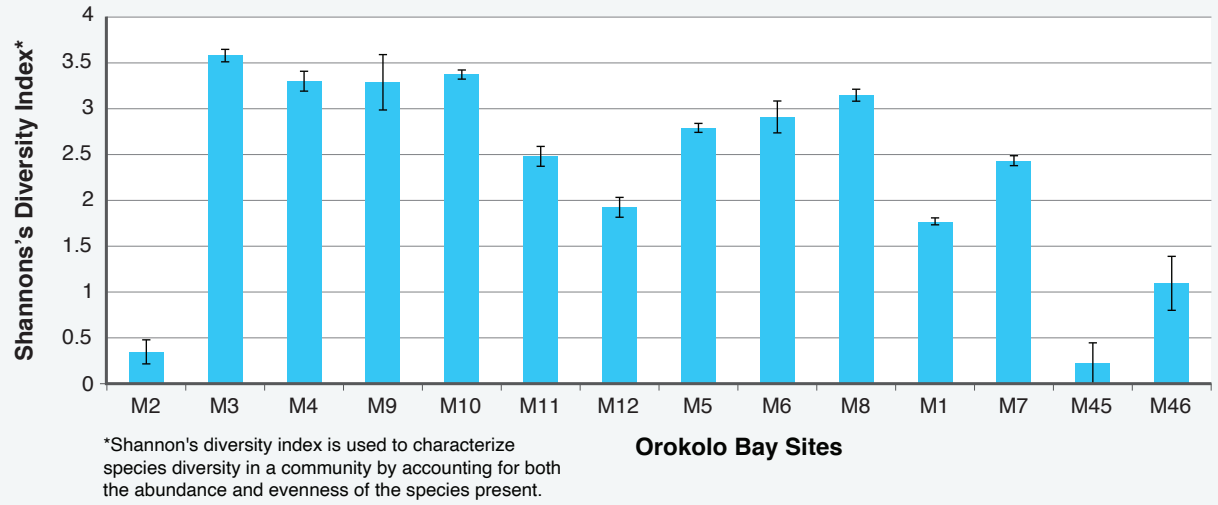
OROKOLO BAY BENTHIC MACROINVERTEBRATE COMMUNITY METRICS

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FIGURE 8.22







I Standard error

Species richness, diversity and abundance was highest at one site west of Yule Island, where the sediment was predominantly sand with shell grit, which may explain the differences in benthic assemblages at this site (i.e., potential species preference for this habitat type). Similar to Orokolo Bay, the majority of species were observed in low abundance, with less than five individuals for 67% of species recorded. Just three taxa were widespread and abundant; heart urchins (7.7% of the catch), the amphipod *Cheiriphotis* sp. 1 (5% of the catch) and the polychaete worm *Paraprionospio* sp. (3% of the catch).

A sparse cover of epibenthic macrofauna (i.e., animals living on top of the seabed) was observed along the offshore export pipeline corridor, with video footage recording burrowing gobies, crinoids, sponges, sea pens, cerianthid anemones and polychaete worms.

Caution Bay

No sediment samples were collected in Caution Bay during the 2016 and 2017 surveys, due to the risk from unexploded ordnances.

Sampling of benthic infauna undertaken for the PNG LNG project identified 68 morphospecies in Caution Bay (CNS, 2008a). The majority of these were crustaceans and polychaetes, with lesser numbers of gastropods, bivalves and echinoderms. While the taxa numbers differed across samples, polychaete worms and crustaceans were numerically dominant in all samples.

8.5.3.2 Fish

Much of the information on the structure and characteristics of fish and shellfish assemblages of the Gulf of Papua is based on commercial fishing data, including by-catch. Part 12 of Volume 2 identifies that the following species numerically dominate the bycatch of prawn trawls from the Gulf of Papua (Gulf Province), Orangeria Bay (Milne Bay Province) and Torres Strait (Western Province):

- Clupeidae (sardines and herrings) (20% of total fish catch).
- Leiognathidae (ponyfishes) (15% of total fish catch).
- Engraulidae (anchovies) (10% of total fish catch).
- Lutjanidae (snappers) (8% of total fish catch).
- Mullidae (goatfishes) (4% of total fish catch).

Studies undertaken near the Purari River delta identified 143 fish species from 58 families (Haines, 1979). Gulf fish assemblages can vary greatly both spatially and temporally. Historical studies report higher numbers of ariids (catfishes), sciaenids (croakers), polynemids (threadfins), engraulids (anchovies) and synodontids (lizardfishes) in the west of Orokolo Bay, while the east was dominated by leiognathids (ponyfishes), theraponids (grunters), carangids (trevallies), synodontids, priacanthids (bigeyes) and mullids (goatfishes) (Kailola & Wilson, 1978, in Watson, 1984). This was attributed to habitat conditions, with areas in the west having a muddier substrate and being more strongly influenced by fluvial inputs than areas in the east.

Studies in Caution Bay identified fish from 14 predominantly reef fish families, with Pomacentrids (damselfishes) accounting for more than half of all fish observations (CNS, 2008a). An absence of larger fish such as snappers, emperors and sharks has also been previously noted, with observations of mainly small-bodied fish less than 10 cm long recorded, which may have been due to fishing pressure in the area (CNS, 2008a).

Fish surveys conducted at three reef sites in Caution Bay in January 2017 are described in Part 12 of Volume 2. These surveys identified 42 species, with Chaetodontids (butterflyfishes),

Pomacentrids (damselfishes) and Labrids (wrasses) accounting for over half of the species observed (Figure 8.23 and Plate 8.20). More, larger-bodied species were identified in these surveys than in the CNS (2008a) studies, with species of Carangids (trevallies), Lutjanids (snappers), Serranids (groupers and rockcods), Acanthurids (surgeonfishes) and Caesionids (fusiliers) recorded (Plate 8.21). This is likely due to the different survey method adopted for the present study, which used baited remote underwater video stations to survey fishes rather than visual observations by divers. This survey technique favors identification of larger predatory fish, which are attracted to the baited station but evade divers (Kulbicki, 1998).

Plate 8.20 – Examples of Reef Fish

Bird-wire cod (*Epinephelus merra*)



Saddled butterflyfish (*Chaetodon ephippium*)



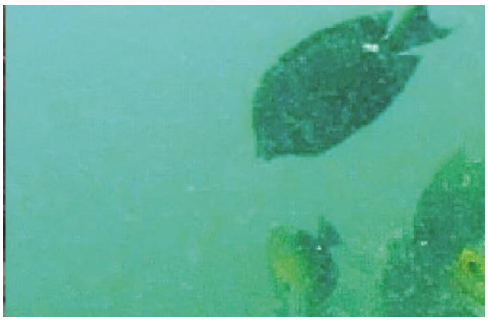
Moorish idol (*Zanculs cornutus*)



Dot-dash goatfish (*Purapeneus barberinus*)



Surgeonfishes (Acanthuridae)



Brown-barred rock cod (*Cephalopholis boenak*) and doublebanded soapfish (*Diploprion bifasciatum*)

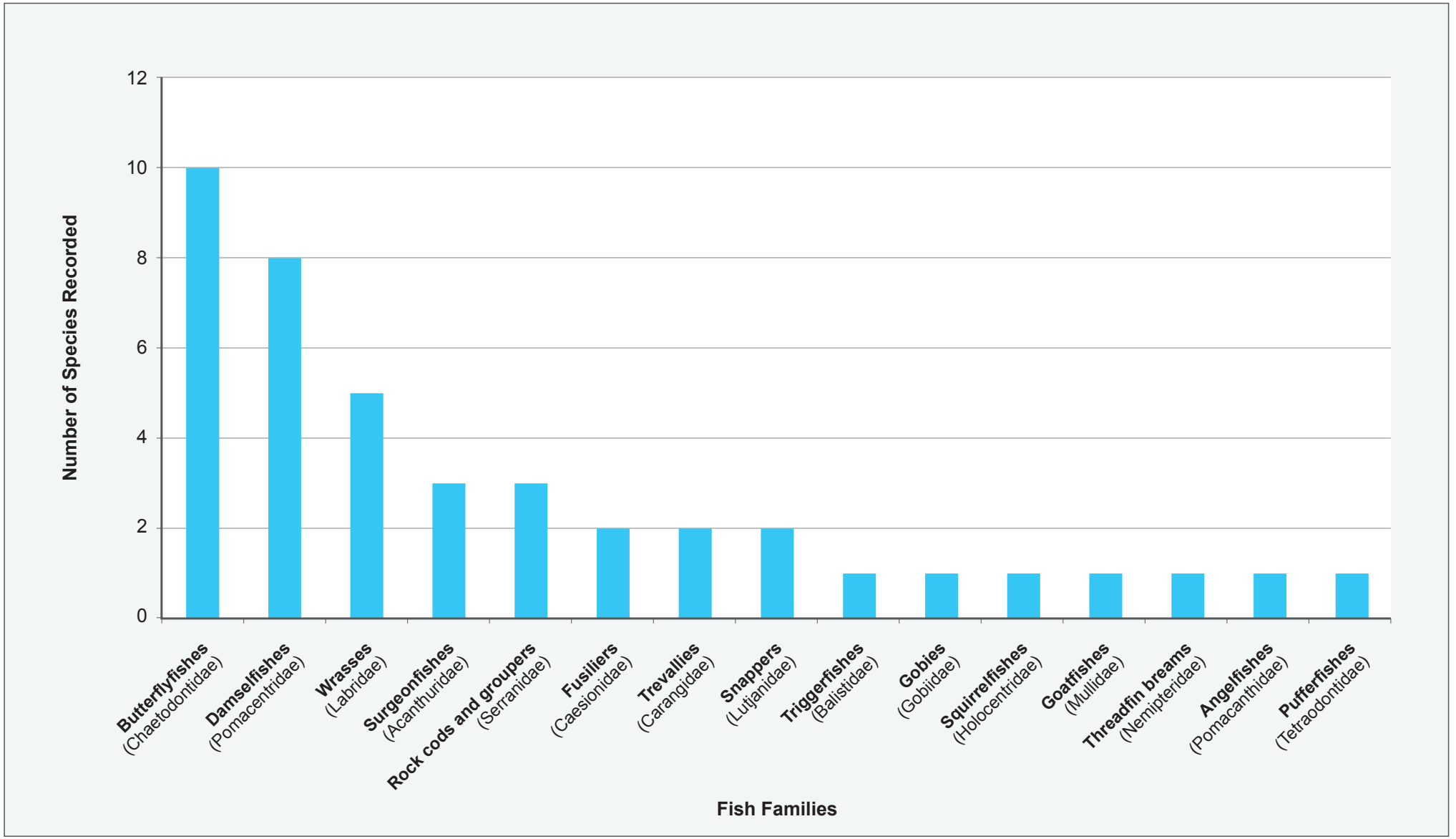


Photos: BMT WBM.

NUMBER OF FISH SPECIES RECORDED PER FAMILY IN CAUTION BAY

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FIGURE 8.23



ERIAS Group | 01215B_23_F8.23_v1

Plate 8.21 – Examples of Larger-bodied Fish (Bigtail Fusiliers, *Pterocaesio marri*) Observed in Caution Bay



Photo: BMT WBM.

Several species of elasmobranchs, a subclass of cartilaginous fish with five to seven pairs of gills, which includes many shark and ray species, are considered likely to occur in the study area, including:

- Two sawfish species (*Anoxypristis cuspidata* and *Pristis pristis*).
- Seven shark species (*Carcharhinus leucas, C. macloti, Glyphis garricki, G. glyphis, Hemiscyllium hallstromi, Rhizoprionodon acutus* and *Eusphyra blochii*).
- Five ray species (*Glaucostegus typus, Aetobatus narinari, Manta birostris, M. alfredi* and *Mobula eregoodootenkee).*

As further described in Part 12 of Volume 2, many of these species are considered to be sensitive species (Section 8.5.4.1). Table 8.1 summarizes information on threatened or important marine fauna and the likelihood of their occurrence in the study area.

8.5.3.3 Marine Mammals and Reptiles

Marine mammals, including whales, dolphins and marine reptiles such as sea turtles, crocodiles and sea snakes, potentially occur in the study area. Dugongs are not known to occur in the study area, although some suitable foraging habitat may exist in Caution Bay, particularly to the north where sparse beds of the seagrass *Halophila* spp. are present. Further detail is provided in Part 12 of Volume 2.

Seven dolphin species are known to or are likely to occur in the study area, and these include two threatened species, the Australian snubfin (*Orcaella heinsohni*) and Australian humpback dolphin (*Sousa sahulensis*), as described in Table 8.1. Whales are not often reported in the Gulf of Papua (CNS, 2008b).

Six turtle species are known to occur in PNG waters and are all considered to potentially be present in the study area. In particular, the coral reefs and seagrass meadows of Caution Bay may provide sea turtle foraging habitat. Five of these six species are considered threatened (Table 8.1). No major turtle nesting sites are known to occur in the Gulf of Papua; however, low-density nesting of green turtles (*Chelonia mydas*) has been reported to occur along the beaches

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area

Group	Species Name	Common Name	IUCN Listing*	CITES Listing#	Other	Habitat Used	Orokolo Bay	Offshore Export Pipeline Corridor	Caution Bay
Sawfish (Pristidae)	*Pristis pristis*	Largetooth sawfish	CR	I	Migratory	Coastal waters alongside mangrove-dominated coastlines Coastal waters near large river mouths	Likely	Possible	Unlikely
	Pristis zijsron	Green sawfish	CR	I	Migratory	Shallow coastal waters near large river mouths	Possible	Unlikely	Unlikely
	Anoxypristis cuspidata	Narrow sawfish	EN	I	Migratory	Coastal waters near large river mouths	Known	Possible	Unlikely
Requiem sharks (Carcharhinidae)	*Glyphis glyphis*	Speartooth shark	EN	-	-	Coastal waters near large river mouths	Likely	Unlikely	Unlikely
	Glyphis garricki	Northern river shark	CR		-	Coastal waters near large river mouths	Possible	Unlikely	Unlikely
	Carcharhinus leucas	Bull shark	NT	-	-	Coastal waters to the edge of the continental shelf	Likely	Likely	Likely
	Carcharhinus macloti	Hardnose shark	NT	-	-	Coastal waters to the edge of the continental shelf	Likely	Likely	Known
Hammerhead sharks (Sphyrnidae)	*Eusphyra blochii*	Winghead shark	EN	-	-	Coastal waters to the edge of the continental shelf	Known	Likely	Likely
Bamboo sharks (Hemiscyllidae)	*Hemiscyllium hallstromi*	Papuan epaulette shark	V	-	Endemic	Coastal waters near coral reefs and seagrass meadows	Unlikely	Unlikely	Likely
Giant guitarfish (Glaucostegidae)	*Glaucostegus typus*	Giant shovelnose ray	V	-	-	Coastal waters to the edge of the continental shelf	Likely	Unlikely	Likely
Eagle rays (Aetobatidae)	*Aetobatus narinari*	Spotted eagle ray	NT	-	-	Coastal waters, especially near coral reefs	Likely	Possible	Likely
Whiptail stingrays (Dasyatidae)	*Pastinachus sephen*	Cowtail ray	NT	-	-	Coastal waters, especially near coral reefs	Likely	Possible	Likely

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area (cont'd)

Group	Species Name	Common Name	IUCN Listing*	CITES Listing#	Other	Habitat Used	Orokolo Bay	Offshore Export Pipeline Corridor	Caution Bay
Rays (mantas and mobulas)	*Manta birostris*	Giant manta ray	V	II	Migratory	Pelagic waters	Unlikely	Possible	Unlikely
	Manta alfredi	Reef manta ray	V	II	Migratory	Nearshore to pelagic waters	Possible	Possible	Likely
	Mobula eregoodootenkee	Pygmy devilray	NT	II	Migratory	Nearshore to pelagic waters	Possible	Possible	Possible
Mackerels (Scombridae)	*Scomberomorus multiradiatus*	Papuan seerfish	-	-	Restricted-range	Coastal waters to the edge of the continental shelf	Known	Likely	Likely
	Scomberomorus commerson	Narrow-barred Spanish mackerel	NT	-	Migratory		Likely	Likely	Likely
Serranidae (groupers and rockcods)	*Epinephelus fuscoguttatus*	Brown marbled grouper	V	-	-	Coastal waters near coral reefs and seagrass meadows	Likely	Possible	Likely
Sea cucumbers (Holothuridae)	*Actinopyga echinites*	Deepwater redfish	V	-	-	Coastal waters, estuaries, reef flats, seagrass meadows	Known	Unlikely	Known
	Actinopyga mauritana	Surf redfish	V	-	-				
	Actinopyga miliaris	Hairy blackfish	V	-	-				
	Holothuria fuscogilva	White teatfish	V	-	-				
	Holothuria lessoni	Golden sandfish	EN	-	-				
	Holothuria nobilis	Black teatfish	EN	-	-				
	Holothuria scabra	Sandfish	EN	-	-				
	Stichopus herrmanni	Curryfish	V	-	-				
	Thelenota ananas	Prickly redfish	EN	-	-				

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area (cont'd)

Group	Species Name	Common Name	IUCN Listing*	CITES Listing#	Other	Habitat Used	Orokolo Bay	Offshore Export Pipeline Corridor	Caution Bay
Rock Lobsters (Paniluridae)	*Panulirus ornatus*	Ornate rock lobster	-	-	Migratory/ congregatory	Usually occur in shallow waters (less than 8 m deep) near the coast Migration in waters 40 to 80 m deep through the northern gulf to Yule Island Spawning near Yule Island	Possible	Known	Likely
Dugong (Dugongidae)	*Dugong dugon*	Dugong	V	I	Migratory Protected (*Fauna (Protection and Control) Act 1966)*	Coastal waters near seagrass meadows	Unlikely	Unlikely	Possible
Dolphins (Delphinidae)	*Tursiops aduncus*	Indo-Pacific bottlenose dolphin	-	II	Migratory	Pelagic waters	Likely	Likely	Likely
	Tursiops truncatus	Common bottlenose dolphin	-	II	Migratory	Pelagic waters	Likely	Likely	Likely
	Delphinus delphis	Short-beaked common dolphin	-	II	Migratory	Pelagic waters	Likely	Likely	Likely
	Stenella longirostris	Spinner dolphin	-	II	Migratory	Pelagic waters	Likely	Likely	Likely
	Stenella attenuata	Pantropical spotted dolphin	-	II	Migratory	Pelagic waters	Likely	Likely	Likely

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area (cont'd)

Group	Species Name	Common Name	IUCN Listing*	CITES Listing#	Other	Habitat Used	Orokolo Bay	Offshore Export Pipeline Corridor	Caution Bay
Dolphins (Delphinidae) (cont'd)	*Orcaella heinsohni*	Australian snubfin dolphin	V	I	Migratory	Coastal waters near large river mouths Coastal waters near seagrass meadows	Likely	Unlikely	Likely
	Sousa sahulensis (as S. chinensis)	Australian humpback dolphin	V	I	Migratory	Coastal waters near large river mouths	Likely	Unlikely	Likely
Sea Turtles (Cheloniidae and Dermochelyidae)	*Chelonia mydas*	Green turtle	EN	I	Migratory	Coastal waters near seagrass meadows Low-gradient sandy beaches	Possible	Likely	Likely
	Eretmochelys imbricata	Hawksbill turtle	CR	I	Migratory	Coastal waters near coral reefs and seagrass meadows	Unlikely	Likely	Likely
	Caretta caretta	Loggerhead turtle	V	I	Migratory	Coastal waters near coral reefs and seagrass meadows	Unlikely	Likely	Likely
	Dermochelys coriacea	Leatherback turtle	CR (West Pacific Ocean subpopulation)	I	Migratory Protected (*Fauna (Protection and Control) Act 1966)*	Pelagic waters	Unlikely	Possible	Unlikely

Table 8.1 – Sensitive Marine Fauna Potentially Present in the Study Area (cont'd)

Group	Species Name	Common Name	IUCN Listing*	CITES Listing[#]	Other	Habitat Used	Orokolo Bay	Offshore Export Pipeline Corridor	Caution Bay
Sea Turtles (Cheloniidae and Dermochelyidae) (cont'd)	*Lepidochelys olivacea*	Olive ridley turtle	V	II	Migratory	Coastal waters near coral reefs and seagrass meadows	Unlikely	Likely	Likely
	Natator depressus	Flatback turtle	-	I	Migratory	Coastal waters near coral reefs and seagrass meadows	Possible	Likely	Likely
Elapid Snakes (Elapidae)	*Laticauda guineai*	Guinea's sea krait	NT	-	Endemic	Coastal waters near coral reefs	Does not occur	Possible	Likely
Water Snakes (Homolopsidae)	*Cantoria annulata*	Banded water snake	-	-	Restricted-range	Coastal waters near mangroves and nipa palm wetlands	Possible	Unlikely	Unlikely
Crocodiles (Crocodylidae)	*Crocodylus porosus*	Saltwater crocodile	-	II	Migratory	Coastal waters near large river mouths	Known	Unlikely	Possible

*International Union for Conservation of Nature (IUCN) where CR – critically endangered, EN – Endangered, V – Vulnerable, NT – Near Threatened, LC – least concern. Based on the 2018 IUCN Red List.

[#] Convention on the International Trade in Endangered Species (CITES) of Wild Fauna and Flora where I refers to CITES Appendix I (species threatened with extinction); II refers to CITES Appendix II (species in which trade must be controlled).

in Kerema Bay, located approximately 50 km to the east of Orokolo Bay. Other sandy beaches in the north of the gulf also possibly support turtle nesting.

Village surveys undertaken at Orokolo Bay in 2016 for the Upstream Land and Natural Resources Baseline Report (Part 18 of Volume 2) found that marine turtles are encountered only infrequently, and no reports of them nesting at Orokolo Bay existed. CEPA (2015) reports a green turtle aggregation site around Cape Suckling north of Caution Bay, which overlaps with part of the offshore export pipeline corridor (Section 8.5.4.2).

Twenty-three sea snake species are known to occur in the waters of Papua New Guinea of which two are considered threatened, the banded watersnake (*Cantoria annulata)* and Guinea's sea krait (*Laticauda guineai*) (see Table 8.1). A small-banded sea krait (*Laticauda* sp.*)* was observed along the offshore export pipeline corridor during the 2016 southeast trade wind season field survey. Sea snakes are considered likely to occur in the study area, both in nearshore and offshore waters.

Saltwater crocodiles *(Crocodylus porosus*) are known to occur in the Purari River, with one observed in the Purari River during the northwest monsoon season survey (Plate 8.22). They are considered likely to be found in highest abundance in the nearshore, wetland and riverine environments in the study area.

Plate 8.22 – Saltwater Crocodile (*Crocodylus porosus*) in the Purari River



Photo: TEP PNG.

8.5.3.4 Crustaceans

In the Gulf of Papua, banana prawns (*Fenneropenaeus merguiensis* and *F. indicus*), black tiger prawns (*Penaeus monodon* and *P. semisculcatus*) and endeavor prawns (*Metapenaeus ensis, M. endeavouri* and *M. demani*) inhabit coastal waters with muddy and sandy bottoms. Ornate rock lobster (*Panulirus ornatus*) are also found in the gulf, migrating annually from northern Torres Strait to the Gulf of Papua, to spawning grounds offshore from Yule Island. Both banana prawn species and the ornate rock lobster are of important commercial or artisanal value and are discussed in more detail in Section 8.6.

8.5.4 Sensitive Species, Ecosystems and Habitat Features

8.5.4.1 Sensitive Species

Table 8.1 presents 45 sensitive marine fauna species potentially occurring in the study area, sets out their likelihood of occurrence and categorizes each under the following:

- Species listed under the *Fauna (Protection and Control) Act 1966*.
- Species trade-restricted under CITES or the *International Trade (Fauna and Flora) Act 1979*.
- Species with a threatened status under the IUCN Red List of Threatened Species.
- Endemic or restricted-range species.
- Migratory and congregatory species.

Alien and native invasive species are not considered sensitive fauna, even when they occur in one of the above categories. This reflects the negative impact such species have on the ecosystem.

Further details on these categories and the process of classifying species are provided in Part 12 of Volume 2. The study area is expected to support 35 threatened species. These consist of the following, which are grouped based on the threatened status on the International Union for the Conservation of Nature (IUCN) Red List:[2]

- Five species listed as Critically Endangered on the IUCN Red List, two of which are likely to occur in part of the study area while three may possibly occur. These include sea turtles and species of elasmobranchs (i.e., cartilaginous fish), such as sharks, rays and sawfish.
- Eight species listed as Endangered, six of which are known to occur in the study area and two of which are likely to occur. These include species of elasmobranchs, sea turtles and sea cucumbers.
- Fifteen species listed as Vulnerable, five of which are known to occur in the study area, eight of which are likely to occur and two of which may possibly occur. These include species of elasmobranchs, sea turtles, sea cucumbers, dugong and dolphins.
- Seven listed as Near Threatened, one of which is known to occur in the study area, five of which are likely to occur and one of which may possibly occur. These include species of elasmobranchs, stingrays, sea turtles, fish and sea krait.

The Vulnerable listed dugong (*Dugong dugon*) and the Critically Endangered leatherback turtle (*Dermochelys coriacea*) are also listed as protected species under the PNG *Fauna (Protection and Control) Act 1966.*

The remaining 10 species listed in Table 8.1, while not listed as threatened on the IUCN Red List, are sensitive, as they are endemic species, have a restricted range or a migratory or congregatory status, or are restricted from trade under CITES or the *International Trade (Fauna and Flora) Act 1979.*

2 The following changes have been made to the IUCN rankings of recorded or potentially occurring species since undertaking the marine biodiversity baseline study: The orange-spotted grouper (*Epinephelus coioides*) has had its status downgraded from Near Threatened to Least Concern; the brown marbled grouper (*Epinephelus fuscoguttatus*) and Australian snubfin dolphin (*Orcaella heinsohni*) have had their status upgraded from Near Threatened to Vulnerable; and the cowtail ray (*Pastinachus sephen*) has had its status upgraded from Not Evaluated Deficient to Near Threatened. There are no changes to nationally Protected status.

8.5.4.2 Sensitive Ecosystems and Habitat Features

As described in Section 8.5.2, the study area supports a range of marine habitat types, which include important areas for the spawning, aggregation and migration of marine fauna, areas that provide habitat for a high diversity of marine species or particular threatened species, or areas that may promote species endemism. Such areas are considered to be sensitive. Marine habitats found in the study area include:

- Coral reefs.
- Ornate rock lobster migratory path (northern gulf between Purari River and Yule Island, between 40 and 80 m deep).
- Ornate rock lobster (*Panulirus ornatus)* spawning ground (Yule Island).
- Green turtle (*Chelonia mydas*) aggregation site (Cape Suckling).
- Seagrass meadows (Caution Bay).
- Highly turbid waters adjacent to the Purari and Vailala rivers.
- Turtle nesting beaches.
- Soft sediment benthic substrate, including sand, silts and mud.
- Rocky reefs.

The sensitivity of these habitat types is categorized in Table 8.2, based on their vulnerability and irreplaceability. The methods and criteria used in this assessment are further described in Part 12 of Volume 2[3].

Table 8.2 – Sensitivity Rating of Marine Habitats

Marine Habitat	Sensitivity Rating	Comments/Applicable Criteria
Coral reefs	High	Potentially supports coral species with extreme vulnerability. Provides habitat used by non-coral species with moderate, high and extreme vulnerability, although not considered to be critical to the survival or life cycle functions of these species. Due to uncertainty regarding the presence of coral species with extreme vulnerability, the overall sensitivity rating is high rather than extreme.
Panulirus ornatus migratory path	High	Area in the migration route for migratory species (*P. ornatus*) that occurs only in the Gulf of Papua and Southeast Papua New Guinea ecoregions.
P. ornatus spawning ground	High	Area in the spawning ground for migratory species (*P. ornatus*) that occurs only in the Gulf of Papua and Southeast Papua New Guinea ecoregions.
Chelonia mydas aggregation site	High	Area used by congregatory species (*C. mydas*) that is of extreme vulnerability but is represented in other parts of the ecoregions of the study area and surrounds.

3 Sensitivity is redefined in Chapter 12 consistent with ratings in Chapter 3. The different rating terminology used in baseline reflects the approach at the time the baseline was undertaken.

Table 8.2 – Sensitivity Rating of Marine Habitats (cont'd)

Marine Habitat	Sensitivity Rating	Comments/Applicable Criteria
Seagrass meadows	Moderate	Supports seagrass species (including *Enhalus acoroides*, which has a decreasing global population) with moderate vulnerability. Provides habitat used by non-seagrass species with moderate, high and extreme vulnerability, although not considered critical to the survival or life cycle functions of these species.
Highly turbid waters adjacent to large rivers	Moderate	Provides primary feeding habitat for species with high (*O. heinsohni*, *S. sahulensis*) and extreme (*G. glyphis*) vulnerability.
Turtle nesting beaches	Moderate	Potentially provides habitat important to life-cycle functions of a species with moderate, high or extreme vulnerability (*C. mydas*). Due to the uncertainty regarding the use of specific locations for nesting, the overall rating for all possible nesting beaches is moderate rather than high or extreme.
Soft sediment benthic substrate	Low	Habitat type does not provide suitable habitat for species of moderate, high or extreme vulnerability and is not considered to be unique.
Rocky reefs	Low	Habitat type does not support specific life-cycle functions of species with moderate, high or extreme vulnerability and is not considered to be unique.

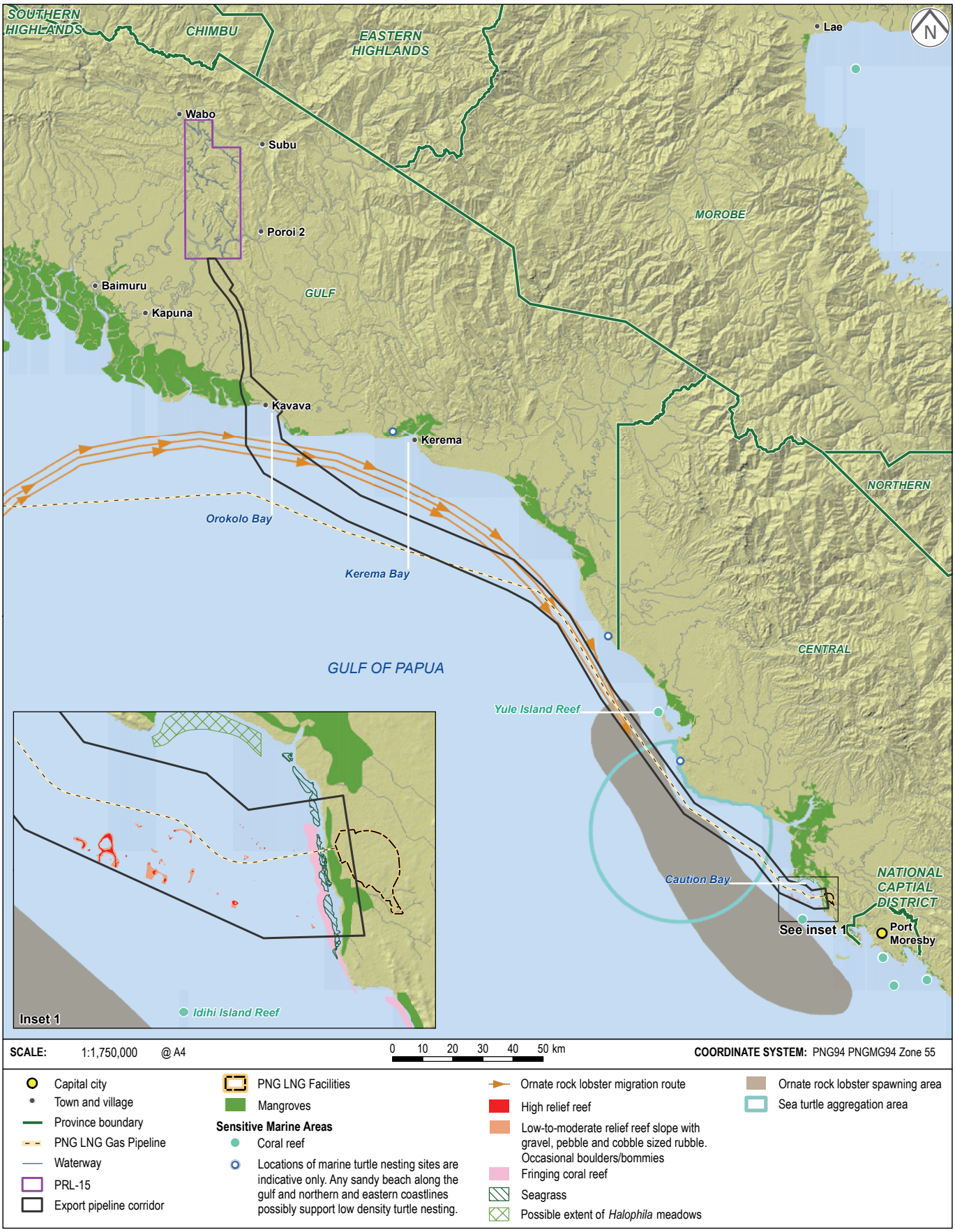
As shown in Table 8.2, some marine habitats in the study area are considered to be of moderate to high sensitivity, due to their intrinsic value or support of threatened species. These more sensitive environments of the study area include the coral reefs and seagrass meadows in Caution Bay, the highly turbid waters adjacent to large rivers in Orokolo Bay the ornate rock lobster migratory path and spawning ground that overlaps the offshore export pipeline corridor and the Cape Suckling aggregation area for green turtles that also overlaps the offshore export pipeline corridor (Figure 8.24). Mangrove habitats are considered in Section 7.6.4.

8.5.5 Introduced and Invasive Species

Few invasive or introduced species have been documented in Papua New Guinea; however, many of the reef-associated species of northern Australia and the Great Barrier Reef are common to Papua New Guinea and move between the Torres Strait, the northern Great Barrier Reef and fringing reefs of Papua New Guinea. Current marine pests of northern Australia include the Asian green mussel (*Perna viridis*) and Caribbean tubeworm (*Hydroides sanctaecrucis*). These species have not yet been recorded outside of port areas, but may be present in Port Moresby given shipping movements between it and Cairns.

Acanthaster planci (crown-of-thorns seastar), although native to the Indo-Pacific reefs, can be considered an invasive species when in high abundance and can devastate coral reefs. *A. planci* has been recorded in Bootless Bay, approximately 15 km southeast of Port Moresby. Up to 85% coral mortality has been recorded in the bay, with an average density of 162 *A. planci* per hectare (Pratchett et al., 2009). Given the relatively close proximity of this outbreak to Caution Bay, the area may be prone to a future outbreak.

FIGURE 8.24


SOUTHERN HIGHLANDS
CHIMBU
EASTERN HIGHLANDS
Lae
N
Wabo
Subu
Poroi 2
MOROBE
Baimuru
Kapuna
GULF
Kavava
Kerema
NORTHERN
Orokolo Bay
Kerema Bay
CENTRAL
GULF OF PAPUA
Yule Island Reef
Caution Bay
NATIONAL CAPTIAL DISTRICT
See inset 1
Port Moresby
Inset 1
Idihi Island Reef
SCALE: 1:1,750,000 @ A4
0 10 20 30 40 50 km
COORDINATE SYSTEM: PNG94 PNGMG94 Zone 55
Capital city
Town and village
Province boundary
PNG LNG Gas Pipeline
Waterway
PRL-15
Export pipeline corridor
PNG LNG Facilities
Mangroves
Sensitive Marine Areas
Coral reef
Locations of marine turtle nesting sites are indicative only. Any sandy beach along the gulf and northern and eastern coastlines possibly support low density turtle nesting.
Ornate rock lobster migration route
High relief reef
Low-to-moderate relief reef slope with gravel, pebble and cobble sized rubble. Occasional boulders/bommies
Fringing coral reef
Seagrass
Possible extent of Halophila meadows
Ornate rock lobster spawning area
Sea turtle aggregation area

8.6 Marine Fisheries and Resources

8.6.1 Regional Context

Two broad types of fisheries exist in Papua New Guinea: the larger-scale offshore operations, which primarily target finfish and shellfish, and the small-scale subsistence and artisanal (i.e., small-scale trade) fisheries that target reef fish and invertebrates found primarily in the coastal zone that extends three nautical miles offshore.

The Gulf of Papua is a biologically diverse area that supports commercial prawn, lobster, finfish and, to a lesser extent, bêche-de-mer (sea cucumber) fisheries, and subsistence and artisanal fisheries.

8.6.2 Marine Fisheries and Resource Baseline Characterization

8.6.2.1 Study Overview

The description of marine fisheries and resources in the study area draws on a wide variety of historical and contemporary literature sources, industry databases, fisheries data and reports, and data collected for the current study from marine, estuarine and freshwater biodiversity (Sections 8.5 and 7.6, respectively), and land and natural resource use surveys (Section 9.8).

8.6.2.2 Commercial Fisheries of the Gulf of Papua

Several commercial fisheries in the Gulf of Papua and Torres Strait are relevant to the offshore export pipeline corridor. These are described in the following sections. Figure 8.25 shows the environmental setting of these commercial fisheries.

Gulf of Papua Prawn Fishery

The Gulf of Papua Prawn Fishery (GOPPF) is one of the largest fisheries in Papua New Guinea, with an estimated value of PGK10 million (approximately US$3 million[4]) (Liviko et al., 2016). The fishery covers 9,600 km^2 and extends from about 60 km southeast of Kerema to 30 km east of the Fly River mouth, from three nautical miles from shore to around the 40 m depth contour offshore (Figure 8.25). The coastal waters zone, extending from the shore to the three nautical mile limit, is reserved for subsistence and artisanal fishing; however, Kompas & Kuk (2009) report that about one third of the total catch from the GOPPF comes from this zone, primarily as a result of resource sharing agreements with customary resource owners.

Twenty prawn species have been identified in the GOPPF, with banana shrimp (*Fenneropenaeus merguiensis*) and the Indian banana prawn (*F. indicus*) being the most valuable species, contributing around 50 to 60% of the prawn catch (Plate 8.23).

The mangrove-lined estuaries of the Kikori and Purari rivers are known to be major nursery areas for juvenile prawns where they reside before migrating to deeper water and, as such, maintenance of the ecosystem processes supporting the prawn life cycle is key to maintaining the commercial fishery (Liviko, 2012). The highest abundance of the target prawn species in the GOPPF occurs between April and September, with the peak in April to May (Liviko, 2012). The fishery is closed from 1 December to 31 March to protect brooding females.

4 Currency conversion undertaken at a rate of PGK1 = US$0.30.

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FIGURE 8.25

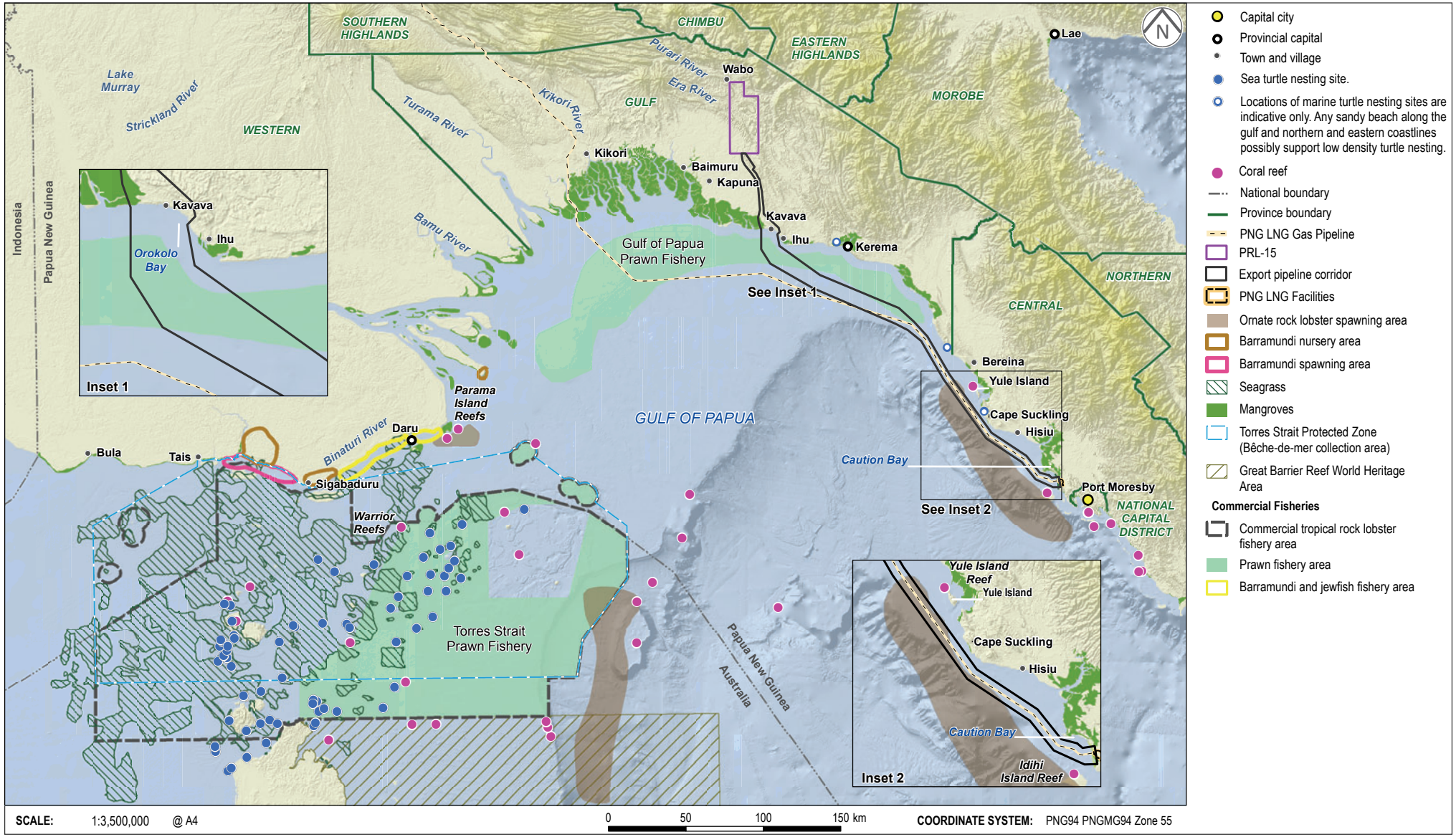


Plate 8.23 – Banana Prawn Catch



Photo: Raptis, 2015.

The National Fishery Authority divides the GOPPF into eight reporting areas, and catch data is reported on the basis of these areas. Vessel positioning data was used to determine the areas where trawling activities were undertaken, using the speed of vessels to distinguish between trawling and transiting activities. Part 13 of Volume 2 provides further detail. The final dataset included 26,600 vessel positions that represented the location of all vessels in the prawn fishery reporting area over all times for which data was available between 2010 and 2016. The density of vessel position data points was visualized as a heat map with warmer colors representing higher density and therefore greater trawling activity (Figure 8.26).

As shown in Figure 8.26, trawling activity is highest in the inshore areas around Kerema Bay and Freshwater Bay, with other high-activity areas occurring around the Purari River and Cape Blackwood. The offshore export pipeline corridor overlaps an area of relatively low prawn trawling activity in Orokolo Bay and an area of moderate activity in West Kerema Bay, neither of which is considered a high productivity area. Marine transport routes to the Purari River delta will also traverse areas of the GOPPF, potentially traversing high productivity areas of the Cape Blackwood, Purari and Orokolo Bay reporting areas.

Rock Lobster

Papua New Guinea shares the Torres Strait Tropical Rock Lobster Fishery with Australia. The fishery targets the ornate rock lobster (*Panulirus ornatus*) (Plate 8.24) in the Torres Strait Protected Zone (TSPZ), specifically in the Australian jurisdiction (see Figure 8.25), and is estimated to have a total annual export value of about PGK4 million (approximately US$1.2 million[5]) (Jogo, 2015).

Divers are used to collect lobsters from the reefs in the TSPZ, particularly from the Warrior Reefs about 300 km southwest of the Purari River mouth (see Figure 8.25). Daru, 50 km north of the Warrior Reefs, in Western Province, is the main port used in Papua New Guinea for exporting lobsters, which are mostly frozen and sent mainly to the United States.

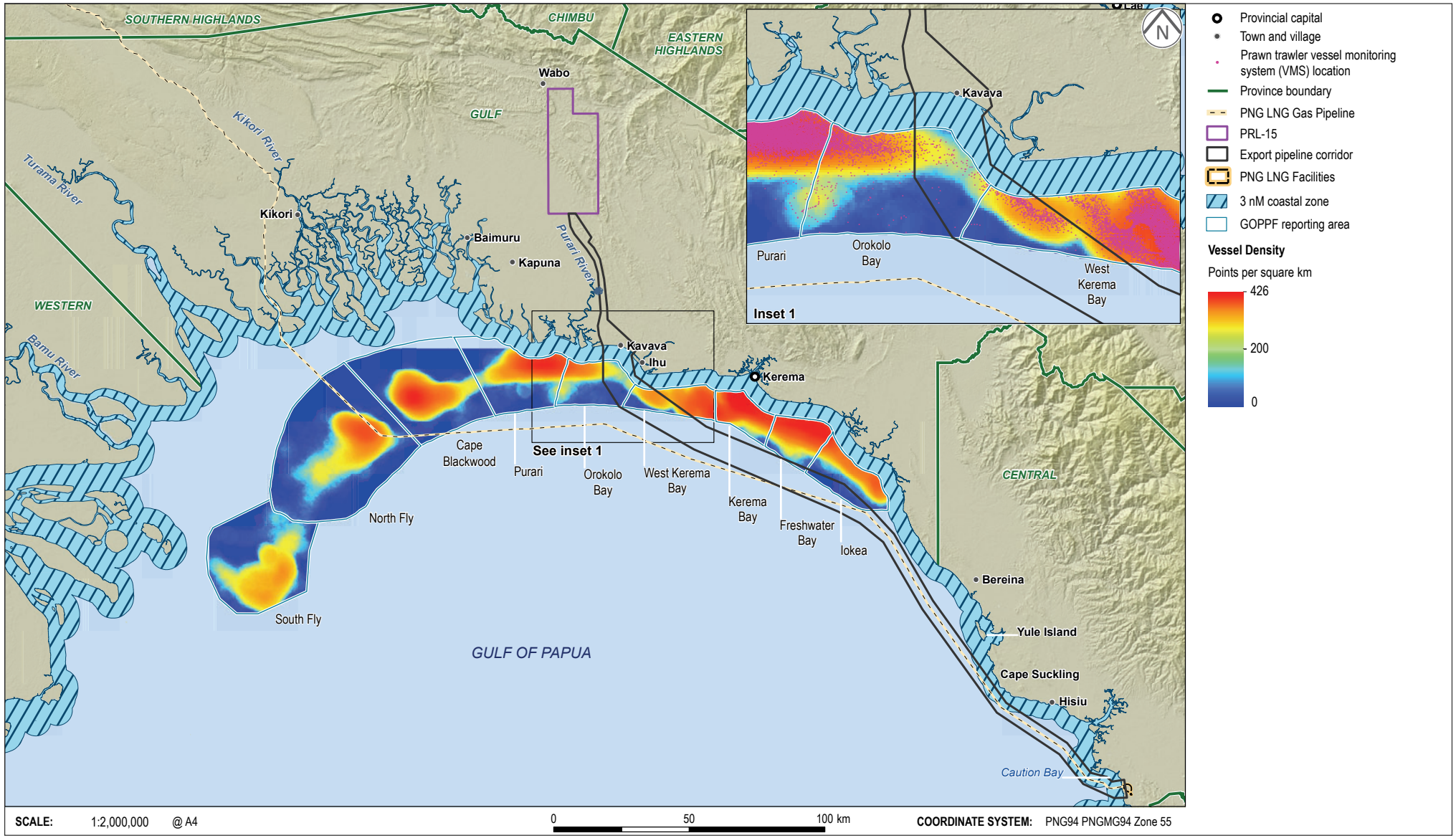
Lobster catches and the number of active freezer vessels operating have reportedly declined in recent years, with 192 t, amounting to 66% of the total allowable catch, exported in 2014 to 2015 (Williams & Mazur, 2016) and with only one of the seven licensed freezer vessels reportedly active (Jogo, 2015).

5 Currency conversion undertaken at a rate of PGK1 = US$0.30.

DENSITY OF PRAWN TRAWLER POSITIONS IN THE GOPPF REPORTING AREAS

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FIGURE 8.26



Color range represents scale of trawler positions per square kilometer with warm colors representing higher density.
Area 9 (South Fly) is established from the present study and Areas 1 - 8 are standard NFA reporting areas.

Plate 8.24 – Ornate Rock Lobster (*Panulirus ornatus*)



Photo: CSIRO, 2016 (Robert Kerton).

While the focus of the fishery is in the northern Torres Strait, the ornate rock lobster undergoes a migration from this area into the Gulf of Papua (Figure 8.27). Lobsters leave the Torres Strait from early September to late November and walk up to 400 km into the Gulf of Papua to the main spawning site at Yule Island and other reefs throughout Central Province (Moore & MacFarlane, 1984), arriving between late November and early April. Parama Island near the Fly River delta is also a known spawning site. The migrating lobsters from the Torres Strait are thought to move against the prevailing bottom current and to orientate with respect to this current, rather than follow a specific depth contour or substratum type (Moore & MacFarlane, 1984). Migrating lobsters have the potential to intersect with the proposed offshore export pipeline corridor and potential marine transport routes. While Yule Island is located east of the export pipeline corridor, the corridor transects a small area of the spawning area (see Figure 8.25).

The arrival of lobsters at Yule Island and other reefs in the Gulf of Papua is the basis of a seasonal subsistence and artisanal fishery (Section 8.6.2.3). There is mass natural post-spawning mortality of lobsters in the vicinity of Yule Island, and there is no return migration from the Gulf of Papua back into Torres Strait fishery by migrating adults (Dennis et al., 1992).

Little is known about the spawning area southeast of the TSPZ (see Figure 8.25). This area is not thought to form the basis of a targeted fishery. This spawning area may be linked to lobster populations from the Great Barrier Reef rather than those from the Torres Strait. It is also unknown whether spawning lobsters return to the Great Barrier Reef from this spawning area.

Bêche-de-mer

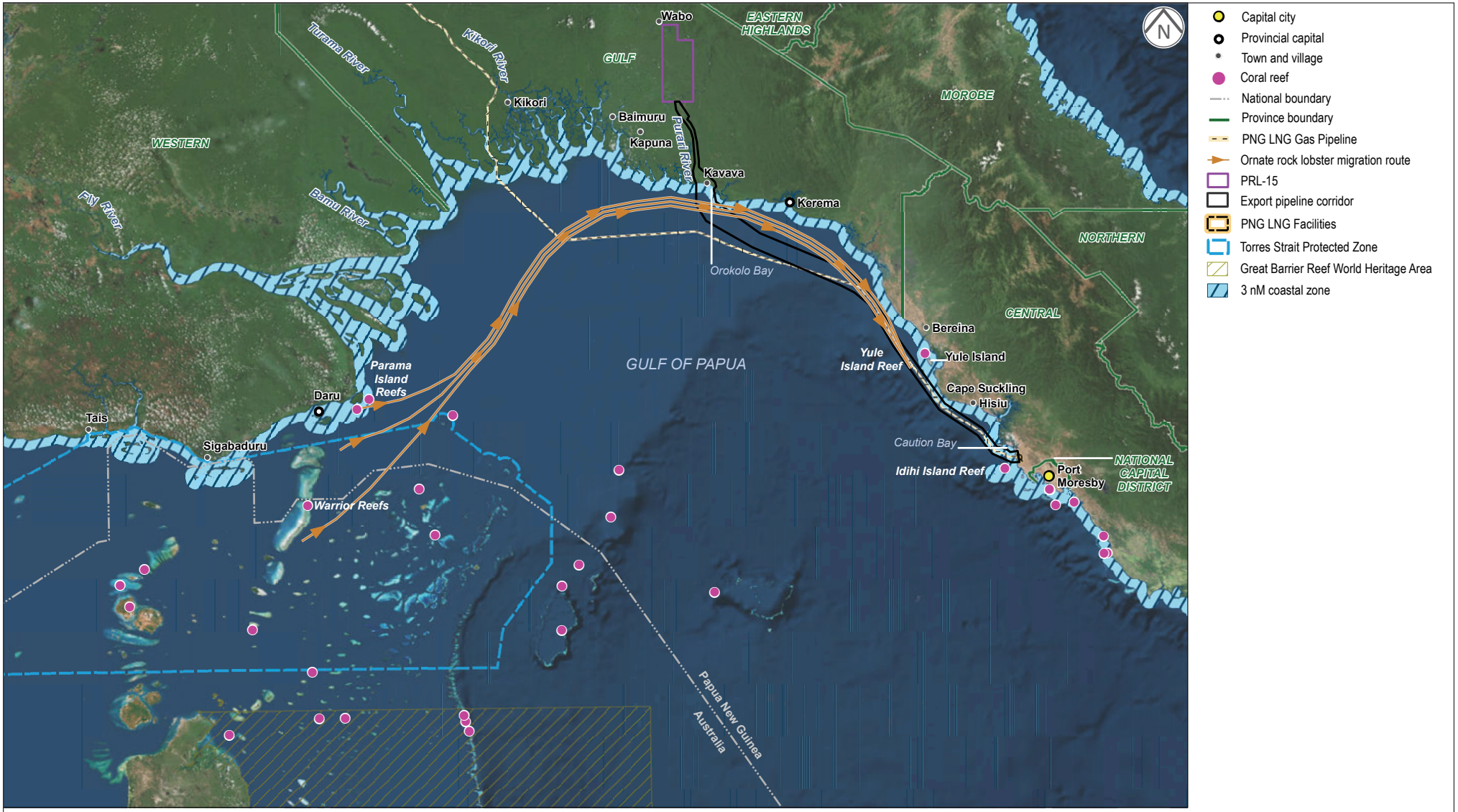
Bêche-de-mer are collected from the Torres Strait, in the TSPZ, in the same area that supports the tropical rock lobster fishery (see Figure 8.25), with the focus of the fishery being the Warrior Reefs, and the coastal zone of Papua New Guinea such as in the Gulf of Papua (i.e., within three nautical miles of the coast; see Figure 8.26). The proposed export pipeline corridor intersects with the coastal zone in Orokolo Bay, near Cape Suckling, and to the northeast and within Caution Bay (see Figure 8.26).

In the TSPZ, the four main bêche-de-mer species of commercial interest are black teatfish *(Holothuria whitmaei)*, prickly redfish *(Thelenota ananas)*, sandfish (*Holothuria scabra*) and white

MIGRATION ROUTE OF THE ORNATE ROCK LOBSTER

Papua LNG Project | Environmental Impact Statement

FIGURE 8.27



ERIAS Group | 01215B_23_F8-27_v1

teatfish (*Holothuria fuscogilva*). The current degree of participation in the fishery is unclear, but Daru is considered the major port supporting the fishery, with the Warrior Reefs being the focus area for fishing (Lokani et al., 1996; Long et al., 1996) (see Figure 8.25).

In the coastal waters of Papua New Guinea, the total annual bêche-de-mer export is estimated to average around 400 t and to be worth PGK21 million (approximately US$6.3 million[6]), which is almost double the annual average export value of prawns (ADB, 2009). Twenty-nine bêche-de-mer species are known to occur in the coastal waters of Papua New Guinea, with lollyfish (*Holothuria atra*), greenfish (*Stichopus chloronotus*) and amberfish (*Thelenota anax*) the most abundant species. These three species account for nearly 75% of the commercial fishery (Skewes et al., 2006). Milne Bay Province is the main focus of the PNG bêche-de-mer fishery, and it is the most important coastal fishery in that province (Skewes et al., 2006).

A moratorium was placed on the PNG bêche-de-mer fishery in 2009 due to concerns about overfishing; however, exploitation of the fishery continued in some areas. Associated with the fishery concerns are potential negative impacts to mangroves and other coastal forests associated with wood harvesting for bêche-de-mer smoking (Jogo, 2015). The moratorium was lifted on 1 January 2017, with a compulsory closed season from 1 October to 31 March. A catch limit will be allocated to each province in due course. Historical data indicates that the Gulf of Papua contributes relatively small catches to the bêche-de-mer fishery, with a previous total allowable catch of 1 t compared to 140 t for Milne Bay (Kinch et al., 2008). The future status of the commercial bêche-de-mer fishery in the Gulf of Papua is uncertain; but if operating, the fishery would likely focus on the reefs around Caution Bay and Yule Island, rather than to the north of the gulf. These same areas may also be used for subsistence and artisanal bêche-de-mer harvesting.

Barramundi and Jewfish

Barramundi (*Lates calcarifer*) are only found naturally in rivers in the southern part of the country. They are most abundant in rivers with substantial lake and swamp systems, and with extensive estuarine reaches, such as those of the gulf. The species migrates from adult freshwater foraging habitat to coastal spawning grounds. A spawning migration is well documented in the Gulf of Papua whereby fishes from all rivers in the gulf migrate to spawning grounds on the southern coast of Western Province, west of Daru (see Figure 8.25).

The barramundi fishery in the Gulf of Papua was historically one of the largest fisheries in Papua New Guinea, but it declined substantially in the 1990s. This is thought to be a result of overfishing and, for Fly River populations, impacts from mine waste from the Ok Tedi copper mine (Swales et al., 2000; Blaber et al., 2009). The two bases for the barramundi fishery were Daru and Baimuru. The Daru-based fishery exploited the Fly River-Lake Murray area and along the coast from the mouth of the Fly River to the mouth of the Binaturi River west of Daru. The Baimuru-based fishery exploited the northern Gulf of Papua, including the Turama, Kikori, Era and Purari rivers. On-shore freezer facilities were located at Ihu, Baimuru and Kikori.

Today the fishery is based primarily in Western Province (see Figure 8.25) and serviced out of Daru. Wild-caught barramundi are supplemented by jewfish (Sciaenidae) (Busilacchi et al., 2014). The main spawning and breeding grounds between Sigabaduru village and the Papua New Guinea/Irian Jaya border are closed during peak spawning periods from 1 October to 30 November each season. Barramundi are also an important part of the subsistence and artisanal fishery, discussed in Section 8.6.2.3.

6 Currency conversion undertaken at a rate of PGK1 = US$0.30.

Other Commercial Fisheries

A commercial shark fishery that primarily caught hammerhead shark (*Sphyrna lewini*) existed in the Gulf of Papua during the 1970s and 1980s. This fishery is not active today, but sharks are a major component of GOPPF bycatch, and the region supports significant shark populations that are an important resource in subsistence and artisanal fisheries.

Fishing trials for commercially valuable fish species, such as jewfish, snapper and emperors, were conducted in the Gulf of Papua in 2015, but no commercial fishery currently exploits these species.

8.6.2.3 Subsistence and Artisanal Fisheries

Fishing and harvesting of marine and estuarine resources are integral to subsistence lifestyles and cultural identity in most coastal areas of Papua New Guinea. The total volume and economic value of the coastal artisanal (i.e., small-scale trade) fishery is estimated to exceed that of the commercial fisheries (ADB, 2009).

Subsistence and artisanal fishing mostly occurs in the coastal zone, zero to three nautical miles offshore (see Figure 8.26), which is a zone where commercial fishing operations are prohibited. Fishing effort is highly targeted toward maximum yields from the habitats that are available to people in their customary areas and toward seasonal abundance and movements of species. As such, communities located near mangrove-lined estuaries with no coastal reef systems focus their efforts on maximizing yields from the estuarine system. The offshore export pipeline corridor comes within three nautical miles of the coast in Orokolo Bay, near Cape Suckling and to the northeast and within Caution Bay (see Figure 8.26).

Further detail regarding the social and economic value of fishing in the study area is provided in Section 9.8 and the Upstream Land and Natural Resource Baseline Report (Part 18 of Volume 2). The following sections describe the key coastal subsistence and artisanal fisheries in three relevant Project regions.

Orokolo Bay and the Purari River Delta

Community-level surveys undertaken in coastal villages at Orokolo Bay indicate that fishing is important for subsistence but that the primary motivation for fishing was commercial benefit, with direct consumption being a secondary motivation. Household-level surveys; however, showed a low volume of sales and a high volume of household consumption, indicating that most of the catch was consumed rather than sold (Part 18 of Volume 2). The survey results suggest a degree of opportunistic artisanal sale or trade during times of excess fisheries resources and when the occasion exists for cash income.

The predominant practice at Orokolo Bay appears to be one of fishers going throughout the coastal zone with a focus in and around river mouths. This fishing principally occurs during the calm period of November to April, using mainly gill nets and hook-and-line techniques to target elasmobranchs (i.e., sharks, sawfishes and rays), threadfin salmon, beach salmon, croakers and barramundi. In addition, hand-netting for small fishes and prawns is common in shallow areas.

Fishing is limited in Orokolo Bay during the southeast trade wind season from May to October due to strong winds creating hazardous conditions for dugout canoes and banana boats. Household surveys estimate around 400 dugout canoes and 40 dinghies belong to the coastal villages of Aire, Apiope, Akoma/Kairu'u, Harevavo, Herekela and Iuki; however, these numbers do not necessarily reflect the numbers used for fishing (Part 22 of Volume 2). Fishing during the southeast trade wind season is restricted to the Purari River delta and occurs mainly in the smaller tributaries rather than in the main channel. Most fishing grounds are within customary

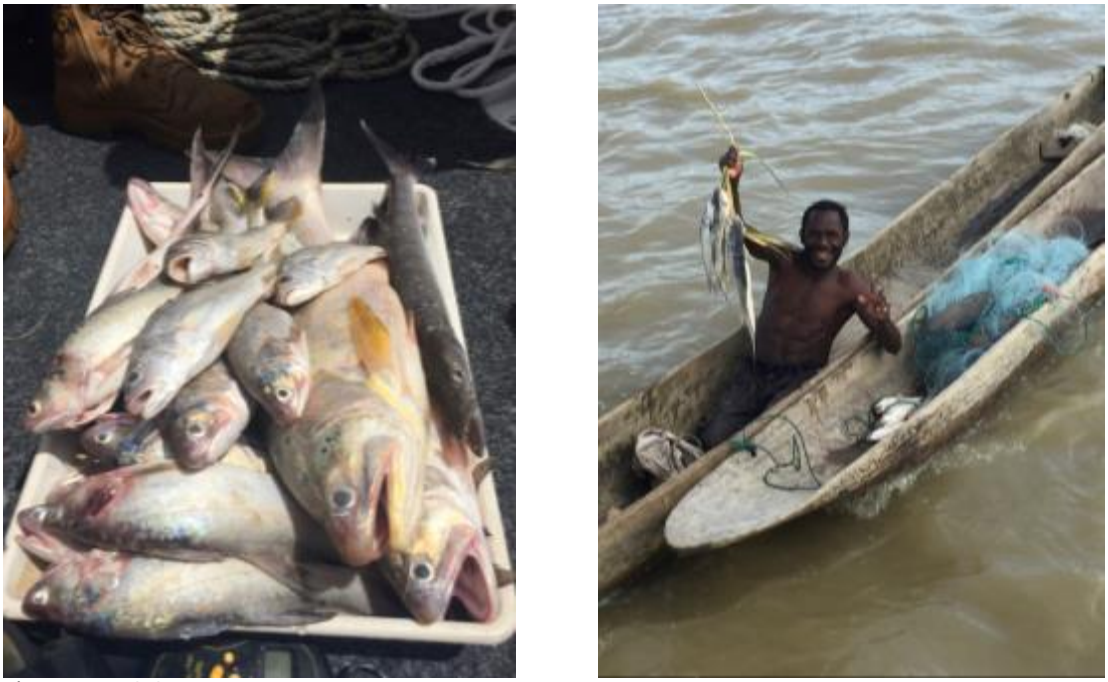
lands in the Purari River delta, although the main channels of the Purari River are openly accessible by local villagers.

Traditional techniques, such as the use of *Derris* root poisoning, woven fish traps and v- and y-shaped scoop nets, are still used. More modern equipment, such as hook and line, and gill nets, are also used. Both powered and unpowered dugout canoes, banana boats and small outrigger canoes are used for fishing activities.

Villagers are also reported to purchase or trade bycatch from the prawn trawlers, the transactions of which represent at least 75% of the total biomass of trawls. This was observed at least once during field surveys (Part 18 of Volume 2).

Household surveys revealed that barramundi, prawns and sharks were the top three fisheries species consumed in Orokolo Bay coastal villages. Threadfin salmon (family Polynemidae) were reported to be seasonally abundant and particularly targeted from April to July (Plate 8.25).

Plate 8.25 – Threadfin Salmon Caught in the Purari River Delta Estuary



Photos: ERIAS Group.

Qualitative observations of subsistence catches at Orokolo Bay coastal villages in 2016 are in general agreement with historical studies of Haines and Stevens (1983) with respect to faunal composition. Elasmobranchs, barramundi, threadfin salmon (family Polynemidae) and mullet (family Mugilidae) were recorded in subsistence catches in marine and river mouth habitats (Plate 8.26). In estuarine reaches, dominant species were black bass (*Lutjanus goldiei)* and emperors (family Lethrinidae); and in the estuarine and lower freshwater zones, several catfish species dominated the catch. Prawns are widespread throughout the system and in some villages are more often consumed than finfish or sharks. These observations are also broadly consistent with previous studies in the nearby Omati-Kikori delta, which found barramundi, threadfin salmon, catfish, black bass, bream, nursery fish, ponyfish, prawns (including the giant river prawn), mudcrab and crocodile in subsistence catches (CNS, 2008c).

Plate 8.26 – Species Observed in Subsistence Fish Catches from the Orokolo Bay Region

Blue threadfin (*Eleutheronema tetradactylum*)



Juvenile sharks (family Carcharhinidae)



Lesser queenfish (*Scomberoides lysan*)



Narrow sawfish (*Anoxypristis cuspidata*)



Dorab wolf herring (*Chirocentrus dorab*)



Winghead shark (*Eusphyra blochii)*



Mackerel (*Scomberomorus* sp.)



Trevally (possibly *Caranx herberi*)



Scaly jewfish (*Nibea squamosa*)



Longfin beach salmon (*Leptobrama pectoralis*)



Photos: Ken Aplin.

Yule Island

The offshore export pipeline corridor overlaps the three nautical mile coastal zone south of Yule Island near Cape Suckling. As described in Section 8.6.2.2, ornate rock lobsters gather at the reefs around Yule Island east of the export pipeline corridor to spawn from November to April. The spawning aggregation results in a seasonal artisanal and subsistence dive fishery around Yule Island, with peak catches from mid-January to mid-February. Historically, lobsters were processed at a facility on Yule Island, with catches of nearly 1 t (whole lobster weight) reported from 1988 and 1989 (Dennis et al., 1992). The current status of the processing facility is unknown; however, the subsistence and artisanal fishery is still considered active today.

Caution Bay

The subsistence and artisanal fisheries in Caution Bay target the fringing, barrier and deep coral reefs; the pelagic environment; seagrass meadows; mangroves habitats; and beaches found throughout the area. A diverse range of equipment is used, including hook-and-line, netting, trapping and spearing techniques, with a predominance of hook-and-line fishing from non-motorized canoes. A variety of resources are targeted, including small fish, such as goatfish (Mullidae), threadfin bream (Nemipteridae) and small emperors (Lethrinidae); large-bodied fish, such as trevallies (Carangidae), mackerel and tuna (Scombridae) and long toms (Belonidae); and invertebrates, such as crabs and snails.

As described in Section 8.5.3.2, fish surveys at coral reef sites in Caution Bay using baited remote underwater video stations identified large-bodied fish species, such as trevallies, snappers (Lutjanidae), groupers and rockcods (Serranidae) and surgeonfish (Acanthuridae). This finding was in contrast to previous studies that reported an absence of these larger fish, with most observations being of small ornamental reef fish less than 10 cm long (CNS, 2008a). An interview with men from Boera village indicated that the outer deep reefs of Caution Bay were the main focus for subsistence fishing, targeting hammerhead sharks, snapper and trevally (Niniga & Madaha, pers. com., 2017).

8.7 Underwater Noise

This section describes the ambient acoustic environment, i.e., underwater noise, of the marine, estuarine and riverine areas relevant to the export pipeline corridor and marine and river transport corridors. A description of the existing underwater acoustic environment has been included in Volume 2 (ESBS Dossier), as the Project will have underwater noise sources such as those associated with marine traffic and transport and with construction activities. An understanding of the existing ambient acoustic conditions therefore forms part of the description of the existing environment and is required for the impact assessment in Chapter 13.

Technical units and terms are used to describe underwater noise levels in this section; hence, a brief explanation of each is provided below:

- Frequency: the rate of oscillation or vibration measured in cycles per second, hertz (Hz), or in kilohertz (kHz) equivalent to 1,000 cycles per second.
- Decibel (dB): used to describe the intensity of sound by comparison to a logarithmic scale. The reference pressure for freshwater and seawater is 1 micropascal (µPa) (compared to 20 µPa for air).
- Sound pressure level: the unit is the pascal (Pa), which is equivalent to a newton per meter squared (N/m^2) and is expressed in terms of decibels with reference to 1 micropascal at 1 meter, expressed as dB re 1 µPa at 1 m, where ‘re’ denotes ‘with reference to’.

In this section, noise sources levels are reported as units of dB re 1 µPa at 1 m while sound received levels are reported as units of dB re 1 µPa rms, where rms denotes root mean square. Received level is an imprecise term but is typically used to distinguish received levels from source levels and generally refers to the sound level received by a receptor such as marine fauna. For the baseline characterization, received levels have been calculated at an estimated mid-water depth[7] at each assessment location.

8.7.1 Regional Context

In the Gulf of Papua, underwater noise is predominantly ambient noise, i.e., environmental background noise, and does not have a single source or point (MMS, 2001). This ambient noise includes both natural and anthropogenic noise, which can be continuous or intermittent from both low and high frequencies. Natural variation in background noise can be as much as 20 dB per day. In the Gulf of Papua, ambient noise is expected to be highly variable and to come from a wide variety of sources.

Figure 8.28 shows the ambient noise spectra levels that are generated by natural and anthropogenic (e.g., vessel traffic) noise sources. For example, noise source levels at a frequency of 600 Hz for Beaufort scales[8] 1, 2, 3, 5 and 8 in Figure 8.28 are 46.5, 55.0, 66.0, 73.0 and 81.0 dB re 1 µPa at 1 m, respectively.

Natural sources include physical sources, such as wind, waves, rainfall, thunder and earthquakes, and biological sources, such as marine mammals, fish and macroinvertebrates. Biological sources of underwater noise are expected to be generally intermittent and of short duration, although some sources, such as snapping shrimp, may produce more continuous noise.

Ambient background noise is site-specific; however, in general, the natural background noise levels in the undisturbed ocean vary from around 90 dB re 1 µPa rms to 110 dB re 1 µPa rms, depending on ambient weather conditions (Entrix, 2004). Table 8.3 presents ambient natural underwater noise levels for a range of marine environments.

Anthropogenic underwater noise sources in the Gulf of Papua include both commercial and community vessels; oil and gas exploration activities, such as seismic surveys and sonar systems; and functioning oil terminal platforms, such as the Kumul Marine Terminal. Section 10.5 provides further detail on the coastal and river shipping routes and the types and quantity of commercial vessels in the Gulf of Papua, and in the Purari River and its distributaries.

8.7.2 Baseline Characterization

8.7.2.1 Study Overview

The main natural noise sources in the study area are snapping shrimp, soniferous fish and, to a lesser extent, wind and waves. Barges and community vessels are the main anthropogenic noise sources.

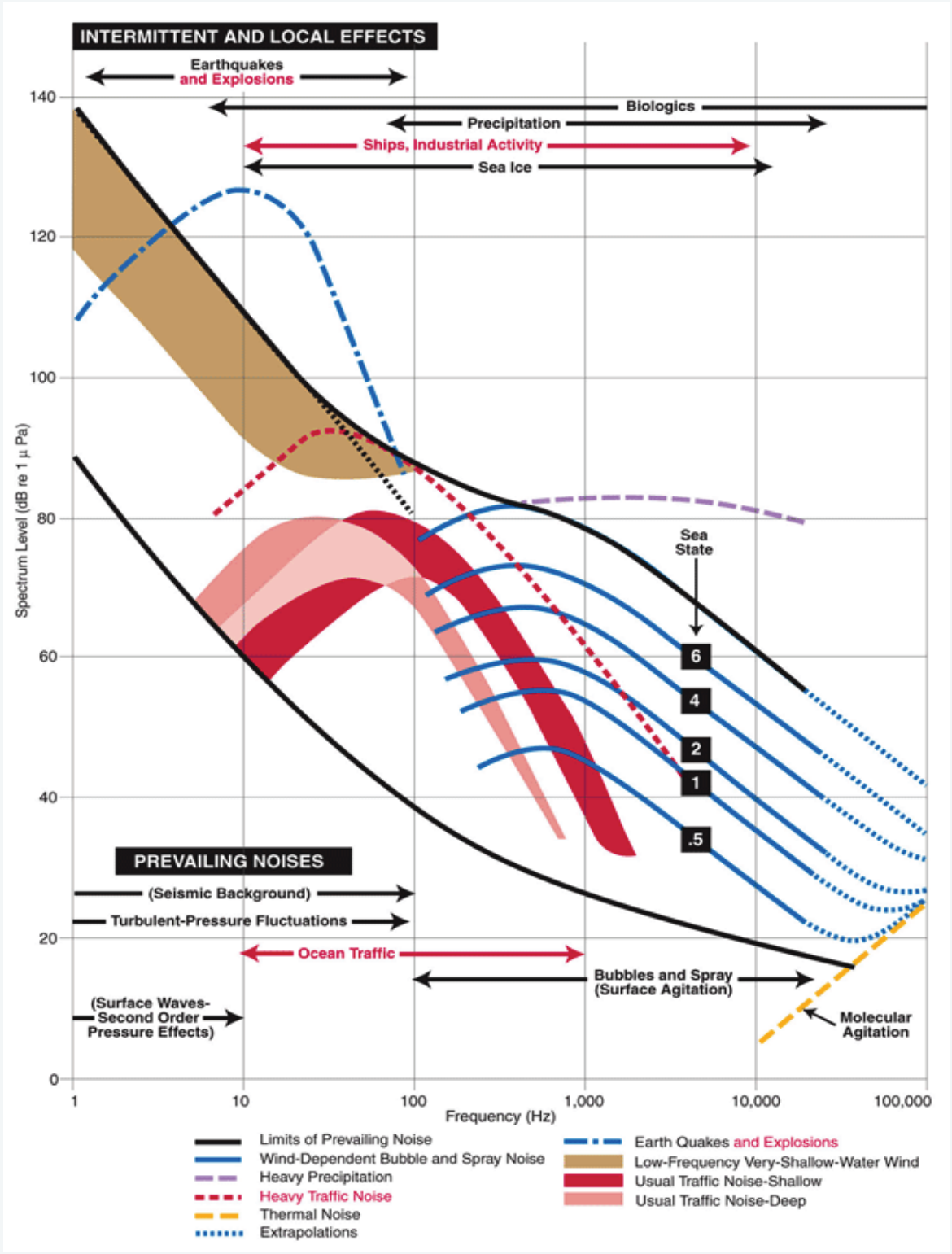
A desktop study assessed the existing underwater acoustic environments of rivers, estuaries, and nearshore and offshore areas in the study area. Seven assessment locations were selected, which included the riverine environment of the upstream onshore Project area in PRL-15, in the

7 Mid-water depth was selected as a representative point to be consistent between ambient underwater noise predictions at each location.
8 The Beaufort Scale relates wind speed to observed conditions at sea and on land on a scale from 0 to 12 for wind speeds from less than 1 knot to greater than 64 knots.

AMBIENT UNDERWATER NOISE SPECTRA LEVELS IN THE MARINE ENVIRONMENT

Papua LNG Project I Environmental Impact Statement

FIGURE 8.28



Source: NRC (2003) adapted from Wenz (1962)

Table 8.3 – Ambient Natural Underwater Noise Levels in the Marine Environment

Location	Broadband Frequency	Broadband Ambient Level	Reference
Undisturbed ocean in general	Not stated	Range 90 to 110 dB re 1 µPa at 1 m.	Entrix (2004)
Timor Sea	Not stated	93 dB re 1 µPa at 1 m. Maximum of 110 dB in Beaufort Scale winds of between 5 and 7.*	McCauley (1998)
North Pacific Ocean	10 to 100 Hz	90 dB re 1 µPa at 1 m.	Baggeroer et al. (2005)
Open ocean (off the coast of central California)	Not stated (Wind Beaufort scale between 3 and 5*)	74 to 100 dB re 1 µPa at 1 m.	Heathershaw et al. (2001)
Open sea	10 to 100 Hz	40 to 100 dB re 1 µPa at 1 m.	Wenz (1962)
Scott Reef (Australia)	Not stated	90 to 100 dB re 1 µPa at 1 m with daily spikes by fish choruses to 120 to 130 dB re 1 µPa at 1 m.	McCauley (2008)
Exposed ocean (i.e., offshore environment without protection from land) (Otway Basin, Bass Strait)	Not stated	90 to 110 dB re 1 µPa.	APPEA (2005)

* The Beaufort Scale relates wind speed to observed conditions at sea and on land on a scale from 0 to 12 for wind speeds from less than 1 to greater than 64 knots.

proposed export pipeline corridor and in the river transport corridor (Figure 8.29). Existing underwater noise is described for the relevant Project components based on a desktop literature study. As such, existing underwater noise levels have been estimated based on known or calculated noise levels from natural and anthropogenic sources such as those listed in Tables 1, 3, 4, 5 and 6 in Attachment 8.1.

Underwater noise transmission is a complex process affected by the location of the sound source, water depth, seabed or riverbed type, bathymetry, water density and temperature, and absorption and refraction of sound energy. These are discussed in more detail in Attachment 8.1. As point source underwater sound energy propagates through the marine environment, it spreads over a larger area and the intensity of the sound energy decreases. This is known as transmission loss (Collins, 2017).

Seafloor conditions have a strong effect on shallow-water ambient noise, with generally higher levels of ambient noise where the seafloor is very reflective and lower where it is absorptive (Urick, 1983). The amount of energy lost into the bottom varies with the bottom composition, the sound frequency, and the striking angle of the sound wave. The total of these losses can vary from as low as 2 dB/bounce to greater than 30 dB/bounce. In general, bottom loss will tend to increase with frequency and with the angle of incidence. Soft bottoms, such as mud, are usually

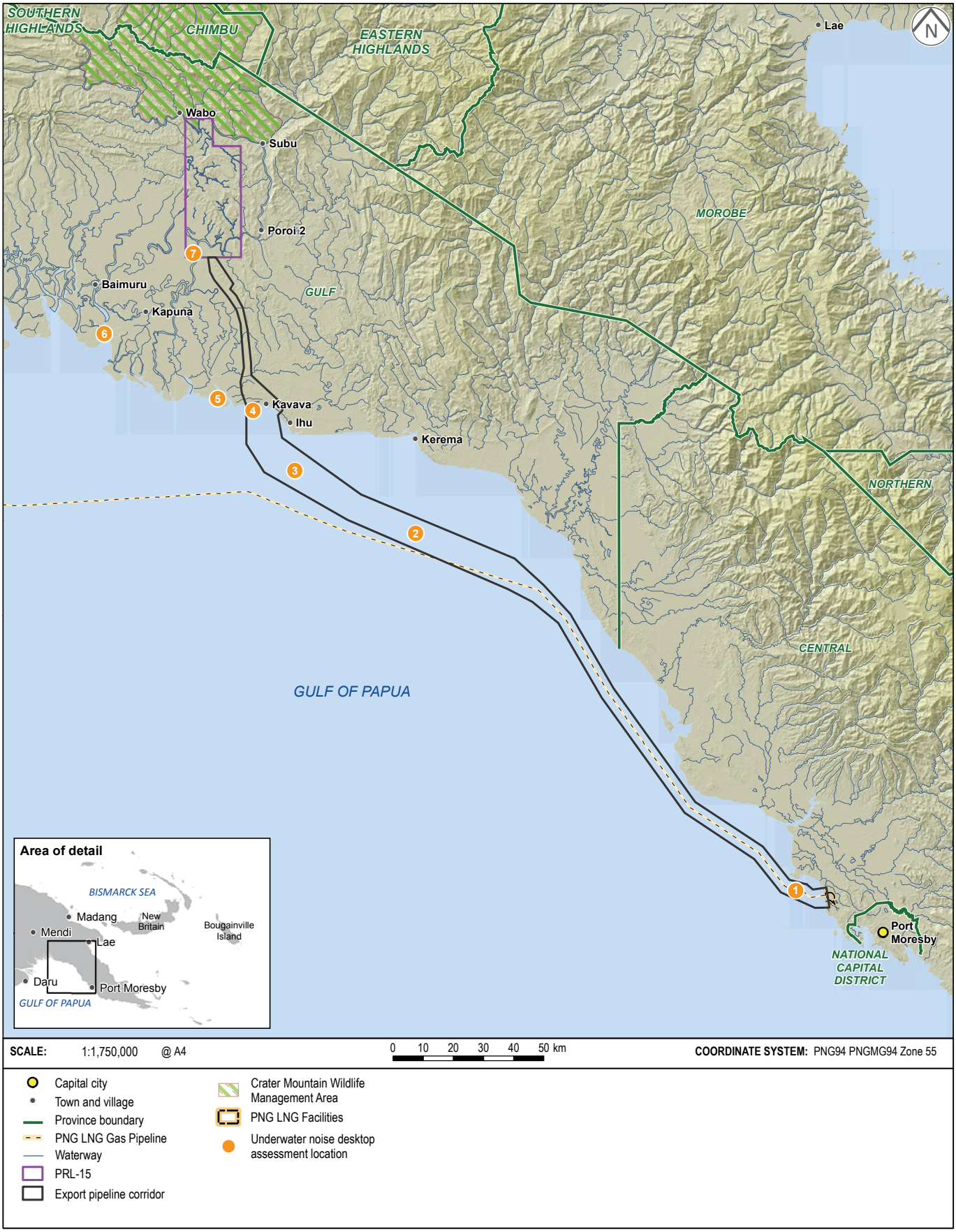
associated with high bottom losses (i.e., 10 to 30 dB/bounce); hard bottoms, such as smooth rock or sand, produce lower losses. The seafloor in the Project area varies from silty muds, (e.g., Orokolo Bay and along most of the export pipeline corridor) to sand and reef (e.g., Caution Bay and near Yule Island) with these areas expected to have high and low bottom loss, respectively.

This study used a basic underwater sound-spreading model to estimate sound levels from anthropogenic sources at each location for a mid-water depth. In all cases, a spherical spreading model (i.e., 20log10[R], where R is the radial distance from the noise source in meters) was used to assess anthropogenic noise generated in the immediate vicinity of the seven assessment

UNDERWATER NOISE DESKTOP ASSESSMENT LOCATIONS

Papua LNG Project | Environmental Impact Statement

FIGURE 8.29



locations. Natural noise levels from physical and biological sources were based on background ambient levels reported in the literature, such as those presented in Attachment 8.1.

8.7.2.2 Underwater Noise Desktop Assessment

Table 8.4 summarizes the underwater noise levels for the seven assessment locations, considering the contribution of both natural biological and physical noise sources and anthropogenic noise sources. Underwater noise levels along the offshore export pipeline corridor south of Kerema and Ihu (i.e., assessment locations 2 and 3) are assessed to be notably lower than other locations, ranging from 75 to 127 dB re 1 µPa rms at mid water depth. At these two locations, the ambient noise from natural physical and biological noise sources would include wind, waves and snapping shrimp, with distant shipping and trawlers being the main anthropogenic noise sources.

Table 8.4 – Summary of Underwater Noise Levels and Key Noise Sources at Assessment Locations

Project Area	Assessment Location	Depth (m)	Key Noise Sources	Baseline Characterization Level (dB re 1 µPa rms)
Caution Bay	1 (Caution Bay)	30	Soniferous fish, snapping shrimp, commercial shipping traffic including LNG carriers and tugboats	90 to 161
Offshore export pipeline corridor	2 (South of Kerema)	80	Wind, waves, snapping shrimp, barges and trawlers	75 to 127
	3 (South of Ihu)	50		
Orokolo Bay	4 (Orokolo Bay)	12	Wind, waves, rainfall, soniferous fish, snapping shrimp, marine mammals, barges and community vessels	85 to 163
Purari River delta	5 (Aievi Passage)	6	Rainfall, soniferous fish, marine mammals, barges and community vessels	75 to 175
	6 (Port Romilly)	8		
PRL-15	7 (Purari River)	6	Wind, rainfall, soniferous fish, barges and community vessels	75 to 170

The closer proximity of the other locations to boat and shipping traffic means these locations have higher underwater noise levels, from 75 to 175 dB re 1 µPa rms at mid water depth. Natural physical and biological noise sources would include wind, waves and snapping shrimp, with community vessels, port traffic and transiting barges the main anthropogenic noise sources.

The close proximity of the assessment locations to vessel traffic results in the upper noise levels being higher (i.e., up to 175 dB re 1 µPa rms) than the upper ambient noise levels of up to 110 dB re 1 µPa rms reported in the literature for marine locations elsewhere in the world (see Table 8.3).

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Attachment 8.1
Underwater Noise Desktop Baseline Technical Paper

Papua LNG Project

Underwater Noise
Technical Paper

Prepared for: ERIAS Group and Total E&P PNG Limited

Report No. TR 167/2, December 2017



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Executive Summary

Introduction

An underwater noise desktop baseline characterization study was undertaken to assess the existing underwater acoustic environments (soundscapes) of representative rivers, estuaries, nearshore and offshore areas of the Project Area of Influence. Seven underwater noise desktop assessment locations were selected for baseline characterization, which were:

- Assessment Location 1 (Caution Bay): Nearshore approach to Caution Bay.
- Assessment Location 2 (south of Kerema): Offshore marine environment.
- Assessment Location 3 (south of Ihu): Offshore marine environment.
- Assessment Location 4 (Orokolo Bay): Nearshore marine environment.
- Assessment Location 5 (Aievi Passage): Purari Delta estuary.
- Assessment Location 6 (Port Romilly): Pie River estuary.
- Assessment Location 7 (Purari River): Purari River downstream of Herd Base.

Assessment locations 1 through 4 were representative of existing underwater soundscapes along the Project's proposed offshore export pipeline corridor, assessment locations 5 and 6 were representative of shallow-water estuaries of the Project's river transport corridor, and assessment location 7 was representative of the riverine environments of the Project's upstream onshore area.

Study Approach

This report is based on a desktop study of the literature; however, the review did not reveal any underwater noise measurement data for the Gulf of Papua, Purari Delta estuaries or Purari River. Therefore, background ambient noise levels were estimated based on known or calculated noise levels from natural (i.e., physical and biological) sources and anthropogenic sources (e.g., ships).

In the case of anthropogenic noise source levels from shipping and fishing vessels, a list of the types and size of ships known to frequent in the Gulf of Papua, Caution Bay and the Purari River was complied. Based on the key shipping and fishing vessel routes in the Gulf of Papua, the distance from the nearest approach point of a shipping route to each assessment location was determined, and the distances used in sound transmission loss equations (e.g., spherical or cylindrical models) to calculate the received sound levels at the assessment locations. By this means, existing anthropogenic noise levels at the assessment locations could be calculated.

In addition, the literature was examined for background underwater noise measurements in similar tropical water environments and used as comparative analogues, with the aim of confirming average background ambient noise levels estimated for the seven assessment locations selected within the Project's area of influence.

Study Findings

Characterization of background ambient noise at the seven assessment locations was as follows:

Assessment Location 1 (Caution Bay)

Background ambient underwater noise at the nearshore Caution Bay assessment location is assessed as a typical range of between 90 to 110 dB re 1 µPa rms, with a maximum transient noise source level of 180 dB 1 µPa at 1 m for shipping (e.g., a LNG carrier) increasing the range of the upper value to 161 dB re 1 µPa rms, which represents a noise transmission loss of 19 dB between the noise source (propellers at 6 m depth) and the mid-water depth assessment point of 15 m.

Assessment Location 2 (South of Kerema)

Background ambient underwater noise at the offshore Gulf of Papua assessment location from natural physical and biological sources and anthropogenic sources (i.e., distant shipping) is expected to be in the range 75 to 95 dB re 1 µPa rms, with maximum transient noise from a trawler passing directly over the assessment location, increasing the range upper value to 123 dB re 1 µPa rms for a mid-water depth assessment point at 40 m.

Assessment Location 3 (South of Ihu)

Background ambient underwater noise from natural physical and biological sources and anthropogenic sources (i.e., distant shipping) is expected to be in the range 75 to 95 dB re 1 µPa rms, with transient noise from a trawler actively fishing increasing the range upper value to 127 dB re 1 µPa rms for a mid-water depth assessment point at 25 m.

Assessment Location 4 (Orokolo Bay)

Background ambient underwater noise from natural physical and biological sources and anthropogenic sources (i.e., distant shipping) at the Orokolo Bay assessment location is assessed as a typical range of between 85 to 95 dB re 1 µPa rms, with transient noise from a supplies barge (passing directly over the assessment location) or an outboard motor-driven banana boat (travelling along the coast, about 2 km distance from the assessment location) increasing the range upper value to 163 dB re 1 µPa rms or 130 dB re 1 µPa rms, respectively for a mid-water depth assessment point at 6 m.

Assessment Location 5 (Aievi Passage)

Background ambient noise at the estuarine Aievi Passage assessment location in the Purari River delta is assessed as a typical range of between 75 and 85 dB re 1 μPa rms, with transient noise from a supplies barge (i.e., 64-m-long MV GFS Marine 01) passing directly over the assessment location increasing the upper range value to 175 dB re 1 μPa rms for a mid-water depth assessment point at 3 m.

Assessment Location 6 (Port Romilly)

Background ambient underwater noise at the estuarine Port Romilly assessment location is assessed as a typical range of between 80 and 90 dB re 1 μPa rms, with transient noise from a logging barge/landing craft passing directly over the assessment location increasing the upper range value to 164 dB re 1 μPa rms for a mid-water depth assessment point at 4 m.

Assessment Location 7 (Purari River)

Background ambient underwater noise at the Purari River assessment location is assessed to be a typical range of between 75 to 85 dB re 1 µPa rms, with transient noise from a supplies barge passing directly over the assessment location increasing the range upper value to 170 dB re 1 µPa rms at a mid-water depth assessment point at 3 m.

CONTENTS

Executive Summary i

1. Introduction 1

1.1 Study Scope 1

1.2 Study Objectives 1

2. Legislative Framework 3

3. Underwater Sound Terminology and Units 3

3.1 Fundamentals of Underwater Noise and Vibration 3

3.2 Underwater Sound Transmission Loss 4

3.3 Factors Affecting Underwater Sound Propagation 6

4. Sources of Ambient Underwater Noise in the Gulf of Papua 7

4.1 Natural Physical Sources 8

4.2 Natural Marine Biological Sources 12

4.3 Anthropogenic Noise Levels 13

5. Baseline Underwater Noise Desktop Characterization 17

5.1 Purari River 18

5.2 Purari River Delta Estuary 19

5.3 Nearshore Gulf of Papua 20

5.4 Offshore Gulf of Papua 22

6. Conclusions 23

7. Data Limitations 24

8. Abbreviations and Glossary 24

8.1 Abbreviations 24

8.2 Glossary 25

9. References 27

TABLES

Table 1 – Natural Physical Noise Sources, Frequencies and Levels....9

Table 2 – Beaufort Wind Scale and Sea State....10

Table 3 – Marine Mammal Communication and/or Echolocation Frequencies....12

Table 4 – Other Marine Biological Sound Sources....13

Table 5 – Typical Underwater Source Levels of Anthropogenic Noise....14

Table 6 – Details of Commercial Vessels Known to the Gulf of Papua....17

FIGURES

Figure 1 – Project Area of Influence and Baseline Underwater Noise Desktop Assessment Locations....2

Figure 2 – Diagram of a Spherical Spreading Model....5

Figure 3 – Diagram of a Cylindrical Spreading Model....6

Figure 4 – Wenz Curves Ambient Noise Spectra Levels....11

1. Introduction

Total E&P PNG Limited (TEP PNG), a wholly owned subsidiary of TOTAL S.A. (TOTAL), is the largest partner in a joint venture to develop the Elk-Antelope gas field, located in Petroleum Retention License 15 (PRL-15) in Gulf Province, Papua New Guinea. This Project, known as the Papua LNG Project, will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a liquefied natural gas (LNG) plant site at Caution Bay, Central Province, 20 km northwest of Port Moresby.

TEP PNG is preparing an environmental impact statement (EIS) and an environmental, social and health impact assessment (ESHIA) for the development of the Elk-Antelope gas field in Papua New Guinea. An environmental and social baseline study (ESBS) is being prepared for the Project's EIS/ESHIA. This technical paper provides an underwater noise baseline characterization, which is a component of the ESBS.

1.1 Study Scope

The study scope is to characterize the ambient background acoustic environment of the marine, estuarine and riverine environments within the Project's area of influence and neighboring areas. The following areas are covered for the underwater noise desktop baseline characterization:

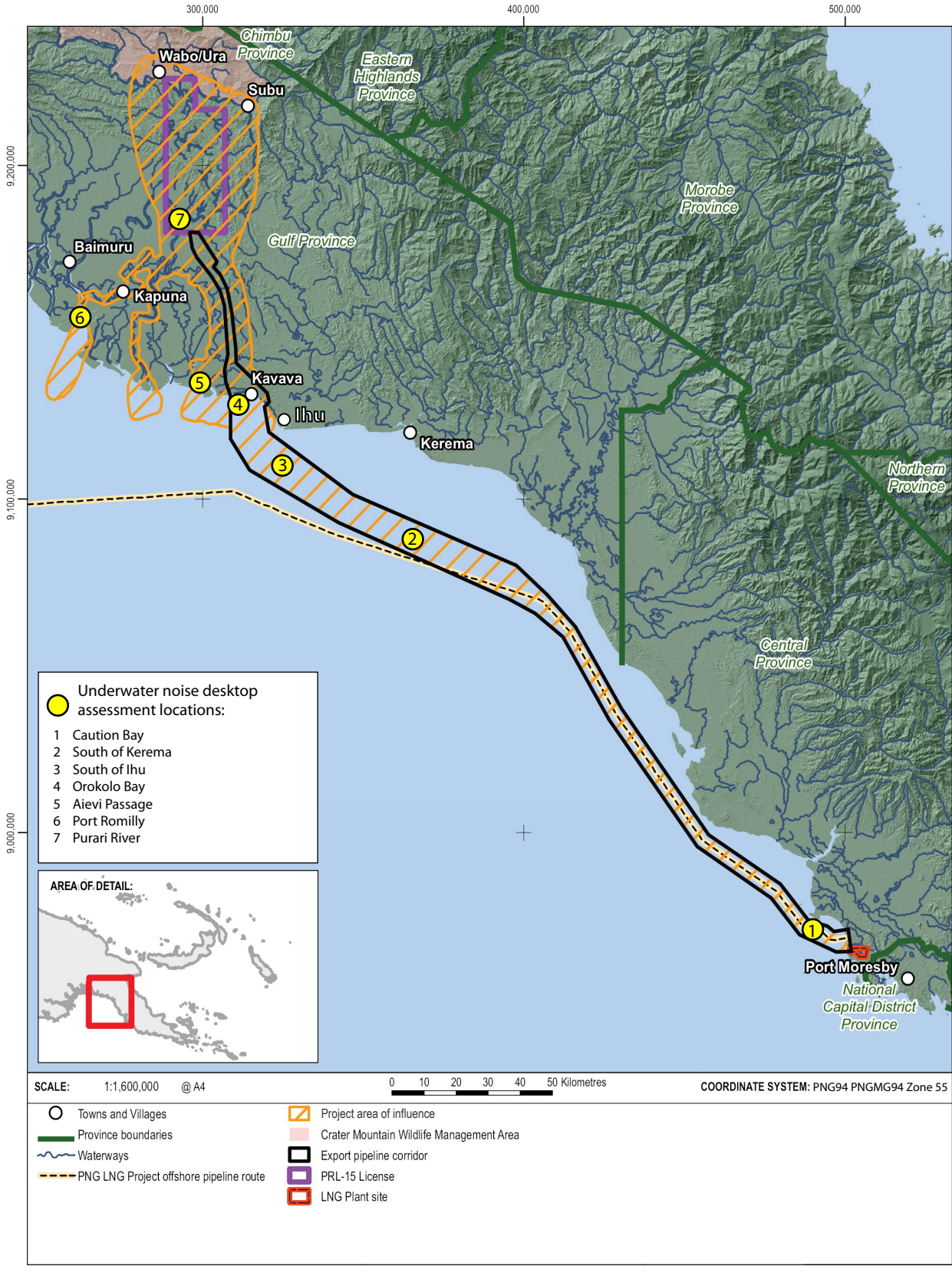
- Offshore marine environment of the Gulf of Papua (export pipeline corridor).
- Nearshore marine environment of Orokolo Bay (export pipeline corridor).
- Nearshore environment of Caution Bay (export pipeline corridor and the PNG LNG marine terminal).
- Estuaries of the Purari, Urika and Wame rivers (river transport corridors).
- Purari, Urika-Ivo and Wame-Varoi rivers (river transport corridor options for Project vessels).

Figure 1 shows the upstream Project Area of Influence (PAOI) and also shows the assessment locations where background underwater noise has been characterized.

1.2 Study Objectives

The key objectives of the underwater noise desktop characterization study are to:

- Characterize existing levels of underwater ambient noise from natural sources, including physical sources (e.g., wind, rain, surface waves, earthquakes, lightning) and biological sources (e.g., whales, dolphins, fish choruses and snapping shrimp).
- Characterize existing levels of underwater noise from anthropogenic sources:
  - Marine, estuarine and riverine commercial shipping traffic (e.g., ships, tugs, LNG carriers, barges and trawlers).
  - Coastal, estuarine and riverine village watercraft (e.g., outboard motor-driven dugout canoes, banana boats and dinghies).
- Characterize the combined baseline natural and anthropogenic ambient noise in the above-mentioned Project areas of influence (see Section 1.1).



Source: Base map from ERIAS Group and Mipela GeoSolutions (2017)

EnviroGulf Consulting	Job No: 167 File No: 167-1-F1	To: ERIAS Group Pty Limited Project: Papua LNG Project	**Project Area of Influence and Baseline Underwater Noise Desktop Assessment Locations**	Figure No: 1

2. Legislative Framework

Papua New Guinea legislation and regulations do not specify underwater noise level criteria or standards, and there is a corresponding lack of international standards related to underwater noise. During the EIS approvals process for oil and gas projects in Papua New Guinea, the Conservation and Environment Protection Authority (CEPA) typically includes conditions in an Environment Permit issued under Section 65 of the *Environment Act 2000*, which typically require a proponent to address baseline ambient terrestrial and underwater noise.

With respect to international legislation and guidance, the Internatioal Finance Corporation (IFC) environmental health and safety (EHS) guidelines for onshore oil and gas (IFC, 2007) do not mention underwater noise. Both the IFC EHS guidelines for offshore oil and gas (IFC, 2015) and for ports, harbors and terminals (IFC, 2017) refer to underwater noise and vibration levels which may be generated from several sources, including offshore infrastructure installations (e.g., pipelines) dredging, ship traffic, port operations and operational phases. The guidelines state that underwater noise from these activities may adversely impact aquatic habitats and the health and behaviors of aquatic life, including fish, marine mammals, and sea turtles. These guidelines state that assessments should be conducted to (i) identify where and/or when underwater noise has the potential to impact aquatic life significantly and (ii) to identify appropriate mitigation measures. The IFC EHS guidelines for offshore oil and gas also make several recommendations to mitigate or reduce underwater noise levels but primiarly for anthropogenic impact noise sources, rather than the type of continuous broadband noise from shipping operations of pipeline installation.

3. Underwater Sound Terminology and Units

Prior to characterizing baseline underwater noise, a brief overview of underwater acoustic terminology and units is given below.

3.1 Fundamentals of Underwater Noise and Vibration

There are several components that are used in describing underwater sound:

- ***Frequency:*** most underwater sounds are composed of many different frequencies, which are referred to as the frequency spectrum or bandwidth. The rate of oscillation or vibration measured in cycles per second or hertz (Hz).
- ***Wavelength:*** the length of the fundamental oscillation of the sound in the propagation medium, measured in meters (m).
- ***Acoustic wave velocity:*** in seawater, the velocity is close to 1,500 m/s (typically between 1,450 and 1,550 m/s), depending on pressure, salinity and temperature. For a sound velocity of 1,500 m/s, underwater acoustic wavelengths will be 150 m for 10 Hz, 1.5 m at 1 kHz and 0.0015 m at 1 MHz (Lurton, 2010).
- ***Seawater density:*** density is approximately 1,030 kg/m^3 on average, but depends on pressure, salinity and temperature.
- ***Decibel:*** the decibel is used to describe sound the 'base 10 logarithmic function of the ratio of the pressure fluctuation to a reference pressure'. The reference pressure for marine water or freshwater is 1 μPa compared to 20 μPa for air. The reference level must be known to allow proper interpretation of the dB value.
- ***Sound pressure level (SPL):*** the unit is the Pascal (Pa), which is equivalent to a Newton per meter squared (N/m^2), as defined by the International System of Units (S.I.). The SPL

unit is expressed in terms of dB referenced to 1 microPascal at 1 meter (i.e., dB re 1 μPa at 1m), where 're' denotes 'with reference to'. A 10 dB increase represents a ten-fold increase in power, a 20 dB increase would be a 100-fold increase and 30 dB would be a 1,000-fold increase.

- ***Sound Exposure Level (SEL):*** total noise energy over a measurement period expressed in units of referenced to 1 microPascals-squared in one second (i.e., dB re 1 $\mu Pa^2 \cdot s$). The SEL is commonly used for impulsive noise sources because it allows a comparison of the energy contained in impulsive signals of different duration and peak levels.

- ***Power Spectral Density:*** the decibel unit is the mean square pressure per unit bandwidth in microPascal squared per hertz (i.e., dB re 1 $\mu Pa^2/Hz$). Note that the bandwidth of the power spectral density is explicitly part of the unit. In some cases, ambient background noise in the literatures is presented as spectral densities rather than as sound pressure levels.

- ***Peak Sound Pressure Level (SPL_p):*** The maximum noise level recorded during a measurement period expressed in dB re 1 µPa. The peak level is commonly used as a descriptor for impulsive noise sources, such as impact pile driving or marine seismic survey operating airguns.

- ***Peak-to-peak Sound Pressure Level (SPL_{p-p}):*** Difference between the maximum and minimum noise level recorded during a measurement period, expressed in units of dB re 1 µPa at 1 m. The peak-to-peak level is also commonly used as a descriptor for impulsive noise sources.

All underwater noise source levels referenced in this technical paper are expressed in terms of dB re 1 μPa at 1m. Note that dB values for sounds in air are calculated for a reference pressure of 20 μPa, as opposed to the 1 μPa in seawater or river water, but both were chosen to be near the limit of human hearing.

While sound source levels are measured as dB re 1 µPa at 1 m, received sound levels at distance from the source are expressed in units of dB re 1 µPa root mean square (rms). Root-mean-square pressure is what a marine animal perceives via its auditory system or what a hydrophone[1] measures.

In the following sections, where underwater noise source levels are outside the Project's area of influence, extrapolation of the source noise levels (dB re 1 µPa at 1 m) to received noise levels (dB re 1 µPa rms) at a given location from the noise source requires the use of sound transmission loss equations to estimate the received noise levels at the given location.

3.2 Underwater Sound Transmission Loss

There are several factors that affect underwater sound propagation and transmission loss. Sound propagation in water is a complex phenomenon, and is affected by location (e.g., position and orientation of the sound source in the water column), water depth, seabed type, and water column temperature/density. Received sound levels are a function of both source and receiver depth, where the receiver could be a measuring device (e.g., a hydrophone) or a marine animal (e.g., fish or whale).

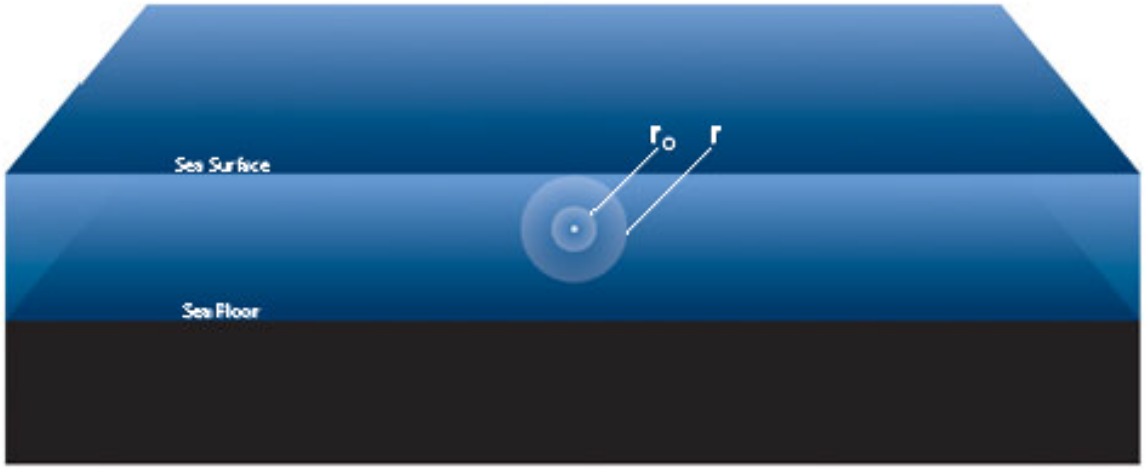
1 An underwater microphone that will listen to, or pick up, acoustic sugnals.

3.2.1 Underwater Sound Spreading Models

As a point source of underwater sound energy propagates through the sea it spreads over a larger volume and the intensity of the sound energy decreases. This is called the term transmission loss (TL), which describes the drop in sound energy level as it propagates from one point in the ocean to another (Collins, 2017). The transmission loss is defined as the ratio of the acoustic intensity at the particular point, to the level at some reference position.

A generalized spreading model (i.e., nlog10[R], where R means radial distance from the noise source in meters) can be used to estimate sound propagation or transmission loss (i.e., by attenuation) in the marine environment. For example, a spherical spreading (20log10[R]) TL formula is normally applied to noise sources in moderate to deep water, where the spreading is spherical to a radial distance (i.e. R) approximately equivalent to water depth. Figure 2 shows a diagram representative of a spherical spreading model.

Figure 2 – Diagram of a Spherical Spreading Model



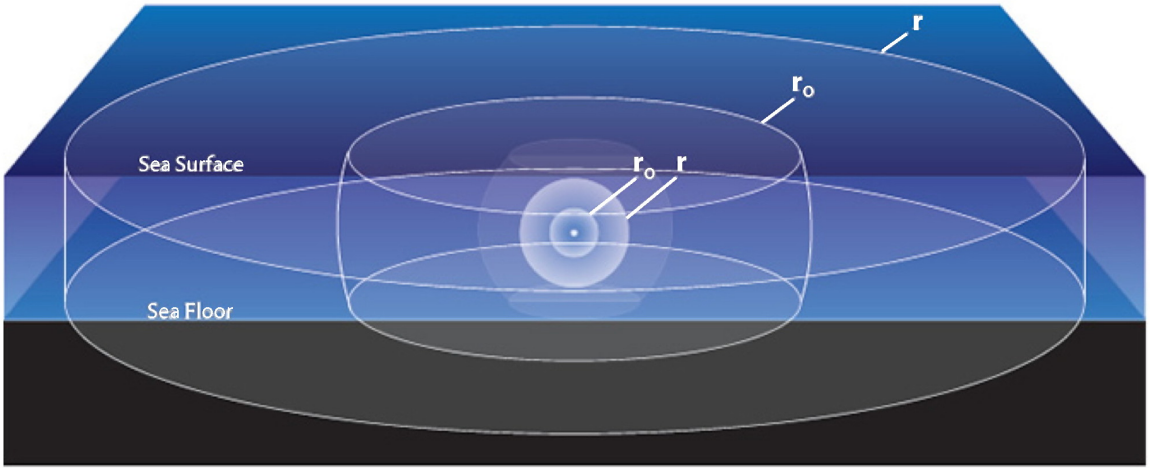
Source: DOSITS (2017).

In Figure 2 sound generated by a sound source (shown as a white dot) at mid-depth in the sea or ocean is radiated equally in all directions. Sound levels are therefore constant on spherical surfaces surrounding the sound source. Sound levels decrease rapidly as sound spreads out from a sphere with a radius of r_0 to a larger sphere with a radius (r).

Spherical spreading results in a general 6 dB decrease in the intensity[2] of noise per doubling of distance. The spherical TL formula can be applied at short range from a point or a line noise source. As R increases, boundary interactions begin to focus the sound (e.g., by reflection from the sea surface and seafloor) and a cylindrical spreading model (10log[R]) may provide a closer approximation to TL, such as in the case of shallow coastal waters (e.g., Orokolo Bay and Caution Bay) or the Purari River delta inlets (i.e., estuaries) of the Project study area. Figure 3 shows a diagram representative of a cylindrical spreading model. Cylindrical spreading results in a general 3 dB decrease in the intensity of noise per doubling of distance.

2 Intensity is the average amount of sound energy transmitted per unit time through a unit area in a specified direction.

Figure 3 – Diagram of a Cylindrical Spreading Model



Source: DOSITS (2017).

In Figure 3 sound generated by a source (shown as a white dot) in the sea cannot continue to spread uniformly in all directions once it reaches the sea surface or the sea floor. Once the sound is trapped between the top and bottom of the ocean it gradually begins to spread cylindrically, with sound radiating horizontally away from the source. Sound levels decrease more slowly as sound spreads from a cylinder with a radius of r_0 to a larger cylinder with radius r compared with the rate of decrease for spherical spreading.

The water depths along the Project's offshore section of the export pipeline corridor vary from 30 m near the coastline at both Orokolo Bay and Caution Bay and a general 100 m along the continental shelf route within the inner continental shelf of the Gulf of Papua. In this case, cylindrical spreading formula is more appropriate for these shallow waters; however, in the case of ships transiting the central part of the Gulf of Papua where the water depth varies between 1,600 m and 4,200 m deep, the spherical spreading formula is appropriate. In general, at a horizontal distance of about 1.5 times the water depth in the central Gulf of Papua, sound transmission loss by cylindrical spreading takes over from spherical spreading as sound at distance from anthropogenic noise point sources (e.g., ships) can be ducted by sea surface and seafloor reflections.

For the purposes of the present technical paper, both spherical spreading and cylindrical spreading transmission loss formulae are used when appropriate.

3.3 Factors Affecting Underwater Sound Propagation

Sound propagation in water is a complex phenomenon, and is affected by location (e.g., position and orientation of the sound source in the water column), water depth, seabed or river bed type, and water column temperature/density.

There are several factors that affect underwater sound propagation and transmission loss, which are briefly described below.

Absorption

As sound waves propagate, they interact at a molecular level with the constituents of seawater through a range of mechanisms, resulting in absorption of sound energy (Francois and Garrison 1982a, 1982b; Medwin 2005). This occurs even in completely suspended particulate-free waters, and is in addition to scattering that may occur from objects such as phytoplankton, zooplankton or suspended sediments.

The absorption of sound energy by water contributes to sound transmission loss linearly with distance (range) and is given by an attenuation (absorption) coefficient in units of decibels per kilometer (dB/km). Absorption coefficients can be computed from empirical equations and increases with the square of frequency. For example, for typical temperate open-ocean values of temperature of 10°C, pH 8.0 and a salinity of 35 practical salinity units (PSU), the equations presented by Francois and Garrison (1982a,b) yield the following values for sound attenuation near the sea surface:

- 0.001 dB/km at 100 Hz.
- 0.06 dB/km at 1 kHz.
- 0.96 dB/km at 10 kHz.
- 33.6 dB/km at 100 kHz.

The above absorption coefficients clearly indicate that low frequencies (e.g., 100 Hz) can propagate over long distances (ranges) with low sound attenuation whereas high frequencies (e.g., 100 kHz) propagate over short distances, since transmission loss rates are higher. This property of low frequency sound is used by large whales to communicate over hundreds of kilometers in the ocean. In general, as most ships transiting the Gulf of Papua generate low-frequency (20 Hz to <1 kHz) continuous noise, absorption losses will be small to negligible.

Refraction

Reflections from the water surface cause interference with direct sound waves from a noise source, a phenomenon often referred to as the Lloyd's Mirror effect (Robinson et al. (2011). Refraction refers to a change of direction in a propagating wave due to spatial variations in sound speed within the medium. As a wave travels across a sound speed interface or gradient, portions of the wave front travel at different speeds, resulting in bending of the ray path (Medwin, 2005). By affecting travel paths within the medium, refraction controls the angle of arrival of the sound at a receiver (e.g., marine fauna or hydrophone) as well as the angle of incidence upon boundaries (e.g., the seafloor).

Bathymetry

Water depth has a very large influence on underwater sound propagation, especially at low to mid frequencies (less than a few kilohertz) where scattering losses are low. In shallow water (<100 m depth), which will be the case along Project's export pipeline corridor, propagation loss is dominated by reflection and scattering of sound from the seabed. In deep water (>1,000 m depth) sound propagation is dominated by refraction in the water column, which will be the case for ships plying the central Gulf of Papua where the water depth range is between 1,600 m and 4,200 m. At intermediate depths, propagation loss is influenced by a combination of these two factors.

4. Sources of Ambient Underwater Noise in the Gulf of Papua

A review of the literature did not reveal any underwater noise measurements for the Gulf of Papua. Therefore, background noise levels measured in similar offshore environments have been researched and used as comparative analogues, with the aim of deriving average background ambient noise levels along the offshore section of Project's export pipeline corridor in the Gulf of Papua.

The underwater acoustic environment of the Gulf of Papua consists mainly of ambient noise, which is defined as environmental background noise lacking a single source or point (MMS,

2001). In general, natural and anthropogenic sources of ambient noise may be continuous or intermittent and may be concentrated at low or high frequencies. Ambient noise levels at a given frequency and location typically can vary as much as 20 dB or more from one day to the next. In general, the ambient background noise in the Gulf of Papua is expected to be highly variable at a given time and place, and a broad range of sources may be combined.

Baseline ambient noise sources include natural physical and biological sources, as well as anthropogenic sources such as ships, trawlers and marine seismic geophysical surveys. Typical natural physical noise sources in the Gulf of Papua are summarized below.

4.1 Natural Physical Sources

There are several natural physical sources of underwater sound that may be expected to be present in the Project's area of influence and the broader area of the Gulf of Papua, these are:

- Sea surface sound sources:
  - Surface wind is a major contributor.
  - Breaking waves, bubbles and sea spray.
  - Rainfall noise at the sea surface.
- Lightning and thunder sound sources.
- Earthquake and tremor sound sources.

Table 1 gives a summary of natural physical sources and typical sound levels, which may be expected to occur in the Gulf of Papua.

4.1.1 Sea Surface Sound Sources

The dominant source of naturally occurring noise across the frequencies from 1 Hz to 100 kHz is associated with waves generated by the wind acting on the sea surface (NRC, 2003).

The dominant sources of ambient noise and their frequencies at the sea surface may be summarized as:

- Surface wind is a major contributor (100 Hz to 30 KHz) (Simmonds et al., 2003).
- Breaking waves, bubbles and spray (100 Hz to 20 kHz) (Richardson et al., 1995).
- Rainfall (100 Hz to 30 kHz) (Richardson et al., 1995).

In Table 1 it is evident that wind will be a major contributor to background ambient noise in the Gulf of Papua. In the absence of anthropogenic and biological sound, ambient physical noise in the gulf will be wind dependent and over an extremely broad frequency band from below 1 Hz to at least 100 kHz. At frequencies below 10 Hz, interactions of surface waves are likely to be the dominant mechanisms for sound generation. Across the remainder of the band from 10 Hz to 100 kHz, oscillating bubbles in the water column are the primary noise source, both as individual bubbles and as bubble clouds (Hildebrand, 2005).

In Table 1 Richardson et al. (1995) note that winds of <1 knot, 11 to 16 knots and 22 to 27 knots have source levels at the sea surface of 60, 97 and 102 dB re 1 µPa at 1 m, respectively. Mean wind speeds in the Gulf of Papua average 14 knots with a maximum of 30 knots during the winter southeast trade wind season (May to October), which could generate surface sea noise levels of around 100 dB re 1 µPa at 1 m along the export pipeline corridor.

Table 1 – Natural Physical Noise Sources, Frequencies and Levels

Source	Aspect	Sound Source Level	Reference
Wind	<1 knot 100 Hz to 30 kHz	60 dB re 1 μPa at 1 m	Richardson et al. (1995)
	11 to 16 knots 100 Hz to 30 kHz	97 dB re 1 μPa at 1 m	Richardson et al. (1995)
	22 to 27 knots 100 Hz to 30 kHz	102 dB re 1 μPa at 1 m	Richardson et al. (1995)
Rainfall	<2 mm/hr (wind 6 m/s) at (0.5 kHz)	63 dB re 1 μPa at 1 m peak	Pensieri et al (2015)
	2 to 10 mm/hr (wind >10 m/s) at (0.5 kHz)	65 dB re 1 μPa at 1 m peak	Pensieri et al (2015)
	10 to 20 mm/hr (wind <10m/s) at (0.5 kHz)	67 dB re 1 μPa at 1 m peak	Pensieri et al (2015)
	>20 mm/hr (wind >10 m/s) at (0.5 kHz)	66 dB re 1 μPa at 1 m peak	Pensieri et al (2015)
Lightning and thunder	5 to 10 km Sudden short pulse	Peak energy between 50 and 250 Hz producing up to 15 dB above background	Hildebrand (2005)
	<100 km Sudden short pulse	Peak energy between 5 and 20 Hz producing 30 to 40 dB above background	Schreiner et al (1995)
	Lightning strike on sea surface; 20 to 1,000 Hz	250 dB re 1 μPa at 1 m	Heathershaw et al. (2001)
Earthquakes	Sudden irregular transient of low frequency 10 to 100 Hz	220 to 250 dB re 1 μPa at 1 m	Baggeroer et al. (2005)
	Undersea earthquake of magnitude 4.0 on Richter scale (energy integrated over 50 Hz bandwidth); 20 to 1,000 Hz	272 dB re 1 μPa at 1 m	Heathershaw et al. (2001)

During the northwest monsoon season (December to March), winds are from the northwest and generally relatively weak with an average <10 knots (Slingerland et al., 2008), which would generate noise source levels of between 60 and 95 dB re 1 µPa at 1 m. Short-lived squalls, known locally as *Gubas*, are common during the northwest monsoon in the Gulf of Papua but their duration is generally short (< 1 hour) with wind speeds of between 30 and 35 knots (ERIAS Group, 2016a), which can generate noise source levels of >110 dB re 1 µPa at 1 m. Winds during the changeover periods (months) following the end of southeast trade wind season (April) and the beginning of the northwest monsoon season (November) represent periods when wind strengths and direction are variable but of short duration (i.e., <1 month).

Wind and sea state affect underwater noise levels and Table 2 gives the 12-level Beaufort Scale for winds and associated sea states.

Figure 4 shows the ambient noise spectra[3] levels that are generated by natural and anthropogenic (shipping traffic) noise sources. For example, noise sources levels at a frequency of 600 Hz for Beaufort scales 1, 2, 3, 5 and 8 in Figure 4 are 46.5, 55.0, 66.0, 73.0 and 81.0 dB re 1 µPa at 1 m, respectively.

3 In Figure 4 the noise level spectra level unit of dB re 1 µPa2 is the same as dB re 1 µPa at 1m.

Table 2 – Beaufort Wind Scale and Sea State

Wind Speed (knots)	Beaufort Scale	Sea State	Wave Height (m)	*WMO terms	Description
<1	0	0	0	Calm	Flat glassy
1–2	1	0.5	0.1	Light air	Ripples without crests
3 to 6	2	1	0.2	Light breeze	Small wavelets, glassy crests
7 to 10	3	2	0.6	Gentle breeze	Large wavelets, crests begin to break
11 to 15	4	3	1	Moderate breeze	Small waves, whitecaps
16 to 20	5	4	2	Fresh breeze	Moderate waves, some foam + spray Large waves with foam crests
21 to 26	6	5	3	Strong breeze	Large waves with foam crests
27 to 33	7	6	4	Near gale	Sea heaps up, foam begins to be blown
34 to 40	8	6	5.5	Gale	High waves, breaking crests form spindrift, streaks of foam
41 to 47	9	6	7	Strong gale	High waves with dense foam, crests roll over
48 to 55	10	7	9	Storm	Storm Considerable tumbling of waves with heavy impact, large amounts of airborne spray reduce visibility
56 to 63	11	8	11.5	Violent storm	Very large patches of foam driven before the wind cover much of the sea surface
>64	12	9	>14	Hurricane[#]	Sea completely white with foam, air filled with spray

Source: Erbe (2011). * World Meteorological Organization. [#] Hurricanes are known as cyclones in Southern Hemisphere.

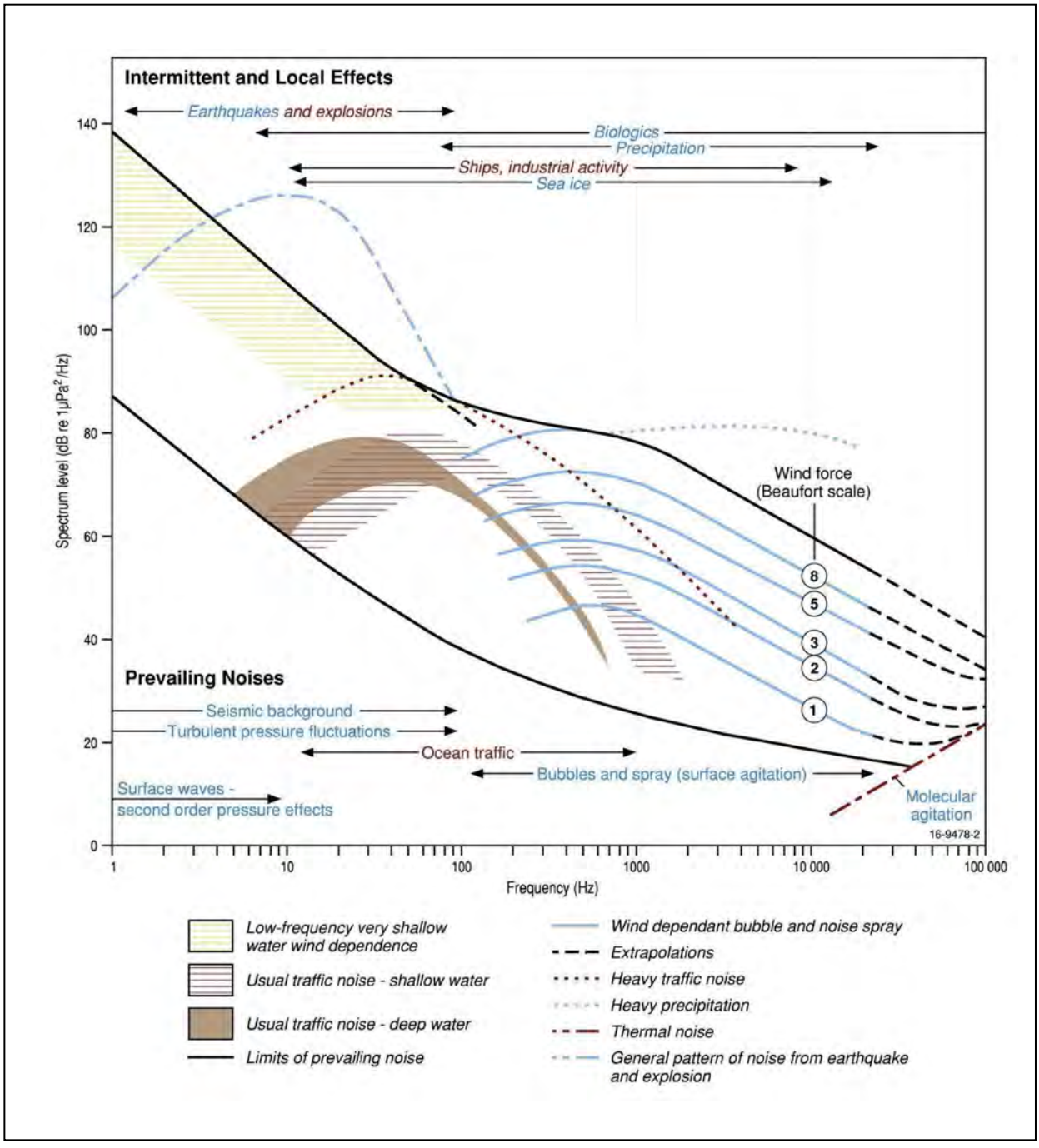
4.1.2 Lightning and Thunder

Lightning and thunder are transient natural sound sources. A lightning strike at the sea surface can produce a noise source level of 250 dB re 1 µPa at 1 m with frequencies in the range 20 to 1,000 Hz. Actual underwater recordings of lightning/thunder from storms 5 to 10 km distant from a measuring point show peak energy between 50 and 250 Hz, and up to 15 dB above background levels (Hildebrand, 2005; Dubrovsky and Kosterin, 1993). Storms and lightning strikes would be expected to be a common occurrence in the wet tropical environment of the Gulf of Papua and along its coastline.

4.1.3 Earthquakes

The Project's export pipeline corridor is in the northern and eastern sections of the Gulf of Papua and lies within seismic Zone 3 near the coast of Gulf Province and Zone 4 offshore (PNGNSC, 1982).

Volcanic and tectonic noise generated by earthquakes on land or in water propagates as low frequency and locally generated T-phase (i.e., tertiary) waves in addition to the usual P-phase (primary) and S-phase (secondary) seismic waves that are observed on land. At ranges of less than 100 km, T-phase energy can have frequencies greater than 100 Hz with peak energy at 5 to 20 Hz. It can be as much as 30 to 40 dB above background noise, with a sharp onset, and can last from a few seconds to several minutes (Schreiner et al. 1995). An undersea earthquake of magnitude 4.0 on the Richter scale (energy integrated over 50 Hz bandwidth) was observed to produce a noise source level of 272 dB re 1 µPa at 1 m (Heathershaw et al., 2001).



Source: Based on Carroll et al. (2016) and Wenz (1962)

EnviroGulf Consulting	Job No: 167 File No: 167-1-F4	To: ERIAS Group Pty Limited Project: Papua LNG Project	**Wenz Curves** **Ambient Noise Spectra Levels**	Figure No: 4

4.2 Natural Marine Biological Sources

There are several natural biological sources of underwater sound that may be expected to be present in the Project's offshore export pipeline corridor in the Gulf of Papua, which are principally from marine mammals (whales and dolphins), some fish species with air bladders and decapod crustaceans (e.g., snapping shrimps).

Table 3 presents underwater source levels of sounds emitted by various marine mammals for communication or echolocation[4] purposes, which cover a broad frequency spectrum. Richardson et al. (1995) described the dominant sources of ambient noise due to biological sources as having frequencies in the range 10 Hz to 100 kHz.

Table 3 – Marine Mammal Communication and/or Echolocation Frequencies

Species	Communication Frequency (kHz)	Echolocation Frequency (kHz)	Estimated Source Level (dB re 1 μPa at 1 m)	Reference
Odontocetes (Toothed Whales)				
Common dolphin*	0.2 to 150	23 to 67	–	a, b
Irrawaddy dolphin	1.1 to 6.0	–	–	a
Bottlenose dolphin*	0.05 to 150	110 to 130	218-228	a, b
Risso's dolphin*	0.1 to 23.7	65	-	a, b
Killer whale	0.1 to 35	12 to 25	180	a, b
Sperm whales	0.1 to 4	0.1 to 20	236	e
Delphinid whistles/squeaks	_	>10 kHz	10 to 195	d
Toothed whale sonar	–	>10 kHz	190 to 232	d
Mysticetes (Baleen Whales)				
Southern right	0.03 to 2.2	–	172-192	a, b
Pygmy right	0.06 to 0.135	–	165-179	a, b
Humpback*	0.02 to 10	–	144-192	a, b
Fin	0.02 and 1.5 to 2.5	–	155-186	a, b
Blue	0.012 to 0.4	–	130-188	a, b
Bryde's*	0.124 to 0.900	–	152-174	a, b
Dwarf minke*	0.06 to 6	–	151-175	a, b

Sources: a = Richardson et al. (1995); b = NRC (2003); c = SCAR (2002); d = URS (2009); e = Richardson et al (1995).
* denotes species expected to be present in the Gulf of Papua (ERIAS Group, 2016a).

Marine mammals use sound for social interaction and communication between individuals and pods as well as for echolocation and navigation purposes, reproduction, predator avoidance, feeding and in perception of their environment (McCauley, 1994; Richardson et al., 1995; SCAR, 2002).

Other marine fauna also generate biological noise at different frequencies, such as dugongs (2 to 5 kHz), rock lobster (2 to 10 kHz), and fish (0.1 to 5 kHz) (Richardson et al., 1995). Table 4 lists non-cetacean biological sound sources and/or frequencies that may be present in the Gulf of Papua.

4 the ability by which animals can produce mid- or high-frequency sounds and detect echoes of these sounds that bounce back off distant objects to determine physical features of their surroundings.

Table 4 – Other Marine Biological Sound Sources

Source	Frequencies	Sound Source Level	Reference
Fish			
General fish sounds and choruses	0.1 to 5 kHz	Mean of 120 dB re 1μPa at 1 m Maximum of 160 dB re 1μPa at 1 m	Mann (2012), Richardson et al. (1995)
Air bladder sounds	75 to 150 Hz	Not stated	URI (2017)
	4 to 60 Hz	Not stated	Tsai (2009)
Stridulatory* sounds	150 to 8000 Hz	Not stated	URI (2017)
Macroinvertebrates			
Snapping shrimp	Peak 1 kHz (range 1 to 50 kHz)	86 dB re 1 μPa at 1 m	APPEA (2005)
	5 kHz to 300 kHz	Not stated	McCauley (1994)
Rock lobster	2 to 10 kHz	Not stated	McCauley (1994)

* The act of producing sound by rubbing together certain body parts.

In general, sounds produced by soniferous (sound-producing) fish for communication are generally associated with either reproductive activities (e.g., courtship or spawning) or stressful conditions (e.g., aggression or territorial defense).

Bony fish (Osteichthyes) produce sounds by means such as striking bony structures against one another, or by muscle movement amplified by the gas-filled swim bladder (or air bladder) (NRC, 2003). Sciaenid fish, such as croakers and jewfish that are present in the Gulf of Papua, also emit underwater noise by drumming their swim bladders with their sonic muscles and producing short pulses of between 45 and 60 Hz but generally less than 500 Hz (Tsai, 2009). Some marine catfish also emit low frequency sound (<1,000 Hz), while other catfish species emit sounds up to 8 kHz (Tsai, 2009).

Other marine fauna also generate biological noise at different frequencies, such as rock lobster (2 to 10 kHz) and fish (0.1 to 5 kHz) (Richardson et al., 1995). Snapping shrimps, stomatopods and some sea urchins have been reported to produce high frequency sounds (McCauley, 1994). Snapping shrimps have been reported to produce high frequency sounds at around 2,500 Hz (McCauley et al., 2000). Overall, the frequencies used by marine fauna cover a broad frequency spectrum (NRC, 2003; McCauley, 1994).

In general, marine biological sources of underwater noise in the Gulf of Papua will generally be intermittent and of short duration, whereas some biological generated noise may be more or less continuous broadband noise, such as that produced by snapping shrimp (e.g., 60 to 90 dB re 1 μPa at 1 m in the frequency range 1 to 10 kHz).

4.3 Anthropogenic Noise Levels

There is a wide range of human-generated (anthropogenic) sounds in the marine environment, including sources such as distant ships, oil and gas exploration (seismic surveys and explorations drilling) and operations (machinery, helicopters and service vessels) and commercial fishing trawlers (e.g., the GOPPF). These include anthropogenic underwater noise sources, such as:

- Distant ships in the Gulf of Papua and Coral Sea shipping traffic lanes.
- Oil and gas explorations activities in the Gulf of Papua:
  - Marine seismic surveys.

– Sonar systems.

– Oil terminal platforms (e.g., Kumul Marine Terminal).

Given the scarcity of underwater noise measurements in the Gulf of Papua and a lack of underwater noise source level data for ships and vessels currently plying the Gulf, a literature review was carried out to characterize underwater noise source levels for a range of vessel types, equipment and activities (e.g., drilling, dredging and marine seismic surveys). Table 5 presents a summary of the literature review and gives examples of recorded noise source levels and frequencies, which have been used as comparative analogues to determine typical anthropogenic noise source levels that may be applicable to the Gulf of Papua (EGC, 2017).

Table 5 – Typical Underwater Source Levels of Anthropogenic Noise

Aspect	Speed/Frequency	Sound Source Level	Reference
Large Ships			
Super tanker (337 m long)	Fast moving (20 knots)	195 dB re1 µPa at 1 m	Hildebrand (2005)
Super tanker (337 m long)	Fast moving (18 knots) Peak 23 Hz	185 dB re 1 μPa at 1 m	Hildebrand (2005)
Three crude oil tanker (229 to 243 m long)	Slow speed (6.5 to 7.5 knots)	179 to 182 dB re 1 μPa at 1 m	McKenna et al. (2012)
Two product tankers (180 to 182 m long)	Slow speed (7.1 to 8.0 knots)	109 to 111 dB re 1 μPa at 1 m	McKenna et al. (2012)
Six container ships (214 to 298 m long)	Moderate speed (10.4 to 11.2 knots)	114 to 119 dB re 1 μPa at 1 m	McKenna et al. (2012)
Medium size container ship (173 m long)	High speed (16 knots); 40 to 100Hz	192 dB re 1 μPa at 1 m	Hildebrand (2009)
Fishing Vessels			
Small fishing vessels	Transiting	140 dB re 1 μPa at 1 m	Hildebrand (2005)
Operating fishing trawler	Slow moving (6 to 8 knots)	150-160 dB re 1 μPa at 1 m	Statoil (2000)
Fishing vessel (12 m long)	Moderate speed (7 knots); Peak 300 Hz	151 dB re 1 μPa at 1 m.	Hildebrand (2005)
Tugs and Barges			
Tugs (maneuvering a barge) shallow water	4 knots	144 dB re 1 μPa at 60 m peak to peak 170 dB re 1 μPa at 1 m	Seiche (2008)
Tug towing a barge (19.5 m long, 8.2 m beam and 1 m draft)	Unloaded underway at 7.4 knots; 0.01 to 20 kHz	173 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Tug towing a barge (19.5 m long, 8.2 m beam and 1 m draft)	Unloaded underway at 8.7 knots; 0.01 to 20 kHz	182 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Tug towing a barge (19.5 m long, 8.2 m beam and 1 m draft)	Partially loaded and underway at 6.4 knots; 0.01 to 20 kHz	177 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Self-propelled barge (43 m long by 12 m beam)	Unloaded underway at 5.5 knots; 0.01 to 1 kHz (cavitation tones up to 20 kHz)	163 dB re 1 μPa at 1 m	Zykov and Hannay (2006)

Table 5 – Typical Underwater Source Levels of Anthropogenic Noise (cont'd)

Aspect	Speed/Frequency	Sound Source Level	Reference
Tugs and Barges (cont'd)			
Self-propelled barge (43 m long by 12 m beam)	Fully loaded underway at 4.9 knots; 0.01 to 1 kHz (cavitation tones up to 20 kHz)	168 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Self-propelled barge (43 m long by 12 m beam)	Fully loaded underway at 5.8 knots; 0.01 to 20 kHz	174 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Offshore Support Vessels			
Offshore Support Vessel (67 m long)	Dynamic positioning with four main engines, two 600 HP thrusters and one 800 HP thruster; 0.001 to 20 kHz	187.7 dB re 1 μPa at 1 m	Austin et al. (2005)
Offshore Support Vessel and anchor handling tug (67.6 m long)	Full speed underway; 10,560 BHP main engine; 0.01 to 8 kHz	190.3 dB re 1 μPa at 1 m	Chorney et al. (2010)
Offshore Support Vessel and anchor handling tug (45 m long)	Full speed underway; 6,600 BHP main engine; 0.01 to 8 kHz	202.7 dB re 1 μPa at 1 m	Chorney et al. (2010)
Seismic Survey Vessel (84.9 m long	Underway profiling; Five diesel electric engines; 0.01 to 20 kHz	125 to 132 dB re 1 μPa at 1 m	Ireland et al. (2009)
Dive support vessel (107 m long by 35 m beam)	Stationary and dynamically positioned using thrusters operating between 20% and 30% of maximum thrust (a typical level)	178 dB re 1 μPa at 1 m Thrusters operating between 20 and 30% of maximum thrust (a typical level)	Seiche (2008)
Small and Recreational Boats			
Crew boat (8.5 m long); inboard diesels	0.01 to 20 kHz	166 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Flat-bottom workboat (7 m long)	Idling 90 HP outboard motor; 0.01 to 10 kHz	141 dB re 1 μPa at 1 m	Galli et al. (2003)
Flat-bottom workboat (7 m long)	Full speed 90 HP outboard motor; 0.01 to 10 kHz	163 dB re 1 μPa at 1 m	Galli et al. (2003)
Skiffs (2.4 to 5.5 m long)	Low speed <10 knots; 25 to 40 HP outboard motors; 0.01 to 40 kHz	157 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Skiffs (2.4 to 5.5 m long)	High speed 20 knots; 20 to 40 HP; 0.01 to 40 kHz	163 dB re 1 μPa at 1 m	Zykov and Hannay (2006)
Oil and Gas Exploration Activities			
Exploration drill rig (drilling)	110 m water depth 0.01 to 10 kHz	115 dB re 1 μPa at 405 m	Todd et al. (2007)
Drilling ship	17m depth 0.02 to 1.0 kHz	122 dB re 1 μPa at 1 m	Green (1987).
Jack-up drill rig	0.02 to 1.4kHz	120 dB re 1 μPa at 1 m	Todd et al. (2007)

Table 5 – Typical Underwater Source Levels of Anthropogenic Noise (cont'd)

Aspect	Speed/Frequency	Sound Source Level	Reference
Marine Geophysical Surveys			
Seismic exploration (marine seismic surveys)	Array peak pressure levels frequency range 5 to 300 Hz	259 dB re 1 µPa at 1 m	Greene and Moore (1995)
24-airgun array	Airgun volume 3,147 cubic inch; 2,000 psi*; 0.005 to 20 kHz	256 to 272 dB re 1 μPa at 1 m	Patterson (2007)
12-airgun array	Airgun volume 2,869 cubic inch; 2,000 psi; 0.02 to 20 kHz	222 dB re 1 μPa at 1 m	Greene (1988)
Multibeam echo sounder (hull mounted)	Peak frequency 12 kHz	235 dB re 1 μPa at 1 m	Hildebrand (2005)
Sidescan sonar	50 to 500 kHz	220 to 230 dB re 1 μPa at 1 m	Heathershaw et al. (2001)
Depth sounders	12 to 36 kHz	180 to 220 dB re 1 μPa at 1 m	Heathershaw et al. (2001)
Bottom profiler	0.4 to 30 kHz	200 to 230 dB re 1 μPa at 1 m	Heathershaw et al. (2001)

Notes: Skiff is a shallow, flat-bottomed open boat with a sharp bow and square stern. * psi = pounds per square inch.

The highest noise source levels presented in Table 5 were associated with marine seismic surveying with a maximum level of 259 dB re 1 µPa at 1 m reported (Greene and Moore, 1995).

Shipping

Underwater noise generated by ships is primarily from (a) propeller action, (b) propulsion machinery, and (c) hydraulic flow over the hull (Hildebrand, 2005). In general, underwater noise levels are related to ship size, speed and mode of operation. Reference to Table 5 reveals that for shipping, super tankers transiting at high speeds 18 and 20 knots had the highest underwater noise source levels of 185 and 195 dB re 1 μPa at 1 m, respectively.

In general, the noise source levels presented in Table 5 indicate that fully laden barges produce more noise than unladen barges, and that noise increases with a ship's speed. Small ships (e.g., offshore supply vessels and barge landing craft) tend to have noise spectra around the 300 Hz level due to their higher-speed engines and propellers, compared to the lower-speed engines of large coastal and international ships whose noise spectra are around the 50 to 100 Hz level. Shipping noise also tends to dominate other ambient noise at frequencies between 20 and 300 Hz.

At distant ranges in the open ocean, multiple ships contribute to the background noise, and the sum of many distant sources creates broad spectral peaks of noise in the 5 to 500 Hz band (Hildebrand, 2005). In the Gulf of Papua the main shipping lanes from Port Moresby, as well as those from the eastern seaboard of Australia, converge to the south of the gulf prior to passing through Great North East Channel, which is the eastern gateway to and from the Torres Strait.

Propeller noise is associated with cavitation (Ross 1987), the creation of voids from zones of pressure below the ambient water pressure. The reduction in pressure causes the bubbling in cavitation, which form and collapse creating loud noise (AMC, 2015). Cavitation creates both broadband and tonal sounds, which accounts for between 80 and 85% of ship-radiated noise power (Ross, 1987).

Based on the general source noise levels of ships and vessels given in Table 5, Table 6 presents the adopted source noise levels for vessels known to transit the Gulf of Papua as described in EGC (2017). This information is required as part of the baseline characterization of shipping noise levels received at the assessment locations (1 through 3) indicated in Figure 1.

Table 6 – Details of Commercial Vessels Known to the Gulf of Papua

Vessel	Length (LOA*) (m)	Beam (m)	Gross Tonnage (GRT) (t)	Estimated Underwater Noise Source Level (dB re 1 μPa at 1 m)	
				Range	Average
Kumul Marine Terminal Crude Tankers					
Crude Oil Tankers	229 to 243	35	–	179 to 182	180
MV Venture (tug)*	50	16	1,524	144 to 182	165
MV Vision (tug)*	50	16	1,524	144 to 182	165
Ok Tedi Mining Copper Concentrate Barges					
MV *Fly Prosperity*	90.4	23.0	3,500	135 to 145	140
MV *Fly Alliance*	91.8	19.4	3,577	135 to 145	140
LNG Carriers to PNG LNG Marine Terminal (Caution Bay)					
MV *Spirit of Hela*	298	46	114,277	185 to 195	190
MV *Gigera Laitebo*	298	46	114,277	185 to 195	190
MV *Papua*	290	47	114,166	185 to 195	190
MV *Kumul*	290	47	114,166	185 to 195	190
MV *LNG Flora*	272	47	106,151	180 to 190	185
SL *Logohu**	32	13	495	145 to 185	165
SL *Siage**	32	13	495	145 to 185	165
SL *Korowi**	32	13	495	145 to 185	165
SL *Jamba**	32	13	495	145 to 185	165
Gulf of Papua Prawn Fishery Fishing Trawlers					
FV *Charisma*	21.4	–	138	145 to 155	150
FV *Ma Mori*	22.8	–	134	145 to 155	155
FV *Siwi*	29.3	–	113	145 to 160	155
FV *Diana*	25.6	–	134	145 to 155	150
TOTAL Exploration Phase Barge Landing Craft					
MV *Balimo Chief*	45.5	11.0	498	165 to 175	170
MV *GFS Marine 01*	64.0	14.0	878	170 to 180	175
Rimbunan Hijau Log Barge Landing Craft					
MV *Swift No. 5*	44.9	11.6	442	165 to 175	170

Source: EGC (2017); Notes: TOTAL Papua LNG Project exploration phase barge landing craft (information provided by TEP PNG.); Log ship (Rimbunan Hijau, 2017). * denotes tugs maintaining dynamic positioning or actively towing a barge or ship.

5. Baseline Underwater Noise Desktop Characterization

This section preesents the finding of the desktop assessment of ambinet underwater natural and anthorpogenic noise levels in the Project's area of influence. Seven underwater noise desktop assessment locations were selected for baseline characterization, which were:

- Assessment Location 1 (Caution Bay): Nearshore approach to Caution Bay.
- Assessment Location 2 (south of Kerema): Offshore marine environment.

- Assessment Location 3 (south of Ihu): Offshore marine environment.
- Assessment Location 4 (Orokolo Bay): Nearshore marine environment.
- Assessment Location 5 (Aievi Passage): Purari Delta estuary.
- Assessment Location 6 (Port Romilly): Pie River estuary.
- Assessment Location 7 (Purari River): Purari River downstream of Herd Base.

The following subsections present the findings and estimated ambient baclkground noise levels at each desktop assessment location.

5.1 Purari River

Underwater noise in rivers is affected by abiotic sources, such as water flow, velocity and turbulence, wind, waves and rainfall, as well as biological sources (Amoser and Ladich 2011; Wysocki et al., 2007) such as soniferous fish (e.g., certain fork-tailed catfish species). In addition, short-duration anthropogenic ambient noise sources include transiting barges and outboard motor-driven canoes, banana boats and dinghies. Paddle-driven canoes generate low noise source levels of anthropogenic noise.

In rivers, fast-flowing reaches generate higher noise sources levels than slow-flowing reaches or backwater areas. For example, Amoser and Ladich 2011) found a typical mean underwater noise level of 112 dB re 1 µPa at 1 m in a boulder- and cobble-bed tributary of the Danube River (Triesting stream), which they attributed to changes in water volume and high flows and turbulence. In comparison, the main channel of the Danube River had a cobble substratum and a mean source noise level of 133 dB re 1 µPa at 1; however, comparison of the Danube River with the Purari River is not tenable given the former's high river traffic density and presence of a cobble substratum and the latter's very low river traffic density and very fine sand and silt substratum (see below).

5.1.1 Assessment Location 7 (Purari River)

Assessment Location 7 (7° 22' 25.36" S, 145° 7' 2.61" E) named 'Purari River' is located in the main channel of the Purari River about 1 km downstream of Mapaio Fish Camp and 8.5 km downstream of Herd Base. This site is considered to be representative of the underwater acoustic environment related to the river pipeline crossings.

The Purari River at the assessment location is about 580 m wide at bank full and estimated to be 6 m deep. The river bed is comprised mainly of very fine sands and silts, so is unlikely to be a major source of noise as water flows over the river bed. The principal natural physical noise sources are expected to be wind and waves, rainfall and noise generated at the river banks where the flow passes through vegetation. The main natural biological sound sources are expected to be soniferous fish, such as catfish and other fish species that make grunting sounds for communication and courtship display purposes. Fish grunts tend to be low frequency sound <100 Hz.

Anthropogenic noise in the Purari River may be generated by a transiting TEP PNG contracted barge (e.g., MV *GFS Marine 01*) typically with a noise source level of 175 dB re 1 μPa at 1 m and at low frequencies 10 to 1,000 Hz. In addition, outboard motor-driven dugout canoes, banana boats or dinghies used by river communities generate typical noise source levels of about 163 dB re 1 μPa at 1 m when transiting at high speed (20 knots) and using the typical size of outboard motors (i.e., between 20 and 40 horsepower (HP). At slower transit speeds (<10 knots), the noise

source levels are around 157 dB re 1 μPa at 1 m, while the noise source level at idling is typically less than 110 to 120 dB re 1 μPa at 1 m.

Overall, a baseline characterization of underwater ambient noise at the Purari River assessment location is assessed to be a typical range of between 75 to 85 dB re 1 µPa rms, with transient barges passing directly over the assesment location increasing the upper range value to 170 dB re 1 µPa rms at mid-water depth (3 m) in the river.

5.2 Purari River Delta Estuary

The literature was reviewed for examples of underwater noise measurements in tropical estuaries, similar to those of the Purari River delta. There were few measurement data available and most knowledge about ambient noise mainly pertains to the marine environment and, by contrast, baseline data from tropical estuaries are limited.

Bittencourt et al. (2014) measured underwater noise in a quiet embayment (Guapimirim Environmental Protection Area) of the Guanabara Bay in Brazil and recorded received noise levels of 93.2 dB re 1 μPa rms at < 1kHz and levels averaging about 60 dB re 1 μPa rms for the frequency range to 24 kHz. These recorded values represent generally low ambient noise source levels for a tropical estuary when powered boats or other vessels are absent.

5.2.1 Assessment Location 5 (Aievi Passage)

Assessment Location 5 (7° 50' 3.81" S, 145° 10' 45.10" E) named 'Aievi Passage' is located at the mouth of the Purari River, west of Aievi Island. This assessment location was selected as it is one of the Project's preferred river traffic corridors in the Purari River delta, the other delta corridors are the Wame-Varoi and Urika-Ivo distributaries. Aievi Passage is representative of the type of estuarine environment typical of the Purari River delta. The water depth at this location is about 6 m.

Ambient noise in the Aievi Passage includes natural physical sources, such water and tidal flow, water velocity, wind, rainfall, waves and surf (along the nipa- and mangrove-lined estuary banks); however, river flow and flows are low given the very low gradient of the lower Purari River in the Aievi Passage and are therefore unlikely to be significant source of ambient physical noise. The soft bottom sediment of the estuary also reduces the level of noise due to turbulence that would be associated more with coarse sediment types, such as boulders and stones. Given the high rainfall (about 3,000 mm/yr) of the Purari River delta, rain when it occurs can be a significant source of ambient physical noise in the shallow waters of Aievi Passage. For example, heavy rain is about 30 dB higher than sea state noise and has a frequency range of 1 to 100 kHz.

Natural biological sources will include soniferous fish (e.g., catfish) and marine mammals' echolocation and communication clicks and squeals at high frequencies. The Omati-Kikori-Purari delta complex harbors a number of inshore species of dolphin. Examples include the snubfin dolphin (*Orcaella heinsohni*) sighted in the Era River (ERIAS Group, 2016b), Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) found in the Kikori delta (Bonaccorso et al., 2000), Indo-Pacific humpback dolphin (*Sousa chinensis*) found in the Kikori Delta (Leary, 2000) and the Australian humpback dolphin (*Sousa sahulensis*) has been found recently in the Kikori delta by Beasley et al. (2015). For example, bottlenose dolphins have high communication frequencies in the range 0.05 to 150 kHz and very high echolocation frequencies in the range 110 to 130 kHz, which produce noise source levels of between 218 and 228 dB re 1 μPa at 1 m; however, these biological noise sources are transient.

Anthropogenic noise in Aievi Passage will be generated by transiting TEP PNG contracted barges typically with a noise source level of between 170 and 175 dB re 1 μPa at 1 m at low frequencies 10 to 1,000 Hz. In addition, outboard motor-driven dugout canoes, banana boats or dinghies used by estuarine and coastal communities generate typical noise source levels of about 163 dB re 1 μPa at 1 m when transiting at high speed (20 knots) and using the typical size of outboard motors (i.e., between 20 and 40 horsepower (HP). At slower transit speeds (<10 knots), the noise source levels are around 157 dB re 1 μPa at 1 m, while the noise source level at idling is typically less than 110 to 120 dB re 1 μPa at 1 m.

Based on the relatively sheltered location within Aievi Passage and data from Bittencourt et al. (2014), a baseline characterization of underwater noise at the Aievi Passage assessment location is assessed as a typical range of between 75 and 85 dB re 1 μPa rms, with TEP PNG contracted barges (i.e., 64-m-long MV *GFS Marine 01*) passing directly over the assessment location increasing the upper range value to 175 dB re 1 μPa rms at a mid-water depth (3 m)

5.2.2 Assessment Location 6 (Port Romilly)

Assessment Location 5 (7° 38' 48.01" S, 144° 50' 29.69" E) named 'Port Romilly' is located in the middle of the wide estuary of the Pie River into which the Wame-Varoi distributary flows. This assessment location was selected as there are few commercial ships transiting this estuary and there are virtually no villages along its low-lying nipa- and mangrove-lined banks.

The lower estuary of Port Romilly is about 1.8 km wide and is expected to be shallow (estimate of 8 m) at the assessment location. Therefore, most natural physical and biological noise sources will be the same as for the Aievi Passage assessment above. Port Romilly is a much larger and open and exposed estuary than Aievi Passage, therefore, wind and wave action may be expected to generate more noise than within the latter; however, anthropogenic noise sources are anticipated to be lower, given the lack of villages along the estuary banks and, therefore, fewer outboard motor-driven small watercraft transiting the estuary.

ERIAS Group (2016b) conducted community level surveys of villages along the Wame River and confirmed that local villagers stated that barges passed their villages, which means that barge traffic occasionally transit Port Romilly to enter the Wame River. It is suspected that the barges are indeed log ships or log barge-landing craft. In that case, the noise source level for a typical logging barge is 170 dB re 1 μPa at 1 m.

Overall, based on the relatively more exposed location within Port Romilly and data from Bittencourt et al. (2014), a baseline characterization of underwater noise at the Port Romilly assessment location is assessed as a typical range of between 80 and 90 dB re 1 μPa rms, with a logging barge/landing craft (e.g., the 45-m-long MV *Swift No. 5*) passing directly over the assessment location having a noise source level of 170 dB re 1 μPa at 1 m increasing the upper received noise range value to 164 dB re 1 μPa rms at a mid-water depth (4 m), which represents a transmission loss of 6 dB.

5.3 Nearshore Gulf of Papua

A baseline characterization of the nearshore marine environment of the Gulf of Papua within the Project's export pipeline corridor was determined for two assessment locations:

- Assessment Location 1 (Caution Bay).
- Assessment Location 4 (Orokolo Bay).

The southeastern limit of the Gulf of Papua has been not clearly delineated based on a literature review. Therefore, the Caution Bay nearshore assessment location may actually be part of the northern Coral Sea. For the purposes of this technical paper, the Caution Bay assessment location has been included as part of the nearshore Gulf of Papua.

5.3.1 Assessment Location 1 (Caution Bay)

Assessment Location 1 (9° 18' 28.38" S, 146° 54' 9.03" E) named 'Caution Bay' is located at the northwestern approach taken by LNG carriers to the navigation channel leading to the PNG LNG marine terminal in Caution Bay. This assessment location was selected as it lies on a major shipping lane crossed by both LNG carriers as well as an array of coastal shipping (e.g., barges, container ships, fishing vessels). Altogether, shipping noise is relatively high at this location and regularly generates transient underwater noise that augments natural background noise.

In the absence of actively crossing or passing shipping, underwater ambient noise levels from natural sources will be dominated by sea surface noise (wind and wave action) in the 0.020 to 100 kHz frequency range due to the shallow water depth of 30 m at this location. In addition, transient natural biological sources will also be present, such as nearby snapping shrimp (60 to 90 dB re 1 µPa at 1 m in the 1 to 10 kHz frequency range). A typical range might be 65 to 85 dB re 1 µPa rms in the absence of shipping. Due to the presence of the major coastal shipping lane near the entrance to Caution Bay and regular LNG carrier and tug activity at the PNG LNG marine terminal in Caution Bay, a maximum transient noise of around 180 dB re 1 µPa rms at mid-water depth (15 m) could be expected from an LNG carrier passing directly over the assessment location.

Overall, a baseline characterization of underwater ambient noise at the Caution Bay assessment location is assessed as a typical range of between 90 to 110 dB re 1 µPa rms, with transient noise from a LNG carrier (passing directly over the assessment location) with a noise source level of 180 dB r re 1 µPa at 1 m (near the propellers at an assumed depth of 6 m) increasing the range upper value to 161 dB re 1 µPa rms at the mid-water depth of 15 m, which represents transmission loss of 19 dB. The adopted ambient background range includes higher frequency (1 to 10 kHz) biological noise sources, as well as low-frequency (10 to 500 Hz) from distant shipping (e.g., Great North East Shipping Channel to Torres Strait). The ambient noise range at the Caution Bay assessment location is higher than at all other assessment locations as may be expected given the increased frequency of shipping traffic in this shallow coastal area, as well as breaking surf, wind-induced breaking wave, and biological noise sources due to the presence of nearby coral reefs (e.g., snapping shrimps and other noise-emitting crustaceans, and soniferous fish).

5.3.2 Assessment Location 4 (Orokolo)

Assessment Location 2 (7° 52' 46.81" S, 145° 16'1 9.41" E) named 'Orokolo Bay' is located within the export pipeline corridor about 2.76 km from the shore, which is the mid-point of the three nautical mile zone. This site was selected to characterize the ambient noise levels typical of the nearshore environment close to coastal villages. The depth of the water at this location is about 12 m.

The nearshore environment at Orokolo Bay is shallow and natural physical noise sources will predominate, such as wind, sea state (waves), turbulence rainfall and surf. Natural biological noise sources, will include transient echolocation and communication sounds from marine mammals (e.g., inshore dolphins), fish choruses, stridulatory fish (e.g., some species of jewfish common in the area), fish choruses and distant snapping shrimp.

The main anthropogenic noise sources are expected to be alongshore transit of outboard motor-driven banana boats and dinghies. Outboard-driven dugout canoes may be expected to be less common than in the estuaries and rivers, given their small freeboard and instability under sea conditions. Transiting coastal village outboard motors are typically 20 and 40 horse power four-stroke engines, which generate a noise level of 155 dB re 1 µPa at 1 m at moderate speed (10 knots) and 165 dB re 1 µPa at 1 m at high speed (20 knots). In addition, TEP PNG contracted barges transit through this Orokolo Bay assessment location and generate a noise source level of between 170 and 175 dB re 1 μPa at 1 m at low frequencies 10 to 1,000 Hz.

In the case of the larger TEP PNG contracted barge (i.e., the 64-m-long MV *GFS Marine 01*) passing directly over the assessment location in Orokolo Bay, the noise source level of 175 dB re 1 μPa at 1 m (10 to 1,000 Hz) near the stern (propellers located at 2 m depth) produces a received noise level of 163 dB re 1 μPa rms at the mid-water depth level of 6 m at the assessment location, which represents a transmission loss of 12 dB.

In the case of a 40-HP outboard motor-driven banana boat driven parallel to the coast and at a distance of 2 km from the assessment location in Orokolo Bay, the noise source level of 163 dB re 1 μPa at 1 m (0.01 to 40 kHz) near the stern (propellers located at 1.2 m depth) produces a received noise level of 130 dB re 1 μPa rms at the mid-water depth level of 6 m at the assessment location, which represents a transmission loss of 33 dB over the intervening 2 km of shallow coastal water.

Overall, a baseline characterization of underwater ambient noise at the Orokolo Bay assessment location is assessed as a typical range of between 85 to 95 dB re 1 µPa rms, with noise from a transient barge passing directly over the assessment location or an outboard motor-driven banana boat 2 km away increasing the upper range value to 163 dB re 1 µPa rms or 130 dB re 1 µPa rms at mid-water depth (6 m).

5.4 Offshore Gulf of Papua

Ambient underwater noise in the offshore marine environment of the Gulf of Papua within the Project's export pipeline corridor was determined for two assessment locations:

- Assessment Location 2 (South of Kerema).
- Assessment Location 3 (South of Ihu).

5.4.1 Assessment Location 2 (South of Kerema)

Assessment Location 2 (8° 15' 49.19" S, 145° 49' 52.70" E) named 'South of Kerema' is located within the export pipeline corridor about 35 km south of Kerema and on the inner continental shelf of the Gulf of Papua. This assessment location was selected as it lies outside the GOPPF trawling grounds and the main shipping routes of the Gulf of Papua, except for occasional trawler transits. The depth of water at this location is about 80 m.

This location lies outside the GOPPF reporting area known as Kerema Bay, which lies about 5 km to the north; however, a number of GOPPF trawlers occasionally transit the area of this assessment point. Trawlers underway at about 7 to 8 knots have a noise source level of around 155 dB re 1 µPa at 1 m at a peak frequency of 300 Hz. Below the stern of the trawler, the sound transmission loss using the spherical spreading formula described in Section 3.2.1 is about 32 dB giving a received sound level of 123 dB re 1 µPa rms at a mid-water depth of 40 m at this location.

Overall, the background ambient noise from natural physical and biological sources is expected to be in the range 75 to 95 dB re 1 µPa rms and, with the addition of low-frequency noise (10 to 500 Hz) from distant shipping, baseline characterization of ambient noise is assessed to be in the range of 85 to 95 dB re 1 µPa rms, with a trawler's passing directly over the assessment location increasing the upper range value to 123 dB re 1 µPa rms.

5.4.2 Assessment Location 3 (South of Ihu)

Assessment Location 3 (8° 5' 4.29" S, 145° 26' 26.81" E) named 'South of Ihu' is located within the export pipeline corridor about 15 km south of Kerema and on the inner continental of the Gulf of Papua. This assessment location was selected as it lies within the main trawling ground of the GOPPF reporting area known as Kerema Bay and it is also located on the transit route of TEP PNG exploration barges to and from Port Moresby to Herd Base on the Purari River in PRL-15, as well as log ships to and from the Evara logging camp on the Purari River and Port Moresby. The water depth at this location is about 50 m.

In the absence of actively crossing ships or active trawling, underwater ambient noise levels from natural sources will be dominated by sea surface noise (wind and wave action) in the 0.020 to 100 kHz frequency range due to the shallow water depth of 50 m at this location. In addition, residual noise from natural biological sources will also be present, such as nearby snapping shrimp (60 to 90 dB re 1 µPa at 1 m in the 1 to 10 kHz frequency range). A typical ambient noise range might be 65 to 85 dB re 1 µPa rms in the absence of shipping or active trawling.

In the presence of trawlers actively fishing at about 3 knots, the average noise source level is around 155 dB re 1 µPa at 1 m at a peak frequency of 300 Hz. Below the stern of the trawler, the sound transmission loss using the spherical spreading formula described in Section 3.2.1 is about 28 dB giving a received sound level of 127 dB re 1 µPa rms at a mid-water depth of 25 m at this assessment location.

Overall, the background ambient noise from natural physical and biological sources is expected to be in the range 75 to 95 dB re 1 µPa rms and, with the addition of low-frequency noise (10 to 500 Hz) from distant shipping, baseline characterization of ambient noise is assessed to be in the range of 85 to 95 dB re 1 µPa rms, with transient actively fishing trawler noise increasing the range upper value to 127 dB re 1 µPa rms.

6. Conclusions

This underwater noise desktop baseline characterization study was undertaken to assess the existing underwater acoustic environments (soundscapes) of representative rivers, estuaries, nearshore and offshore areas of the upstream Project area. The assessment has characterized the soundscapes for seven assessment locations and examined the contribution of both natural biological and physical noise sources and anthropogenic noise sources. The study assessed that the existing underwater noise levels along the offshore export pipeline corridor south of Kerema and Ihu (assessment locations 2 and 3) to be notably lower than other locations, ranging from 75 to 127 dB re 1 µPa rms at mid water depth. At these two locations, the ambient noise from natural physical and biological noise sources would include the wind, waves and snapping shrimp with distant shipping and trawlers being the main anthropogenic noise sources.

The proximity of the assessment locations to vessel traffic results in the upper noise levels (up to 175 dB re 1 µPa rms) being higher than the upper ambient noise levels reported in the literature for marine locations elsewhere in the world of up to 110 dB re 1 µPa rms

This underwater noise desktop baseline characterization study undertaken describes the underwater noise environments in the river, nearshore and offshore marine environments of the upstream Project to support the impact assessment of potential underwater noise impacts from Project development activities in the EIS/ESHIA.

7. Data Limitations

The baseline characterization of underwater noise in this technical paper provides a reasonable but basic picture of the baseline underwater sound environments of the Gulf of Papua, Purari Delta and Caution Bay, which is based mainly on a literature search. Both natural and anthropogenic noise vary widely in space and time, depending on wind and surface water states, as well as whether vessels are transiting an assessment location directly or nearby; however, based on the literature review and published measured ambient noise levels in the marine and coastal water environments, the present desktop characterization of ambient underwater noise in the PAOI is sufficient for the purposes of undertaking an impact assessment in the EIS/ESHIA.

8. Abbreviations and Glossary

8.1 Abbreviations

The following abbreviations are used in this technical report:

µPa: microPascal

%: per cent

AIS: Automatic Identification System

CEPA: Conservation and Environmental Protection Authority

dB: decibel

dB re 1 µPa at 1 m: decibels with reference to 1 microPascal at 1 m (sound source level unit)

dB peak: decibels measured in terms of peak sound pressure

dB rms: decibels measured in terms of root-mean-square pressure

DP: dynamic positioning

DEC: Department of Environment and Conservation (forerunner to CEPA)

DWT: Dead Weight Tons

EHS: environmental, health and safety

EIR: Environmental Inception Report

EIS: Environmental Impact Statement

EP: Environmental Plan (forerunner to the EIS in Papua New Guinea)

ESHIA: Environmental, Social and Health Impact Assessment

ft^3: cubic feet

GIS: Geographic Information Systems

GOPPF: Gulf of Papua Prawn Fishery

HSC: High Speed Craft

IFC: International Finance Corporation

IMO: International Maritime Organization

km: kilometer

kg: kilogram

kHz: kilohertz

km: kilometer

km/h: kilometers per hour

KML: Kumul Marine Terminal

L: liter

L/s: liters per second

LNG: liquefied natural gas

LPG: liquefied petroleum gas

m: meter

MV: Motor Vessel (vessel class prefix)

NFA: National Fisheries Authority

NMSA: National Maritime Safety Authority

Pa: Pascal

OCIMF: Oil Companies International Marine Forum

OVMSA: Offshore Vessel Management and Self Assessment

PNGPCL: Papua New Guinea Ports Corporation Limited

RV: Research Vessel (vessel class prefix)

SL: Smit Lamnalco (vessel class prefix)

SOLAS: Safety of Life at Sea

TEU: Twenty-foot Equivalent Unit

8.2 Glossary

abiotic; physical rather than biological; not derived from living organisms.

ducted: channeling of sound waves between the sea surface and seabed in shallow water.

hydrophone: an underwater microphone that will listen to, or pick up, acoustic signals.

peak sound pressure (or zero-to-peak (0–P) sound pressure): the maximum sound pressure during a stated time interval. A peak sound pressure may arise from a positive or negative sound pressure, and the unit is the Pascal (Pa). This quantity is typically useful as a metric for a pulsed waveform, though it may also be used to describe a periodic waveform.

peak to peak (P–P) sound pressure: the sum of the peak compressional pressure and the peak rarefactional pressure during a stated time interval. This quantity is typically most useful as a metric for a pulsed waveform, though it may also be used to describe a periodic waveform. Peak-to-peak sound pressure is expressed in pascals (Pa).

received level (RL): a somewhat imprecise term meaning the level of an acoustic quantity at a specific spatial position within an acoustic field, usually the position of a marine receptor (which could be a hydrophone or an animal).

root mean square (rms) sound pressure: the square root of the mean square pressure, where the mean square pressure is the time integral of squared sound pressure over a specified time interval divided by the duration of the time interval.

soniferous: capable of producing sound, such as in some fish species with air bladders.

sound energy: the energy contained in a sound wave in a specified time duration. For an acoustic pulse, it is the total energy contained in the pulse when radiated by the source, and is equal to the spatial integral of the sound energy flux density over all directions. The unit is the joule (J).

sound exposure level (SEL): total noise energy over a measurement period expressed in units of referenced to 1 microPascals-squared in one second (i.e., dB re 1 $\mu Pa^2 \cdot s$). The SEL is commonly used for impulsive noise sources because it allows a comparison of the energy contained in impulsive signals of different duration and peak levels.

sound intensity: the average amount of sound energy transmitted per unit time through a unit area in a specified direction.

sound pressure level (SPL): the unit is the Pascal (Pa), which is equivalent to a Newton per meter squared (N/m^2), as defined by the International System of Units (S.I.). The SPL unit is expressed in terms of dB referenced to 1 microPascal at 1 meter (i.e., dB re 1 μPa at 1m), where 're' denotes 'with reference to'. A 10 dB increase represents a ten-fold increase in power, a 20 dB increase would be a 100-fold increase and 30 dB would be a 1,000-fold increase.

source level (SL): source level decibels referenced to 1 m from sound source.

spectral density: any quantity expressed as a contribution per unit of bandwidth. An example is sound exposure spectral density, expressed in units of Pa2·s/Hz.

stridulatory: the act of producing sound by rubbing together certain body parts.

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