Gorgon Gas Development and Jansz Feed Gas Pipeline:

Coastal and Marine Baseline State and Environmental Impact Report

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Terms, Definitions and Abbreviations

Terms, definitions and abbreviations used in this document are listed below. These align with the terms, definitions and abbreviations defined in Schedule 2 of the Western Australian Gorgon Gas Development and Jansz Feed Gas Pipeline Ministerial Implementation Statements No. 800 and No. 769 respectively (Statement No. 800 and 769) and the Commonwealth Gorgon Gas Development and Jansz Feed Gas Pipeline Ministerial Approvals (EPBC Reference: 2003/1294, 2008/4178 and 2005/2184).

μE/m^2/s	Microeinsteins per second per square meter
μm	Micrometre. 1 μm = 10^{-6} metre = 0.000001 metre or one millionth of a metre.
2π quantum sensor	A light sensor that records down-welling irradiance, or light from one hemisphere
3CCD	Three charge-coupled devices; technology that allows a camera to record red, green and blue light on three separate signals for better video quality.
3D	Three dimensions, or three-dimensional
ABU	Australasia Business Unit
AHC	Ah Chong monitoring site
ANOVA	Analysis of Variance, which is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form ANOVA gives a statistical test of whether the means of several groups are all equal.
Anoxia	Depletion of dissolved oxygen in the aquatic environment
ANT	Ant Point Reef monitoring site
APASA	Asia Pacific Applied Science Associates
ARI	Assessment on Referral Information (for the proposed Jansz Feed Gas Pipeline dated September 2007) as amended or supplemented from time to time.
ASSD	Accumulated Sediment Surface Density
At risk	Being at risk of Material Environmental Harm or Serious Environmental Harm and/or, for the purposes of the EPBC Act relevant listed threatened species, threatened ecological communities and listed migratory species, at risk of Material Environmental Harm or Serious Environmental Harm.
Autocorrelation	The relationship between the values of a variable taken at certain times in the series and values of a variable taken at other times. Or more simply, it is the similarity between observations as a function of the time separation between them.

BAT	Batman Reef monitoring site
Bathymetric	Relating to measurements of the depths of oceans or lakes.
Benthic	Living upon or in the seabed.
Benthic Habitats	Areas of the seabed that support living organisms. Examples include, limestone pavement, reefs, sand and soft sediments.
Benthic Primary Producer	Photosynthesising organisms (mangroves, seagrasses, algae) or organisms that harbour photosynthetic symbionts (corals, giant clams).
Berm	A narrow ledge or shelf typically at the top or bottom of a slope.
Biofouling	Unwanted marine growth on vessels or marine infrastructure.
Biomass	The total mass or amount of living organisms in a particular area or volume.
Biota	All the plant and animal life of a particular region.
Biotic	Of or relating to living organisms.
BOM	Australian Bureau of Meteorology
Bombora	Raised, dome-shaped, limestone feature, >1 m high, often formed by coral of the genus *Porites*.
BPPH	Benthic Primary Producer Habitat; benthic habitats that support primary producers.
BR	Biggada Reef
BRUV	Baited Remote Underwater Video system
Caisson	A large watertight chamber used for construction under water.
Calcarenite	Rock formed by the percolation of water through a mixture of calcareous shell fragments and quartz sand causing the dissolved lime to cement the mass together.
CALM	Former Western Australian Department of Conservation and Land Management (now DPaW)
CALM Act	Western Australian *Conservation and Land Management Act 1984*
Carbon Dioxide (CO_2) Injection System	The mechanical components required to be constructed to enable the injection of reservoir carbon dioxide, including but not limited to compressors, pipelines and wells.
CDEEP	Construction Dredging Environmental Expert Panel
Clade	A group of biological taxa or species that share features inherited from a common ancestor.

cm	Centimetre
cm^2	Square centimetre
CO_2	Carbon Dioxide
Construction	Construction includes any Proposal-related (or action-related) construction and commissioning activities within the Terrestrial and Marine Disturbance Footprints, excluding investigatory works such as, but not limited to, geotechnical, geophysical, biological and cultural heritage surveys, baseline monitoring surveys and technology trials.
Coral	Marine organisms from the class Anthozoa that exist as small sea-anemone-like polyps, typically in colonies of many identical individuals. Includes ‘hard corals’ within the order Scleractinia which secrete calcium carbonate to form a hard skeleton and form reefs; and ‘Soft corals’ within the order Alcyonacea which have no hard skeleton and are not considered reef-building organisms.
Coral Definitions	*Coral Assemblages* are benthic areas (minimum 10 m^2) or raised seabed features over which the average live coral cover is equal to or greater than 10%. *The Change in coral mortality* is determined by subtracting the baseline extent of Gross coral mortality from the extent of Gross coral mortality measured on a sampling occasion. *Detectable Net Mortality* is the result of subtracting the Change in coral mortality at the Reference Site(s) from the Change in coral mortality at the Monitoring Site. *Average Net Detectable Mortality* is the result of averaging the net detectable mortality of all monitoring sites within the Zone i.e. the mean of net detectable mortality of any Zone. *Gross coral mortality* at a site is expressed as a percentage of total coral cover at the time of sampling at that monitoring location. In determining the coral loss, measurement uncertainty is to be taken into consideration.
Corymbose	Coral colonies with horizontal interlocking branches and short upright branches.
CPCe	Coral Point Count with Excel extensions (software for the determination of coral cover from photographs)
Crustose	Forming a crust which is firmly attached to the substrate over its entire area.
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity-Temperature-Depth
Cth	Commonwealth of Australia

DEC	Former Western Australian Department of Environment and Conservation (now DPaW)
Demersal	Living on the seabed or just above it.
DEWHA	Former Commonwealth Department of the Environment, Water, Heritage and the Arts (now DotE)
Diurnal	Daily
DO	Dissolved Oxygen
DoF	Western Australian Department of Fisheries
DotE	Commonwealth Department of the Environment
DPaW	Western Australian Department of Parks and Wildlife
Dolphin (structure)	A fixed man-made marine structure that extends above the water level and is not connected to shore. Typical uses include extending a berth (a berthing dolphin) or providing a point to moor to (a mooring dolphin). Dolphins are also used to display regulatory information like speed limits, navigation information, lighted aids to navigation, etc.
DomGas	Domestic Gas
Dominant	Most common (relating to the following ecological elements: macroalgae, seagrass, mangroves, non-coral benthic invertebrates and demersal fish).
Dominant Coral Species	Species with the highest relative percentage cover. Percentage cover is expressed as the proportion of total coral cover.
DoT	Western Australian Department of Transport
DUG	Dugong Reef monitoring site
Ebb Tide	The period between high tide and the next low tide in which the sea is receding.
Ecological Element	Element listed in listed in Condition 14.2 of Statement No. 800, Condition 12.2 of Statement No. 769 and Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178.
EIS/ERMP	Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Gorgon Gas Development (dated September 2005) as amended or supplemented from time to time.
Environmental Harm	Has the meaning given by Part 3A of the *Environmental Protection Act 1986* (WA).
EP Act	Western Australian *Environmental Protection Act 1986*
EPA	Western Australian Environmental Protection Authority

EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
EPBC Reference: 2003/1294	Commonwealth Ministerial Approval (for the Gorgon Gas Development) as amended or replaced from time to time.
EPBC Reference: 2005/2184	Commonwealth Ministerial Approval (for the Jansz Feed Gas Pipeline) as amended or replaced from time to time.
EPBC Reference: 2008/4178	Commonwealth Ministerial Approval (for the Revised Gorgon Gas Development) as amended or replaced from time to time.
EPCM	Engineering, Procurement and Construction Management
Epiphyte	A plant which naturally grows upon another plant but does not derive any nourishment from it.
ESRI	Environmental Systems Research Institute
Feed Gas Pipeline	Pipeline from the wells to the Gas Treatment Plant
Fines	Fine particles
Flood Tide	The period between low tide and the next high tide in which the sea is rising.
g	Gram
GDA	Geocentric Data of Australia
GEMS	Global Environmental Modelling Systems
Geostrophic	The horizontal movement of surface water arising from a balance between the pressure gradient force and the Coriolis force.
GIS	Geographic Information System
Globose	Having the shape of a sphere or ball.
Gorgon Gas Development	The Gorgon Gas Development as approved under Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178 as amended or replaced from time to time.
GPS	Global Positioning System
Gravid	Carrying eggs in the oviduct.
Ground Truth	To verify the correctness of remote sensing information by use of ancillary information such as field studies.
ha	Hectare
Habitat	The area or areas in which an organism and/or assemblage of organisms lives. It includes the abiotic factors (e.g. substrate and topography) and the biotic factors.

Halocline	A strong, vertical salinity gradient; the (sometimes indistinct) border between layers of water that contain different amounts of salt.
HDD	Horizontal Directional Drilling, a trenchless installation process by which a pipeline is installed beneath obstacles or sensitive areas. It is often the preferred method for pipeline shore crossings.
Hermatypic	Hermatypic corals are corals that contain and depend upon zooxanthellae (algae) for nutrients.
HES	Health, Environment and Safety
IMCRA	Integrated Marine and Coastal Regionalisation of Australia
ISO	International Organization for Standardization
Isobath	A line on a chart joining places of equal depth of water; a depth contour.
ITIS	Integrated Taxonomic Information System (http://www.itis.gov)
Jack-up	Jack-up platforms (or jack-ups) are platforms that can be jacked up above the sea using legs that can be lowered, much like jacks. These platforms are typically used in water depths up to 120 m, although some designs can go to 170 m, depth. They are designed to move from place to place, and then anchor themselves by deploying the legs to the ocean bottom using a rack and pinion gear system on each leg.
Jansz Feed Gas Pipeline	The Jansz Feed Gas Pipeline as approved in Statement No. 769 and EPBC Reference: 2005/2184 as amended or replaced from time to time.
kg	Kilogram
KJVG	Kellogg Joint Venture Gorgon
km	Kilometre
km/h	Kilometres per hour
L	Litre
LAC	Light Attenuation Coefficient
LADS	Laser Airborne Depth Sounder (used for bathymetry mapping)
LCT	Landing Craft Tank
Light Attenuation	The absorption and scattering of light underwater
Littoral	A shore; the zone between high tide and low tide; of, or related to the shore, especially the seashore.
LNG	Liquefied Natural Gas

LNG0	East Barrow Ridge monitoring site
LNG1	East Barrow Ridge monitoring site
LNG2	East Barrow Ridge monitoring site
LNG3	East Barrow Ridge monitoring site
LONE	Lone Reef monitoring site
LOW	Southern Lowendal Shelf monitoring site
LTD	Light-Turbidity-Deposition
m	Metre
m/s	Metres per second
m^{-1}	Incident light absorbed per meter water depth
m^2	Square metre
m^3	Cubic metre
Macroalgae	Benthic marine plants which are non-flowering and lack roots, stems and vascular tissue. Can be seen without the aid of a magnification; includes large seaweeds.
Macrofauna	Animals whose shortest dimension is greater than or equal to 0.5 mm and can be seen without the aid of magnification; includes polychaetes, snails and amphipods.
Macro-invertebrates	An invertebrate animal (an animal without a backbone [vertebral column]) large enough to be seen without the aid of magnification; includes sponges, crinoids, hydroids, sea pens, sea whips, gorgonians, snails, clams, crayfish and sea cucumbers.
Mangrove	Tropical evergreen trees or shrubs with stilt-like roots and stems that grow in shallow coastal water.
Marine Disturbance Footprint	The area of the seabed to be disturbed by construction or operations activities associated with the Marine Facilities listed in Condition 14.3 of Statement No. 800 and Condition 12.3 of Statement No. 769 and Condition 11.3 in EPBC Reference: 2003/1294 and 2008/4178 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and dredge spoil disposal) and as set out in this Report.

Marine Facilities	In relation to Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178, the Marine Facilities are the: • Materials Offloading Facility (MOF) • LNG Jetty • Dredge Spoil Disposal Ground • Offshore Feed Gas Pipeline System and marine component of the shore crossing • Domestic Gas Pipeline Condition 14.3 of Statement No. 800 relates only to components of the Marine Facilities within State waters (i.e. specifically the Offshore Feed Gas Pipeline System). For the purposes of Statement No. 800 Marine Facilities also include: • Marine upgrade of the existing WAPET landing. In relation to Statement No. 769, Marine Facilities are the Offshore Feed Gas Pipeline System and marine component of the shore crossing.
Marine Facilities Footprint	The area of seabed associated with the physical footprint of the Marine Facilities, but excluding the area of the seabed disturbed by dredging an dredge spoil disposal, or for example, by anchoring.
Material Environmental Harm	Environmental Harm that is neither trivial nor negligible.
MBACI	Multiple Before–After, Control–Impact statistical design.
mg/cm	Milligrams per centimetre
mg/L	Milligrams per litre
MGA 50, GDA 94	Map Grid of Australia Zone 50 (WA); projection based on the Geocentric Datum of Australia 1994.
mL	Millilitre
mm	Millimetre
MOF	Materials Offloading Facility
MOF1	Materials Offloading Facility monitoring site
MOF2	Materials Offloading Facility monitoring site
MOF3	Materials Offloading Facility monitoring site
Motile	Capable of movement.
MTPA	Million Tonnes Per Annum
NATA	National Association of Testing Authorities

Neap Tide	A less than average tide occurring at the first and third quarters of the moon.
Nearshore	Close to shore; or within 3 nautical miles of Barrow Island.
nm	Nautical Miles
NS	No Sampling or Not Sampled
NTU	Nephelometric Turbidity Unit
OBS	Optical Backscatter Sensor
OE	Operational Excellence
OEMS	Operational Excellence Management System
Operations (Gorgon Gas Development)	In relation to Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178, for the respective LNG trains, this is the period from the date on which the Gorgon Joint Venturers issue a notice of acceptance of work under the Engineering, Procurement and Construction Management (EPCM) contract, or equivalent contract entered into in respect of that LNG train of the Gas Treatment Plant; until the date on which the Gorgon Joint Venturers commence decommissioning of that LNG train.
Operations (Jansz Feed Gas Pipeline)	In relation to Statement No. 769, for the pipeline, this is the period from the date on which the Proponent issues a notice of acceptance of work under the Engineering, Procurement and Construction Management (EPCM) contract, or equivalent contract entered into in respect of that pipeline; until the date on which the Proponent commences decommissioning of that pipeline.
PAR	Photosynthetically Active Radiation
Pelagic	Living in the open sea rather than in coastal or inland waters.
PER	Public Environmental Review for the Gorgon Gas Development Revised and Expanded Proposal (dated September 2008), as amended or supplemented from time to time.
PGPA	Policy, Government and Public Affairs
pH	Measure of acidity or basicity of a solution
PIO	Pilbara Offshore Marine Bioregion
Planula	Flat ciliated free-swimming larva of hydrozoan coelenterates.
ppt	Parts Per Thousand

Practicable	For the purposes of Statement No. 800 and 769 means reasonably practicable having regard to, among other things, local conditions and circumstances (including costs) and to the current state of technical knowledge. For the purposes of the conditions of EPBC Reference: 2003/1294 and 2008/4178 which include the term "practicable", when considering whether the draft plan meets the requirements of these conditions, the Commonwealth Minister will determine what is 'practicable' having regard to local conditions and circumstances including but not limited to personnel safety, weather or geographical conditions, costs, environmental benefit and the current state of scientific and technical knowledge.
PSD	Particle-size Distribution
PSU	Practical Salinity Units, equivalent to parts per thousand (ppt)
p-value	In statistical hypothesis testing, the probability of obtaining a result at least as extreme as the one that was actually observed, assuming that the null hypothesis is true.
QA/QC	Quality Assurance/Quality Control
Quadrat	A rectangle or square measuring area used to sample living things in a given site; can vary in size.
Reference Sites	Specific areas of the environment that are not at risk of being affected by the proposal or existing developments, that can be used to determine the natural state, including natural variability, of environmental attributes such as coral health or water quality.
Regionally Significant Areas	Are the regionally significant areas outside the Zones of High Impact, Moderate Impact and Influence on the eastern margins of the Lowendal Shelf to the southern boundary of the Montebello Islands Marine Park, and Dugong Reef, Batman Reef and Southern Barrow Shoals.
Root Mean Square Water Depth	Shows the variation in water depth within a time and is an indication of wave height. Calculated as follows: $D_{rms} = \sqrt{\sum_{n=1}^{10} (D_n - \overline{D})^2 / n}$ Where D_n is the *nth* of 10 sequential readings and $\overline{D}$ is the mean water depth of the *n* readings.
Rugose	Having wrinkles, creases or ridges; having a rough, wrinkled surface.
RVA	Rapid Visual Assessment
s	Second (time)
SBS	Southern Barrow Shoals monitoring site

Scleractinian	Corals that have a hard limestone skeleton and belong to the order Scleratinia.
SE	Standard Error
SEACAT Profiler	Seabird Electronics SBE19 SEACAT Profiler
Seagrass	Benthic marine plants which have roots, stems, leaves and inconspicuous flowers with fruits and seeds much like terrestrial flowering plants. Unrelated to seaweed.
Serious Environmental Harm	Environmental harm that is: a) irreversible, of a high impact or on a wide scale; or b) significant or in an area of high conservation value or special significance and is neither trivial nor negligible.
Sessile	Permanently attached directly to the substratum by its base (i.e. immobile), without a stalk or stem.
SEWPaC	Former Commonwealth Department of Sustainability, Environment, Water, Population and Communities (now DPaW)
sp. (plural: spp.)	Species
Spoil Disposal Ground	The area where dredged and excavation material is to be disposed of at sea.
Spring Tide	The highest tides in a lunar month, occurring near new and full moons.
SSBA	Surface-Supplied Breathing Apparatus
SSC	Suspended Sediment Concentration
Statement No. 748	Western Australian Ministerial Implementation Statement No. 748 (for the Gorgon Gas Development) as amended from time to time [superseded by Statement No. 800].
Statement No. 769	Western Australian Ministerial Implementation Statement No. 769 (for the Jansz Feed Gas Pipeline) as amended from time to time.
Statement No. 800	Western Australian Ministerial Implementation Statement No. 800 (for the Gorgon Gas Development) as amended from time to time.
Stressor	An environmental condition or influence that stresses (i.e. causes stress for) an organism.
Subdominant Coral Species	Species, excluding Dominant Coral Species, which have greater than or equal to 5% cover. Percentage cover is expressed as the proportion of total coral cover.
Substrate	The surface a plant or animal lives upon. The substrate can include biotic or abiotic materials. For example, encrusting algae that lives on a rock can be substrate for another animal that lives above the algae on the rock.

Surficial	Of or pertaining to the surface.
Taxon (plural: taxa)	A taxon (plural taxa), or taxonomic unit, is a name designating an organism or a group of organisms.
TC	Tropical Cyclone
Temporal	Relating to, or limited by, time
Terrestrial Disturbance Footprint (TDF)	The area to be disturbed by construction or operations activities associated with the Terrestrial Facilities listed in Condition 6.3 of Statement No. 800 and Condition 6.3 of Statement No. 769 and Condition 5.2 of EPBC Reference: 2003/1294 and 2008/4178, and set out in the Terrestrial and Subterranean Baseline State and Environmental Impact Report required under Condition 6.1 of Statement No. 800 and Condition 6.1 of Statement No. 769 and Condition 5.1 of EPBC Reference: 2003/1294 and 2008/4178.
Terrestrial Facilities	In relation to Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178, the terrestrial facilities are the: • Gas Treatment Plant • Carbon Dioxide Injection System • Associated Terrestrial Infrastructure forming part of the Proposal • Areas impacted for seismic data acquisition • Onshore Feed Gas Pipeline System and terrestrial component of the shore crossing. In relation to Statement No 769, terrestrial facilities are the Onshore Feed Gas Pipeline System and terrestrial component of the shore crossing, as approved under Statement No. 769.
Thermocline	A layer within a body of water or air where the temperature changes rapidly with depth.
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
Transect	The path along which a researcher moves, counts and records observations.
TSS	Total Suspended Solids
t-test	A statistical test to determine whether the difference between two sample means is statistically significant.
Turbidity	The cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.

Vessel	Craft of any type operating in the marine environment including hydrofoil boats, air-cushion vehicles, submersibles, floating craft and fixed or floating platforms. Also includes seaplanes when present on and in the water.
Vouchering	Collection of fauna specimens for scientific purposes.
WA	Western Australia (or Western Australian)
WAPET	West Australian Petroleum Pty Ltd.
WAPET Landing	Proper name referring to the site of the barge landing existing on the east coast of Barrow Island prior to the date of Statement No. 800.
Waters Surrounding Barrow Island	Refers to the waters of the Barrow Island Marine Park and Barrow Island Marine Management Area (approximately 4169 ha and 114 693 ha respectively), as well as the port of Barrow Island, representing the Pilbara Offshore (PIO) Marine Bioregion which is dominated by tropical species that are biologically connected to more northern areas by the Leeuwin Current and the Indonesian Throughflow, resulting in a diverse marine biota that is typical of the Indo–West Pacific flora and fauna.
West Coast Marine Facilities	In relation to Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178, the West Coast Marine Facilities are the: • Offshore Feed Gas Pipeline System (in State waters) and the marine component of the shore crossing • Condition 14.3 of Statement No. 800 relates only to components of the Marine Facilities within State waters (i.e. specifically the Offshore Feed Gas Pipeline System). In relation to Statement No. 769, Marine Facilities are the • Offshore Feed Gas Pipeline System and the marine component of the shore crossing.
WST	Western Standard Time (Australia)
Zone of High Impact	An area where long-term impacts to corals are predicted to result directly from disturbance during Horizontal Directional Drilling, dredging or construction of infrastructure on the seabed and burial during dredge spoil disposal, or indirectly from smothering due to elevated sedimentation and/or from deterioration in water quality. As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.
Zone of Influence	This area is predicted to be indirectly influenced by dredging and spoil disposal activities (e.g. marginal increases in turbidity and sedimentation), but at levels that will have no measurable impact on corals. As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.

Zone of Moderate Impact	An area where short-term moderate impacts (e.g. some partial mortality of corals) is predicted to result indirectly from Horizontal Directional Drilling, dredging, dredge spoil disposal, due to deterioration in water quality and/or an increase in sedimentation rates. Moderate impacts are likely to include some partial mortalities among fast growing, more sensitive coral species (e.g. *Acropora* sp.) but less, if any, mortality of longer living, generally more resilient species (e.g. *Porites* sp., *Turbinaria* sp.). As set out in Schedule 1 of Statement No. 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.

Executive Summary

This Coastal and Marine Baseline State and Environmental Impact Report ('Marine Baseline Report') has been prepared to meet the requirements of Condition 14 of Ministerial Implementation Statement No. 800 and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178.

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former Western Australian Department of Environment and Conservation (DEC) (now the Department of Parks and Wildlife [DPaW]) under delegation from the Minister.

The Marine Baseline Report for the Materials Offloading Facility (MOF), LNG Jetty and the Dredge Spoil Disposal Ground (Conditions 14.3.i, 14.3.ii and 14.3.iii, Statement No. 800; Conditions 11.3.I, 11.3.II and 11.3.III, EPBC Reference: 2003/1294 and 2008/4178) was initially approved on 7 April 2010 by the former DEC (under delegation from the Minister) and on 14 April 2010 by former the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) (under delegation from the Minister); and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. This revision of the Marine Baseline Report is being submitted for approval specifically in respect to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground.

The Marine Baseline Report for the Offshore Feed Gas Pipeline System and the marine component of the shore crossing (Condition 12.3, Statement No. 769), the Offshore Feed Gas Pipeline System (Condition 14.3.iv, Statement No. 800) and the Offshore Feed Gas Pipeline System in State waters (Condition 11.3.IV, EPBC Reference: 2003/1294 and 2008/4178) was initially approved on 19 August 2010 by the former DEC and on 27 August 2010 by the former DEWHA under delegation from the Minister, respectively; and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. No further approval is sought in relation to these Marine Facilities, therefore material related to these Marine Facilities in this Report is provided for information only. In accordance with Condition 14.4 of Statement No. 800 and Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178, the Marine Baseline Report for the (Offshore) Domestic Gas Pipeline will be submitted for approval at a later date, before construction commences for that specific element.

The purpose of this Report is to:

- describe and map the hard and soft corals, non-coral benthic macro-invertebrates, macroalgae, seagrass, mangroves and surficial sediments within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground
- describe and map the hard and soft corals, non-coral benthic macro-invertebrates, macroalgae, seagrass, mangroves and surficial sediments at Reference Sites not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty and Dredge Spoil Disposal Ground
- describe the demersal fish and water quality (including turbidity and light attenuation) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground
- describe the demersal fish and water quality (including turbidity and light attenuation) at Reference Sites not at risk of Material or Serious Environmental Harm due to due to construction or operation of the MOF, LNG Jetty and Dredge Spoil Disposal Ground.

Coral Monitoring

Twelve coral monitoring sites have been established under the Marine Baseline Program, at locations within the Zones of High and Moderate Impact, the Zones of Influence and at Reference Sites. Corals have been sampled for a range of population parameters, including identification of the dominant and subdominant species/taxa, colony size-class frequency distributions of dominant hard coral taxa, survival and growth of dominant hard coral taxa or selected indicator coral taxa, and the recruitment of hard coral taxa within these communities.

The coral monitoring sites are variable and cover a range of coral assemblage types that can be classified into three broad groups according to species composition:

- Sites dominated by *Acropora* species, including *A. austera*, *A. intermedia*, *A.* cf. *arafura*, *A. florida*, *A. muricata* and *A. nasuta* in high abundance: Ant Point Reef and Southern Lowendal Shelf
- Sites dominated by *Porites* species, mostly *P. lutea*, *P. australiensis* and *P. cylindrica* and also including *P. lichen*, *P. rus* and *P. nigrescens*: LNG0, LNG1, Lone Reef, Ah Chong and LNG3
- Sites without an obvious dominant genus and where the most abundant coral species were from several coral families, including *Diploastrea heliopora* (Faviidae), *Pachyseris speciosa* (Agariciidae) and *Porites australiensis* (Poritidae) at MOF1; *Goniastrea retiformis* (Faviidae) and *Acropora nasuta* (Acroporidae) at Biggada Reef; *Acropora* spp. (Acroporidae), *Porites* spp. (Poritidae), *Montipora aequituberculata* (Acroporidae), *Galaxea astreata* (Oculinidae), *Pectinia lactuca* (Pectiniidae) and *Goniastrea pectinata* (Faviidae) at Dugong Reef; and *Echinopora lamellosa* (Faviidae), *Merulina ampliata* (Merulinidae) and *Pectinia lactuca* (Pectiniidae) at Batman Reef.

Live coral percentage cover and composition was variable among the coral monitoring sites, with coral cover ranging from <20% to ~80% on the first survey. Coral cover was >50% at five sites: Ah Chong, Ant Point Reef, Lone Reef, Dugong Reef and Batman Reef. Coral cover was lowest (<20%) at MOF1 and Biggada Reef. The monitoring site at Ant Point Reef had the highest percentage cover of live coral compared to other monitoring sites (>75%) in May 2008. There was a decline in the sample means of coral cover to ~15% in March 2009 and ~8% in August 2009. The decline in estimates of percentage cover of live corals over this period was primarily due to a reduction in the cover of acroporids. High densities of the corallivorous snail *Drupella* sp. were observed at Ant Point Reef, and it is considered that these are likely to have been one of the potential causes of the observed coral mortality at this site.

Soft corals covered >5% of the substratum at only one site. Three genera – *Lobophytum*, *Sarcophyton* and *Sinularia* – together comprised ~15% of the hard substratum present at Biggada Reef in June 2009 before reducing to ~5% in October 2009.

Surveys identified 196 species of hard coral in 48 genera from the order Scleractinia and seven soft coral genera from the suborder Alcyoniina. There were 17 new taxonomic records identified, including six new records for Australia, nine new records for Western Australia and two new records for the North West Shelf. The site with the greatest coral species diversity was Ah Chong (108 species) and the site with the lowest species diversity was LNG0 (46 species).

Growth of hard corals was variable among genera, sites and seasons. Growth rates of non-branching corals were highest in the faviids (4.5 ± 3.2% per month over 12 months) and *Acropora* (3.3 ± 4.7% per month over 12 months); and lowest in *Mussidae* (1.0 ± 1.9% per month over 12 months). Positive monthly growth rates over the 12-month Marine Baseline Program ranged from <1% at Biggada Reef to 7.6 ± 3.0% at LNG1 for *Acropora*, and were 3.1 ± 1.5% at Southern Barrow Shoals for *Montipora,* and 4.5 ± 2.3% at Biggada Reef for Faviids. Negative growth over the 12-month Program was observed at Lone Reef for Lobophyllia (-0.3% per month over 12 months). For genera pooled within sites, growth was highest at LNG1 and lowest at Biggada Reef.

There are two distinct coral recruitment periods at Barrow Island: autumn and spring. In autumn 2009, the mean number of recruits was ~1555 per m^2. On average, ~430 recruits per m^2 were recorded in spring 2008, compared to ~710 per m^2 in summer 2008–2009. Recruitment was generally lower in winter, with a mean of ~18 recruits per m^2 in 2008 and ~60 recruits per m^2 in 2009. Recruitment of coral larvae was also spatially variable and coral recruitment varied significantly among the monitoring sites. During the autumn 2008 spawning period, for example, the highest numbers of coral recruits were recorded at Dugong Reef (~2660 recruits per m^2) and Batman Reef (~1070 recruits per m^2). The lowest number of coral recruits was recorded at Ant Point Reef. The composition of coral recruits at the monitoring sites was generally variable through time, with different patterns in different seasons as well as inter-annual variation. The results from the Marine Baseline Program indicate that recruitment rates at Barrow Island are more similar to the tropical areas of Ningaloo Reef and Scott Reef than the subtropical Houtman-Abrolhos.

Non-coral Benthic Macro-invertebrates, Macroalgae and Seagrass

Non-coral benthic macro-invertebrates, macroalgae and seagrass were surveyed in spring/summer and winter at 20 to 28 sites where these ecological elements were identified as being present through broadscale habitat mapping. Sites were located within the Zones of High and Moderate Impact, the Zones of Influence and at Reference Sites outside the Zones of Influence. The dominant species of benthic macro-invertebrates, macroalgae and seagrass that characterised the communities at each of the survey sites were recorded.

Benthic macro-invertebrates (Alyconiidae, ascidians, and a variety of different morphological types of sponges, gorgonians, hydroids, sea whips and *Turbinaria*) were generally sparsely distributed and relatively homogenous across broad areas of similar substratum. Distinct assemblages were observed on the different substrate types (sand or soft sediment and limestone pavement). Benthic macro-invertebrates often occurred with macroalgae. The only areas where benthic macro-invertebrates were the most common or abundant benthic biota were in the deeper (>10 m) sand habitats, even though they were generally in lower abundances than on limestone pavements.

Seagrass assemblages were reported in soft sediment habitats and on veneers of sand overlying limestone pavement, generally as small sparse patches rather than distinct beds. *Halophila spinulosa* was the most common species recorded in soft sediments, although abundance was generally low with the seagrass occurring in small (<5 m^2) patches. The seagrass on the limestone pavement with sand veneers on the east coast of Barrow Island was most commonly small patches of *Halophila ovalis*, mixed with macroalgae and benthic macro-invertebrates. The greatest species richness was recorded at site DI1 located on the inshore limestone pavement north of Town Point. At the majority of sites, seagrass species were generally recorded as being sparse (5-25% cover). The highest percentage cover recorded for any one species was 40% for *H. ovalis* in spring/summer. The highest mean biomass in spring/summer was recorded at the Dredge Spoil Disposal Ground. Seagrass assemblages were spatially variable in terms of their percentage cover, biomass and species richness.

There were no clear patterns in seagrass percentage cover, biomass and species richness in relation to the location of sites in the Zones of High and Moderate Impact compared to sites in the Zones of Influence and Reference Sites outside the Zones of Influence. Similarly, there was no indication of marked differences in the estimates of abundance or diversity of benthic macro-invertebrates at sites in the Zones of High and Moderate Impact compared to sites in the Zones of Influence or at Reference Sites outside the Zones of Influence. Nevertheless, all the benthic macro-invertebrate and seagrass taxa recorded at sites in the Zones of High and Moderate Impact were also recorded at sites within the Zones of Influence and at Reference Sites. All the benthic macro-invertebrate and seagrass taxa at risk of Serious or Material Environmental Harm were well represented elsewhere.

Macroalgal assemblages represent the most extensive benthic habitat in the waters around Barrow Island. Percentage cover, biomass and species richness (excluding turfing and crustose coralline species) of the macroalgal assemblages were spatially variable, both between and within sites. The number of dominant species varied between one per site, up to a maximum of 15 species recorded in spring/summer at a site located near the northern extent of the Zone of Influence, near the Lowendal Islands. At the majority of sites, all the macroalgae species were generally recorded as being sparse (5–25% cover) in spring/summer. The highest percentage cover recorded for any one species was 45% for *Sargassum* sp.1 in spring/summer at a site near the northern extent of the Zone of Influence near the Lowendal Islands. Estimates of percentage cover and biomass were generally highest on the areas of shallow limestone pavements and lowest on soft sediments. The highest mean biomass and percentage covers were recorded in spring/summer at the sites located near the Lowendal Islands and at Biggada Reef on the west coast.

Estimates of macroalgal percentage cover, biomass and species richness were generally slightly lower at sites in the Zones of High Impact than at sites in the Zones of Influence. Many of the macroalgae species recorded at sites in the Zones of High and Moderate Impact were also recorded at sites within the Zones of Influence and at Reference Sites, including the red macroalgae *Galaxaura rugosa*; the brown macroalgae *Dictyopteris australis*, *Hormophysa cuneiformis*, *Padina boryana*, Phaeophyceae sp., *Sargassopsis decurrens*, *S. oligocystum*, *Sargassum* sp.2; and the green macroalgae *Udotea argentea*, *U. orientalis* and *Udotea* sp. However, a number of taxa at sites within the Zones of High and Moderate Impact were not recorded at any other sites; e.g. *Amphiroa fragilissima* and *Laurencia* sp. (LNGI2 only) and *Hypnea pannosa* and *Coelathrix irreqularis* (TP5 only).

Mangroves

The grey mangrove (*Avicennia marina*) is the only species found around Barrow Island. This species grows as a narrow fringe in the sheltered embayments on the southern and eastern coasts from Bandicoot Bay to Shark Point, with a small communities further north at Mattress Point, Ant Point and Square Bay. There are no stands of *A. marina* in the immediate vicinity of Gorgon Gas Development facilities; the closest stands are located at the Donald River mouth, approximately 5 km north of Town Point. There are no mangroves within the Zones of High and Moderate Impact on the east coast of Barrow Island, i.e. there is no mangrove cover relevant to the construction of the Materials Offloading Facility, LNG Jetty, Dredge Spoil Disposal Ground, or marine upgrade of the existing WAPET Landing. Similarly, there are no mangroves within the area at risk of Material or Serious Environmental Harm on Barrow Island.

Vegetation surveys, which included both quantitative (light infiltration, pneumatophores density and leaf pathology) and qualitative (visual tree health score) assessments of the mangrove communities on the east coast of Barrow Island, indicated there was natural spatial variability in mangrove condition, with variability generally observed at the quadrat, tree, transect and site scales. This variability was observed across sites in the Zone of Influence and at Reference Sites.

Demersal Fish

Demersal fish surveys in coral, macroalgal, sand with sessile invertebrates and bare sand communities, were undertaken in October 2008 (150 stereo-BRUV deployments) and March 2009 (183 stereo-BRUV deployments). In the October 2008 survey, 11 393 individuals were recorded from 248 species and 52 families. 13 440 individuals from 247 species and 54 families were recorded in the March 2009 survey. On average 17.5 ± 0.8 and 17.0 ± 0.8 species were observed during each stereo-BRUV deployment in 2008 and 2009 respectively. The greatest species richness for a single deployment was 49 species during the October 2008 survey and 50 species during March 2009, both of which were recorded at a reference coral monitoring site.

There were significant differences in fish assemblages characteristic of coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and sand communities, in terms of species richness, relative abundance and composition, indicating different community-types were used by distinctly different fish assemblages. Coral communities exhibited the greatest diversity of species, followed by macroalgae, soft sediments with sessile macro-invertebrates and bare sand. As well as being more diverse, coral habitats also supported a greater proportion of larger-bodied fish. Within habitats, species richness was generally similar, suggesting little variation in diversity within habitats across the Zones of High and Moderate Impact and the Zones of Influence.

The demersal fish assemblages that characterised mangrove communities were surveyed in December 2009 using a combination of gill, seine, throw and scoop nets with varying mesh sizes. The fish assemblages characteristic of mangrove communities in representative areas in the Zone of Influence and Reference Sites were generally similar, with differences reflecting the different substrate types (e.g. rocky substrate, sandy substrate), as well as the sampling methodologies. The size structure of the most abundant species recorded in the mangrove communities indicates that these communities provide habitat for juveniles and adults of small fish species, as well as juveniles of larger species. Larger fish (e.g. Giant Trevally [*Caranx ignobilis*], Giant Queenfish [*Scomberoides commersonnianus*] and Milkfish [*Chanos chanos*]), rays (e.g. Giant Shovelnose Ray [*Rhinobatus typus*]) and sharks (e.g. Nervous Shark [*Carcharhinus cautus*]) were observed using the mangrove habitat and adjacent intertidal flats as feeding areas during periods of inundation at high tide.

Water Quality (Turbidity and Light Attenuation)

In the waters around Barrow Island, turbidity and concentrations of suspended sediments were generally low (<5 mg/L) and indicative of clear water environments. There were very low levels of sediment deposition over the duration of the Marine Baseline Program (generally below the limits of instrument detection) and any deposition that did occur was temporary and rapidly resuspended by waves and tidal flow.

At most sites, wave activity was significant in contributing to local resuspension of sediments, resulting in elevated turbidity and suspended sediment concentrations. In winter, easterly winds can generate wind seas that propagate into the east coast of Barrow Island. Thus at the majority of the sites there was a measurable effect on water quality, with suspended sediment concentrations generally higher during winter when easterly winds are more common. The west coast of Barrow Island is exposed to the open ocean and a relatively vigorous wave climate, bringing long period Southern Ocean swells and shorter-period local wind waves, particularly during the summer months, when winds prevail from the south-west. Extreme weather events, such as tropical cyclones, also had a strong influence on water quality. Short periods of elevated suspended sediment concentrations, reduced light levels and elevated light attenuation as a consequence of increased turbidity in the water column, coincided with the passage of tropical cyclones. Higher average particle flux rates were also recorded during periods of increased wave activity and elevated suspended sediment concentrations, as well as following the passage of a tropical cyclone. Conversely, relatively low flux rates were observed during extended periods of calm conditions.

Water quality and sediment deposition varied markedly between sites in close proximity to each other and sites responded dissimilarly to the same hydrodynamic conditions (e.g. waves). Seasonal patterns, such as higher light levels in summer than in winter, were also more evident at some sites than others. Similarly, the influence of environmental parameters on water quality also varied over relatively small spatial scales.

Sedimentation and turbidity are major influences on the health and survival of scleractinian corals and other benthic primary producers through alteration of both physical and biological processes. The extent and severity of impacts related to turbidity, light attenuation and sedimentation are highly variable and depend on a number of factors including the species and morphology of corals, sediment grain size, and water temperature. Additionally, the magnitude, duration and frequency of turbidity and sedimentation events, as well as the pre-event condition of the coral, also affects the extent and severity of impacts. Coral health data collected during the baseline program showed no discernible impacts on coral health associated with water quality (turbidity and light attenuation) or sediment deposition.

Post-development Surveys

Post-development Coastal and Marine State and Environmental Impact Surveys will be undertaken within three months of completion of dredging and spoil disposal activities to determine whether changes have occurred to the ecological elements. The Post-development Surveys will include determination of the Permanent Loss of Coral Assemblages within the Zones of High Impact and Zones of Moderate Impact compared with 22 hectares or the area of Loss of Coral Assemblages calculated prior to the commencement of dredging and spoil disposal activities and Marine Facilities construction activities.

1.0 Introduction

1.1 Proponent

Chevron Australia Pty Ltd (Chevron Australia) is the proponent and the person taking the action for the Gorgon Gas Development on behalf of the following companies (collectively known as the Gorgon Joint Venturers):

- Chevron Australia Pty Ltd
- Chevron (TAPL) Pty Ltd
- Shell Development (Australia) Proprietary Limited
- Mobil Australia Resources Company Pty Limited
- Osaka Gas Gorgon Pty Ltd
- Tokyo Gas Gorgon Pty Ltd
- Chubu Electric Power Gorgon Pty Ltd

pursuant to Statement No. 800 and EPBC Reference: 2003/1294 and 2008/4178.

Chevron Australia is also the proponent and the person taking the action for the Jansz Feed Gas Pipeline on behalf of the Gorgon Joint Venturers, pursuant to Statement No. 769 and EPBC Reference: 2005/2184.

1.2 Project

Chevron Australia proposes to develop the gas reserves of the Greater Gorgon Area (Figure 1-1).

Subsea gathering systems and subsea pipelines will be installed to deliver feed gas from the Gorgon and Jansz–Io gas fields to the west coast of Barrow Island. The feed gas pipeline system will be buried as it traverses from the west coast to the east coast of the Island where the system will tie in to the Gas Treatment Plant located at Town Point. The Gas Treatment Plant will comprise three Liquefied Natural Gas (LNG) trains capable of producing a nominal capacity of five Million Tonnes Per Annum (MTPA) per train. The Gas Treatment Plant will also produce condensate and domestic gas. Carbon dioxide (CO_2), which occurs naturally in the feed gas, will be separated during the production process. As part of the Gorgon Gas Development, Chevron Australia will inject the separated CO_2 into deep formations below Barrow Island. The LNG and condensate will be loaded from a dedicated jetty offshore from Town Point and then transported by dedicated carriers to international markets. Gas for domestic use will be exported by a pipeline from Town Point to the domestic gas collection and distribution network on the mainland (Figure 1-2).

1.3 Location

The Gorgon gas field is located approximately 130 km and the Jansz–Io field approximately 200 km off the north-west coast of Western Australia. Barrow Island is located off the Pilbara coast 85 km north-north-east of the town of Onslow and 140 km west of Karratha. The Island is approximately 25 km long and 10 km wide and covers 23 567 ha. It is the largest of a group of islands, including the Montebello and Lowendal Islands.

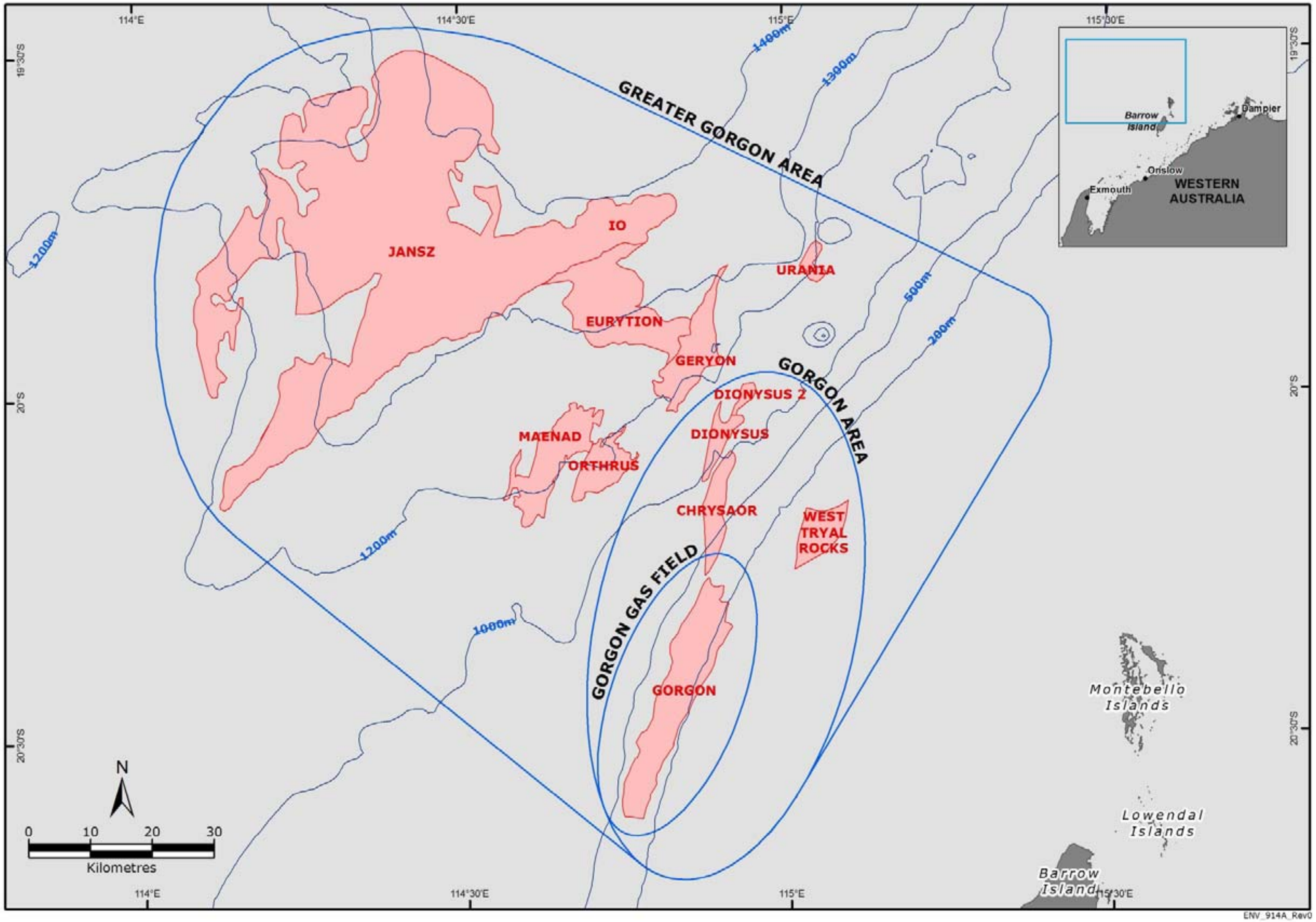


Figure 1-1 Location of the Greater Gorgon Area

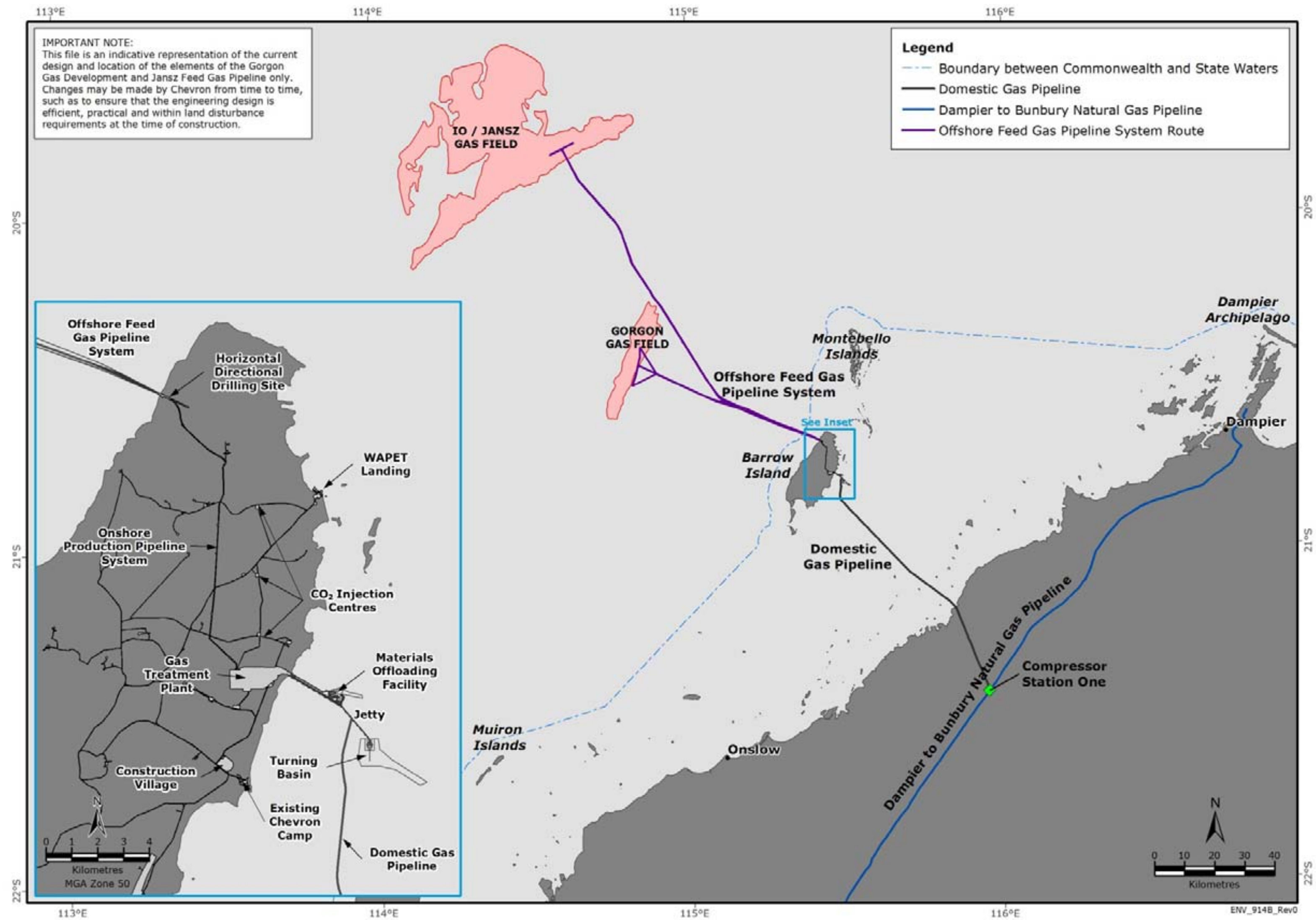


Figure 1-2 Location of the Gorgon Gas Development and Jansz Feed Gas Pipeline

1.4 Environmental Approvals

The initial Gorgon Gas Development was assessed through an Environmental Impact Statement/Environmental Review and Management Programme (EIS/ERMP) assessment process (Chevron Australia 2005, 2006).

The initial Gorgon Gas Development was approved by the Western Australian State Minister for the Environment on 6 September 2007 by way of Ministerial Implementation Statement No. 748 (Statement No. 748) and the then Commonwealth Minister for the Environment and Water Resources on 3 October 2007 (EPBC Reference: 2003/1294).

In May 2008, under section 45C of the Western Australian *Environmental Protection Act 1986* (EP Act), the Environmental Protection Authority (EPA) approved some minor changes to the Gorgon Gas Development that it considered ‘not to result in a significant, detrimental, environmental effect in addition to, or different from, the effect of the original proposal’ (EPA 2008). The approved changes are:

- excavation of a berthing pocket at the Barge (WAPET) Landing facility
- installation of additional communications facilities (microwave communications towers)
- relocation of the seawater intake
- modification to the seismic monitoring program.

In September 2008, Chevron Australia sought both State and Commonwealth approval through a Public Environment Review (PER) assessment process (Chevron Australia 2008) for the Revised and Expanded Gorgon Gas Development to make some changes to ‘Key Proposal Characteristics’ of the initial Gorgon Gas Development, as outlined below:

- addition of a five MTPA LNG train, increasing the number of LNG trains from two to three
- expansion of the CO_2 Injection System, increasing the number of injection wells and surface drill locations
- extension of the causeway and the Materials Offloading Facility (MOF) into deeper water.

The Revised and Expanded Gorgon Gas Development was approved by the Western Australian State Minister for the Environment on 10 August 2009 by way of Ministerial Implementation Statement No. 800 (Statement No. 800). Statement No. 800 also superseded Statement No. 748 as the approval for the initial Gorgon Gas Development. Statement No. 800 therefore provides approval for both the initial Gorgon Gas Development and the Revised and Expanded Gorgon Gas Development, which together are known as the Gorgon Gas Development.

On 26 August 2009, the then Commonwealth Minister for the Environment, Heritage and the Arts issued approval for the Revised and Expanded Gorgon Gas Development (EPBC Reference: 2008/4178) and varied the conditions for the initial Gorgon Gas Development (EPBC Reference: 2003/1294).

Since the Revised and Expanded Gorgon Gas Development was approved, further minor changes have also been made and/or approved to the Gorgon Gas Development and are now also part of the Development. Further changes may also be made/approved in the future. This Report relates to any such changes, and where necessary will be specifically revised to address the impacts of those changes.

The Jansz Feed Gas Pipeline was assessed via Environmental Impact Statement/Assessment on Referral Information (ARI) and EPBC Referral assessment processes (Mobil Australia 2005, 2006).

The Jansz Feed Gas Pipeline was approved by the Western Australian State Minister for the Environment on 28 May 2008 by way of Ministerial Implementation Statement No. 769 (Statement No. 769) and the then Commonwealth Minister for the Environment and Water Resources on 22 March 2006 (EPBC Reference: 2005/2184).

The Coastal and Marine Baseline State and Environmental Impact Report (hereafter referred to as the 'Marine Baseline Report') covers the Gorgon Gas Development as approved under Statement No. 800 and as approved by EPBC Reference: 2003/1294 and EPBC Reference: 2008/4178. In addition, the Marine Baseline Report covers the Jansz Feed Gas Pipeline System and the marine component of the shore crossing (in State waters), as approved by Statement No. 769 and EPBC Reference: 2005/2184.

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former Western Australian Department of Environment and Conservation (DEC) under delegation from the Minister. The Marine Baseline Report for the MOF, LNG Jetty and the Dredge Spoil Disposal Ground (Conditions 14.3.i, 14.3.ii and 14.3.iii, Statement No. 800; Conditions 11.3.I, 11.3.II and 11.3.III, EPBC Reference: 2003/1294 and 2008/4178) was intially approved on 7 April 2010 by the former DEC (under delegation from the Minister) and on 14 April 2010 by the former Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) (under delegation from the Minister); and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. This revision of the Marine Baseline Report is being submitted for approval specifically in respect to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground.

The Marine Baseline Report for the Offshore Feed Gas Pipeline System and the marine component of the shore crossing (Condition 12.3, Statement No. 769), the Offshore Feed Gas Pipeline System (Condition 14.3.iv, Statement No. 800) and the Offshore Feed Gas Pipeline System in State waters (Condition 11.3.IV, EPBC Reference: 2003/1294 and 2008/4178) was intially approved on 19 August 2010 by the former DEC and on 27 August 2010 by the former DEWHA under delegation from the Minister, respectively; and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. No further approval is sought in relation to these Marine Facilities, therefore material related to these Marine Facilities in this Report is provided for information only. In accordance with Condition 14.4 of Statement No. 800 and Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178, the Marine Baseline Report for the (Offshore) Domestic Gas Pipeline will be submitted for approval at a later date, before construction commences for that specific element.

In respect of the Carbon Dioxide Seismic Baseline Survey Works Program, which comprises the only works approved under Statement No. 748 before it was superseded, and under EPBC Reference: 2003/1294 before the Minister approved a variation to it on 26 August 2009, note that under Condition 1A.1 of Statement No. 800 and Condition 1.4 of EPBC Reference: 2003/1294 and 2008/4178 this Program is authorised to continue for six months subject to the existing approved plans, reports, programs and systems for the Program, and the works under the Program are not the subject of this Report.

1.5 Purpose of this Report

1.5.1 Legislative Requirements

1.5.1.1 State Ministerial Conditions

This Report is required under Condition 14.2 of Statement No. 800, which is quoted below:

> *Prior to commencement of construction of marine facilities as listed in Condition 14.3, the Proponent shall submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 14.6, as determined by the Minister, unless otherwise allowed in Condition 14.4.*

The Marine Facilities referred to are defined in Condition 14.3 of Statement No. 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty

- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine upgrade of the existing WAPET landing.

Condition 14.3 of Statement No. 800 relates only to components of the Marine Facilities within State waters (i.e. specifically the Offshore Feed Gas Pipeline System).

This Report is also required under Condition 12.2 of Statement No. 769, which is quoted below:

> *Prior to commencement of construction of marine facilities, as defined in Condition 12.3, the Proponent shall submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 12.5, as determined by the Minister, unless otherwise allowed in Condition 12.4.*

The Jansz Marine Facilities referred to are defined in Condition 12.3 of Statement No. 769 as the Offshore Feed Gas Pipeline System and marine component of the shore crossing.

1.5.1.2 Commonwealth Ministerial Conditions

This Report satisfies the requirements of Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178, which is quoted below:

> *Prior to commencement of construction of marine facilities as listed in Condition 11.3, the person taking the action must submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 11.6, and the requirements set out in Conditions 11.7 and 11.8 as determined by the Minister, unless otherwise allowed in Condition 11.4.*

1.5.2 Scope

Condition 14.4 of Statement No. 800 provides for this Marine Baseline Report to be submitted in a staged approach:

> *In the event that portions of the Report related to specific elements or sub-elements (the marine facilities listed in Condition 14.3) of the Proposal are not submitted as required by Condition 14.1, the Proponent shall submit the portion of the Report relevant to that element or sub-element to the Minister prior to the commencement of construction of that element or sub-element. All portions of the Report shall meet the purposes identified in Condition 14.6 and the requirements of Condition 14.7 and 14.8 as determined by the Minister.*

Condition 12.4 of Statement No. 769 similarly provides for this Marine Baseline Report to be submitted in a staged approach:

> *In the event that any portions of the Report related to specific elements or sub-elements (Schedule 1) of the Proposal are not submitted as required by Condition 12.2, the Proponent shall submit the portion of the Report relevant to that element or sub-element to the Minister prior to the commencement of construction of that element or sub-element. All portions of the Plan shall meet the purposes identified in Condition 12.6 and the requirements of Condition 12.7 and 12.8 as determined by the Minister.*

Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178 also provides for this Marine Baseline Report to be submitted in a staged approach:

> *In the event that portions of the Report related to specific elements or sub-elements (the marine facilities listed in Condition 11.3) of the action are not submitted as required by Condition 11.2, the person taking the action must submit the portion of the Report relevant to that element or sub-element to the Minister prior to the commencement of construction of that element or sub-element. All portions of the Report must meet the purposes identified*

in Condition 11.6 and the requirements of Condition 11.7 and 11.8 as determined by the Minister.

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC under delegation from the Minister. The Marine Baseline Report for the MOF, LNG Jetty and the Dredge Spoil Disposal Ground (Conditions 14.3.i, 14.3.ii and 14.3.iii, Statement No. 800; Conditions 11.3.I, 11.3.II and 11.3.III, EPBC Reference: 2003/1294 and 2008/4178) was intially approved on 7 April 2010 by the former DEC and on 14 April 2010 by the former DEWHA under delegation from the Minister, respectively; and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. This revision of the Marine Baseline Report is being submitted for approval specifically in respect to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground.

The Marine Baseline Report for the Offshore Feed Gas Pipeline System and the marine component of the shore crossing (Condition 12.3, Statement No. 769), the Offshore Feed Gas Pipeline System (Condition 14.3.iv, Statement No. 800) and the Offshore Feed Gas Pipeline System in State waters (Condition 11.3.IV, EPBC Reference: 2003/1294 and 2008/4178) was initially approved on 19 August 2010 by the former DEC and on 27 August 2010 by the former DEWHA under delegation from the Minister, respectively; and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. No further approval is sought in relation to these Marine Facilities; therefore material related to these Marine Facilities in this Report is provided for information only. In accordance with Condition 14.4 of Statement No. 800 and Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178, the Marine Baseline Report for the (Offshore) Domestic Gas Pipeline will be submitted for approval at a later date, before construction commences for that specific element.

1.5.3 Purpose

The purposes of this Marine Baseline Report, as stated in Condition 14.6 of Statement No. 800, are to:

- Describe and map the ecological elements referred to in Condition 14.2(i-vi) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.
- Describe and map the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact that are to be used to calculate the Area of Loss of Coral Assemblages according to the following formula:

  $a = h + (m \times 30\%)$

  where:

  a = the area (ha) of loss of Coral Assemblages

  h = the area (ha) of Coral Assemblages within the Zones of High Impact

  m = the area (ha) of Coral Assemblages within the Zones of Moderate Impact.
- Describe and map the benthic ecological elements referred to in Condition 14.2(i-vi) that are at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing.
- Describe and map the benthic ecological elements referred to in Condition 14.2(i-vi) at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing.
- Describe the ecological elements referred to in Condition 14.2(vii and viii) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of

Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.

- Describe the ecological elements referred to in Condition 14.2(vii and viii) that are at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing.
- Describe the ecological elements referred to in Condition 14.2(vii and viii) of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and marine upgrade of the existing WAPET Landing.

The purposes of this Marine Baseline Report, as stated in Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178 are to:

- Describe and map the ecological elements referred to in Condition 11.2(I-VI) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.
- Describe and map the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact that are to be used to calculate the Area of Loss of Coral Assemblages according to the following formula:

  $a = h + (m \times 30\%)$

  where:

  a = the area (ha) of loss of Coral Assemblages

  h = the area (ha) of Coral Assemblages within the Zones of High Impact

  m = the area (ha) of Coral Assemblages within the Zones of Moderate Impact.
- Describe and map the benthic ecological elements referred to in Condition 11.2(I-VI) at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty and Dredge Spoil Disposal Ground.
- Describe the ecological elements referred to in Condition 11.2(VII and VIII) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.
- Describe the benthic ecological elements referred to in Condition 11.2(VII and VIII) of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty and Dredge Spoil Disposal Ground.

The approved methodologies to be used in the Marine Baseline Program are detailed in the Coastal and Marine Baseline State and Environmental Impact Report Scope of Works (RPS 2009).

1.5.4 Requirements

The requirements of this Marine Baseline Report, as stated in Condition 14 of Statement No. 800 and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178, are listed in Table 1-1. Table 1-1 also references the specific sections of this Marine Baseline Report where each requirement is addressed. The material provided in Table 1-1 on the marine upgrade of the existing WAPET Landing is provided for information only.

Table 1-1 Requirements of this Marine Baseline Report

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
Statement No. 800	14.2	The Report shall cover the following ecological elements: i. Hard and soft corals ii. Macroalgae iii. Non-coral benthic macro-invertebrates iv. Seagrass v. Mangroves vi. Surficial sediment characteristics vii. Demersal fish viii. Water quality (including measures of turbidity and light attenuation).	 Section 6.0 Section 8.0 Section 7.0 Section 9.0 Section 10.0 Section 12.0 Section 11.0 Section 13.0
Statement No. 800	14.5	In preparing the Report the Proponent shall consult with the Construction Dredging Environmental Expert Panel (CDEEP), the Department of Environment and Conservation (DEC) (now DPaW), the Department of Transport (DoT), the Department of Fisheries (DoF) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) (now DotE).	Section 1.5.7
Statement No. 800	14.6.i	The purpose of the Report is to: • describe and map the ecological elements referred to in Condition 14.2(i-vi) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.	Figure 2-3 depicts the extent of the Zones of High Impact, Zones of Moderate Impact and the Zones of Influence relevant to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground. Maps of the ecological elements within the Zones of High Impact and the Zones of Moderate Impact and representative areas within the Zone of Influence can be found in the figures listed below.
		i. Hard and soft corals;	Sections 6.4.1.1 and 6.4.1.3; Figure 6-1, Figure 6-2, Figure 6-5 to Figure 6-7 and Figure 6-8 to Figure 6-9
		ii. Macroalgae;	Sections 8.4.4 and 8.4.6; Figure 8-2.
		iii. Non-coral benthic macro-invertebrates;	Sections 7.4.3 and 7.4.5; Figure 7-2

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
		iv. Seagrass;	Sections 9.4.4 and 9.4.6; Figure 9-2
		v. Mangroves;	There are no mangroves within the Zones of High and Moderate Impact. There are sparse mangrove stands within the Zone of Influence. Sections 10.4.1 and 10.4.2; Figure 10-1 and Figure 10-2
		vi. Surficial sediment characteristics	Sections 12.4.1 and 12.4.3; Figure 12-2
Statement No. 800	14.6.ii	The purpose of the Report is to: • describe and map the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact which are to be used to calculate the Area of Loss of Coral Assemblages according to the following formula: $a = h + (m \times 30\%)$ where: a = the area (ha) of loss of Coral Assemblages. h = the area (ha) of Coral Assemblages within the Zones of High Impact. m = the area (ha) of Coral Assemblages within the Zones of Moderate Impact.	Coastal and Marine Baseline State and Environmental Impact Report Supplement: Area of Coral Assemblages (Chevron Australia 2010).
Statement No. 800	14.6.iii	The purpose of the Report is to: • describe and map the benthic ecological elements referred to in Condition 14.2(i-vi) which are at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System, Domestic Gas Pipeline and Marine upgrade of the existing WAPET Landing.	Approval for the Marine upgrade of the existing WAPET Landing was received on 3 November 2009. Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
		i. Hard and soft corals	Section 6.4.1.2. (no Coral Assemblages were at risk of Material or Serious Environmental Harm at WAPET Landing)
		ii. Macroalgae	Section 8.4.5; Figure 8-2

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
		iii. Non-coral benthic macro-invertebrates	Section 7.4.4; Figure 7-2
		iv. Seagrass	Section 9.4.5; Figure 9-2
		v. Mangroves	There are no mangroves at or near the existing WAPET Landing
		vi. Surficial sediment characteristics	Section 12.4.2; Figure 12-2
Statement No. 800	14.6.iv	The purpose of the Report is to: • describe and map the benthic ecological elements referred to in Condition 14.2(i-vi) at Reference Sites which are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground, Offshore Feed Gas Pipeline System, Domestic Gas Pipeline and Marine upgrade of the existing WAPET Landing.	Figure 2-3 depicts the extent of the Zones of High Impact, Zones of Moderate Impact and the Zones of Influence relevant to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground. Maps of the ecological elements at Reference Sites which are not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty or Dredge Spoil Disposal Ground can be found in the figures listed below. Approval for the marine upgrade of the existing WAPET Landing was received on 3 November 2009. Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
		i. Hard and soft corals	Section 6.4.1.4; Figure 6-10 to Figure 6-14
		ii. Macroalgae	Section 8.4.7; Figure 8-1 and Figure 8-2
		iii. Non-coral benthic macro-invertebrates	Section 7.4.6; Figure 7-1 and Figure 7-2
		iv. Seagrass	Section 9.4.7; Figure 9-1 and Figure 9-2
		v. Mangroves	Sections 10.4.1 and 10.4.2; Figure 10-1 and Figure 10-2

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
		vi. Surficial sediment characteristics	Section 12.4.3; Figure 12-2
Statement No. 800	14.6.v	The purpose of the Report is to: • describe the ecological elements referred to in Condition 14.2(vii and viii) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground. vii. Demersal fish viii. Water quality (including measures of turbidity and light attenuation)	 Sections 11.4.3 and 11.4.5 Sections 13.3.1.1, 13.4.2.1, 13.4.2.3, 13.4.3.1 and 13.4.3.2. The site at Lone Reef was established to measure turbidity, light attenuation and sediment deposition associated with the Dredge Spoil Disposal Ground.
Statement No. 800	14.6.vi	The purpose of the Report is to: • describe the ecological elements referred to in Condition 14.2(vii and viii) which are at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System, Domestic Gas Pipeline and the Marine upgrade of the existing WAPET Landing. vii. Demersal Fish viii. Water quality (including measures of turbidity and light attenuation)	Approval for the marine upgrade of the existing WAPET Landing was received on 3 November 2009. Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time. Section 11.4.4 Section 13.4.2.2

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
Statement No. 800	14.6.vii	The purpose of the Report is to: • describe the ecological elements referred to in Condition 14.2(vii and viii) of Reference Sites which are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground, Offshore Feed Gas Pipeline System, Domestic Gas Pipeline and the Marine upgrade of the existing WAPET Landing .	Approval for the marine upgrade of the existing WAPET Landing was received on 3 November 2009. Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
		vii. Demersal Fish	Section 11.4.6
		viii. Water quality (including measures of turbidity and light attenuation)	Sections 13.4.2.4 and 13.4.3.3
Statement No. 800	14.7	The geographic extent of the Report shall be: i. the Marine Facilities listed in Condition 14.3 ii. Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence including those that contain significant benthic communities including coral assemblages iii. the Marine Disturbance Footprint associated with the facilities listed in Condition 14.3 in State Waters iv. Reference Sites outside the Zone of Influence.	Section 2.0 provides detail of the geographic extent of the Report required by this Condition, including relevant figures.
Statement No. 800	14.8.i	The Report shall: • contain spatially accurate (i.e. rectified and geographically referenced) maps showing the locations and spatial extent of the marine coastal facilities listed in Condition 14.3.	Figure 2-1
Statement No. 800	14.8.ii	The Report shall: • present the results of the surveys described in Condition 14.1.	Sections 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0 and 13.0
Statement No. 800	14.8.iii	The Report shall record the:	
		• existing dominant and subdominant hard and soft coral species/taxa	Section 6.4.2
		• dominant species of macroalgae	Section 8.4.2
		• dominant species of non-coral benthic macro-invertebrates	Section 7.4.1
		• dominant species of seagrass	Section 9.4.2
		• dominant species of mangroves	Section 10.4
		• demersal fish assemblages that characterise these communities.	Section 11.4

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
Statement No. 800	14.8.iv.a	The Report shall record the: • population structure of coral communities as colony size-class frequency distributions of dominant hard coral taxa.	Section 6.4.3
Statement No. 800	14.8.iv.b	The Report shall record the: • population statistics of survival and growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities.	Sections 6.4.4 and 6.4.5
Statement No. 800	14.8.iv.c	The Report shall record the: • recruitment of hard coral taxa within these communities.	Section 6.4.6
Statement No. 800	14.8.v	The Report shall: • contain descriptions and spatially accurate (i.e. rectified and geographically referenced) maps in accordance with the purposes set out in Condition 14.6.	See maps in Sections 6.0, 7.0, 8.0, 9.0, 10.0, 11.0 and 12.0 (refer to Condition 14.6 in this Table)
Statement No. 800	14.8.vi	The Report shall: • present data in an appropriate Geographic Information System (GIS) format.	Existing figures represent GIS data that is up-to-date and complete for the MOF, LNG Jetty and Dredge Spoil Disposal Ground. All relevant GIS data were provided in digital format with Revision 2 of this Marine Baseline Report.
Statement No. 800	14.8.vii	The Report shall establish and report on: • background water quality (including measures of turbidity and light attenuation) • the natural rates and spatial patterns of sediment deposition • the physical characteristics of the deposited sediment and characteristics of surficial sediments where dredging and dredge spoil disposal may affect the environment and at Reference Sites where the environment will not be affected.	Section 13.4.2 Section 13.4.2 Affected or at Risk: Sections 12.4.1, 12.4.2, 13.4.2.1, 13.4.2.2 and 13.4.2.3 Not affected or at Risk: Sections 12.4.3 and 13.4.2.4
Statement No. 800	14.9	To meet the requirements of Condition 14.8, the Proponent shall collect water quality data and data on natural rates and spatial patterns of sediment deposition for at least one full annual cycle prior to the construction of the Marine Facilities listed in Condition 14.3.	Sections 13.2 and 13.3.3, Table 13-3
EPBC Reference: 2003/1294 and 2008/4178	3.2.1	A description of the EPBC listed species and their habitat likely to be impacted by the components of the action which are the subject of the Marine Baseline Report.	Appendix 1

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
EPBC Reference: 2003/1294 and 2008/4178	3.2.2	An assessment of the risk to these species from the components of the action the subject of that plan, relevant to the Marine Baseline Report.	Appendix 1
EPBC Reference: 2003/1294 and 2008/4178	11.2	The Report must cover the following ecological elements:	
		I. Hard and soft corals	Section 6.0
		II. Macroalgae	Section 8.0
		III. Non-coral benthic macro-invertebrates	Section 7.0
		IV. Seagrass	Section 9.0
		V. Mangroves	Section 10.0
		VI. Surficial sediment characteristics	Section 12.0
		VII. Demersal fish	Section 11.0
		VIII. Water quality (including measures of turbidity and light attenuation).	Section 13.0
EPBC Reference: 2003/1294 and 2008/4178	11.5	In preparing the Report the person taking the action must consult with the Construction Dredging Environmental Expert Panel (CDEEP), the Western Australian Department of Environment and Conservation (DEC) (now DPaW), the Western Australian Department of Transport (DoT), the Western Australian Department of Fisheries (DoF) and the Department of Environment, Water, Heritage and the Arts (DEWHA) (now DotE).	Section 1.5.7
EPBC Reference: 2003/1294 and 2008/4178	11.6.I	The purpose of the Report is to: • describe and map the ecological elements referred to in Condition 11.2(I-VI) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.	Figure 2-3 depicts the extent of the Zones of High Impact, Zones of Moderate Impact and the Zones of Influence relevant to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground. Maps of the ecological elements within the Zones of High Impact and the Zones of Moderate Impact and representative areas within the Zone of Influence can be found in the figures listed below.
		I. Hard and soft corals;	Sections 6.4.1.1 and 6.4.1.3; Figure 6-1, Figure 6-2, Figure 6-5 to Figure 6-7 and Figure 6-8 to Figure 6-9
		II. Macroalgae;	Sections 8.4.4 and 8.4.6; Figure 8-2

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
		III. Non-coral benthic macro-invertebrates;	Sections 7.4.3 and 7.4.5; Figure 7-2
		IV. Seagrass;	Sections 9.4.4 and 9.4.6; Figure 9-2
		V. Mangroves;	There are no mangroves within the Zones of High and Moderate Impact. There are sparse mangrove stands within the Zone of Influence. Sections 10.4.1 and 10.4.2; Figure 10-1 and Figure 10-2
		VI. Surficial sediment characteristics	Sections 12.4.1 and 12.4.3; Figure 12-2
EPBC Reference: 2003/1294 and 2008/4178	11.6.II	The purpose of the Report is to: • describe and map the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact which are to be used to calculate the Area of Loss of Coral Assemblages according to the following formula: *a = h + (m x 30%)* where: a = the area (ha) of loss of Coral Assemblages. h = the area (ha) of Coral Assemblages within the Zones of High Impact. m = the area (ha) of Coral Assemblages within the Zones of Moderate Impact.	Coastal and Marine Baseline State and Environmental Impact Report Supplement: Area of Coral Assemblages (Chevron Australia 2010).
EPBC Reference: 2003/1294 and 2008/4178	11.6.III	The purpose of the Report is to: • describe and map the benthic ecological elements referred to in Condition 11.2(I-VI) which are at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in state waters and Offshore Domestic Gas Pipeline.	Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
EPBC Reference: 2003/1294 and 2008/4178	11.6.IV	The purpose of the Report is to: • describe and map the benthic ecological elements referred to in Condition 11.2(I-VI) at Reference Sites which are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground, Offshore Feed Gas Pipeline System in state waters and Offshore Domestic Gas Pipeline.	Figure 2-3 depicts the extent of the Zones of High Impact, Zones of Moderate Impact and the Zones of Influence relevant to the MOF, LNG Jetty and the Dredge Spoil Disposal Ground. Maps of the ecological elements at Reference Sites which

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
			are not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty or Dredge Spoil Disposal Ground can be found in the figures listed below. Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
		I. Hard and soft corals	Section 6.4.1.4; Figure 6-10 to Figure 6-14
		II. Macroalgae	Section 8.4.7; Figure 8-1 and Figure 8-2
		III. Non-coral benthic macro-invertebrates	Section 7.4.6; Figure 7-1 and Figure 7-2
		IV. Seagrass	Section 9.4.7; Figure 9-1 and Figure 9-2
		V. Mangroves	Sections 10.4.1 and 10.4.2; Figure 10-1 and Figure 10-2
		VI. Surficial sediment characteristics	Section 12.4.3; Figure 12-2
EPBC Reference: 2003/1294 and 2008/4178	11.6.V	The purpose of the Report is to: • describe the ecological elements referred to in Condition 11.2(VII and VIII) within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground.	
		VII. Demersal fish	Section 11.4.3 and 11.4.5

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
		VIII. Water quality (including measures of turbidity and light attenuation)	Sections 13.3.1.1, 13.4.2.1, 13.4.2.3, 13.4.3.1 and 13.4.3.2. The site at Lone Reef was established to measure turbidity, light attenuation and sediment deposition associated with the Dredge Spoil Disposal Ground.
EPBC Reference: 2003/1294 and 2008/4178	11.6.VI	The purpose of the Report is to: • describe the ecological elements referred to in Condition 11.2(VII and VIII) which are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in state waters and the Offshore Domestic Gas Pipeline.	Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time.
EPBC Reference: 2003/1294 and 2008/4178	11.6.VII	The purpose of the Report is to: • describe the ecological elements referred to in Condition 11.2 (VII and VIII) of Reference Sites which are not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground, Offshore Feed Gas Pipeline System in state waters and Offshore Domestic Gas Pipeline. VII. Demersal Fish VIII. Water quality (including measures of turbidity and light attenuation)	Approval for the Offshore Feed Gas Pipeline System was received on 19 August 2010. Approval in respect to the Domestic Gas Pipeline will be sought at a future time. Section 11.4.6 Sections 13.4.2.4 and 13.4.3.3
EPBC Reference: 2003/1294 and 2008/4178	11.7	The geographic extent of the Report must be: I. the Marine Facilities listed in Condition 11.3 II. Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence including those that contain significant benthic communities including coral assemblages III. the Marine Disturbance Footprint associated with the facilities listed in Condition 11.3 in State Waters IV. Reference Sites outside the Zone of Influence.	Section 2.0 provides detail of the geographic extent of the Report required by this Condition, including relevant figures.

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
EPBC Reference: 2003/1294 and 2008/4178	11.8.I	The Report must: • contain spatially accurate (i.e. rectified and geographically referenced) maps showing the locations and spatial extent of the marine coastal facilities listed in Condition 11.3.	Figure 2-1
EPBC Reference: 2003/1294 and 2008/4178	11.8.II	The Report must: • present the results of the surveys described in Condition 11.1.	Sections 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0 and 13.0
EPBC Reference: 2003/1294 and 2008/4178	11.8.III	The Report must record the: • existing dominant and subdominant hard and soft coral species/taxa • dominant species of macroalgae • dominant species of non-coral benthic macro-invertebrates • dominant species of seagrass • dominant species of mangroves • demersal fish assemblages that characterise these communities.	 Section 6.4.2 Section 8.4.2 Section 7.4.1 Section 9.4.2 Section 10.4 Section 11.4
EPBC Reference: 2003/1294 and 2008/4178	11.8.IV.a	The Report must record the: • population structure of coral communities as colony size-class frequency distributions of dominant hard coral taxa.	Section 6.4.3
EPBC Reference: 2003/1294 and 2008/4178	11.8.IV.b	The Report must record the: • population statistics of survival and growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities.	Sections 6.4.4 and 6.4.5
EPBC Reference: 2003/1294 and 2008/4178	11.8.IV.c	The Report must record the: • recruitment of hard coral taxa within these communities.	Section 6.4.6
EPBC Reference: 2003/1294 and 2008/4178	11.8.V	The Report must: • contain descriptions and spatially accurate (i.e. rectified and geographically referenced) maps in accordance with the purposes set out in Condition 11.6.	See maps in Sections 6.0, 7.0, 8.0, 9.0, 10.0, 11.0 and 12.0 (refer Condition 11.6 in this Table)
EPBC Reference: 2003/1294 and 2008/4178	11.8.VI	The Report must: • present data in an appropriate Geographic Information System (GIS) format.	Existing figures represent GIS data that is up to date and complete for the MOF, LNG Jetty and Dredge Spoil Disposal Ground. All relevant GIS data were provided in digital format with Revision 2 of this Marine Baseline Report.

Ministerial Document	Condition No.	Requirement	Section Reference in this Report
EPBC Reference: 2003/1294 and 2008/4178	11.8.VII	The Report must establish and report on: • background water quality (including measures of turbidity and light attenuation) • the natural rates and spatial patterns of sediment deposition • the physical characteristics of the deposited sediment and characteristics of surficial sediments where dredging and dredge spoil disposal may affect the environment and at Reference Sites where the environment will not be affected.	Section 13.4.2 Section 13.4.2 Affected or at Risk: Sections 12.4.1, 12.4.2, 13.4.2.1, 13.4.2.2 and 13.4.2.3 Not affected or at risk: Sections 12.4.3 and 13.4.2.4
EPBC Reference: 2003/1294 and 2008/4178	11.9	To meet the requirements of Condition 11.8, the person taking the action must collect water quality data and data on natural rates and spatial patterns of sediment deposition for at least one full annual cycle prior to the construction of the Marine Facilities listed in Condition 11.3.	Sections 13.2 and 13.3.3, Table 13-3

Any matter specified in this Report is relevant to the Gorgon Gas Development or Jansz Feed Gas Pipeline only if that matter relates to the specific activities or facilities associated with that particular development.

The sections in this Report noted in the above table to meet the conditions of EPBC Reference: 2003/1294 and 2008/4178 shall be read and interpreted as only requiring implementation under EPBC Reference: 2003/1294 and 2008/4178 for managing the impacts of the Gorgon Gas Development on, or protecting the EPBC Act matters listed in Appendix 1. The implementation of matters required only to meet the requirements of Statement No. 800 (and Statement No. 769) are not the subject of the EPBC Reference: 2003/1294 and 2008/4178.

1.5.5 Hierarchy of Documentation

This Marine Baseline Report will be implemented for the Gorgon Gas Development and the Jansz Feed Gas Pipeline via the Chevron Australasia Business Unit (ABU) Operational Excellence Management System (OEMS). The OEMS is the standardised approach that applies across the ABU in order to continuously improve the management of safety, health, environment, reliability and efficiency to achieve world-class performance. Implementation of the OEMS enables the Chevron ABU to integrate its Operational Excellence (OE) objectives, processes, procedures, values, and behaviours into the daily operations of Chevron Australia personnel and contractors working under Chevron Australia's supervision. The OEMS is designed to be consistent with and, in some respects, go beyond ISO 14001-2004 (Environmental Management Systems – Requirements with Guidance for Use) (Standards Australia/Standards New Zealand 2004).

Figure 1-3 and Figure 1-4 provide an overview of the overall hierarchy of environmental management documentation within which this Report exists. Data collected during the Marine Baseline Program documented in this Report have been or will be used in the development and/or implementation of the following plans:

- Marine Facilities Construction Environmental Management Plan (Chevron Australia 2012)
- Dredging and Spoil Disposal Management and Monitoring Plan (Chevron Australia 2011a)
- Horizontal Directional Drilling Management and Monitoring Plan (Chevron Australia 2011b)

- Offshore Feed Gas Pipeline Installation Management Plan (Chevron Australia 2012a)
- Marine Environmental Quality Management Plan (not yet developed, but required under Condition 23A of Statement No. 800)
- Post-development Coastal and Marine State and Environmental Impact Report (not yet developed, but required under Condition 24 of Statement No. 800).

The links between these documents and the relevant conditions of Statement No. 800 are shown in Figure 1-5.

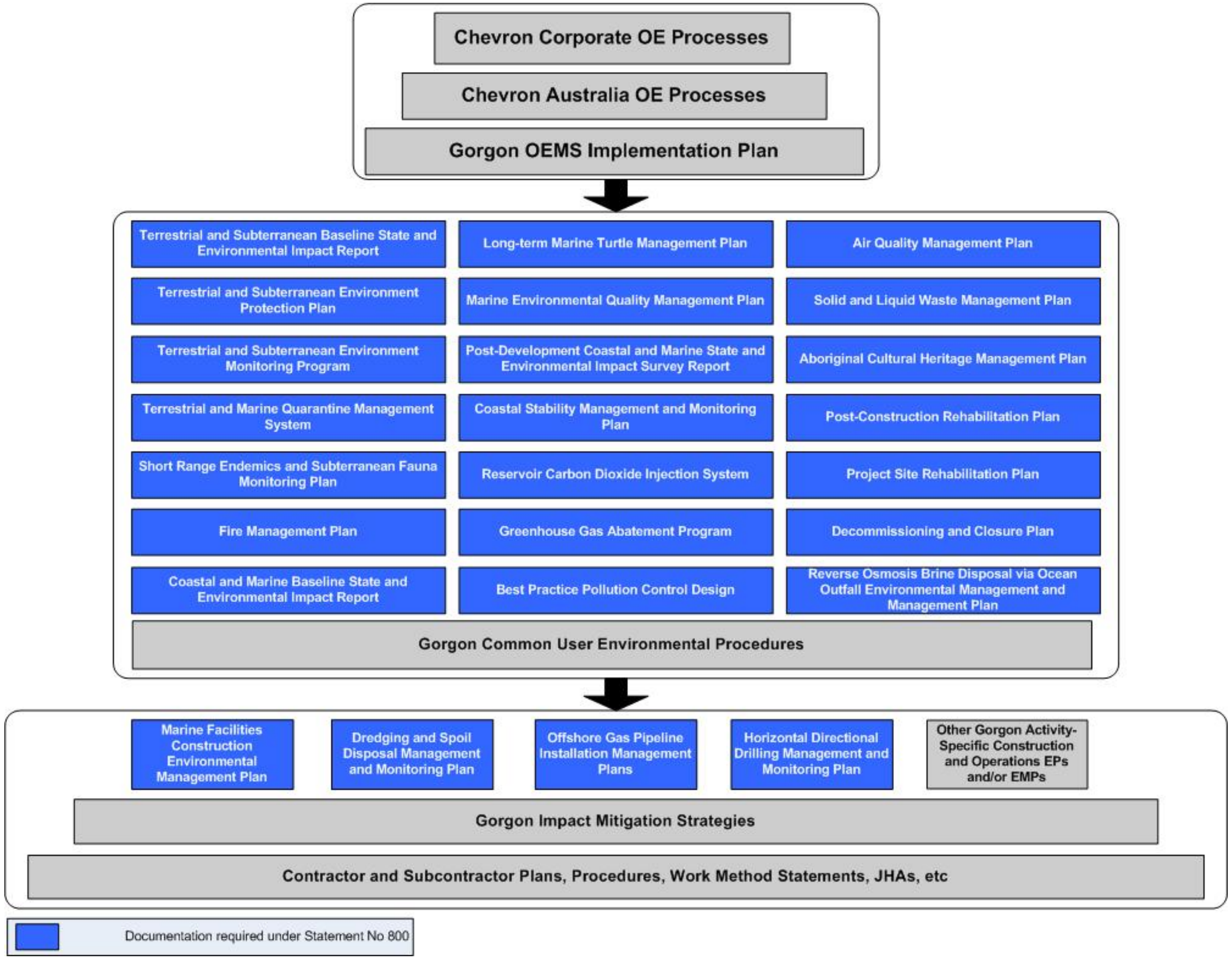


Figure 1-3 Hierarchy of Gorgon Gas Development Environmental Documentation

Note: The above figure refers to all Plans required for Statement No. 800. The Plans are only relevant to EPBC Reference: 2003/1294 and 2008/4178, if required for those Conditions of those approvals.

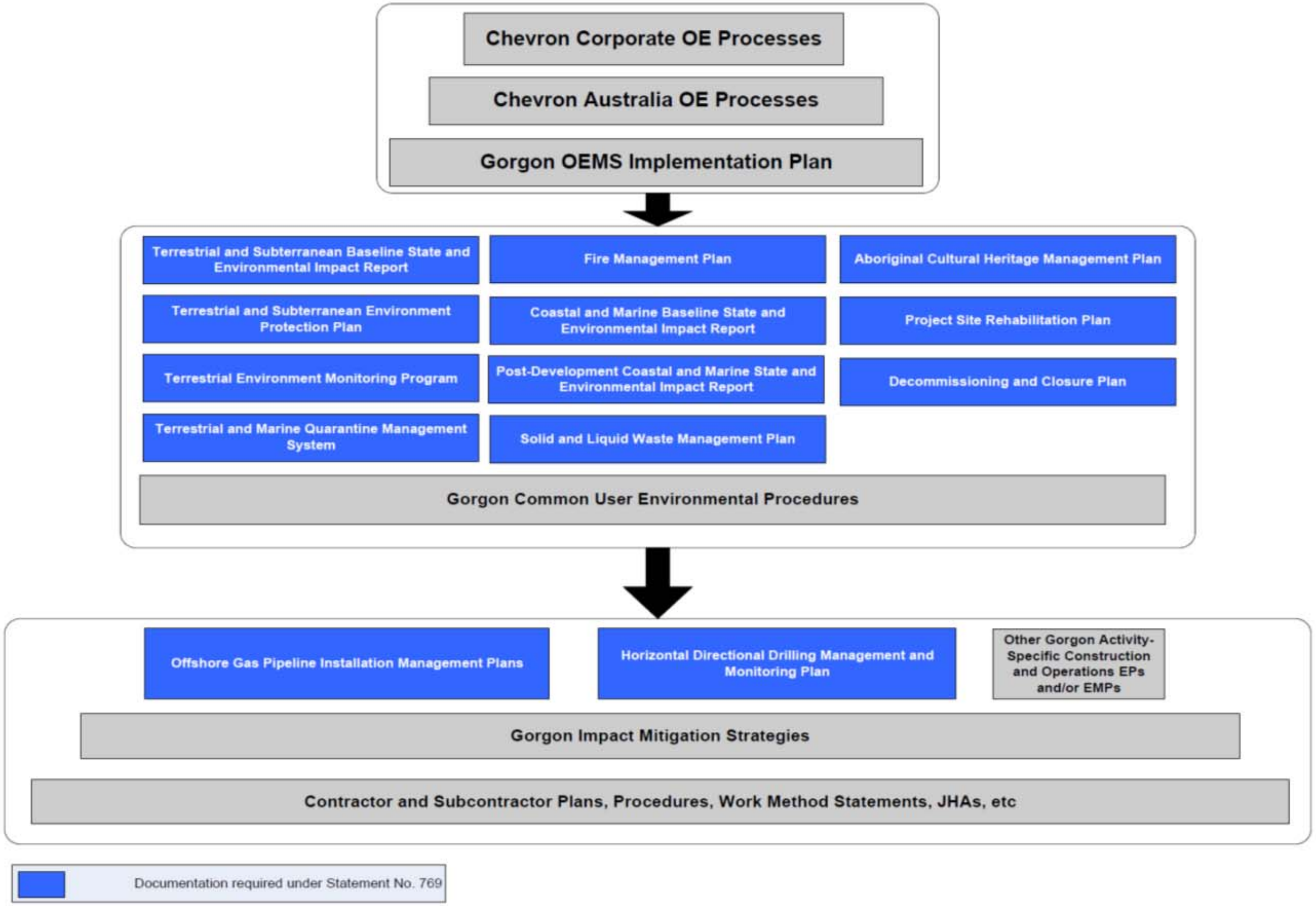


Figure 1-4 Hierarchy of Jansz Feed Gas Pipeline Environmental Documentation

Note: The above figure refers to all Plans required for Statement No. 769. They are only relevant to EPBC Reference: 2005/2184 if required for the Conditions of that approval.

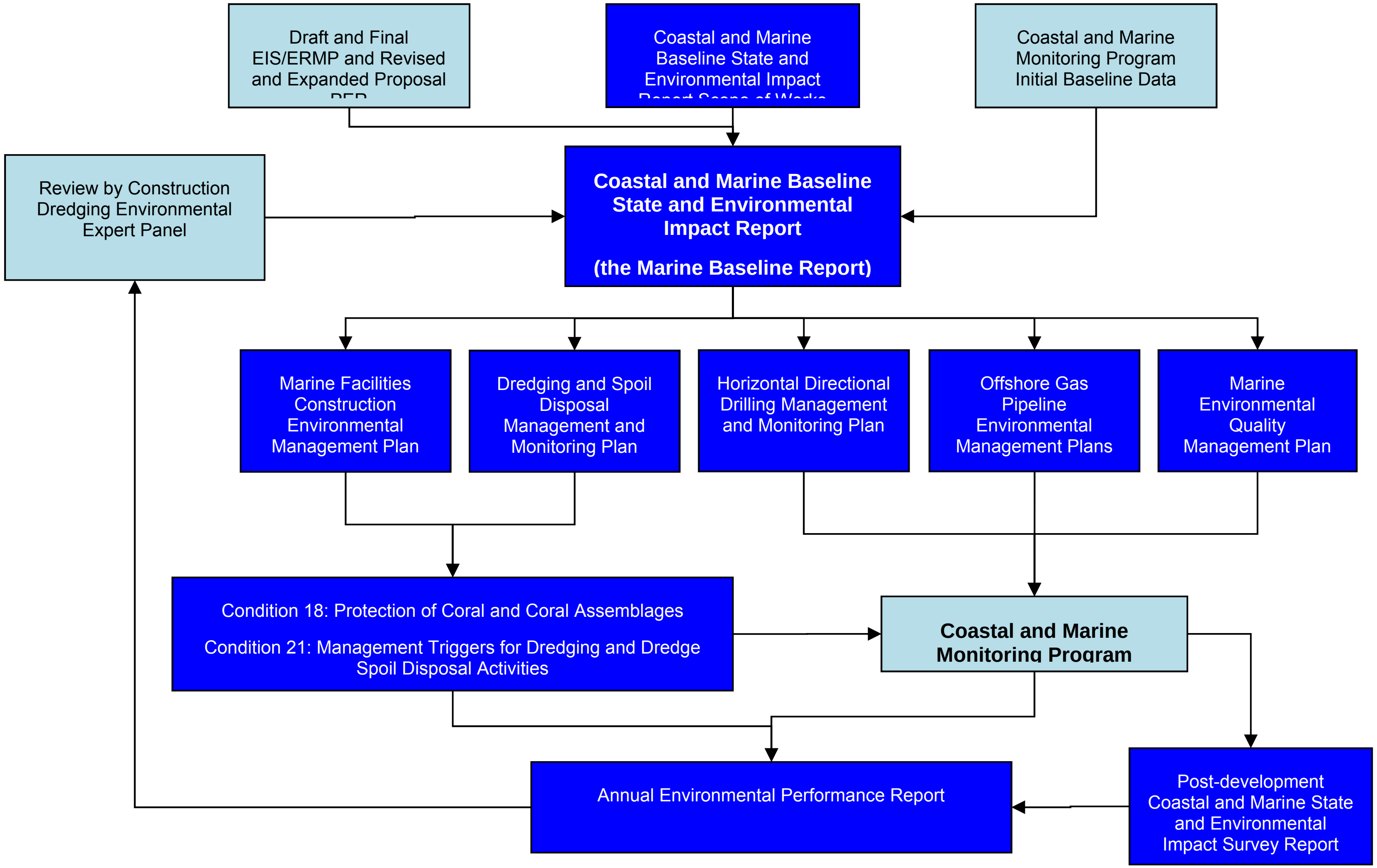


Figure 1-5 Context of the Marine Baseline Report

1.5.6 Relevant Standards and Guidelines

The following standards and guidelines have been taken into account in the development of this Marine Baseline Report:

- EPA Guidance Statement No. 1 – Protection of Tropical Arid Zone Mangroves along the Pilbara Coastline (EPA 2001)
- EPA Guidance Statement No. 29 – Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment (EPA 2004) and EPA Environmental Assessment Guideline No. 3 – Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment (EPA 2009)
- EPA Guidance Statement No. 51 – Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia (EPA 2004a).

1.5.7 Stakeholder Consultation

Consultation with stakeholders has been undertaken by Chevron Australia on a regular basis throughout the development of environmental impact assessment management documentation for the Gorgon Gas Development and Jansz Feed Gas Pipeline. This has included engagement with the community, government departments, industry operators and contractors to Chevron Australia via planning workshops, risk assessments, meetings, teleconferences, and the PER and EIS/ERMP formal approval processes.

Under Condition 14.5 of Statement No. 800, the CDEEP, DPaW (previously DEC), DoT, DoF and Dote (previously the DEWHA) shall be consulted in the preparation of this Marine Baseline Report. Under Condition 11.5 of EPBC Reference: 2003/1294 and 2008/4178, the CDEEP, DPaW (previously DEC), DoT, DoF and DotEpreviously the DEWHA) must be consulted in the preparation of this Marine Baseline Report.

This document has been prepared with input from:

- Associate Professor Eric Paling, Murdoch University, Independent Reviewer: Associate Professor Eric Paling reviewed draft revisions of the Marine Baseline Report and his comments have been incorporated or otherwise resolved.
- The Construction Dredging Environmental Expert Panel (CDEEP): The CDEEP has reviewed and been provided with verbal briefings on this Marine Baseline Report and their comments have been incorporated or otherwise resolved.
- The former Western Australian Department of Environment and Conservation (DEC) (now DPaW): Workshops and meetings were held involving the DEC and Chevron Australia personnel to discuss the scope and content of this Report during its development. The DEC reviewed draft revisions of this Report along with the feedback of the independent reviewer and the CDEEP. The DEC's comments have been incorporated or otherwise resolved.
- The Western Australian Department of Fisheries (DoF): Workshops and meetings were held involving the DoF and Chevron Australia personnel to discuss the scope and content of this Report during its development. The DoF reviewed draft revisions of this Report along with the feedback of the independent reviewer and the CDEEP. The DoF's comments have been incorporated or otherwise resolved.
- The Western Australian Department of Transport (DoT): Workshops and meetings were held involving the DoT and Chevron Australia personnel to discuss the scope and content of this Report during its development. The DoT reviewed draft revisions of this Report along with the feedback of the independent reviewer and the CDEEP. The DoT's comments have been incorporated or otherwise resolved.
- The Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA; now DotE): The DEWHA reviewed draft revisions of this Report along with the feedback of the

independent reviewer and the CDEEP and their comments have been incorporated or otherwise resolved.

The process for development, review and approval of this Marine Baseline Report is shown in Figure 1-6.

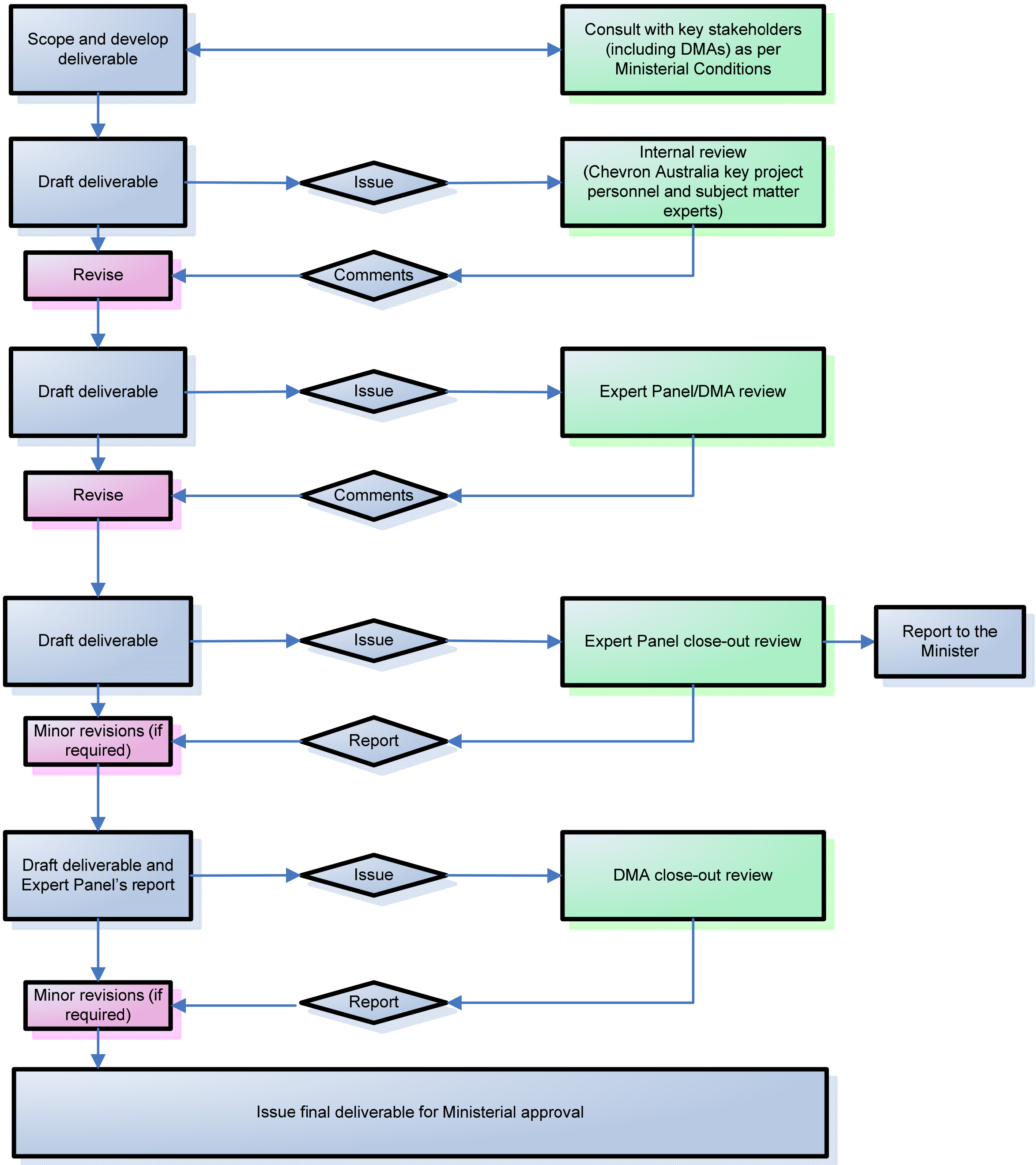


Figure 1-6 Deliverable Development, Review and Approval Flowchart

1.5.8 Public Availability

This Marine Baseline Report will be made public as and when determined by the Minister, under Condition 35 of Statement No. 800, Condition 20 of Statement No. 769, and Condition 22 of EPBC Reference: 2003/1294 and 2008/4178.

2.0 Relevant Facilities and Areas

2.1 Marine Facilities and Activities

2.1.1 Overview

This Marine Baseline Report covers activities associated with construction and operation of the Marine Facilities, which are shown in Figure 2-1. The Marine Facilities for the Gorgon Gas Development are defined in Condition 14.3 of Statement No. 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine upgrade of the existing WAPET Landing.

Condition 14.3 of Statement No. 800 relates only to components of the Marine Facilities within State waters (i.e. specifically the Offshore Feed Gas Pipeline System).

The Marine Facilities for the Jansz Feed Gas Pipeline are defined in Condition 12.3 of Statement No. 769 as the:

- Offshore Feed Gas Pipeline System and marine component of the shore crossing.

The Marine Facilities for the Gorgon Gas Development are defined in Condition 11.3 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System in State waters
- Offshore Domestic Gas Pipeline.

As described in Section 1.5.2, the Marine Baseline Report for the Offshore Feed Gas Pipeline System and the marine component of the shore crossing (Condition 12.3, Statement No. 769), the Offshore Feed Gas Pipeline System (Condition 14.3.iv, Statement No. 800) and the Offshore Feed Gas Pipeline System in State waters (Condition 11.3.IV, EPBC Reference: 2003/1294 and 2008/4178) was initially approved on 19 August 2010 by the former DEC and on 27 August 2010 by the former DEWHA under delegation from the Minister, respectively; and subsequent revisions have been approved by the former DEC and the former DEWHA under delegation from the Minister, respectively. No further approval is sought in relation to these Marine Facilities, therefore material related to these Marine Facilities in this Report is provided for information only. In accordance with Condition 14.4 of Statement No. 800 and Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178, the Marine Baseline Report for the (Offshore) Domestic Gas Pipeline will be submitted for approval at a later date, before construction commences for that specific element.

The sections that follow summarise the main activities associated with construction of the Marine Facilities that are covered in this version of the Marine Baseline Report (i.e. the MOF, the LNG Jetty, the Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing). Additional details on these Marine Facilities can be found in the Draft EIS/ERMP (Chevron Australia 2005), the section 45C approval (EPA 2008), the PER (Chevron Australia 2008) and the Marine Facilities Construction Environmental Management Plan (Chevron Australia 2012). An overview of the construction schedule for these Marine Facilities is provided in Section 2.2.

Please note that the description of the Marine Facilities provided in subsequent sections is as currently proposed and may be subject to change as design work progresses. More specific details are contained in various Gorgon Gas Development approval and assessment documents, which are issued from time to time.

2.1.2 Materials Offloading Facility (MOF)

The MOF will generally be constructed in the following stages:

- construction of a Pioneer MOF Platform
- construction of the Pioneer MOF Causeway
- extension of the Pioneer MOF to complete the Full MOF.

The Full MOF (Causeway and offloading facilities) extends to a total length of approximately 2120 m.

A Pioneer MOF will initially be required to allow offloading of equipment and materials for the construction of the onshore LNG Plant and associated facilities on Barrow Island, via large barges and Roll-on/Roll-off vessels. Construction activities for the Pioneer MOF Platform include:

- construction of a Pioneer MOF perimeter berm using a combination of suitably-sized dredged material and rock transported from the mainland
- placement of dredged material within the perimeter berm to form the Pioneer MOF Platform. Primary and secondary armour rock sourced from the mainland will then be installed on the external face of the Pioneer MOF platform
- construction of a Pioneer MOF causeway starting from Town Point and progressing outwards to the Pioneer MOF Platform.

A causeway will be constructed to connect the Pioneer MOF Platform to Town Point on the east coast of Barrow Island, using material excavated from Barrow Island. A roadway will be constructed on the surface of the Pioneer MOF Causeway.

Once the Pioneer MOF has been constructed, work will commence on extending the MOF platform seaward and raising part of the existing MOF Causeway, including:

- extending the MOF platform seaward, forming a breakwater to protect tug pen moorings, heavy lift facility and other berths. This work will be completed using material excavated from Barrow Island and dredge material. Suitable dredge material may also be used in place of core fill material from Barrow Island, dependent on the quality and quantity of the core fill material
- constructing a Heavy Lift Facility and tug pens
- raising the existing MOF Causeway by adding an upper causeway section to accommodate an all-weather access road to the LNG Jetty, a pipe rack containing LNG, condensate and other pipelines for export and operations of the jetty offloading facilities. This work will be completed using material excavated from Barrow Island installing armour comprising precast concrete units. Suitable dredged material may be used in place of core fill material from Barrow Island
- installing armour comprising rock and precast concrete units.

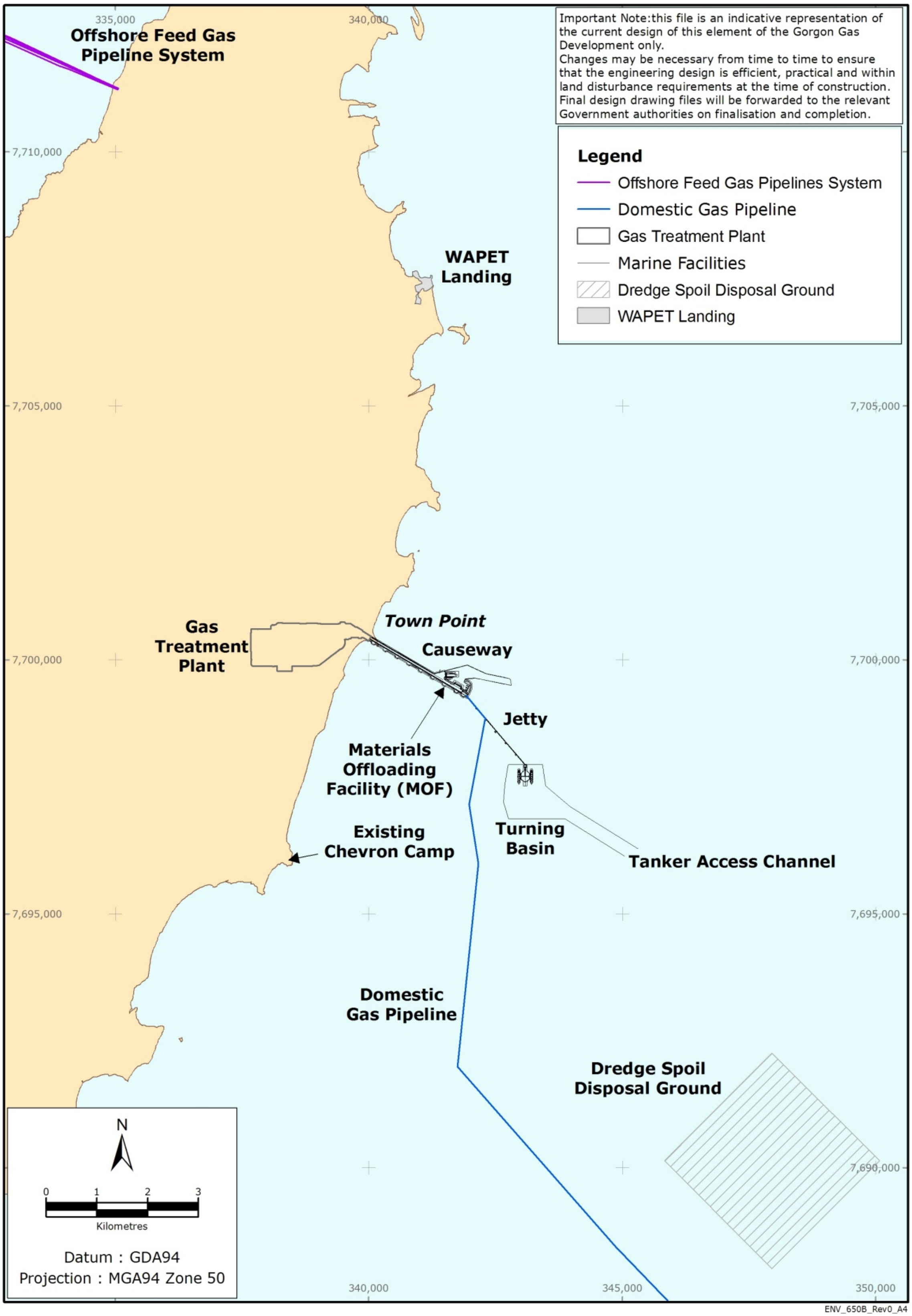


Figure 2-1 Gorgon Gas Development Marine Facilities

2.1.3 LNG Jetty

A two kilometre long jetty will extend from the MOF platform head (Figure 2-1). The LNG Jetty is required to support a series of LNG, condensate, vapour return, firewater and utilities pipelines, connecting the onshore LNG Plant to the loading platforms. The design of the LNG Jetty is based on an open structure with gravity base concrete caissons founded on the seabed. The caissons typically have four piles each that are embedded in the caisson and which support the jetty superstructure.

Construction of the LNG Jetty will include:

- seabed preparation, levelling and placement of the foundation gravel layer for the caissons
- offsite prefabrication of jetty elements
- transport to site, floating into position and immersion to the rock foundation of gravity base concrete jetty supports
- lifting on to the jetty supports of the offsite prefabricated superstructures, including roadways, pipe racks, buildings and pre-assembled units for fire water pumps, emergency shutdown and product loading.

A range of construction vessels will be required for these marine activities. In addition, a number of ancillary vessels will be required, including supply vessels, refuelling vessels, crew change vessels, survey vessels and marine construction support vessels. The scope of work includes installation of navigation aids, channel markers and lead lights. Moorings will also be installed as required for the marine construction activities.

2.1.4 Dredge Spoil Disposal Ground

Dredging is required to provide access channels and berths associated with the MOF and an access channel, berths and a turning basin associated with the LNG Jetty. Dredge spoil generated during dredging activities will be used for reclamation and development of the MOF, in addition to disposal at the designated Dredge Spoil Disposal Ground (Figure 2-1).

The total anticipated dredged volume for the LNG Jetty and MOF is approximately 7.6 million m^3. This comprises approximately 1.1 million m^3 of dredged material from the MOF berths and access channel areas, and approximately 6.5 million m^3 of dredged material from the LNG Jetty berthing pockets, access channel and turning basin.

Approximately 200 000 m^3 of dredge material is required for construction of the Pioneer MOF platform. An additional 500 000 m^3 of dredged material may be reclaimed in the construction of the MOF. The remaining dredged material will require depositing at the Dredge Spoil Disposal Ground located approximately 6 km south-east of the LNG Jetty dredge area. Commonwealth Sea Dumping Permit (SD2004/0030) provides approval to dispose of up to 8.5 million m^3 of dredged material. The dredged material will be transported by hopper barge or Trailing Suction Hopper Dredge from the dredge location to the Dredge Spoil Disposal Ground (Figure 2-1).

The dredging program will generally be undertaken in two stages. The first stage includes:

- dredging the MOF area
- constructing the MOF using a combination of reclaimed material and material from the Gas Treatment Plant site excavation
- dredging the berth pockets in the LNG Jetty turning basin to allow construction of the LNG Jetty berths to commence.

The second stage of the dredging program involves completing the remainder of dredging associated with the LNG Jetty access channel and turning basin.

2.1.5 Marine Upgrade of the Existing WAPET Landing

The WAPET Landing will handle all vessel and freight movement for import to and export from Barrow Island prior to the completion of the MOF. It will also continue to be used as an alternative material offloading facility during peak periods. WAPET Landing has been in use since the 1960s and the area along the Land-backed Wharf and the boat ramps has been disturbed by regular marine supply vessel activity. While the facilities will be expanded slightly, the area of disturbance will be similar to the area of historical disturbance.

The existing material offloading facilities at WAPET to be upgraded are the:

- Landing Craft Tank (LCT) Landing and Barge Berth
- Land-backed Wharf
- Groyne Barge Berth.

2.2 Activity Overview

A summary of the marine construction activities and their timing for the MOF, LNG Jetty and the marine upgrade of WAPET Landing is provided in Table 2-1. More detailed information is also provided in the 'Overview' section of the Marine Facilities Construction Environmental Management Plan (Chevron Australia 2012).

Table 2-1 Marine Construction Activities and Timing

Activity	Timing
Marine drilling	24 hours
Marine blasting	Day shift
Marine impact piling	24 hours
Construction of MOF Causeway (within approximately 500 m from Town Point)	Day shift (occasional night shift may be required to shore up protection to partially constructed works in the event of approaching cyclones or other potentially destructive marine conditions)
Construction of MOF and Causeway (greater than approximately 500 m from Town Point)	24 hours
LNG Jetty Construction	24 hours
WAPET Landing Upgrade construction (marine component)	Day shift

An indicative schedule for the dredging and dredge spoil disposal program is provided in Table 2-2. More detailed information is provided in the 'Works Overview' section of the Dredging and Spoil Disposal Management and Monitoring Plan (Chevron Australia 2011a).

Table 2-2 Indicative Dredging and Dredge Spoil Disposal Program

Commencement Date	Early Finish Date	Late Finish Date
May 2010	Oct 2011	June 2012

Note: *This shows the indicative dredge schedule at the time of writing and may change during execution of the dredge program or as a result of delays.*

2.3 Marine Areas

2.3.1 Geographical Extent

The geographical extent for reports that cover the Gorgon Gas Development Marine Facilities is defined in Condition 14.7 of Statement No. 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine upgrade of the existing WAPET Landing
- Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence, including those that contain significant benthic communities including coral assemblages
- the Marine Disturbance Footprint associated with the Marine Facilities in State waters
- Reference Sites outside the Zone of Influence.

The geographical extent for reports that cover the Jansz Marine Facilities is defined in Condition 12.7 of Statement No. 769 as the:

- Jansz Offshore Feed Gas Pipeline System and marine component of the shore crossing
- Benthic habitats within 200 m of the Jansz Offshore Feed Gas Pipeline System and marine component of the shore crossing in State waters.

The geographical extent for reports that cover the Gorgon Gas Development Marine Facilities is defined in Condition 11.7 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System in State waters
- Offshore Domestic Gas Pipeline
- Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence, including those that contain significant benthic communities including coral assemblages
- the Marine Disturbance Footprint associated with the Marine Facilities in State waters
- Reference Sites outside the Zone of Influence.

2.3.2 Marine Disturbance Footprint

The Gorgon Gas Development Marine Disturbance Footprint is defined in Statement No. 800 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the marine facilities listed in Condition 14.3 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and spoil disposal).*

The Jansz Feed Gas Pipeline Marine Disturbance Footprint is defined in Statement No. 769 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the Marine Facilities listed in Condition 12.3.*

The Gorgon Gas Development Marine Disturbance Footprint is defined in EPBC Reference: 2003/1294 and 2008/4178 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the marine facilities listed in Condition 11.3 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and spoil disposal).*

The Marine Disturbance Footprint includes the Marine Facilities Footprint (the areas of the seabed associated with the physical footprint of the Marine Facilities [the MOF, the LNG Jetty, the marine upgrade of the existing WAPET Landing]) and the extent of the surrounding seabed in which the planned construction and operations activities could be expected to disturb the seabed. The stressors include vessel propeller wash, vessel anchoring and mooring facilities, pipe laying, rock and fill material placement, and pile and navigational aid installation. The boundary of the Marine Disturbance Footprint for the east coast Marine Facilities is presented in Figure 2-2 and encompasses an area extending 300 m from the toe of the facilities. The Marine Disturbance Footprint relevant to the West Coast Marine Facilities is described in the Marine Baseline Report for the Offshore Feed Gas Pipeline System and marine component of the shore crossing (Chevron Australia 2010a).

The Marine Disturbance Footprint does not include areas that will be disturbed by the generation of turbidity and sedimentation from dredging and dredge spoil disposal. However, it does include areas of the seabed that will be directly affected (i.e. removed) by these activities and the impacts of plumes from non-dredging construction activities (e.g. turbidity plumes generated during Horizontal Directional Drilling [HDD] for the shore crossing on Barrow Island and shore crossing activities on the mainland for the Domestic Gas Pipeline). Disturbance to the seabed within the Marine Disturbance Footprint may include: changes in seabed profile and seabed type; sedimentation and smothering of benthic assemblages; and wastewater discharge. The Marine Disturbance Footprint also includes areas that will not be disturbed; e.g. areas between anchor positions and between the anchor positions and the vessel where no anchors or chains contact the seabed, in recognition that each specific activity could not be mapped individually. The levels of disturbance within the Marine Disturbance Footprint will thus vary from negligible to Material Environmental Harm to Serious Environmental Harm (see Section 2.3.4 for further details on these levels).

In addition, the Marine Disturbance Footprint to the east of Barrow Island includes indicative areas where operational and cyclone moorings will be installed (see hatched areas on Figure 2-2); note that the location and extent of the indicative area for operational moorings has been updated since Revision 0 of the Marine Baseline Report. The number and specific location of each mooring is subject to further investigation, including site surveys to identify those areas with suitable sediment cover for holding capacity for moorings. Note that it is not proposed to disturb the entire area of the Marine Disturbance Footprint identified for the installation of moorings in Figure 2-2. Each mooring will create localised disturbance at the points of contact with the seabed and when anchors or clump weights are used instead of moorings, some additional disturbance will be created by anchor chain sweep of the seabed. It is however anticipated that approximately 50-60% of the indicative Marine Disturbance Footprint will be directly disturbed by the moorings (see the Marine Facilities Construction Environmental Management Plan [Chevron Australia 2012] for details on the management of mooring installation).

Figure 2-2 includes an indicative anchoring area on the west coast of Barrow Island that would be targeted for use by those Gorgon construction and support vessels requiring anchoring for safety/emergency reasons on the west coast. The west coast indicative anchoring area is located south of the HDD exit alignment and north of the Barrow Island Marine Park. It is envisaged, based on current construction activities, that the west coast indicative anchoring area will be used at any one time by up to approximately ten vessels of up to approximately 30 m in length. In addition, the indicative mooring/anchorage areas also include four anchoring areas to the east of Barrow Island that will be available for operational vessels requiring anchoring (e.g. Tankers). These anchoring areas are located approximately 30km east of BWI, to the south of the shipping fairway and have a diameter of approximately 1.5nm each. These anchorage areas, located in a featureless area of soft sediments with sparse sessile taxa were chosen because of their low ecological value. The type of anchors deployed, the length of anchor chains on the sea floor, and similar vessel management matters will be at the discretion of the Vessel Master. Where practicable, the Vessel Master will manage vessel anchoring to minimise impacts to the marine environment.

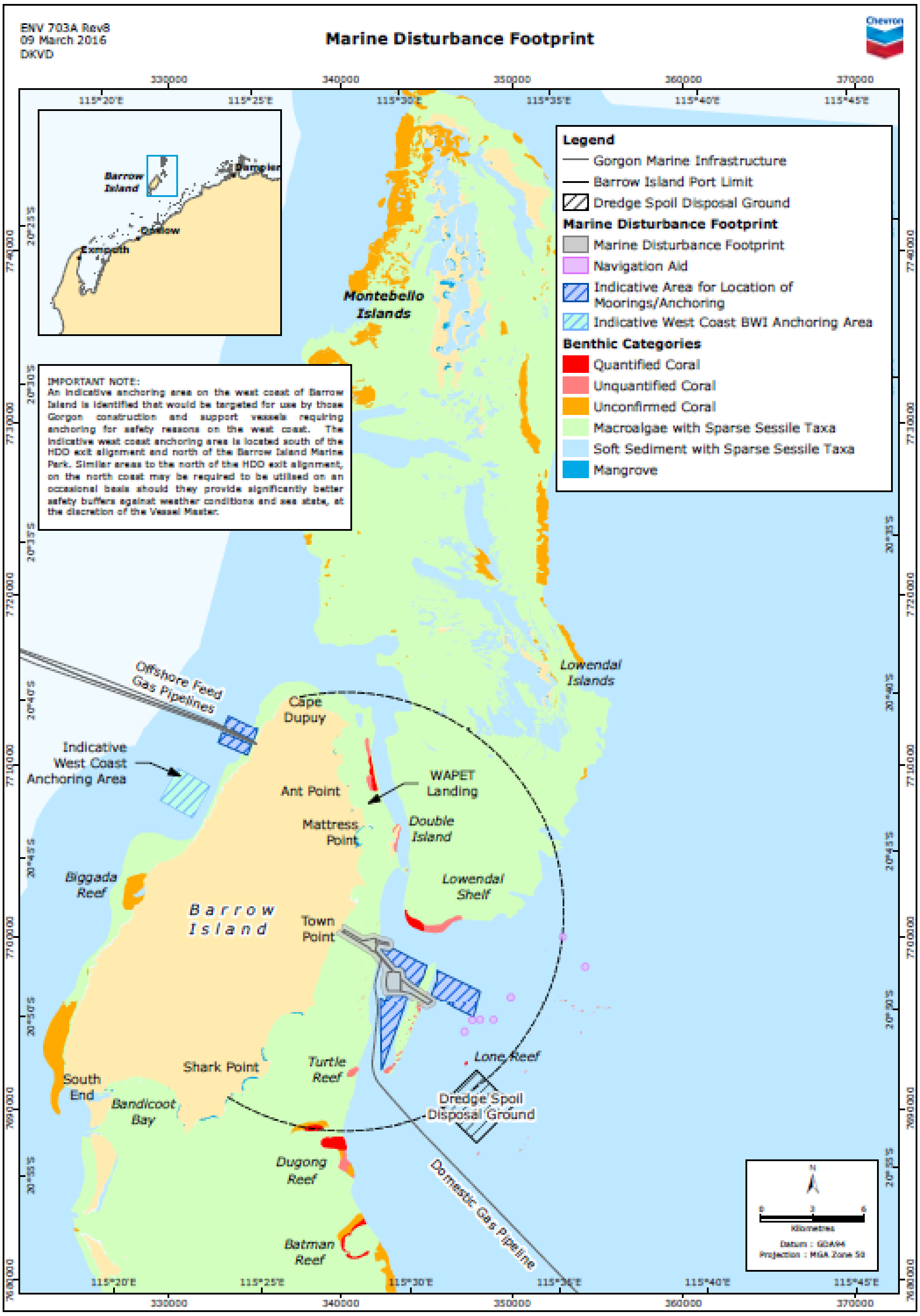


Figure 2-2 Marine Disturbance Footprint

2.3.3 Dredge Management Areas and Plume Modelling

Hydrodynamic modelling was undertaken for the EIS/ERMP (Chevron Australia 2005, 2006) and refined in the Revised and Expanded Proposal PER (Chevron Australia 2008). Models were developed to predict how fine sediments released during dredging and dredge spoil disposal would disperse through the marine environment under the influence of oceanographic processes.

The modelling was carried out in two steps. First, a three-dimensional (3D) ocean circulation model was developed for the Barrow Island and Montebello Islands region. This model predicted ocean circulation patterns over a 16-month period, using the Global Environmental Modelling Systems (GEMS) coastal-ocean model GCOM3D and the SWAN wave model. The dredging program was then simulated over 450 days using a particle-tracking model (DREDGE3D) which simulates the transport and fate of suspended particles based on a detailed dredge log outlining the movements of the dredges (GEMS 2008). Model inputs for the dredging program included particle-size distribution data, duration of the dredging program, type of dredges to be used, detailed dredge logs, volume of sediment to be excavated, and the dredge spoil disposal methods (GEMS 2008).

In undertaking the risk assessment for the EIS/ERMP (Chevron Australia 2005, 2006) and the Revised and Expanded Proposal PER (Chevron Australia 2008), three zones were established to reflect the different levels of predicted impact to corals (Figure 2-3). These zones were established based on sediment load and exposure time above background levels, and took into account published values for acute (short-term), medium-term and chronic (long-term) responses to both sedimentation and elevated total suspended solids (TSS) (Chevron Australia 2005, 2006). These zones are shown in Figure 2-3 and are defined as:

- ‘Zones of High Impact’ – the areas where long-term impacts on corals are predicted from direct disturbance during dredging or construction of infrastructure on the seabed and burial during dredge spoil disposal; or complete but short-term losses are predicted to be caused by increased sedimentation and/or deterioration in water quality.
- ‘Zones of Moderate Impact’ – the areas where short-term moderate impacts (e.g. some partial mortality of corals) is predicted to result indirectly from dredging and/or dredge spoil disposal, due to an increase in sedimentation rates and/or a deterioration in water quality. Moderate impacts are likely to include some partial mortalities among fast-growing, more sensitive coral species (e.g. *Acropora* species.), but less, if any, mortality of longer-living, generally more resilient species (e.g. *Porites* species, *Turbinaria* species).
- ‘Zones of Influence’ – these areas are predicted to be influenced indirectly by dredging and dredge spoil disposal activities such that marginal increases in sedimentation and turbidity will occur, but at levels that will have no measurable impact on corals.

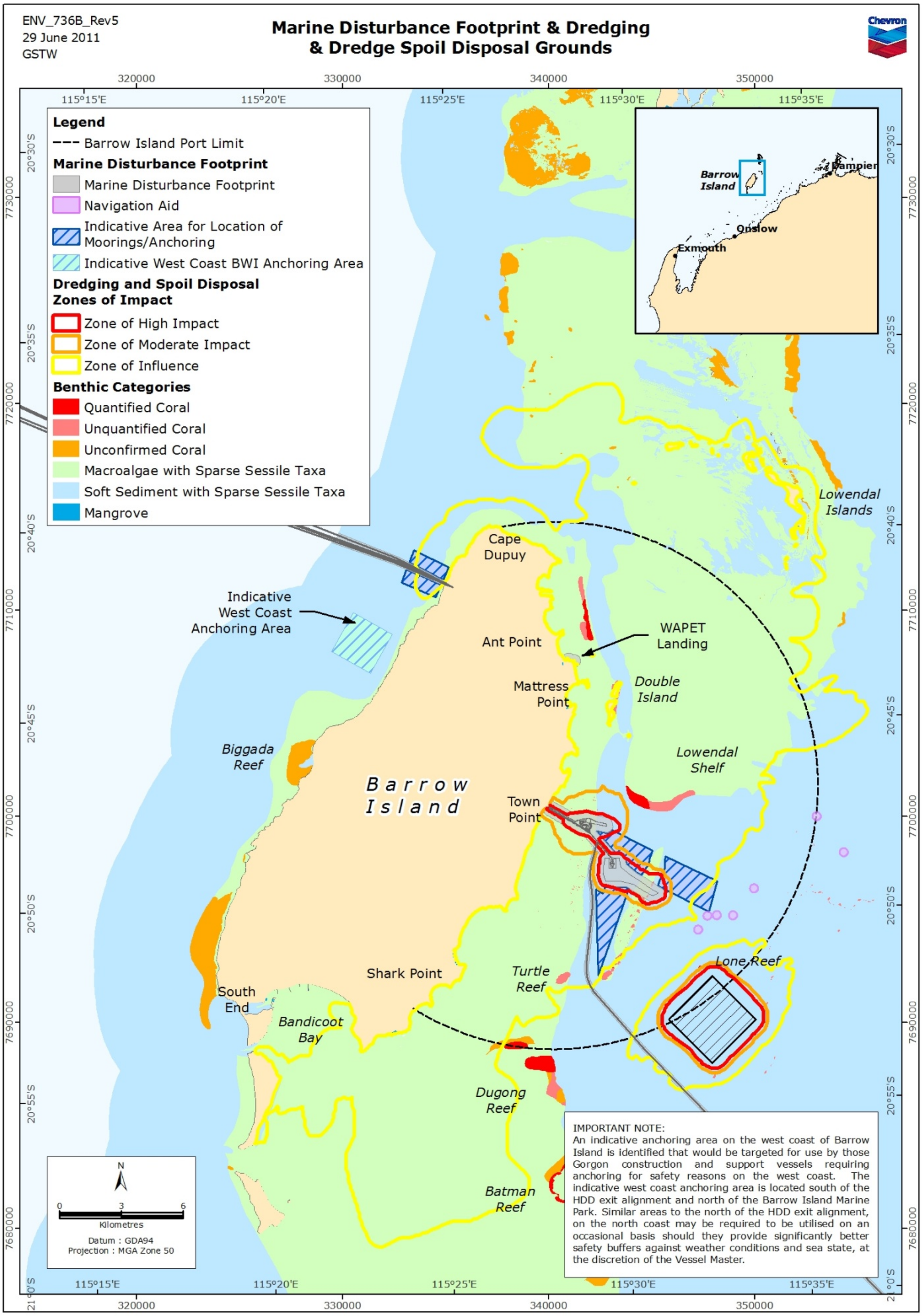


Figure 2-3 Marine Disturbance Footprint and Dredging and Dredge Spoil Disposal Zones of High Impact, Zones of Moderate Impact and Zones of Influence

2.3.4 Areas at Risk of Material or Serious Environmental Harm

Material Environmental Harm is defined as:

> "Environmental harm that is neither trivial nor negligible".

Serious Environmental Harm is defined as:

> "Environmental harm that:
>
> a. is irreversible, of a high impact or on a wide scale; or
>
> b. is significant or in an area of high conservation value or special significance and is neither trivial nor negligible''.

Material or Serious Environmental Harm due to the construction or operation of the Marine Facilities, may occur within the Marine Disturbance Footprint (described in Section 2.3.2) and the Dredge Management Areas (described in Section 2.3.3). The level of harm predicted at a particular location within the Marine Disturbance Footprint and the Dredge Management Areas depends on the types of stressors, the sensitivity of the benthic assemblages at any location, the likelihood of complete or partial recovery from the disturbance, and the management or mitigation measures taken to reduce impacts. Examples of seabed disturbances that are predicted to cause Material Environmental Harm include: localised or short-term (less than five years) impacts such as anchor scouring in a macroalgal bed, seagrass bed, or benthic macro-invertebrate assemblage; and disturbance or resuspension of unconsolidated sediments by vessel propeller wash and pipeline discharges. Examples of seabed disturbances that are predicted to cause Serious Environmental Harm include: permanent loss or removal of substrates (e.g. through the direct placement of the Marine Facilities on the seabed); shading by infrastructure; and physical removal of the substrate through dredging or blasting. These factors were used to determine the areas within the Marine Disturbance Footprint and the Dredge Management Areas that are at risk of Material or Serious Environmental Harm (refer to Figure 2-4 and Figure 2-5).

The areas at risk of Material or Serious Environmental Harm are predicted to be different for hard and soft corals (Figure 2-4) compared to other ecological elements (Figure 2-5). For all ecological elements, Serious Environmental Harm will occur within the Marine Facilities Footprint as the existing substrate and associated ecological elements will be either removed or buried beneath the Marine Facilities. Recovery to the original state will not be possible, although there will be some colonisation of the new hard substrates created by the Marine Facilities.

Within the Dredge Management Areas (beyond the Marine Facilities Footprint) there are likely to be temporary or sub-lethal impacts that may remove or reduce the existing ecological elements. Nevertheless, the substrate will retain its ecological function as benthic habitat and the ecological elements other than coral are predicted to recover in the short-term (less than five years). This is considered to represent Material Environmental Harm. Seagrass and macroalgae are well adapted to cycles of disturbance and recovery, thus macroalgal-dominated limestone reefs, subtidal limestone reef platforms with macroalgae, and reef platform/sand with scattered seagrass are predicted to be temporarily affected (Chevron Australia 2006). Recovery of these assemblages is anticipated within two to five years following cessation of the disturbance when water quality and sedimentation return to their natural range. This is not the case for all hard coral taxa. Some hard corals are predicted to recover or recolonise in the short term following cessation of the disturbance (e.g. corals such as the *Turbinaria* and *Acropora*), while others will take a long time to re-establish and regrow. Consequently, Material and Serious Environmental Harm to corals cannot easily be distinguished within the Zones of High Impact and the Zones of Moderate Impact.

Reference Sites, those areas not at risk of Material or Serious Environmental Harm due to the construction or operation of the Marine Facilities, will include selected areas outside the Marine Disturbance Footprint and the Zones of High and Moderate Impact, including areas within the Zones of Influence suitable for comparison with impacted areas. For ecological elements other than hard and soft corals, sites within the Zones of Influence are considered to be Reference Sites because turbidity and sedimentation are not expected to cause Material or Serious Environmental

Harm at these sites. Note that these sites will not be included as Reference Sites in any analysis if there is evidence that they have been impacted by the generation of turbidity and sediment deposition from construction of or dredging and dredge spoil disposal required for the MOF, LNG Jetty, Dredge Spoil Disposal Ground or the marine upgrade of the existing WAPET Landing.

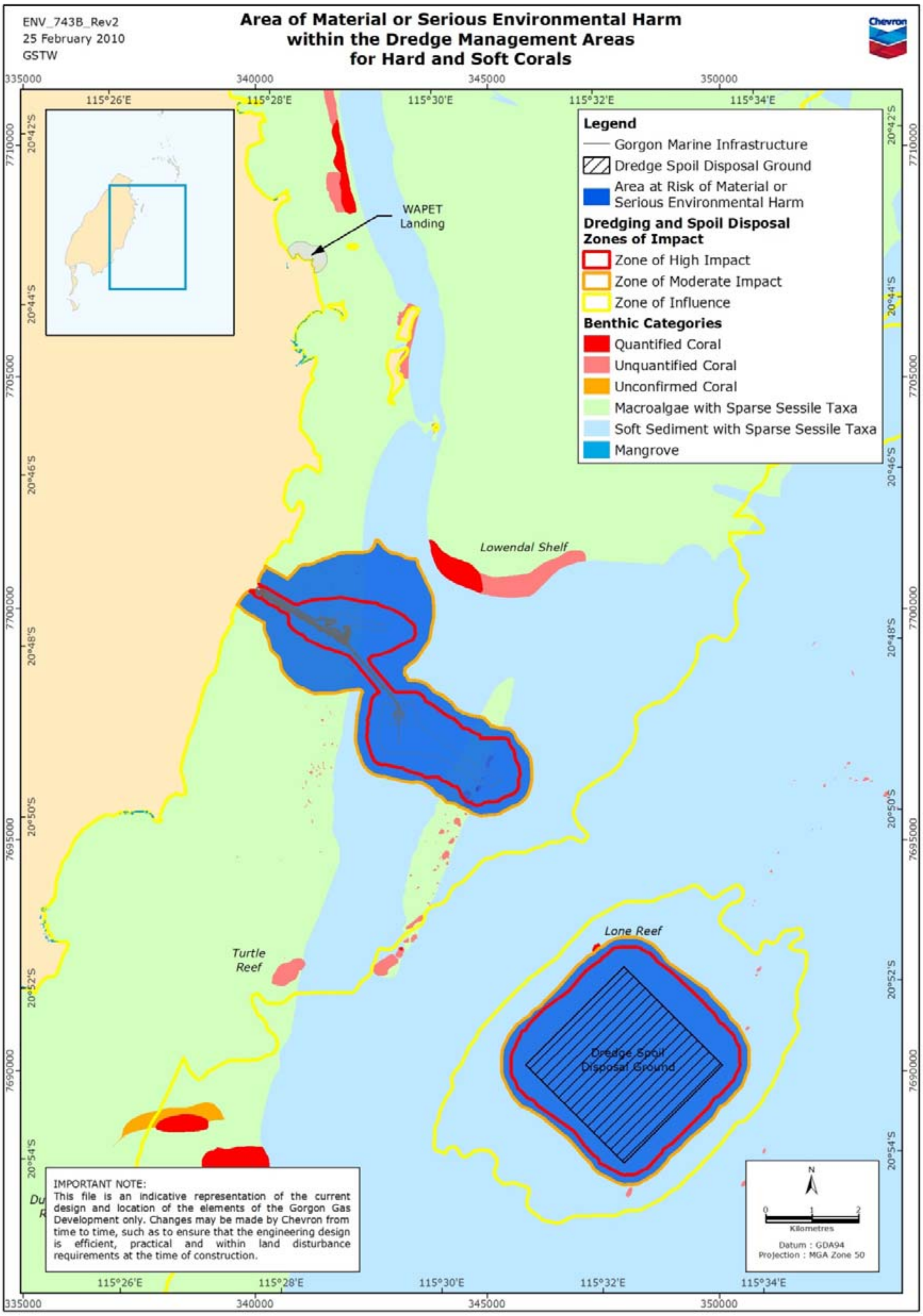


Figure 2-4 Area of Material or Serious Environmental Harm within the Dredge Management Areas for Hard and Soft Corals

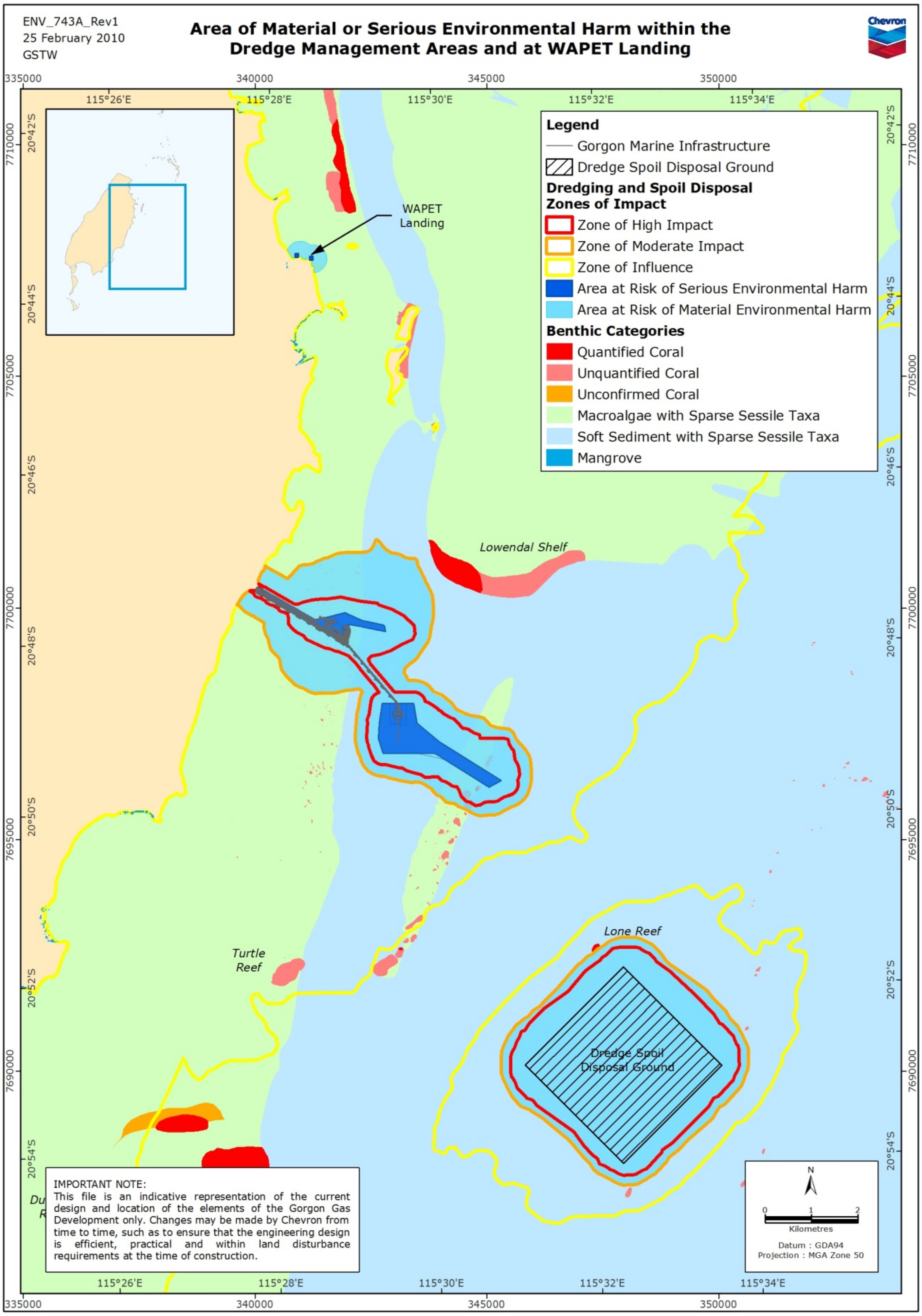


Figure 2-5 Area of Material or Serious Environmental Harm within the Dredge Management Areas and at WAPET Landing for Non-Coral Benthic Macro-invertebrates, Macroalgae, Seagrass and Demersal Fish

3.0 Marine Environment

3.1 Regional Overview

Barrow Island lies approximately 1200 km north of Perth and approximately 130 km west of Dampier and the Burrup Peninsula, within the Pilbara Offshore (PIO) Marine Bioregion (Integrated Marine and Coastal Regionalisation of Australia [IMCRA] Technical Group 1998) (Figure 3-1). Barrow Island is the largest of the group of islands, which include the Montebello and Lowendal Islands to the north-east. The Pilbara Offshore (PIO) Marine Bioregion covers an area of 41 491 km^2 west of the 10 m depth contour between North West Cape and Cape Keraudren (Department of Environment and Conservation [DEC] 2007). The Pilbara Offshore (PIO) Marine Bioregion is characterised by a series of limestone islands on a wide continental shelf (IMCRA Technical Group 1998). The area around the Montebello/Barrow Islands contains reef ecosystems with Indonesian and Pacific affinities and is considered unique to this bioregion due to the complexity of substrate types, oceanographic conditions and habitat diversity (Brewer *et al.* 2007; DEC 2007). The area is considered to be relatively undisturbed due to low human use and successful management of industrial activities including oil and gas developments in the area (DEC 2007).

3.2 Montebello/Barrow Island Marine Conservation Reserves

Barrow Island is a Class A nature reserve for the purposes of 'Conservation of Flora and Fauna' under the Western Australian *Conservation and Land Management Act 1984* (CALM Act) (WA). The *Barrow Island Act 2003* (WA) allows for the implementation of the Gorgon Gas Development and makes provision for areas on Barrow Island to be used for gas processing. Chevron Australia and predecessor companies have operated an oil field on Barrow Island since the 1960s and this operation is expected to continue for another 15 to 20 years.

The State waters around Barrow Island are part of the Montebello/Barrow Islands Marine Conservation Reserves, with the exception of the Barrow Island Port Area on the east coast of the island that contains most of the Gorgon Gas Development Marine Facilities (Figure 3-1). The Port of Varanus, located to the north-east of Barrow Island, is also excluded. These Conservation Reserves are reserved under the CALM Act and management of the reserves is guided by the Management Plan for the Montebello/Barrow Islands Marine Conservation Reserves 2007–2017 (DEC 2007). There are two categories of marine reserve in the waters around Barrow Island. The largest of these is the Barrow Island Marine Management Area, which includes one conservation area, the Bandicoot Bay Conservation Area located in the south of the island. The Bandicoot Bay Conservation Area includes the largest intertidal sand/mudflat community in the reserves and was established for the protection of benthic fauna and seabirds (DEC 2007). The remainder of the Barrow Island Marine Management Area is not zoned. The Barrow Island Marine Park lies on the west coast of Barrow Island, also within the Barrow Island Marine Management Area. The zoning of the Barrow Island Marine Park comprises one sanctuary zone, representing the entire marine park. The Western Barrow Island Sanctuary Zone includes Biggada Reef, an example of significant fringing reef that occurs in the reserves; and Turtle Bay, a significant aggregation/breeding area for Green Turtles (*Chelonia mydas*) and occasionally Hawksbill (*Eretmochelys imbricata*) and Flatback (*Natator depressus*) Turtles (DEC 2007).

The waters around Barrow Island support a diverse assemblage of tropical and subtropical marine fauna. Two major currents, the Leeuwin Current and the Indonesian Throughflow, have a strong influence on species distribution, recruitment and biological productivity in these waters (Kellogg Joint Venture Gorgon [KJVG] 2008). The Leeuwin Current and the Indonesian Throughflow create a biological connection between marine flora and fauna of the Montebello/Barrow Islands region and the more tropical environments to the north and east (DEC 2007). As a consequence, most marine species in this region are widely distributed.

3.3 Meteorology

The mean ambient wind speed around Barrow Island during the summer period (October–March) is 6.6 m/s and the maximum summer wind speed is 16.2 m/s (KJVG 2008). The dominant directions during summer are from the south-west and west. During winter (April–September), winds approach from the east, south and south-west and have a mean speed of 5.8 m/s and a maximum speed of 19.4 m/s. Easterly gales occur between May and August, with speeds in the range of 12.5 to 20 m/s (KJVG 2008).

Barrow Island is in a region of high tropical cyclone frequency, with an average of four cyclones passing within 400 nm of the Island each year (MetOcean Engineers 2006). Tropical cyclones usually form in the Timor and Arafura seas between November and April. They initially travel generally in a south-westerly direction, but as they travel further south their tracks become more variable (MetOcean Engineers 2006).

3.4 Oceanography

3.4.1 Bathymetry

Barrow Island lies on the shallow (generally <5 m deep) limestone shelf that underlies the whole of the Montebello/Barrow Islands group. There is a broad intertidal platform adjacent to the Island, which grades slowly to the subtidal limestone shelf (Chevron Australia 2005). Water depths between the islands and the mainland generally do not exceed 20 m, whereas water depths on the west coast of the Island increase rapidly from the shore down to the 20 m isobath. The water depths near the proposed Marine Facilities on the east coast of the Island range from approximately five to 12 m, with some shallower areas on the limestone pavement near Town Point (Chevron Australia 2005).

3.4.2 Seabed Topography and Sediment Characteristics

On the east coast of Barrow Island, the intertidal limestone reef flats and shallow pavement reef are variably covered by sand, gravel and coral, with scattered pinnacles. Bare sands overlay limestone pavements in many parts of the area, with exposed pavement and more rubble in areas where water currents are stronger (Chevron Australia 2005). The thickness of the unconsolidated sediments overlying the limestone pavements ranges between 0.5 m and 3 m (Chevron Australia 2005). The thicker sediment layers are in deeper water off the nearshore platform (Chevron Australia 2005).

The seabed of the west coast of Barrow Island consists of unconsolidated sediments overlying cemented calcarenite. Sediment layer thickness ranges from >5 m offshore in the vicinity of the Gorgon gas field to a very thin and patchy veneer over large areas of seabed between the Gorgon gas field and Barrow Island (Chevron Australia 2005).

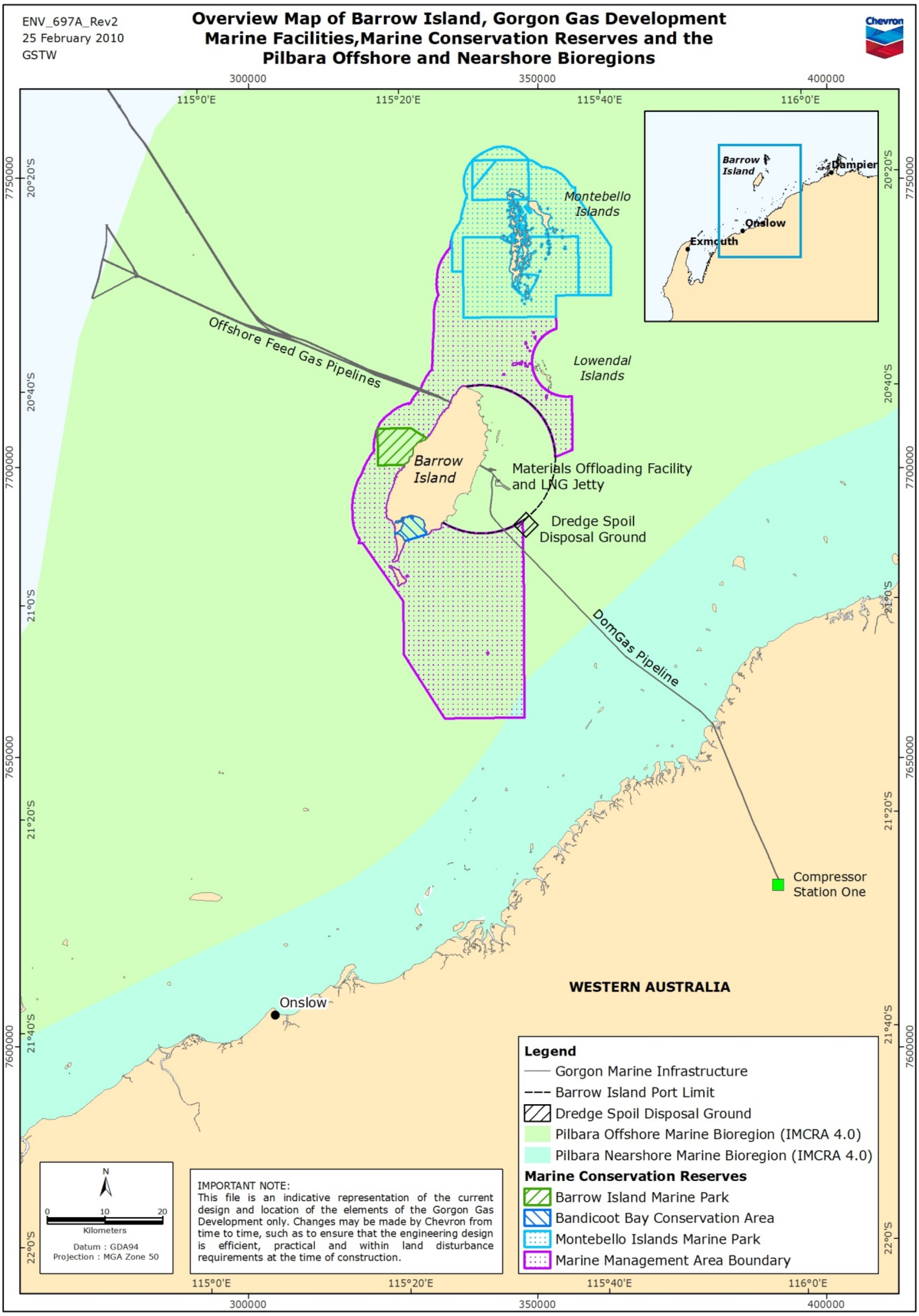


Figure 3-1 Overview Map of Barrow Island, Gorgon Gas Development Marine Facilities, Marine Conservation Reserves and the Pilbara Offshore and Nearshore Bioregions

3.4.3 Tides

Astronomic tides in the Barrow Island region are semidiurnal, comprising two high tides and two low tides per day. The tidal range varies significantly around Barrow Island with a maximum spring tide range on the east coast of just over 4 m; whilst on the west coast the tidal range is less than 2.5 m (Australian Geological Survey Organisation 1998; Australian Hydrographic Service 2008; KJVG 2008). The significant tidal ranges and shallow bathymetry result in large areas of exposed seabed on the east coast of Barrow Island at low tide (West Australian Petroleum 1989).

As a result of the shallow bathymetry, the flood tide cannot fully propagate to the coast across the Barrow Shoals to the south-east, or through the channels between Barrow Island and the Montebello Islands. A large water flux is forced northward along the western side of Barrow Island and then flows to the coast around the northern end of the Montebello Islands. This produces a southward-flowing flood tide on the east coast of the Montebello and Barrow Islands. There is a region near the south-eastern end of Barrow Island where this flow meets the flow coming across the Barrow Shoals and these flow towards the coast.

The ebb tide behaves approximately in the reverse manner to the flood tide, with the majority of the water flux flowing up the eastern side of the Lowendal Shelf and around the northern end of the Montebello Islands. This tidal flow is the major flushing mechanism for waters from the eastern side of Barrow Island into the open sea.

3.4.4 Currents

Currents are driven principally by semidiurnal tidal forcing. The direction of tidal currents is a flood flow towards the south-west and an ebb flow towards the north-east (ChevronTexaco Australia 2003).

The instantaneous current patterns on the eastern side of Barrow Island are strongly dominated by the tide and its spring–neap cycle. However, longer term transports over the inner- and mid-shelf are mainly controlled by wind-driven flow, which follows the seasonal switch from summer monsoon winds to south-easterly trades in winter. The currents on the eastern side of Barrow Island can be quite strong due to the tidal mechanisms.

On the western side of Barrow Island, the balance of the driving forces for ocean currents can be more complex. The tidal currents are weaker, particularly in the deeper waters, but satellite imagery indicates that phenomena associated with large-scale ocean circulations in the Indian Ocean, such as eddies and other geostrophic flows, can impinge on the region.

3.4.5 Waves

The south-western to north-western sides of Barrow Island are exposed to the open ocean and a relatively vigorous wave climate, bringing long period Southern Ocean swells (also referred to as the Indian Ocean swell) and shorter period local wind waves, particularly during the summer months, when winds prevail from the south-west. At times, the Southern Ocean swell can refract around the northern and southern ends of the Island but the shallow bathymetry prevents significant propagation (ChevronTexaco Australia 2003).

Town Point, on the eastern side of Barrow Island, is largely sheltered from ocean swells by Barrow Island, the Lowendal Shelf and the shallow bathymetry between Barrow Island and the mainland (ChevronTexaco Australia 2003; KJVG 2008). The ambient nearshore wave climate is dominated by locally generated sea states derived from easterly sea breezes between the mainland and Barrow Island, which mostly occur during winter. These cause a direct setup of waves against the east coast of Barrow Island and are the most effective in directing wave energy onto the nearshore zone.

Typically wave heights are within the range 0.2–0.5 m with peak periods of 2–4 s (RPS MetOcean 2008). The mean significant wave height at the MOF is 0.47 m, with a maximum wave height of 2.11 m (KJVG 2008). Maximum wave heights are mostly a result of tropical cyclones. However, the maximum wave heights at the MOF are limited by the shallow bathymetry (KJVG 2008).

4.0 General Approach to the Methods

4.1 Introduction

Coastal and marine baseline surveys for the Gorgon Gas Development have been conducted in Barrow Island waters since 2003. The Marine Baseline Program required under Condition 14 of Statement No. 800, Condition 12 of Statement No. 769 and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178, was initiated in November 2007 and will continue until the dredging and dredge spoil disposal activities and Marine Facilities construction activities commence.

The Marine Baseline Program has been designed to provide baseline data for the:

- Marine Facilities Construction Environmental Management Plan required under Condition 17 of Statement No. 800 and Condition 13 of EPBC Reference: 2003/1294 and 2008/4178 (Chevron Australia 2012)
- Protection of Coral and Coral Assemblages required under Condition 18 of Statement No. 800 (Chevron Australia 2010)
- Dredging and Spoil Disposal Management and Monitoring Plan required under Condition 20 of Statement No. 800 and Condition 14 of EPBC Reference: 2003/1294 and 2008/4178 (Chevron Australia 2011a)
- Initial Water Quality Criteria for Dredging and Spoil Disposal Activities required under Condition 21 of Statement No. 800 (Chevron Australia 2010b)
- Horizontal Directional Drilling Management and Monitoring Plan required under Condition 22 of Statement No. 800, Condition 13 of Statement No. 769 and Condition 15 of EPBC Reference: 2003/1294 and 2008/4178 (Chevron Australia 2011b)
- Offshore Feed Gas Pipeline Installation Management Plan required under Condition 23 of Statement No. 800, Condition 14 of Statement No. 769 and Condition 16 of EPBC Reference: 2003/1294 and 2008/4178 (Chevron Australia 2012a)
- Marine Environmental Quality Management Plan (required by Condition 23A of Statement No. 800)
- Post-development Coastal and Marine State and Environmental Impact Report (required by Condition 24 of Statement No. 800, Condition 15 of Statement No. 769 and Condition 17 of EPBC Reference: 2003/1294 and 2008/4178).

4.2 Sampling Sites

The Marine Baseline Program was designed to include sites within the Dredge Management Areas, as well as Reference Sites outside these areas that are not at risk of Material or Serious Environmental Harm (Section 2.3.4). Particular focus has been given to coral assemblages within the Zones of High Impact, the Zones of Moderate Impact and representative areas within the Zones of Influence, as well as at Reference Sites and sites in Regionally Significant Areas. The majority of the coral monitoring sites established during the Marine Baseline Program will be monitored during the dredging and dredge spoil disposal program which is detailed within the Dredging and Spoil Disposal Management and Monitoring Plan (Chevron Australia 2011a).

The location of the Marine Facilities and information from the existing broadscale benthic habitat map of the Montebello/Barrow Islands area (DEC 2007), aerial photographs, Laser Airborne Depth Sounder (LADS), Multi-Beam Sonar and Side-Scan Sonar data (described further in Section 5.0) were used to assist in the selection of survey sites for the other ecological elements (i.e. non-coral benthic macro-invertebrates, macroalgae, seagrass, mangroves and demersal fish). For each ecological element, where practicable, sampling sites were selected in the Zones of High Impact and the Zones of Moderate Impact, as well as at representative areas within the Zones of Influence and at Reference Sites not at risk of Material or Serious Harm.

For ecological elements other than hard and soft corals, sites within the Zones of Influence are considered to be Reference Sites because turbidity and sedimentation are not expected to cause Material or Serious Environmental Harm at these sites. Note that these sites will not be included as Reference Sites in any analysis if there is evidence that they have been impacted by the generation of turbidity and sediment deposition from construction of or dredging and dredge spoil disposal required for the MOF, LNG Jetty, Dredge Spoil Disposal Ground or the marine upgrade of the existing WAPET Landing.

4.3 Sampling Frequency and Temporal Scope

The sampling frequency and temporal scope for each ecological element sampled during the Marine Baseline Program are summarised in Table 4-1. Sampling frequency has been designed to account for predicted seasonal differences. For example, the seagrass and macroalgae surveys were conducted over summer and winter to capture seasonal differences, while water quality was measured continuously over a 12-month period to capture tidal, daily and seasonal variations. Other ecological elements without predicted seasonal influences, such as surficial sediments, were sampled on different occasions during the baseline period.

The broadscale camera tow surveys and spot dive surveys that commenced in 2003 for the Gorgon Gas Development EIS/ERMP (Chevron Australia 2005, 2006) were extended between November 2007 and February 2009 to address proposed changes to the Marine Facilities.

Table 4-1 Marine Baseline Program Sampling Frequency and Temporal Scope

Ecological Element	Survey Type/Method	Sampling Frequency	Temporal Scope
Hard and soft corals (Section 6.0)	Mapping	Once at each of 11 coral monitoring sites	Oct 2008–Mar 2009
	Rapid Visual Assessment (RVA)	Once at each of the 12 coral monitoring sites	Oct 2008–Jan 2009
	Coral size-class frequency transect surveys	Once at each of 10 coral monitoring sites	Oct 2008–Jan 2009
	Coral growth (photo-quadrats, tagged colonies)	Measured at approximately 6-monthly intervals at 12 coral monitoring sites	May 2008–data collection ongoing over 1 Baseline Year
	Coral survival (photo-quadrats, tagged colonies)	Measured at approximately 6-monthly intervals at 12 coral monitoring sites	May 2008–data collection ongoing over 1 Baseline Year
	Coral recruitment tiles	Every 8–12 weeks at 11 coral monitoring sites	Mar 2008–Jul 2009
Non-coral benthic macro-invertebrates (Section 7.0)	Video transects	Surveyed in spring/ summer and winter at 6 sites 20 sites 13 sites (2 new sites)	Nov 2008 Jan 2009 Jul 2009
Macroalgae (Section 8.0)	Photo-quadrats and biomass	Surveyed in spring/ summer and winter at 8 sites 11 sites 12 sites (2 new sites)	Nov 2008 Jan 2009 Jul 2009

Ecological Element	Survey Type/Method	Sampling Frequency	Temporal Scope
Seagrass (Section 9.0)	Photo-quadrats and biomass	Surveyed in spring/ summer and winter at 5 sites 14 sites 15 sites (2 new sites)	Nov 2008 Jan 2009 Jul 2009
Mangroves (Section 10.0)	Analysis of aerial photography Vegetation Surveys	Mapped for EIS/ERMP in 2005 Surveyed at 8 sites in spring	Barrow Island aerial photograph (2005) Nov 2009
Demersal fish (Section 11.0)	Baited remote underwater stereo-video (stereo-BRUVs) systems Seine nets, gill nets, throw and scoop nets in mangroves	38 sites 47 sites 3 sites	Oct 2008 Mar 2009 Dec 2009
Surficial sediments (Section 12.0)	Surface scrapes	185 sites	Oct 2008–April 2009 (and some samples collected in 2004 and 2007)
Water quality (Section 13.0)	Light-Turbidity-Deposition (LTD) loggers Sediment trap arrays	16 sites Deployed ~monthly at 5 water quality monitoring sites	Data continuously recorded for at least 12 months Dec 2007–ongoing during Marine Baseline Program Jun 2008–ongoing during Marine Baseline Program

4.4 Basis of Program Design

The Marine Baseline Program has been designed to provide a dataset against which to compare the data from post-development monitoring (as required under Condition 24 of Statement No. 800, Condition 15 of Statement No. 769 and Condition 17 of EPBC Reference: 2003/1294 and 2008/4178). The basis of the design has been to provide the potential for pre- and post-development data to be analysed using the Multiple Before-After, Control-Impact (MBACI) approach of Keough and Mapstone (1995). This approach involves statistical analyses that test for an interaction between predicted impact and (multiple) reference areas across periods of time before and after predicted impacts occur. It is expected that the main focus of monitoring will be for “press” type impacts, where the dredging and spoil disposal activities and Marine Facilities construction activities cause sustained changes in an ecological element (Figure 4-1). In some cases, however, transient changes such as “pulse” type impacts may also be tested for (Underwood 1992).

The design approach shown in Figure 4-1 will be used to detect whether changes (before–after dredging and spoil disposal activities and Marine Facilities construction activities) at one or more impact sites are greater than changes (before–after dredging and spoil disposal activities and construction activities) across multiple Reference Sites. Impact and Reference Sites will be sampled during the Marine Baseline Program and where possible at multiple times during the period prior to the commencement of dredging and spoil disposal activities and Marine Facilities construction activities. Sampling will then be repeated after the completion of the dredging and dredge spoil disposal activities and Marine Facilities construction activities.

Three reference sites and one impact site are illustrated in Figure 4-1, although for all ecological elements more sites than this will be monitored. Impact sites will be monitored in the Zones of High Impact and the Zones of Moderate Impact. More generally, the main hypothesis being tested for each measure of an ecological element will be that there is a change at impact site(s) between before-and-after the dredging and dredge spoil disposal activities and Marine Facilities construction activities that is greater than the changes occurring over the same time period at Reference Sites.

Impact monitoring sites have been located at varying distances away from the dredging and dredge spoil disposal activities and Marine Facilities construction activities. This will allow for specific statistical tests about impacts at different spatial scales away from the main areas of disturbance, such as those predicted by the dredge plume modelling (Section 2.3.3). This will be achieved by examining changes at impact sites in each of the Zones of High Impact, the Zones of Moderate Impact and the Zones of Influence, against natural changes at Reference Sites (outside these impact zones). The location of the Reference Sites is such that they should always remain independent of the dredging and dredge spoil disposal activities and Marine Facilities construction activities.

Multiple impact and Reference Sites have been sampled during the Marine Baseline Program for each ecological element and will be sampled again after the completion of the dredging and dredge spoil disposal activities and Marine Facilities construction activities. Wherever practicable, sampling has been repeated multiple times within the Marine Baseline Program; each sampling time (at least several weeks apart) will be treated as a replicate measure at a site within the 'before' period. Within three months following completion of the dredging and dredge spoil disposal activities, baseline surveys are to be repeated at the same time of year (where practicable) for at least an additional two years. The test for a "press" impact in the main Before-After/Control-Impact interaction in a MBACI design is equivalent to a two-sample *t*-test comparing the changes between before-and-after periods for the impact sites with the changes between before-and-after periods for the Reference Sites. Thus for each site, the average of sampling occasions before dredging and spoil disposal activities and Marine Facilities construction activities is calculated, as is the average of sampling occasions in the after period. The difference between these two averages is calculated for each site and the *t*-test undertaken on these differences (impact vs. reference). The replicate times nested within the before (and after) periods are not independent of other similar measurements within that level (i.e. they are all 'pseudo-replicates' within a period). However, the average of these nested measurements at a site over a period is treated as an independent estimate in the analysis.

For most ecological elements, where practicable, more Reference Sites have been sampled than impact sites, which is best practice in impact assessment monitoring programs (Downes *et al.* 2002; Quinn and Keough 2002). Sampling prior to the commencement of the dredging and dredge spoil disposal activities and Marine Facilities construction activities has occurred over a single (baseline) year, although sampling has often been repeated over different periods within the year. Therefore, the designs and Analysis of Variance (ANOVA)-based statistical analyses that will be used to detect impacts from the dredging and dredge spoil disposal activities and Marine Facilities construction activities are likely to be asymmetrical, with different numbers of sampling years (and times) within before–after periods and different numbers of sites within reference–impact areas. Time will be treated as a fixed factor because the sampling years are fixed (i.e. non-random) within the before-and-after impact periods. Because the precision of pre- and post-dredging and dredge spoil disposal activities and Marine Facilities construction activities estimates at each site will depend on the number of replicate times each site has been sampled within the before–after periods, the power of the monitoring program to detect impacts will also depend on how many times each site is sampled in each period.

Power analyses and determination of likely effect sizes are not presented in this Marine Baseline Report because these will depend on the:

- sampling achieved before the commencement of dredging and spoil disposal activities and Marine Facilities construction activities

- number of sites sampled post-development
- length of time (and the number of replicate sampling events conducted) post-development.

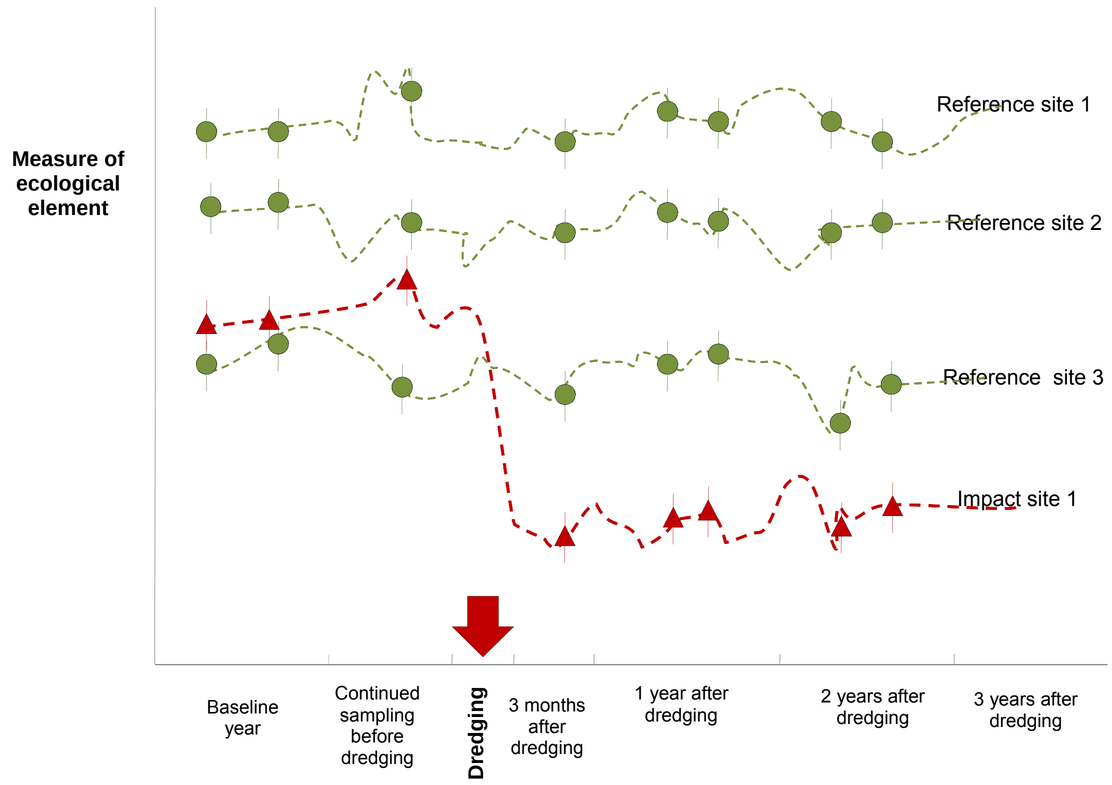


Figure 4-1 Overview of MBACI Sampling Designs – 'Press' Impact shows how Changes will be Detected Before–After Dredging and Spoil Disposal Activities

4.5 Scientific Expertise

The Marine Baseline Program was undertaken by personnel from RPS Australia/SE Asia, supported by Oceanic Offshore Commercial Diving Services and Gun Marine Services Pty Ltd. These surveys have drawn extensively on the expertise of a number of technical specialists, as listed in Table 4-2.

Table 4-2 Technical Specialists Involved in the Marine Baseline Program

Ecological Element	Technical Specialist	Affiliation	Contribution to the Marine Baseline Program
Hard and Soft Corals	Dr Zoe Richardson	Museum of Tropical Queensland and ARC Centre of Excellence, James Cook University, Queensland	Conducted the Rapid Visual Assessment surveys at the coral monitoring sites. Provided specialist taxonomic identification of scleractinian coral species both in situ and from subsequent laboratory identifications of skeletal specimens. Laboratory identifications were checked and confirmed by two other coral taxonomists, Dr C. Wallace, Museum of Tropical Queensland, and Dr J.E.N. Veron.

Ecological Element	Technical Specialist	Affiliation	Contribution to the Marine Baseline Program
Macroalgae and Seagrass	Dr John Huisman	School of Biological Sciences and Biotechnology, Murdoch University	Specialist taxonomic identification of macroalgae and seagrass.
Mangroves	Mr Scott Walker Mr Matt Johnston	Astron Environmental Services	Design and implementation of mangrove vegetation surveys. Statistical analysis, interpretation of results, and reporting.
Demersal Fish	Professor Jessica Meeuwig Dr Dianne Watson Dr Peter Barnes Associate Professor Euan Harvey Dr Kris Waddington	Centre for Marine Futures, University of Western Australia	Input into demersal fish survey design and implementation. Analysis of stereo-BRUVs footage. Statistical analysis, interpretation of results, and reporting.
Demersal Fish (mangroves)	Dr Dean Thorburn	Indo-Pacific Environmental Pty Ltd	Input into demersal fish survey design and implementation. Fish identification.
Surficial Sediments and Water Quality	Professor Peter Ridd Dr James Whinney	School of Mathematics, Physics and Information Technology, James Cook University, Queensland	Analysis and interpretation of raw data downloaded from the LTD loggers. Calibration of LTD loggers and maintenance in event of equipment failure.

The surveys conducted as part of the Gorgon Gas Development Marine Baseline Program have contributed to improving the knowledge of the Barrow Island marine environment.

5.0 Benthic Habitat Classification and Mapping

5.1 Mapping of Benthic Assemblages

5.1.1 Background

The assessment of potential impacts on marine benthic habitats in the EIS/ERMP (Chevron Australia 2005, 2006) required the survey and mapping of the area potentially affected by marine infrastructure, dredging and dredge spoil disposal. The survey area covered the extent of the predicted Dredge Management Areas and the Management Units set up to assess the impacts, which covered thousands of hectares. This necessitated broadscale qualitative assessment and mapping of marine benthic habitats. The objective of the mapping was to refine and confirm the distribution of major reef systems and other benthic habitats in the area likely to be affected by the proposed Marine Facilities. These maps were used primarily to guide marine infrastructure design, environmental impact assessment and as the basis for Benthic Primary Producer Habitat (BPPH) loss calculations in accordance with EPA Guidance Statement No. 29 (EPA 2004).

The broadscale, qualitative, maps of major benthic features and benthic habitats included in the EIS/ERMP (Chevron Australia 2005, 2006) were based on a Geographic Information System (GIS) version of an existing broadscale benthic habitat map of the Montebello/Barrow Islands area (Department of Conservation and Land Management [CALM] 2004; DEC 2007). Areas of potentially significant coral and other habitats near the east and west coast Marine Facilities and along the Offshore Feed Gas Pipeline in State waters and Domestic Gas Pipeline routes, which required ground-truthing to confirm their classification, were identified from the broadscale map (CALM 2004) and geo-rectified aerial photographs.

Ground-truthing involved hundreds of kilometres of towed video camera transects and in-water surveys to confirm that significant benthic communities within the areas covered by the Management Units for the BPPH assessment, were identified. The benthic habitat classifications were consistent with the scheme used in the existing broadscale map (CALM 2004), which was updated for the areas where new qualitative ground-truth data were collected. Only areas where coral cover was estimated to be representative of a coral community (nominally >10%, although this could not be directly measured at this scale) and the underlying and surrounding benthic substrate where corals were likely to be able to grow were mapped as ‘Coral Habitats’. Areas that were classified as ‘Unconfirmed Coral’ in the existing broadscale map (CALM 2004) and had not been surveyed further for the EIS/ERMP (Chevron Australia 2005, 2006) remained as ‘Unconfirmed Coral’ in the EIS/ERMP. Consistent with the existing mapping of the large limestone shelf areas around Barrow Island and the Montebello and Lowendal Islands, isolated bombora were not classified as ‘Coral Habitat’.

The benthic habitat maps in the Gorgon Gas Development Revised and Expanded Proposal PER (Chevron Australia 2008) were used primarily to guide the design of the marine infrastructure for the Revised and Expanded Proposal environmental impact assessment and for the associated revised BPPH loss calculations. The maps in the Revised and Expanded Proposal PER (Chevron Australia 2008) were developed by updating the existing EIS/ERMP maps (Chevron Australia 2005, 2006), incorporating improved or more recent imagery and by using additional ground-truthed data collected since mid-2005. More recent aerial photography and Laser Airborne Depth Sounder (LADS) imagery for some areas were used to identify additional benthic features requiring ground-truthing. The imagery was also used to map the areas where it was proposed to establish Reference Sites (e.g. for the dredging and spoil disposal monitoring program) and to improve definition of boundaries in the existing benthic habitat map. These features were ground-truthed using towed video camera transects and in-water surveys between 2007 and mid-2008. Benthic habitats were classified and BPPH impacts assessed using the same methods in the EIS/ERMP (Chevron Australia 2005) to facilitate comparison of the extent impacts predicted for the Approved and the Revised and Expanded Proposals.

Ministerial Implementation Statement No. 748 included the requirement to define and map the ecological elements (including ‘hard and soft corals’) within areas likely to be affected by the Gorgon Gas Development and at reference areas outside the areas predicted to be impacted. The survey area was thus extended to improve the definition of benthic habitats at potential Reference Sites and the accuracy of maps was improved in these areas. The requirement to 'define and map' ecological elements was addressed through further refinement of the EIS/ERMP (Chevron Australia 2005, 2006) and Revised and Expanded Proposal PER (Chevron Australia 2008) maps, with a shift in emphasis from coral habitats to 'hard and soft corals' as the ecological element. This required refinement of the distribution of corals rather than the substrates they are likely to grow on (as required for the BPPH assessment). These maps show the distribution of coral assemblages in the appropriate areas without providing quantitative estimates of the percentage cover of corals within the assemblages.

The focus of the mapping for the Marine Baseline Program has therefore been the improved qualitative description ('map') of benthic ecological assemblages and a refinement in the survey methods to enable coral assemblages to be quantified. The quantitative maps in the Marine Baseline Report are based on the qualitative maps provided in the Revised and Expanded Proposal PER (Chevron Australia 2008), with the polygon boundaries refined on the basis of additional imagery, LADS data for Reference Sites and Multi-Beam Sonar data for the Marine Facilities and Dredge Management Areas adjacent to Town Point, and redefined according to the level of quantification undertaken for each polygon. Benthic features identified from the imagery were ground-truthed using a combination of transects and photo-quadrats analysed using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006) for percentage cover and diver visual estimates. The boundaries of polygons have then been redrawn to correspond with information from ground-truthing observations and remote sensing.

The criterion for 'Coral Assemblages' has been quantified (diver visual estimate of percentage cover or measured photo-quadrat estimate) as 'a cover of live coral of greater than 10%'. This is consistent with other recent large-scale coral mapping studies (Cochran-Marquez 2005; National Centers for Coastal Ocean Science 2005, 2008). Under this definition of 'Coral Assemblage' (>10% measured live coral cover), many of the polygons resulting from data collected during earlier surveys for the EIS/ERMP (Chevron Australia 2005, 2006) and the Revised and Expanded Proposal PER (Chevron Australia 2008), could not be confirmed to comply with this criterion and could not therefore be classified as 'Coral Assemblages'. Polygons for which there were no quantitative data to support their classification as 'Coral Assemblages' were therefore re-labelled as 'Unconfirmed Coral'. Although many were known to be dominated by coral from earlier qualitative ground-truthing surveys, there were insufficient quantitative data to classify them as 'Coral Assemblage' (>10% measured coral cover). Therefore some polygons presented as 'Confirmed Coral' in the EIS/ERMP (Chevron Australia 2005, 2006) and the Revised and Expanded Proposal PER (Chevron Australia 2008) are now identified as 'Unconfirmed Coral' in maps in the Marine Baseline Report.

In the maps in the Marine Baseline Report the following terms are used:

- 'Quantified Coral': Classifies all polygons that have been either confirmed as Coral Assemblages in a quantitative manner (i.e. point census of photo-quadrats taken along transects at monitoring sites) or confirmed as Coral Assemblages in a qualitative manner (i.e. visual estimation during ground-truthing surveys), as having cover >10%.
- 'Unquantified Coral': Classifies those polygons which are, or may be, potential Coral Assemblages, that have been identified or refined as benthic features using survey data (e.g. remote imagery, in situ surveys), but have not been ground-truthed and classified in accordance with the Barrow Island habitat classification scheme described in Section 5.2 and Appendix 2, thus there are insufficient data for them to be classified as 'Quantified Coral'. Note that these may be classified as 'Quantified Coral' in the future if ground-truthing confirms that live coral cover is >10% and the boundaries are refined such that only Coral Assemblages are present within the mapped polygon.
- 'Unconfirmed Coral', which is unchanged from the CALM (2004) map. Note that these may be classified as 'Quantified Coral' in the future if ground-truthing confirms that live coral cover is

>10% and the boundaries are refined such that only Coral Assemblages are present within the mapped polygon.

The assessment of the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact that are to be used to calculate the Area of Loss of Coral Assemblages as specified in Condition 14.6.ii of Statement No. 800 and Condition 11.6.II of EPBC Reference: 2003/1294 and 2008/4178 will be based on quantitative estimates of cover (RPS 2009). The assessment of Coral Assemblages was undertaken in November 2009, as close as practicable to the commencement of the dredging and spoil disposal activities and Marine Facilities construction activities, to reduce the risk of natural events confounding the assessment of live Coral Assemblages. The results are presented in the Coastal and Marine Baseline State and Environmental Impact Report Supplement: Area of Coral Assemblages (Chevron Australia 2010). Note that the maps in the Marine Baseline Report have also been updated to reflect the results from this field assessment.

5.1.2 Methods

To map the ecological elements as required under Condition 14.6 of Statement No. 800, Condition 12.6 of Statement No. 769, and Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178, seabed features were identified using existing broadscale habitat maps from around Barrow Island (CALM 2004; DEC 2007) and a variety of remote sensing data, including high resolution aerial imagery, LADS data, Multi-Beam Sonar and Side-Scan Sonar data from across the study area and entered into a Geographic Information System (GIS) (Figure 5-1). Note that not all data sources were available for all the areas mapped.

The seabed features identified from the remote imagery were then ground-truthed using towed video camera and in-water surveys (Figure 5-1). Bathymetric irregularities were more intensively ground-truthed than areas of bathymetric similarity (i.e. flat, featureless areas) as previous surveys around Barrow Island have found areas of bathymetric similarity to be more homogenous than areas of bathymetric dissimilarity. Underwater video footage was captured using a MAKO towed video unit fitted with a 3CCD image sensor in a custom-built housing with a protective frame and with top and tail planes fitted for stability. Images were transmitted through an umbilical to a control box on the vessel. Positional information from a Garmin Global Positioning System (GPS) Unit was overlaid on the video footage before it was recorded to DVD. The extensive ground-truthing observations across the study area were plotted over the broadscale benthic habitat map (CALM 2004) and remote sensing data in the GIS (Figure 5-2 and Figure 5-3). Areas beyond the survey sites that were not adequately ground-truthed to enable classification are presented as the underlying habitat category from the existing broadscale benthic habitat map of the Montebello/Barrow Islands area (CALM 2004; DEC 2007).

The benthic habitats were classified in accordance with the Barrow Island habitat classification scheme described in Section 5.2 and Appendix 2. Benthic habitats were classified from the video imagery in real-time using a custom interface in the Environmental Systems Research Institute (ESRI) ArcPad software, also connected to a Garmin GPS unit. Observations were recorded using drop-down menus containing the hierarchical table of biophysical characteristics that make up the habitat classification scheme. In areas of high seabed complexity, observations were recorded approximately every 30 seconds, or when a feature of interest or a change in habitat type was observed. At a towing speed of ~2 knots, observations made every 30 seconds were separated by ~30 m.

The boundaries of polygons were then redrawn to correspond with information from the remote sensing and the ground-truthing observations. The ground-truthing observations were plotted over a map of the polygons representing the identified seabed features and the georeferenced observations were used to assign an ecological element classification (assemblage category) to each polygon. A decision tree was used to define and classify the polygons drawn around seabed features (Figure 5-4). Benthic features with >10% estimated live coral cover was mapped as 'Coral Assemblage' irrespective of the other assemblages present. For example, if a seabed feature had 20% live coral cover and 80% macroalgal cover, it was mapped as a 'Coral Assemblage'. Where coral cover was <10%, but other ecological elements were present at >10%

cover, then the ecological element that covered the greatest percentage of the substrate was recorded as the dominant ecological element. For example, if a seabed feature had 5% live coral cover and 95% macroalgal cover it was mapped as a 'Macroalgal Assemblage'. Where no ecological element covered >10% of the area being described, the polygon was classified as 'Unvegetated'.

High profile reefs, extensive rocky shelves, the surrounding expanses of unconsolidated soft sediments and mangroves have boundaries that can be distinguished from bathymetric data or aerial imagery and can thus be mapped as discrete polygons. Non-coral benthic macro-invertebrates and seagrass that were present in spatially and temporally varying (generally sparse) densities, with no distinct boundaries that can be reliably delineated using remote imagery, cannot readily be mapped as discrete polygons on maps of ecological elements. Because of the difficulties in drawing accurate polygon boundaries, a simplified mapping scheme was used with six mapping classes:

- Quantified Coral (see Section 5.1.1)
- Unquantified Coral (see Section 5.1.1)
- Unconfirmed Coral (see Section 5.1.1)
- Macroalgae with Sparse Sessile Taxa
- Soft Sediment with Sparse Sessile Taxa
- Mangroves.

Features mapped using the 'Macroalgae with Sparse Sessile Taxa' class contained assemblages dominated by macroalgae. Seagrass and non-coral benthic macro-invertebrates often co-existed in areas where macroalgae were the most common ecological element. This mapping class is used to indicate that the mapped area is dominated by macroalgae, but does contain some other sessile taxa at subdominant levels of cover. Note that this is consistent with the existing broadscale habitat maps from around Barrow Island (CALM 2004; DEC 2007), which do not include a seagrass or benthic macro-invertebrate category.

Features mapped using the 'Soft Sediment with Sparse Sessile Taxa' class were mostly composed of unvegetated sand, with no associated sessile biota. Patches of seagrass and non-coral benthic macro-invertebrates were present within this broader landscape of bare sand, but the boundaries of these patches could not be mapped accurately. This mapping class is used to indicate that the mapped area is dominated by unvegetated sand, but does contain some other sessile taxa at subdominant levels of cover.

As required under Condition 14.6 of Statement No. 800, Condition 12.6 of Statement No. 769, and Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178, maps of each of the ecological elements are presented in the Marine Baseline Report. Generally, the boundaries of coral (Section 6.0), macroalgal (Section 8.0) and soft sediment habitats could be clearly identified and were mapped as discrete polygons. Because of the difficulties in drawing polygon boundaries, point observations of non-coral benthic macro-invertebrates (Section 7.0) and seagrass (Section 9.0) are presented on maps as presence/absence data. It is also difficult to delineate distinct boundaries between different surficial sediment types without losing much of the potentially important information on small-scale spatial variability and gradients between sediment types on larger scales. Surficial sediments are therefore presented graphically in terms of the sediment type recorded at each sampling location (Section 12.0).

While they may often exhibit distinct habitat associations, demersal fish assemblages are difficult to map because they are not always spatially restricted to the sampling sites and individual species within the assemblage will exhibit varying levels of site attachment. The relative abundance and diversity of demersal fish characteristic of coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and sand communities in Barrow Island waters are presented in the form of interactive Excel charts (Section 11.0 and Appendix 7).

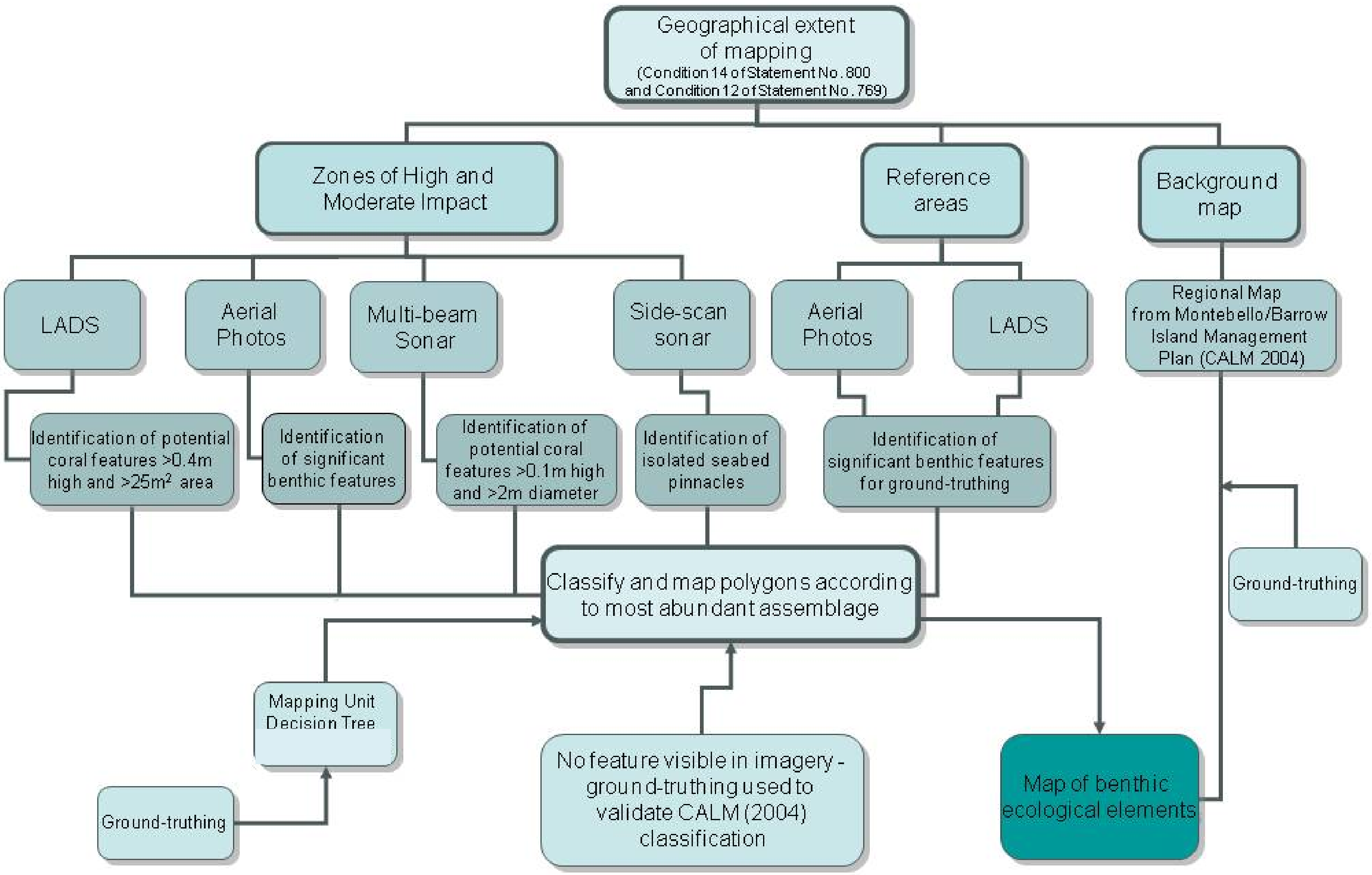


Figure 5-1 Process for Identifying and Mapping Seabed Features

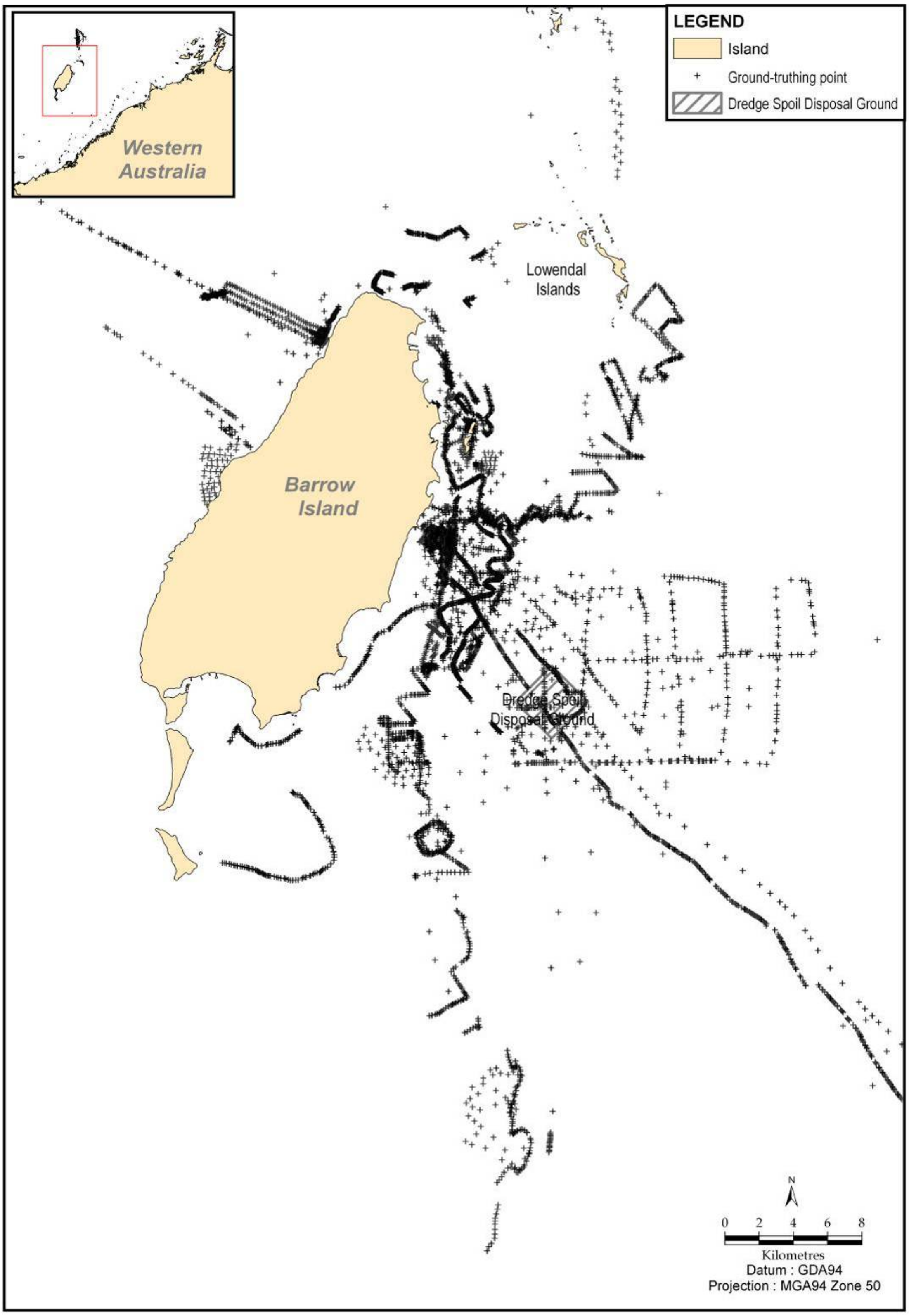


Figure 5-2 Ground-truthing Points across the Marine Baseline Program Area

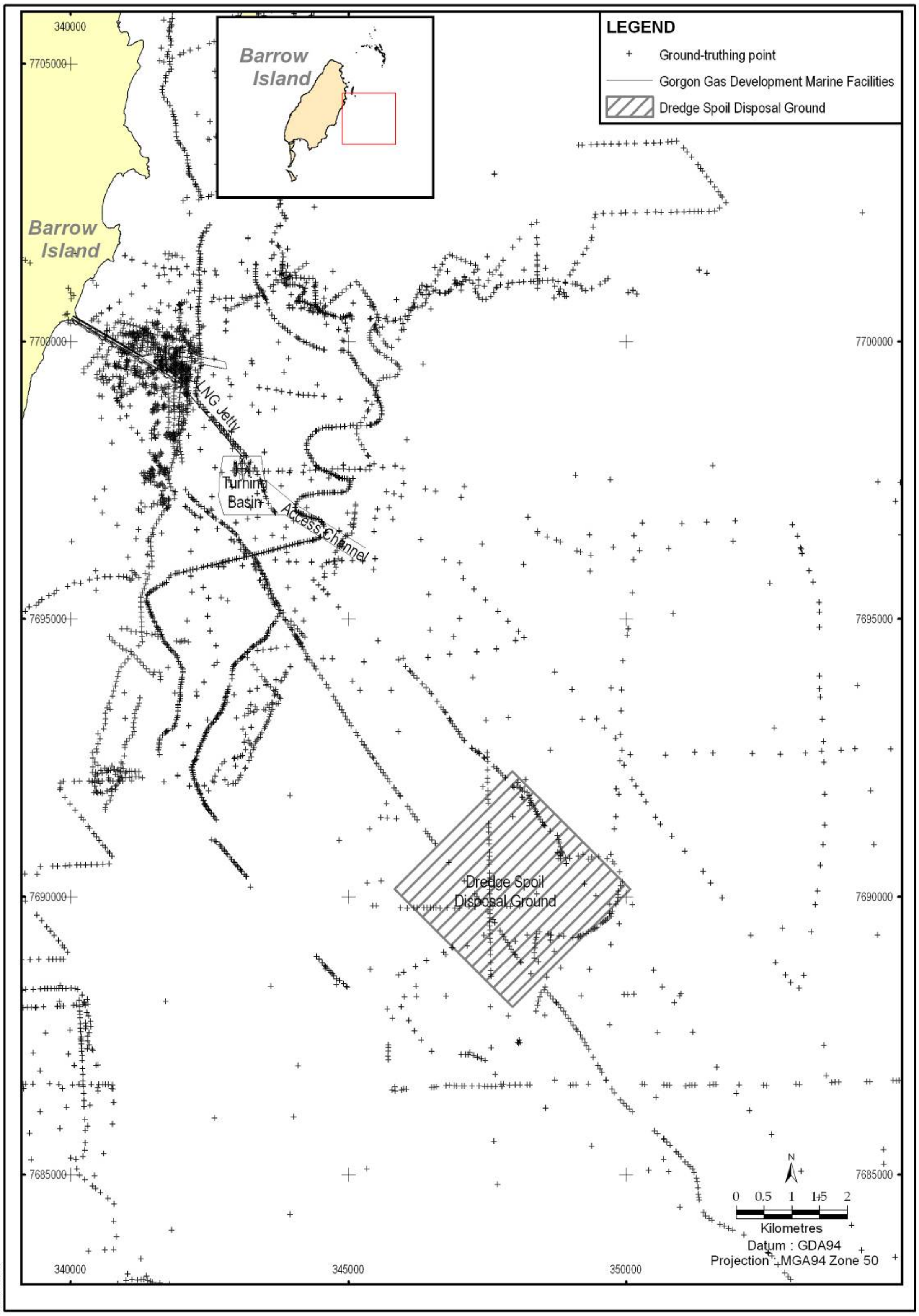


Figure 5-3 Ground-truthing Points in Proximity to the Marine Facilities on the East Coast of Barrow Island

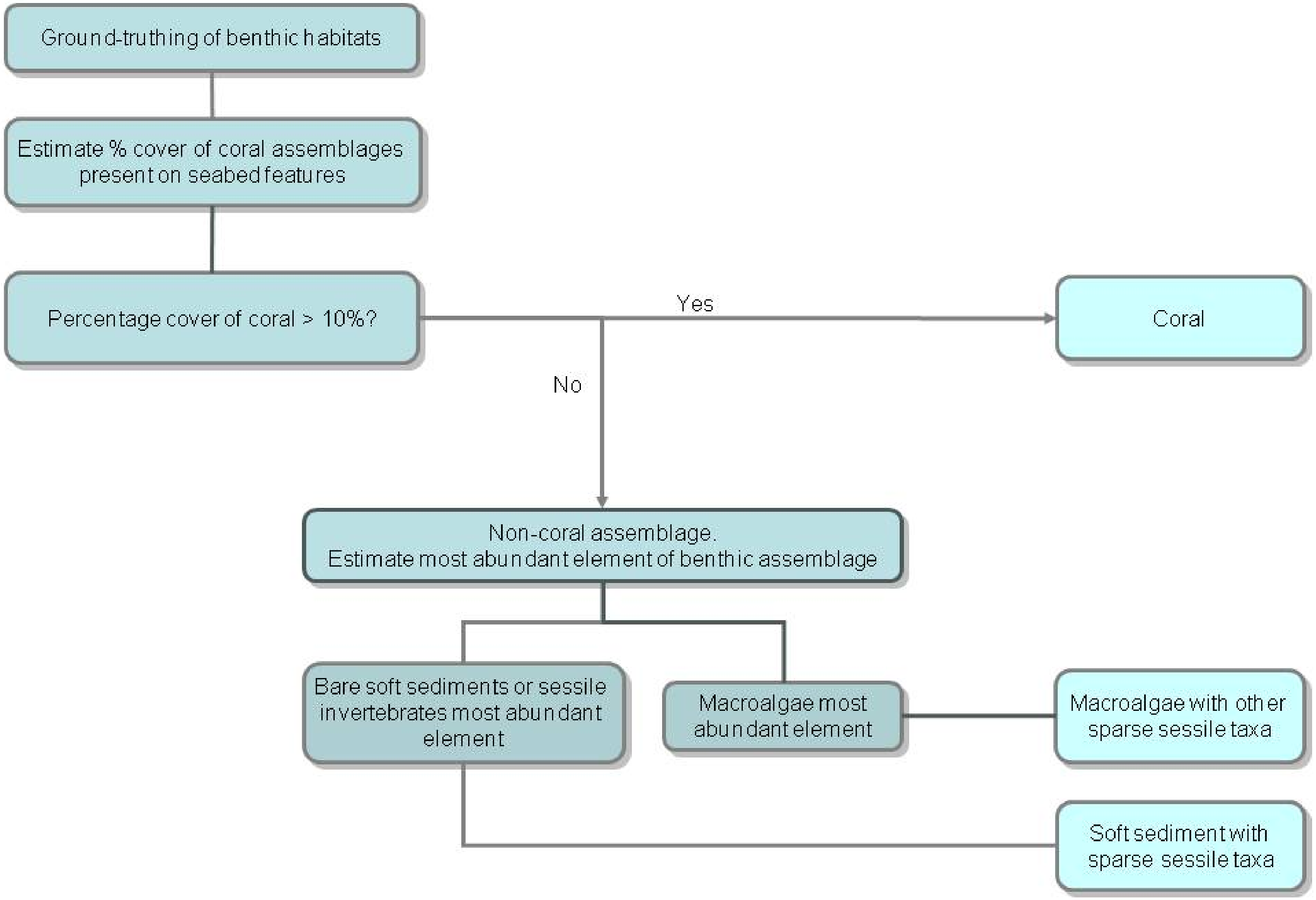


Figure 5-4 Habitat Classification Unit Decision Tree

5.2 Benthic Habitat Classification Scheme

Ground-truthed data were classified according to a hierarchical system of biophysical characteristics designed to facilitate consistent definition of benthic habitats in Barrow Island waters (Appendix 2).

The classification system uses attributes in five categories to describe the habitats:

- most common relief type of the underlying substrate (e.g. flat, gently sloping, steeply sloping, vertical wall, etc.)
- most common substrate type (e.g. silt, rubble, boulders, limestone pavement, low profile reef, high profile reef, etc.)
- most common or dominant ecological element found on the substrate (e.g. seagrass, coral, macroalgae, etc.)
- biological density or percentage cover of the most common taxa (sparse, medium, dense, etc.)
- most common or dominant taxa (family, genera or species where possible) within that assemblage (e.g. *Halophila* spp.), or physical descriptor where no biota were present.

Table 5-1 details the classification scheme categories and attributes.

Table 5-1 Benthic Habitat Classification Categories and Attributes

Category	Attribute	Definition
Relief	Flat or micro-ripples	Slope 0–5° with ripples 0–0.5 m high
	Gently sloping	5–35°
	Steeply sloping	35–70°
	Vertical wall	70–90°
	Macro-ripples	Slope 0–5° and ripples >0.5 m high
Substrate Type	Sand	Unconsolidated sediment 0.63–2 mm in diameter
	Silt	Unconsolidated sediment <0.63 mm in diameter
	Mud	Dense consolidated mixture of silt to sand sized particles
	Gravel	Unconsolidated sediment 2–10 mm in diameter
	Rubble	Unconsolidated sediment 10–250 mm in diameter
	Consolidated rubble	Sediment >10 mm in diameter with a covering of biotic or abiotic material which acts to keep the rubble in place
	Limestone pavement	Horizontal surface of exposed limestone rock
	Limestone pavement with sand veneer	Limestone rock patchily covered with sand; the sand may range in depth from centimetres to metres
	Boulders	Unconsolidated sediment >250 mm in diameter
	Reef – low profile	Reef of biotic or abiotic origin, ranging from flat to vertical; low profile: <1 m vertical change per 1 m horizontal
	Reef – high profile	Reef of biotic or abiotic origin, ranging from flat to vertical; high profile: >1 m vertical change per 1 m horizontal
	Sand with shell fragment	Unconsolidated sediment 0.63–2 mm in diameter, containing large, easily visible pieces of shell
	Silt with shell fragment	Unconsolidated sediment <0.63 mm in diameter, containing large, easily visible pieces of shell

Category	Attribute	Definition
Dominant Ecological Element	Macroalgae	Macroalgae greatest % cover, coral <10%
	Seagrass	Seagrass greatest % cover, coral <10%
	Non-coral benthic macro-invertebrates	Non-coral benthic macro-invertebrates greatest % cover, coral <10%
	Coral – hard and soft	Coral >10 % cover
	Mangroves	Mangrove forests and isolated mangrove trees
	Unvegetated	Benthic assemblages collectively <10% cover
% Cover	Sparse – macroalgae	5–25% estimated cover
	Medium – macroalgae	25–75% estimated cover
	Dense – macroalgae	>75% estimated cover
	Sparse – seagrass	5–25% estimated cover
	Medium – seagrass	25–75% estimated cover
	Dense – seagrass	>75% estimated cover
	Present – Non-coral benthic macro-invertebrates	Presence/absence recorded
	Sparse – coral	0–10% estimated cover
	Medium – coral	10–50% estimated cover
	Dense – coral	50–75% estimated cover
	Very dense – coral	>75% estimated cover
	Present – mangrove	Presence/absence recorded for mangroves
	Unknown density	% cover not recorded

Dominant and subdominant taxa were classified to the greatest practicable taxonomic resolution. For towed video camera surveys, the resolution of the video footage varied according to weather conditions and water clarity. In clear water, it was possible to classify the dominant and subdominant taxon descriptor of the habitat classification to the species level (e.g. flat, limestone pavement with macroalgae, dominated by sparse *Sargassopsis decurrens*). In turbid water, or with poor quality video footage, it was often only possible to identify the dominant/subdominant taxon to phylum or class (e.g. flat limestone pavement with macroalgae, dominated by medium unidentified Phaeophyceae). Less common taxa and associated species were also recorded where possible. While this information increased the level of knowledge of the ecology of the study area, it did not inform habitat classification for mapping purposes.

The scheme is consistent with other habitat classification schemes used in Australia (see CALM 1994, 2000; Roob *et al.* 1995; Roob and Ball 1997; Australian and New Zealand Environment and Conservation Council Task Force on Marine Protected Areas 1998, 1999; Simpson and Bancroft 1998; Ferns 1999; Ferns and Hough 2000; Ball *et al.* 2006; Mount *et al.* 2007). While the hierarchy used is similar to that employed by other schemes (e.g. classifying by relief, then substrate, then biological modifiers such as dominant ecological elements and dominant taxa), the habitat classification scheme developed for Barrow Island waters is tailored around the ecological elements defined in Condition 14.2 of Statement No. 800, Condition 12.2 of Statement No. 769, and Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178.

6.0 Hard and Soft Corals

6.1 Introduction

The marine habitats in the Pilbara region support a variety of coral species that vary spatially, with clearer waters in offshore areas having higher coral density and diversity than that of high turbid nearshore areas (Woodside 2006). Coral surveys in north-western Australia have generally been concentrated in areas associated with industrial development. Approximately 318 hermatypic coral species from 70 genera are known to occur in Western Australia (Woodside 2006). Surveys conducted at the Dampier Archipelago in 2004 found that four coral genera dominated the coral assemblages: *Acropora* (especially plate *Acropora*), *Porites*, *Pavona* and *Turbinaria* (Blakeway and Radford 2005). The fifth most abundant type of coral assemblage was a 'mixed' assemblage, consisting of *Turbinaria*, faviids and other scleractinian corals. A total of 229 species of coral from 57 hermatypic coral genera have been recorded in the Dampier Archipelago (Griffith 2004).

At least 150 species of hard corals from 54 genera were recorded in the Montebello/Barrow Island region during a survey conducted by the Western Australian Museum (Marsh 1993). The fringing reefs in the relatively clear and high energy conditions to the west and south-west of the Montebello Islands, as well bomboras and patch reefs in the more turbid and lower energy waters along the eastern edge of the Montebello Islands, are believed to support the best developed coral communities in the Montebello/Barrow Island region (DEC 2007). For Barrow Island specifically, the most significant coral reefs are located at Biggada Reef on the west coast, Dugong Reef and Batman Reef off the south-east coast, and along the edge of the Lowendal Shelf on the east side of Barrow Island (DEC 2007).

The intertidal pavement reef on the east coast of Barrow Island where the MOF and LNG Jetty will be located supports the growth of hard corals and soft corals (Chevron Australia 2008). The coral assemblage in this area is dominated by various species of the hard coral *Goniastrea* spp. with some colonies exceeding 80 cm in diameter (Chevron Australia 2008). Less common hard corals in this area include *Porites* spp., *Euphyllia* spp., *Lobophyllia* spp., *Plesiastrea* spp., *Favia* spp., *Favites* spp., *Platygyra* spp. and *Acanthastrea* spp. (Chevron Australia 2005). Soft corals recorded in this area include *Sarcophyton* spp., *Lobophytum* spp., *Sinularia* spp., *Nephthea* spp. and *Dendronephthya* spp. (Chevron Australia 2005).

Coral communities on the subtidal pavement reef and the deeper, offshore areas that coincide with the MOF and LNG Jetty vary from almost exclusively coral-dominated assemblages, to areas dominated by macroalgae, but with scattered small hard corals such as *Acropora* spp. and soft corals such as *Rumphella* spp. (Chevron Australia 2008). *Porites* spp. bombora up to one metre high are either interspersed as isolated elements throughout the subtidal reef area or grouped together to form bombora communities (Chevron Australia 2008).

6.2 Scope

This section describes and maps the hard and soft corals:

- within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

In addition, the following are reported:

- the existing dominant and subdominant hard and soft coral species/taxa (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178)
- the population structure of coral communities as colony size-class frequency distributions of dominant hard coral taxa (Condition 14.8.iv.a, Statement No. 800; Condition 11.8.IV.a, EPBC Reference: 2003/1294 and 2008/4178)
- the population statistics of survival of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities (Condition 14.8.iv.b, Statement No. 800; Condition 11.8.IV.b, EPBC Reference: 2003/1294 and 2008/4178)
- the population statistics of growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities (Condition 14.8.iv.b, Statement No. 800; Condition 11.8.IV.b, EPBC Reference: 2003/1294 and 2008/4178)
- the recruitment of hard coral taxa within these communities (Condition 14.8.iv.c, Statement No. 800; Condition 11.8.IV.c, EPBC Reference: 2003/1294 and 2008/4178).

For the purposes of the Marine Baseline Program, 'hard corals' are considered to be the reef-building corals within the order Scleractinia. Corals were classified according to the online Integrated Taxonomic Information System (ITIS) (http://www.itis.gov), as recent taxonomic regrouping of some species and genera into new clades and families based on genetic analyses (Kerr 2005; Fukami *et al.* 2008) are only just being developed and are not yet commonly recognised.

The hard coral *Turbinaria* spp. is common in benthic macro-invertebrate dominated habitats and is covered in Section 7.0 (non-coral benthic macro-invertebrates) rather than in this Section. This is because it is more like other benthic macro-invertebrates (i.e. solitary with a low profile and low benthic cover).

'Soft corals' have no skeleton and are not considered reef-building organisms. For the purposes of the Marine Baseline Program, 'soft corals' are those within the order Alcyonacea (soft corals) and suborder Alcyoniina ('true soft corals') (http://www.itis.gov). Identifying soft corals is generally difficult except for the suborder Alcyoniina and even then the species are difficult to distinguish (Dinesen 1983). Soft corals were identified only to suborder or genus.

The other organisms within the order Alcyonacea include sea whips (suborder Calcaxonia) and sea fans (suborders Holaxonia and Scleraxonia) (http://www.itis.gov). These are included in Section 7.0 (non-coral benthic macro-invertebrates) because they are commonly observed in benthic macro-invertebrate dominated habitats in Barrow Island waters (outside coral reef habitats). They are therefore considered to be an important part of the sessile benthic macro-invertebrate assemblages.

Non-scleractinian corals (e.g. *Millepora* sp.; class Hydrozoa) were recorded only if they were dominant or subdominant and were identified only to genus level.

Condition 14.8.iv.b of Statement No. 800 and Condition 11.8.IV.b of EPBC Reference: 2003/1294 and 2008/4178 require the recording of the survival and growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise the communities. Key indicator species are interpreted as 'sensitive' species (e.g. sensitive to sedimentation, turbidity or bleaching) and 'representative' species that occur at all sites to facilitate future comparisons between sites.

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

6.3 Methods

6.3.1 Site Locations

Twelve coral monitoring sites (Table 6-1; Figure 6-1 and Figure 6-2) were selected for the Marine Baseline Program on the basis of:

- **Dredge Management Areas:** Coral monitoring sites were established in the Zones of High Impact (one site) and Moderate Impact (three sites), representative areas within the Zones of Influence (two sites) and Reference Sites outside the Zones of Influence (six sites, including three Regionally Significant Areas). The Marine Baseline Program sought to maximise the number of independent Reference Sites, with sites located at varying distances from the Zones of High and Moderate Impact and the Zones of Influence, to enable tests of the impacts predicted by the outputs of the dredge plume model. Note that sites were selected to be representative of the overall population being monitored at Barrow Island (in this case, Coral Assemblages, defined as benthic areas [minimum 10 m^2] or raised seabed features over which the average live coral cover is ≥10% coral cover). It is also important to note that, while complementary and centred on the same sites, the different methods used in the Marine Baseline Program assessed coral assemblages at different scales. Thus Rapid Visual Assessments qualitatively assess coral assemblages over larger spatial scales (over hundreds of metres) and provide greater taxonomic resolution; while transects record more precisely on a more restricted spatial scale (50 m radius) with less taxonomic resolution.
- **Distribution of coral assemblages:** Sites were established at four Regionally Significant Areas adjacent to the dredging and spoil disposal activities, specifically Southern Lowendal Shelf (located inside the Zones of Influence), as well as Dugong Reef, Batman Reef and Southern Barrow Shoals located outside the Zones of Influence.
- **Level of coral cover:** Where possible, sites were established in areas of high coral cover (based on visual estimates during reconnaissance surveys) to maximise the number of replicate colonies of each species that could be selected to monitor coral survival and growth. Monitoring areas of high coral cover also provides a greater level of power to detect coral mortality during and after completion of the dredging and spoil disposal activities and Marine Facilities construction activities.
- **Logistical constraints:** The numbers and locations of coral monitoring sites were constrained by the suitability of sites for vessel anchoring, the reach of Surface-Supplied Breathing Apparatus (SSBA) umbilical hoses, tidal conditions and time constraints.

The depth of monitoring sites varied between 1.5 m at Biggada Reef on the west coast of Barrow Island to 9.25 m at Lone Reef adjacent to the Dredge Spoil Disposal Ground (Table 6-1). The area surveyed at the monitoring sites varied between 0.06 ha at MOF1 and 1.54 ha at Dugong Reef, with an average area of 0.70 ha.

The majority of coral monitoring sites monitored through the Marine Baseline Program will continue to be monitored through the Coral Health Monitoring Program required under the Dredging and Spoil Disposal Management and Monitoring Plan (Chevron Australia 2011a). Additional coral monitoring sites will also be established as part of the Coral Health Monitoring Program. Surveys will be repeated at the baseline coral monitoring sites in the Post-Development Coastal and Marine State and Environmental Impact Surveys to be undertaken on completion of dredging and dredge spoil disposal activities (Condition 24 of Statement No. 800 and Condition 17 of EPBC Reference: 2003/1294 and 2008/4178).

Table 6-1 Coral Monitoring Sites

Location	Site Name (Map Reference)	Easting	Northing	Latitude	Longitude	Depth (m)	Area (ha)
		(GDA94, MGA Zone 50)		(GDA94)			
Zones of High Impact	LNG0 (LNG0)	344796	7696108	20° 49.713' S	115° 30.507' E	9.00	0.505
Zones of Moderate Impact	MOF1 (MOF1)	342089	7698785	20° 48.249' S	115° 28.961' E	6.00	0.056
	LNG1 (LNG 1)	344584	7695823	20° 49.867' S	115° 30.384' E	8.75	0.439
	Lone Reef (LONE)	347376	7692607	20° 51.624' S	115° 31.976' E	9.25	1.219
Zones of Influence	Ant Point Reef (ANT)	342065	7708657	20° 42.898' S	115° 29.001' E	4.00	0.749
	Southern Lowendal Shelf (LOW)	344504	7700689	20° 47.229' S	115° 30.363' E	3.00	0.785
Reference Sites	Ah Chong (AHC)	350243	7731659	20° 30.472' S	115° 33.829' E	6.50	0.574
	Biggada Reef (BIG)	328237	7702674	20° 46.068' S	115° 21.001' E	1.50	Not mapped
	LNG3 (LNG3)	343157	7692657	20° 51.575' S	115° 29.544' E	6.50	0.427
Regionally Significant Areas	Dugong Reef (DUG)	340099	7687998	20° 54.085' S	115° 27.755' E	6.25	1.538
	Batman Reef (BAT)	340703	7681301	20° 57.717' S	115° 28.067' E	3.50	0.497
	Southern Barrow Shoals (SBS)	345599	7666195	21° 5.929' S	115° 30.810' E	4.75	0.875

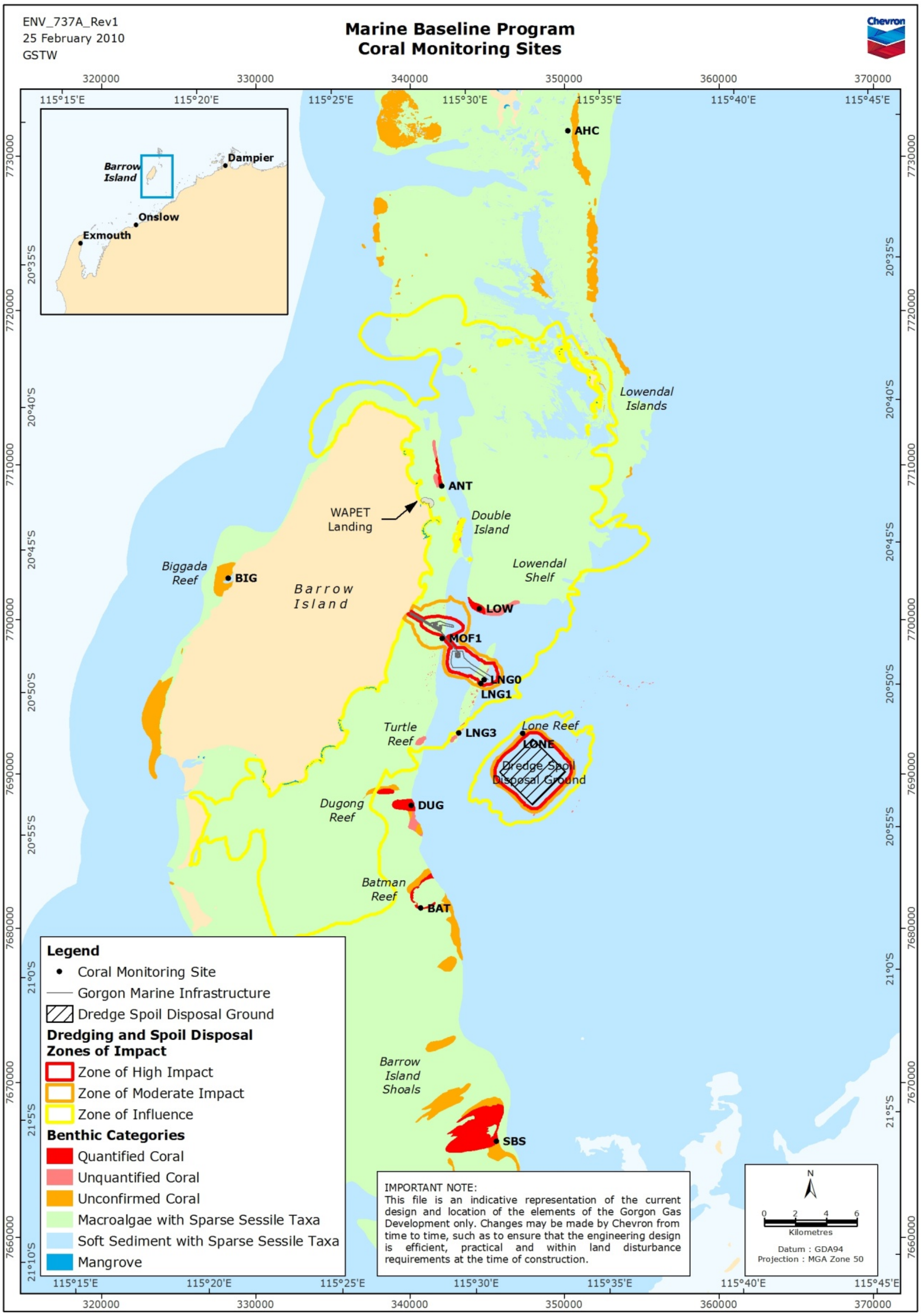


Figure 6-1 Marine Baseline Program Coral Monitoring Sites

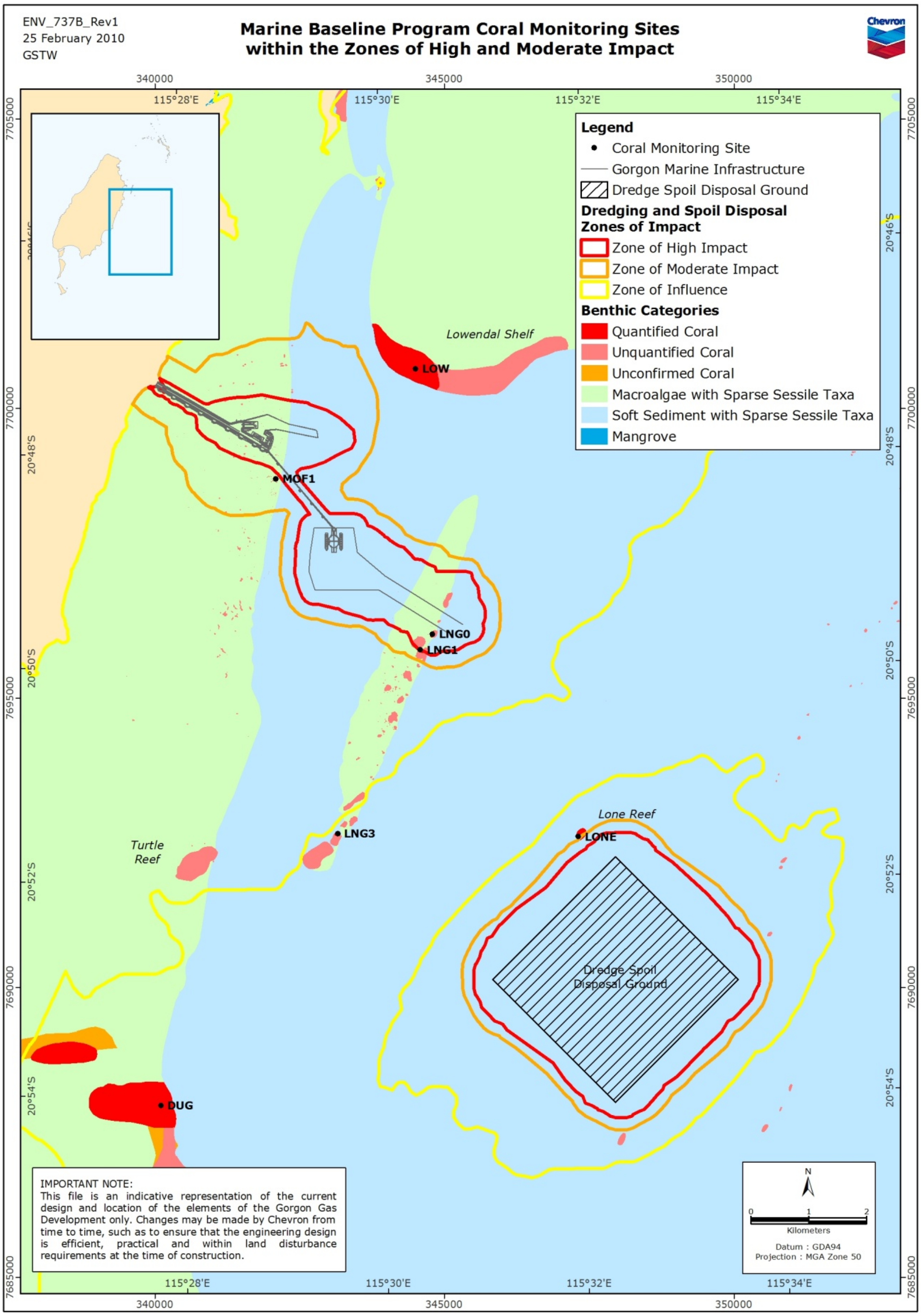


Figure 6-2 Marine Baseline Program Coral Monitoring Sites – Sites within the Zones of High and Moderate Impact

6.3.2 Methods

6.3.2.1 Mapping

6.3.2.1.1 Coral Assemblage Classification

There are no standard mapping methodologies for coral reefs. The classification scheme used in this study followed the general hierarchical approach developed by Mumby and Harborne (1999) for mapping coral reefs in the Caribbean where coral cover and coral diversity are generally low (<10% cover and approximately ten species typically present). At Barrow Island, the variation in coral cover and high species diversity of corals required the development of a specific Benthic Habitat Classification Scheme (Section 5.2; Appendix 2).

6.3.2.1.2 Mapping of Coral Assemblages in the Zones of High Impact and the Zones of Moderate Impact

Within the Zones of High Impact and the Zones of Moderate Impact, three sets of remote sensing data (Multi-Beam Sonar, Laser Airborne Depth Sounder [LADS], Side-Scan Sonar) were used to accurately map the boundaries of potential coral features. Multi-Beam Sonar and Side-Scan Sonar data were available for most of the area within the Zones of High Impact and Zones of Moderate Impact; where this information was not available, the interrogated LADS data were used to identify coral features.

Where available, data from a Multi-Beam Sonar survey were interrogated to locate coral patch reefs using a semi-automated method (Fugro Survey 2007). This identified the boundaries of potential coral features at least 0.1 m high with a diameter of at least two metres. Where these data were not available, a semi-automated method was used to locate potential coral features from the LADS data. This identified potential coral features at least 0.4 m high with an area of at least 25 m^2, or at least 0.2 m high and with an area of 50 m^2. Additional information about the location of potential coral features was determined from a Side-Scan Sonar survey. This information was capable of identifying areas of increased coral density, but was known to have some positional inaccuracies. The potential coral features identified using this dataset were therefore merged with potential coral features identified using the other two datasets which were considered to have greater positional accuracy (Figure 6-3).

The majority of the potential coral features identified from remote imagery are currently mapped as 'Unconfirmed Coral' (Figure 6-1); however, classification of the benthic assemblages has been undertaken at the coral monitoring sites within these areas. The ground-truthing of the potential coral features, including the quantitative assessment of live coral cover (RPS 2009), identified within the Zones of High Impact and the Zones of Moderate Impact to calculate the Area of Loss of Coral Assemblages, as required under Condition 14.6.ii of Statement No. 800 and Condition 11.6.II of EPBC Reference: 2003/1294 and 2008/4178, was undertaken prior to the commencement of the dredging and spoil disposal activities and marine construction activities. This minimised the possibility of natural perturbations confounding the assessments of Coral Assemblages prior to the commencement of works. Quantitative assessment of live coral cover involved the analysis of photo-quadrats along transects using the software program Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006) to assess percentage composition of assemblages (RPS 2009). The results from these surveys are presented in a Supplementary Report to the Marine Baseline Report (the Coastal and Marine Baseline State and Environmental Impact Report Supplement: Area of Coral Assemblages, Chevron Australia 2010).

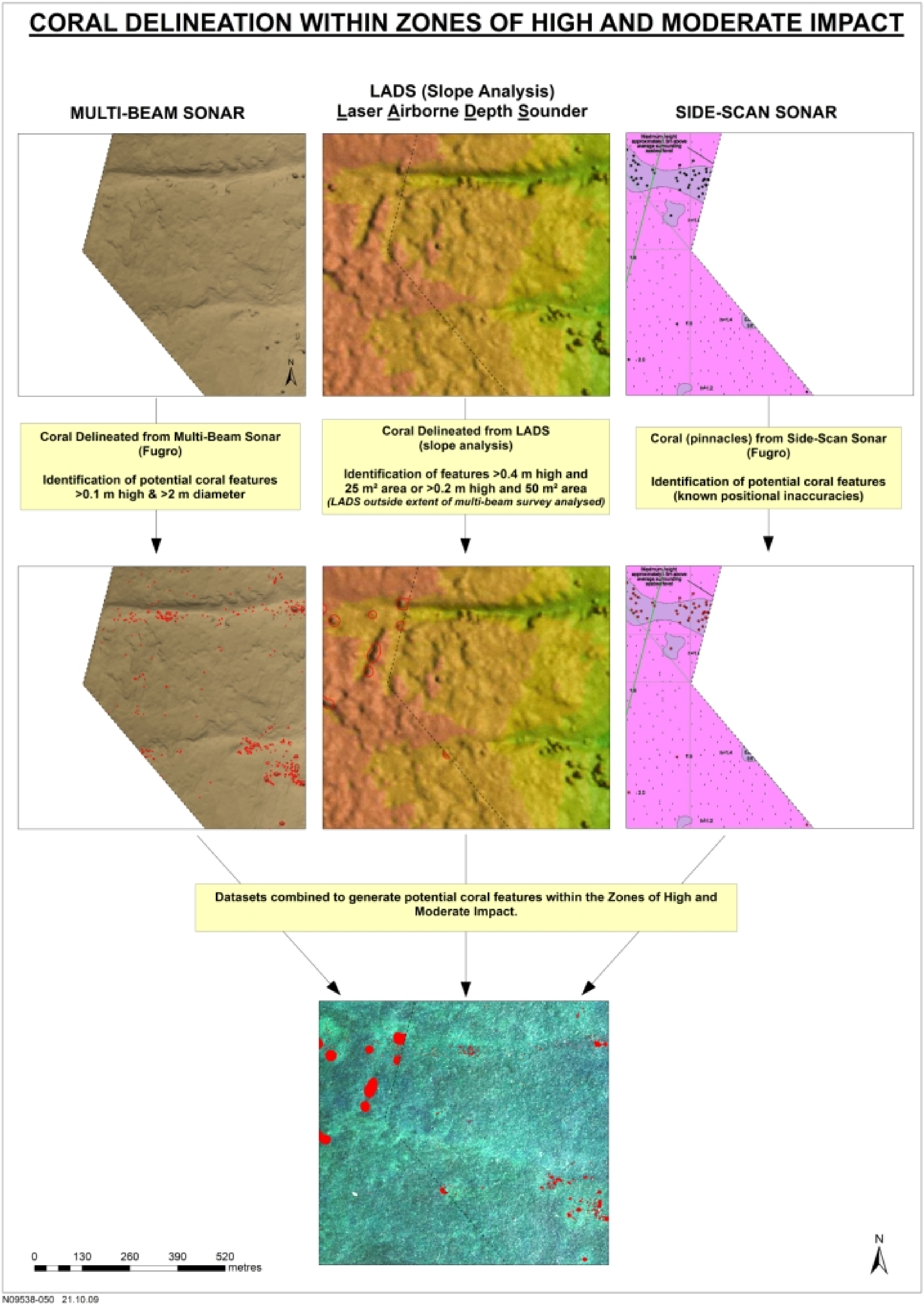


Figure 6-3 Delineation of the Boundaries of Potential Coral Features within the Zones of High Impact and the Zones of Moderate Impact and within the Areas at Risk of Material or Serious Environmental Harm

6.3.2.1.3 Mapping at Representative Areas in the Zones of Influence, Reference Sites and Sites in Regionally Significant Areas

Outside the Zones of High Impact and Zones of Moderate Impact, potential coral features were identified visually using the LADS data and aerial photographs. The aerial photographs were used to identify features that could then be traced around bathymetric contours provided by the LADS data (Figure 6-4).

At the sites in representative areas of the Zones of Influence, Reference Sites and sites in Regionally Significant Areas, the aim of mapping the coral assemblages was to obtain a general description of the reef areas around the coral monitoring sites. Areas of reef were surveyed at each site to identify general assemblage types and their percentage cover. The extent of mapping at each site was determined by where a boundary could be delineated using the combined information from existing broadscale benthic habitat maps (CALM 2004), remote imagery and ground-truthing (e.g. English *et al.* 1997; Hill and Wilkinson 2004). Ground-truthing methods included spot dives, manta tows and video camera tows (RPS 2009). These methods were used interchangeably depending on the spatial extent and depth of the area being surveyed.

The extent of mapping varied among the sites, ranging from 38 ha at Ant Point Reef to 1500 ha at the Southern Barrow Shoals. Sampling grids were overlaid over areas of potential coral assemblages identified from aerial imagery and LADS data using GIS (RPS 2009). The distance between grid points varied between 50 and 500 m and the number of grid points overlaid on an area of reef ranged between 28 and 65, depending on its size. During ground-truthing surveys, the dominant benthic assemblage type and percentage cover at each grid point was classified in accordance with the Benthic Habitat Classification Scheme (Appendix 2). An area of approximately 7850 m^2 was surveyed at each grid point (a circular area of approximately 100 m diameter which represents the reach of the hoses of divers on SSBA). Additional ground-truthing was undertaken at grid points where surface observations along the track lines between the grid points indicated a change in the composition or cover of the dominant assemblages (grid points are symbolised on maps as [+] and track lines as [——]). Boundaries were drawn around the dominant assemblage types for mapping; information on subdominant components of assemblages is also provided within the site descriptions.

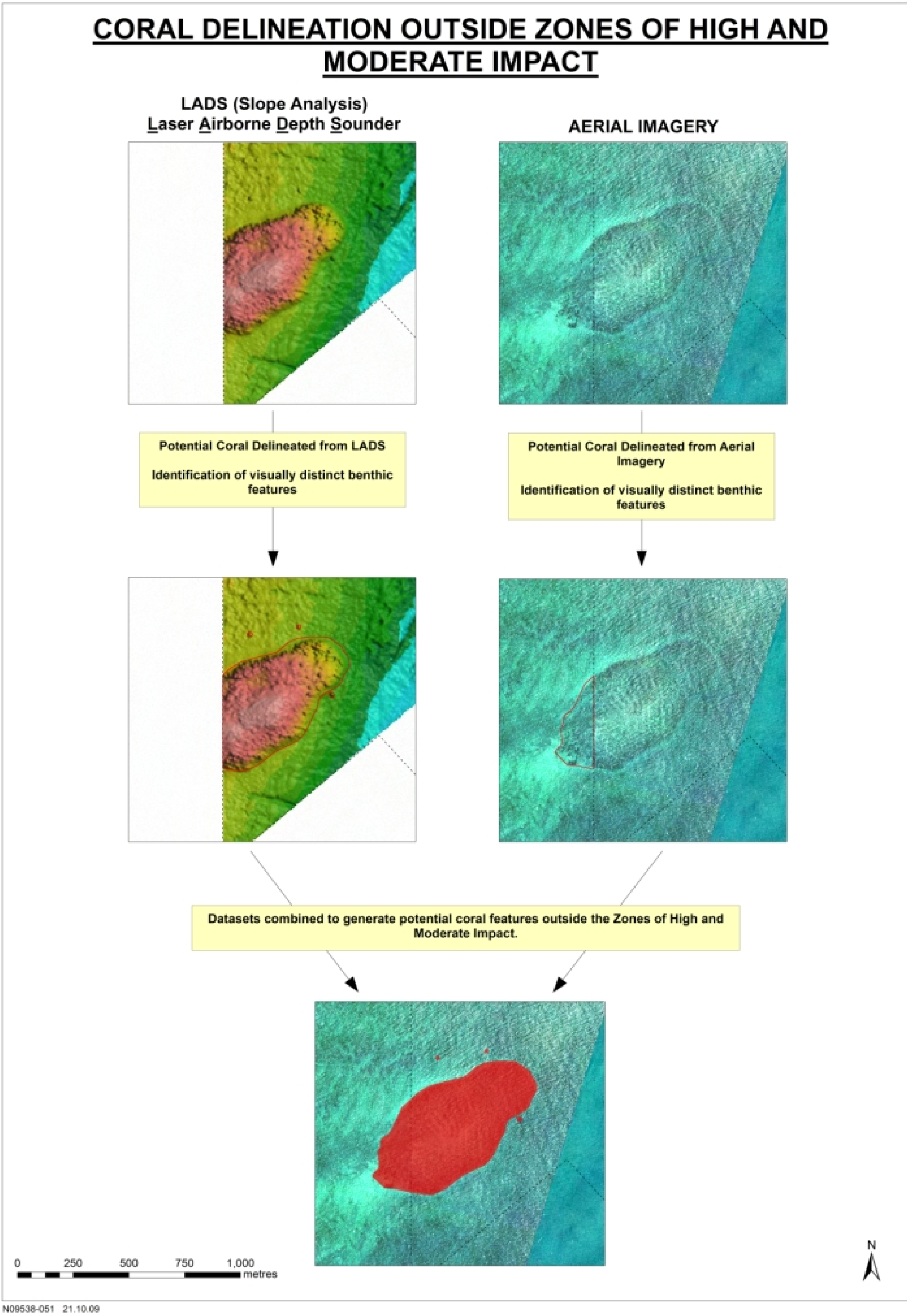


Figure 6-4 Delineation of the Boundaries of Potential Coral Features outside Zones of High Impact and Zones of Moderate Impact and outside Areas at Risk of Material or Serious Environmental Harm

6.3.2.2 Rapid Visual Assessment Surveys

Rapid Visual Assessment (RVA) surveys of coral biodiversity (Oxley *et al.* 2003; Kospartov *et al.* 2006) were undertaken at each of the coral monitoring sites to identify the dominant (species with the highest relative percentage cover, where percentage cover is expressed as the proportion of total coral cover) and subdominant (species, excluding dominant species, with ≥5% cover) hard and soft coral species/taxa. At each site, surveys were conducted for ~120 minutes, or until 'species saturation' was reached (no new species recorded for 15 minutes). Each RVA survey encompassed an area of approximately 100–200 m radius from the location of the water quality logger at each monitoring site.

The relative abundance of each species was estimated on a five-point scale (Table 6-2). The definition of dominant and sub-dominant species in Schedule 2 of Statement No. 800 and Schedule 2 of EPBC Reference: 2003/1294 and 2008/4178, specifically refers to the relative percentage cover, expressed as the proportion of total cover, of individual species, thus the size of colonies was also taken into account in the RVA surveys. In the case of colonies estimated to be >1 m in diameter, each square metre of the colony was counted as one colony (e.g. a large *Porites* colony approximately 5 m^2 was counted as five colonies).

Table 6-2 Abundance Scale for Hard and Soft Corals used in the Rapid Visual Assessment Surveys

Abundance Scale	Number of Colonies	Abundance Term
5	51+	Most Common
4	21–50	Common
3	6–20	Frequent
2	3–5	Infrequent
1	1–2	Rare

For species that were new, uncommon or difficult to identify in the field, a small skeletal sample was collected and bleached for identification by the Museum of Tropical Queensland. Species identifications were verified by Dr C. Wallace and Dr J.E.N. Veron. The specimens were lodged with the Museum of Tropical Queensland and, where multiple samples of a species were collected, the additional samples were lodged with the Western Australian Museum.

The number of species recorded is likely to represent an underestimate of the total number that occurs in the waters surrounding Barrow Island because the RVA surveys were conducted on snorkel (RPS 2009). Conducting the surveys on snorkel meant that some rare species (i.e. species with an abundance scale of <3) may not have been recorded, and that deeper sites were not surveyed as comprehensively as the shallower sites. However, Condition 14.8.iii of Statement No. 800 and Condition 11.8.III of EPBC Reference: 2003/1294 and 2008/4178, only requires that dominant and subdominant species (i.e. those species with an abundance scale of ≥3) are recorded and the RVA surveys achieved this. It will be important that the post-development surveys required under Condition 24 of Statement No. 800 and Condition 17 of EPBC Reference: 2003/1294 and 2008/4178, are repeated using the same methods to ensure the results are comparable.

To confirm that species identified in the RVA surveys as dominant and subdominant in terms of abundance, were also dominant or subdominant in terms of percentage cover, the percentage cover of hard coral families was measured from photo-quadrats (Section 6.3.2.4). Corals were identified to family level in the photo-quadrats and the data were cross-referenced with the RVA survey data to determine the species/taxa that contributed most to the percentage cover of each family and thus represented the dominant and subdominant species/taxa in the assemblages.

Dominant species/taxa were those with the highest abundance scale that also met the criteria of being in the family with the highest percentage cover. Thus, if a species was abundant but not large and therefore did not contribute in terms of percentage cover, the species/taxa would not be classed as dominant.

6.3.2.3 Size-class Frequency Distributions

Size-class frequency distributions of dominant and subdominant hard coral taxa were recorded along belt transects at each of the coral monitoring sites, with the exception of Ant Point Reef and Southern Lowendal Shelf. Size-class frequency distributions were not measured at these two sites because they were dominated by branching *Acropora* thickets. *Acropora* thickets are unsuitable for size-class frequency distribution surveys because individual colonies could not be reliably differentiated (RPS 2009).

Colonies were measured along five randomly-placed 10 m long belt transects radiating out from the anchor point of the vessel. Only four transects were surveyed at deeper sites (Lone Reef) due to constraints on dive time. The maximum linear dimension ('diameter') of colonies >10 cm was measured in a belt transect 1 m wide on the right side of the transect, while colonies <10 cm were measured in a belt transect 25 cm wide on the left side of the transect (Smith *et al.* 2005). The average number of colonies measured was >60 along each transect and >300 at each site. Colonies were categorised into the following size-classes based on maximum colony diameter: 0.1–2.0 cm, 2.1–5.0 cm, 5.1–10.0 cm, 10.1–20 cm, 20.1–50.0 cm, 50.1–100.0 cm, 100.1–200.0 cm, 200.1–500.0 cm and 500.1–1000.0 cm, which is consistent with other studies of size-class frequency distributions (e.g. van Woesik and Done 1997).

To avoid bias associated with boundary effects, if ≥50% of a colony was within the belt transect, it was included in the measurements; if <50% was within the belt transect it was excluded (Zvuloni *et al.* 2008). If a colony was divided by partial mortality into separate patches of living tissue but remained structurally intact as a single entity, it was considered to be one colony (Bak and Meesters 1998). In these cases, the longest linear dimension of the entire colony, including the separate patches, was measured.

Generally, information on coral population structure is collected at the species or genus level due to inherent differences in population structure among coral taxa (Bak and Meesters 1998); however, because of difficulties in identifying corals to the species level in-water, data collected in the Marine Baseline Program were predominantly at the genus level. Some colonies in the families Faviidae, Fungiidae, Agariciidae and Mussidae were not able to be identified to genus level and were thus grouped at the family level. Common genera from the Faviidae family that were grouped included *Goniastrea*, *Platygyra*, *Favia* and *Favites*, which are difficult to distinguish from each another. All other unidentified genera in the Faviidae and other families were likely to be uncommon. The classification system used for coral identification is shown in Table 6-3.

Table 6-3 Classification System Used for Corals in Size-class Frequency Distribution

Family	Genera
Acroporidae	*Acropora, Astreopora, Montipora*
Agariciidae	*Pachyseris*, *Pavona*, "agariciids" genera unknown
Caryophylliidae	*Euphyllia*
Dendrophylliidae	*Tubastraea, Turbinaria*
Faviidae	*Cyphastrea, Diploastrea, Echinopora, Favia, Favites, Goniastrea, Leptoria, Platygyra*
Fungiidae	*Fungia*, *Herpolitha*, "fungiids" genera unknown
Merulinidae	*Hydnophora, Merulina*
Milleporidae	*Millepora*
Mussidae	*Lobophyllia, Symphyllia, "mussids"* genera unknown

Family	Genera
Oculinidae	*Galaxea*
Pectiniidae	*Echinophyllia, Mycedium, Oxypora, Pectinia*
Pocilloporidae	*Pocillopora, Seriatopora, Stylophora*
Poritidae	*Goniopora, Porites*
Siderastreidae	*Coscinaraea, Psammocora*
"Unidentified"	Family Unknown

6.3.2.4 Photo-quadrats – Live Coral Cover and Coral Survival

At each coral monitoring site, five 20 m long random transects were set out and a 1 m^2 quadrat was photographed every two metres along each transect (Plate 6-1) (RPS 2009).[1] Five 20 m long fixed transects were also established at four of the monitoring sites (Ant Point Reef, Southern Lowendal Shelf, Dugong Reef and Batman Reef) to monitor discrete 1 m^2 areas of coral through time. All photographs were taken with a Canon IXUS 860 IS digital camera fixed in a frame mounted to the quadrat to maintain a consistent distance and orientation above the seabed. Taking the photographs at 2 m intervals along each transect ensured that no part of the transect was photographed twice and that there was no bias as to where a photograph was taken. A total of 50 quadrats (ten per transect) were photographed at each site.

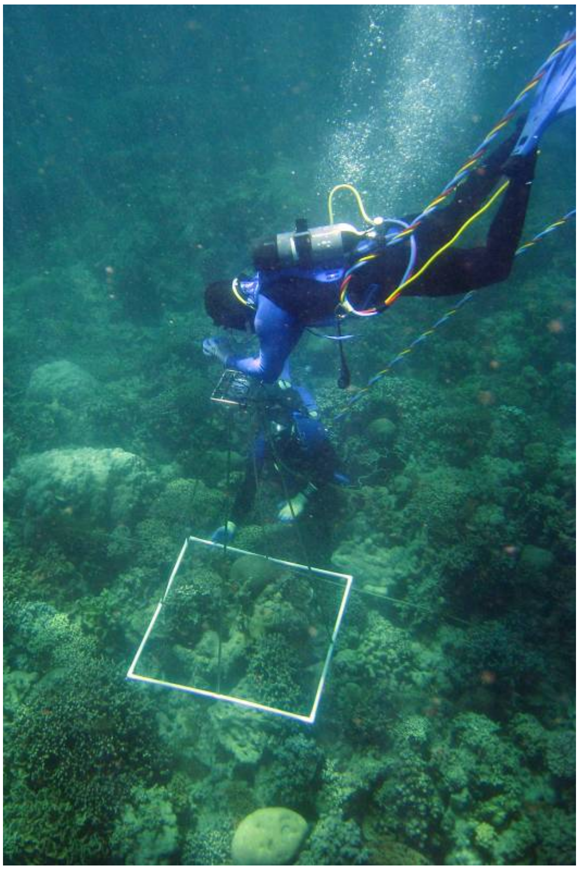


Plate 6-1 Divers Photographing a 1 m² Photo-quadrat

[1] Four 0.25 m^2 quadrats were used to total 1 m^2 when shallow water depths prevented the use of the 1 m^2 quadrat, e.g. at Biggada Reef.

6.3.2.5 Tagged Colonies – Coral Growth and Coral Survival

At each coral monitoring site where colonies were tagged, the intent was to tag a minimum of ten colonies of each genus. Where practicable, additional colonies were tagged as 'contingency' colonies in the event that some colonies died. However, at some sites (MOF1, LNG0, LNG1, LNG3 and Ah Chong) there were insufficient numbers of colonies of each genus present to achieve this level of tagging. Growth in colonies with branching morphologies was measured at five sites (Ant Point Reef, Southern Lowendal Shelf, Ah Chong, Batman Reef and Southern Barrow Shoals) where there were sufficiently abundant numbers of branching colonies. At sites where coral cover was high, a permanent transect was established and healthy colonies were randomly tagged along the transect. At sites dominated by large *Porites* bomboras where coral cover was low, individual colonies of *Acropora* and *Lobophyllia* were located and tagged. Colonies were randomly chosen with no pre-selected criteria other than that they appeared healthy. All photographs were taken with a Canon IXUS 860 IS digital camera.

At three sites (Southern Lowendal Shelf, Dugong Reef and Batman Reef) permanent photo-quadrats were established to monitor the growth of colonies within quadrats through time (Plate 6-2). In each photo-quadrat the maximum number of colonies of each selected genus was monitored.

The genera and number of colonies tagged at each site are presented in Table 6-4. Note that the numbers of tagged colonies declined between the time periods because of coral mortality or tag loss. Colonies were identified to genus level due to the difficulty of identifying corals to species level in-water.

Table 6-4 Genus/Family, Method and Number of Colonies Measured for Growth and Survival at each Site

Location	Site	Number of Colonies of each Genus/Family Measured and Alive at Time 0
Non-branching Tagged Colonies		
Zone of High Impact	LNG0	10 x *Acropora*
Zone of Moderate Impact	MOF1	9 x *Acropora*, 7 x *Lobophyllia*
	LNG1	8 x *Acropora*, 7 x *Lobophyllia*
	Lone Reef	18 x *Acropora*, 2 x *Lobophyllia*
Zone of Influence	Ant Point Reef	17 x *Acropora*
Reference	Ah Chong	10 x *Acropora*, 10 x *Lobophyllia*
	Biggada Reef	14 x *Acropora,* 3 x Faviidae
	LNG3	10 x *Acropora*, 8 x *Lobophyllia*
Regionally Significant Areas	Southern Barrow Shoals	9 x *Acropora*, 11 x *Montipora*
Branching Tagged Colonies		
Zone of Influence	Ant Point Reef	11 x *Acropora*
	Southern Lowendal Shelf	10 x *Acropora*
Reference	Ah Chong	10 x *Porites*
Regionally Significant Areas	Batman Reef	9 x *Porites*
	Southern Barrow Shoals	9 x *Acropora*
Photo-quadrats Non-branching Colonies		
Zone of Influence	Southern Lowendal Shelf	33 x *Acropora*, 11 x *Montipora*
Regionally Significant Areas	Dugong Reef	5 x *Acropora*, 10 x *Montipora*, 3 x *Lobophyllia*, 4 x *Pectinia*
	Batman Reef	11 x Faviidae, 3 x *Lobophyllia*, 6 x *Pectinia*

Acropora colonies with a tabular or corymbose morphology (Plate 6-2) were selected for measuring growth because they are:

- fast growing, so growth can be measured over a short period of time (Wakeford *et al.* 2008)
- moderately sensitive to shading, sedimentation and bleaching (Stafford-Smith and Ormond 1992; Wesseling *et al.* 1999; Marshall and Baird 2000) and therefore are appropriate 'indicator species'
- present in high enough numbers to be able to measure replicates and at all sites (except Batman Reef), which will facilitate future comparisons of coral growth.

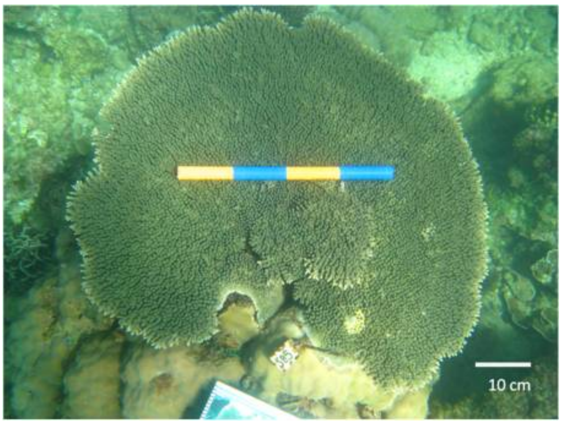
Growth of branching *Acropora* colonies was also measured at monitoring sites where they were the dominant genus and morphology (e.g. Ant Point Reef and Southern Lowendal Shelf) or where they were abundant (e.g. Southern Barrow Shoals) (Plate 6-2).

Lobophyllia colonies with a massive morphology (Plate 6-2) were also selected for measuring growth because they were widely distributed and present at many of the monitoring sites, as well as being present in high enough numbers to be able to measure replicates.

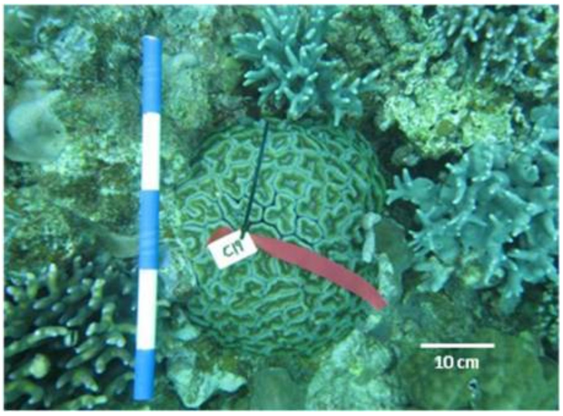
At sites where these genera were not present, or not present in sufficiently high abundances, the dominant genera were monitored (e.g. *Montipora*, *Pectinia* and faviids). Because of their documented very slow growth (~1 cm per year; Chornesky and Peters 1987), which makes the measurement of growth over relatively short timeframes difficult, the growth of massive *Porites* colonies was not monitored in the Marine Baseline Program. However, the growth of branching *Porites* was monitored to assess whether branching colonies grew faster and could therefore be used to monitor coral growth at sites where they were dominant.

Growth in corals with a massive or corymbose morphology was measured as the change in area of the colony over time. Tagged corymbose and massive colonies were photographed from above while maintaining a consistent distance and orientation, with a graduated bar for scaling (Plate 6-2). Photographs of colonies within quadrats included the quadrat for scale. Growth in corals with branching morphology was measured by fixing a cable tie around each of one to four branches per colony and the maximum linear length measured between the cable tie and the growing tip. Note that because of branch breakage, tags were replaced on some colonies after the first monitoring period, with tags placed on different branches to the original branch.

Tagged colonies and photo-quadrats were also used in the measurement of live tissue of individual colonies over time.



Tagged Non-branching *Acropora* Colony (*A. hyacinthus*)



Tagged Non-branching *Lobophyllia* Colony (*L. hemprichii*)

Branching *Acropora* Colony (*A. intermedia*) for which linear branch extension was measured

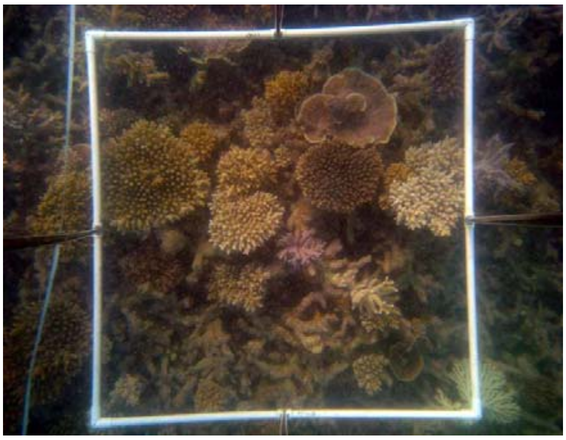


Photo-quadrat to monitor colony growth

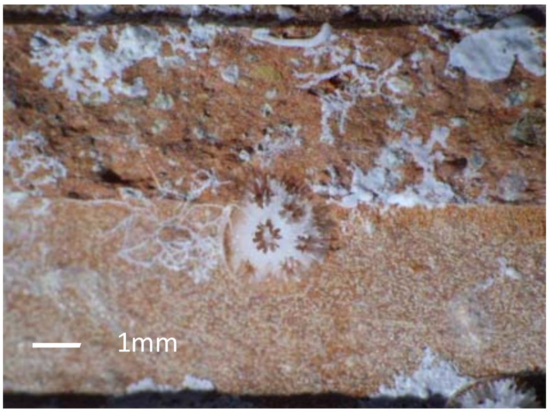
Plate 6-2 Measurement of Coral Growth

6.3.2.6 Coral Recruitment

Coral recruitment was monitored at 11 of the 12 coral monitoring sites. Recruitment was not measured at the Reference Site at Ah Chong. The distance from Barrow Island and the dependency on good weather to access the site, limited the ability to regularly deploy and retrieve recruitment tiles at this site.

At each site, 12 terracotta tiles (145 x 145 x 12 mm) were deployed as uniform artificial recruitment substrates (Wallace 1985; English *et al.* 1997; Mundy 2000; RPS 2009). Each tile was anchored to an 8 kg reconstituted limestone block (300 x 300 x 60 mm) to prevent disturbance by water movement and to maintain a consistent tile orientation (Plate 6-3). Each tile was mounted 2.5 cm above the block to permit water flow and coral recruitment, while restricting herbivore access to the underside of the tiles (Mundy 2000). The tiles were distributed in three groups of four at a consistent depth across each site over a distance of 150 m, with at least three metres between each tile. There was no significant variation among groups of tiles within deployment periods between March 2008 and March 2009, nested within sites (p = 0.240); but there was a significant difference in recruitment among sites (p > 0.05). Thus, averaged across sites and deployment periods, there was no evidence of within site spatial variation in the number of coral recruits among groups of tiles collected at a site/deployment period.

Recruitment Tile attached to Limestone Block



Pocilloporid Coral Recruit on Recruitment Tile

Plate 6-3 Monitoring Coral Recruitment

On retrieval, tiles were bleached for 24 hours prior to inspection under a dissecting microscope (Plate 6-3). The number of recruits on the lower or underside and side surfaces (total area approximately 0.028 m^2) of each tile were counted and each recruit was classified into one of three taxonomic groups (Acroporidae, Pocilloporidae, Poritidae) or 'Unidentified' (English *et al.* 1997). 'Unidentified' recruits are those lacking distinguishing skeletal structures by which they can be identified.

Ten of the 869 tiles (1.2%) deployed over the 16 months of the Marine Baseline Program were lost or otherwise unusable (for example because of burial in sand) for recording coral recruitment.

6.3.3 Timing and Frequency of Sampling

6.3.3.1 Mapping

Ground-truthing and mapping of coral assemblages at each monitoring site was undertaken between October 2008 and April 2009 (Table 6-5).

Table 6-5 Coral Assemblage Mapping Survey Dates

Site	Survey Dates
Coral Assemblages in the Zones of High and Moderate Impact:	
LNG0	January 2009
MOF1	October 2008
LNG1	October 2008
Lone Reef	October 2008
Coral Assemblages outside Zones of Impact and not at risk of Material or Serious Environmental Harm (Zones of Influence, Reference Sites and Regionally Significant Areas):	
Ant Point Reef	November 2008
Southern Lowendal Shelf	November 2008
Ah Chong	November 2008, March 2009
LNG3	December 2008
Biggada Reef	Not mapped
Batman Reef	November 2008
Dugong Reef	November 2008, December 2008
Southern Barrow Shoals	December 2008

6.3.3.2 Rapid Visual Assessment Surveys

The RVA surveys to record the dominant and subdominant hard and soft coral species/taxa were undertaken once at each coral monitoring site between October 2008 and January 2009 (RPS 2009). The RVA survey data were cross-referenced with the first set of photo-quadrat data collected between May 2008 and January 2009 (Table 6-6).

6.3.3.3 Size-class Frequency Distributions

Size-class frequency distributions were measured once between October 2008 and January 2009 (RPS 2009).

6.3.3.4 Photo-quadrats – Live Coral Cover and Survival

The timing and frequency of photographing transects are documented in Table 6-6. Quadrats within random transects were photographed initially and then re-photographed after approximately six months and 12 months. Additional opportunistic sampling was undertaken at other time intervals at some sites (e.g. transects were photographed five times at Ant Point Reef to document the observed decline in coral cover at this site). Quadrats within fixed transects were photographed initially, after two months, and again after approximately six and 12 months. Note that the transects were photographed on different dates at each of the monitoring sites.

Table 6-6 Dates Transects were Photographed for Assessment of Live Coral Cover at each Coral Monitoring Site

Location	Site	Time 0	Time 1	Time 2	Time 3	Time 4
Random Transects						
Zone of High Impact	LNG0	Jan 2009	Aug 2009	Nov 09	-	-
Zone of Moderate Impact	MOF 1	Oct 2008	Apr 2009	Oct 2009	-	-
	LNG 1	Oct 2008	Apr 2009	Aug 2009	Nov 2009	-
	Lone Reef	Oct 2008	Apr 2009	Jun 2009	Nov 2009	-
Zone of Influence	Ant Point Reef	May 2008	Nov 2008	Mar 2009	Jun 2009	Aug 2009
	Southern Lowendal Shelf	May 2008	Nov 2008	May 2009	-	-
Reference	Ah Chong	Sep 2008	Mar 2009	Jun 2009	Oct 2009	-
	Biggada Reef	Oct 2008	Mar 2009	Jun 2009	Oct 2009	-
	LNG3	Sep 2008	Mar 2009	Aug 2009	Nov 2009	-
Regionally Significant Areas	Dugong Reef	May 2008	Nov 2008	Jun 2009	-	-
	Batman Reef	June 2008	Oct 2008	Aug 2009	-	-
	Southern Barrow Shoals	Oct 2008	Apr 2009	Jun 2009	Oct 2009	-
Fixed Transects						
Zone of Influence	Ant Point Reef	May 2008	Jul 2008	Jun 2009	Aug 2009	-
	Southern Lowendal Shelf	May 2008	Jul 2008	May 2009	Aug 2009	-
Regionally Significant Areas	Dugong Reef	May 2008	July 2008	Dec 2008	June 2009	-
	Batman Reef	May 2008	July 2008	Dec 2008	June 2009	-

6.3.3.5 Tagged Colonies – Coral Growth and Coral Survival

The timing and frequency of photographing of tagged colonies and photo-quadrats are documented in Table 6-7. Colonies were photographed initially and then re-photographed after approximately six months and 12 months. Note that the colonies were photographed on different dates at each of the monitoring sites.

Table 6-7 Dates Tagged Colonies were Photographed at each Coral Monitoring Site

Location	Site	Time 0	Time 1	Time 2
Non-branching Tagged Colonies				
Zone of High Impact	LNG0	Jan 2009	Aug 2009	Nov 2009
Zone of Moderate Impact	MOF 1	Oct 2008	Apr 2009	Oct 2009
	LNG 1	Oct 2008	Apr 2009	Nov 2009
	Lone Reef	Oct 2008	Apr 2009	Nov 2009
Zone of Influence	Ant Point Reef	May 2008	Nov 2008	May 2009
Reference	Ah Chong	Sep 2008	Mar 2009	Sep 2009
	LNG3	Sep 2008	Mar 2009	Nov 2009
	Biggada Reef	Oct 2008	Mar 2009	Oct 2009
Regionally Significant Areas	Southern Barrow Shoals	Oct 2008	Apr 2009	Oct 2009
Branching Tagged Colonies				
Zone of Influence	Ant Point Reef	Sep 2008	Mar 2009	Sep 2009
	Southern Lowendal Shelf	Sep 2008	Mar 2009	Nov 2009
Reference	Ah Chong	Sep 2008	Mar 2009	Sep 2009
Regionally Significant Areas	Batman Reef	Sep 2008	Mar 2009	Not measured
	Southern Barrow Shoals	Oct 2008	Apr 2009	Oct 2009
Photo-quadrats Non-branching Colonies				
Zone of Influence	Southern Lowendal Shelf	May 2008	Nov 2008	May 2009
Regionally Significant Areas	Dugong Reef	Jun 2008	Dec 2008	June 2009
	Batman Reef	Jun 2008	Dec 2008	June 2009

6.3.3.6 Coral Recruitment

Deployment of recruitment tiles commenced in March 2008 and continued through to July 2009 (Table 6-8). Tiles were deployed for approximately 8–12 week intervals to monitor temporal variation in the recruitment of hard corals. Note that the tiles were deployed and retrieved over different time periods at each of the monitoring sites.

Tiles were deployed throughout the year to monitor the recruitment of planula brooding species and deployments were timed to coincide with periods of larval settlement following predicted major broadcast spawning events in autumn and spring. Coral larvae require the presence of bacteria and filamentous algae (microflora) on a surface to stimulate settlement (e.g. Loya 1976; Tomascik 1991). Tiles were therefore deployed two weeks prior to predicted mass spawning periods in autumn and spring to allow time for the establishment of microflora to encourage larval settlement (Heyward *et al.* 2002).

Table 6-8 Dates Coral Recruitment Tiles were Deployed at each Monitoring Site

Location	Site	Time 0	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6
Zone of High Impact	LNG0	Jan 2009	Mar 2009	May 2009	-	-	-	-
Zone of Moderate Impact	MOF 1	Mar 2008	Jun 2008	Sep 2008	Dec 2008	Mar 2009	May 2009	-
	LNG 1	Mar 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009	-
	Lone Reef	Mar 2008	Jul 2008	Oct 2008	Dec 2008	Mar 2009	Apr 2009	-
Zone of Influence	Ant Point Reef	Mar 2008	May 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009
	Southern Lowendal Shelf	Mar 2008	May 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009
Reference	Ah Chong	Not Sampled						
	Biggada Reef	Mar 2008	May 3008	Jul 2008	Oct 2008	Jan 2009	Mar 2009	May 2009
	LNG3	Mar 2008	Jun 2008	Sep 2008	Dec 2008	Mar 2009	May 2009	-
Regionally Significant Areas	Dugong Reef	Mar 2008	May 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009
	Batman Reef	Mar 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009	-
	Southern Barrow Shoals	Mar 2008	Jul 2008	Sep 2008	Dec 2008	Mar 2009	May 2009	-

6.3.4 Treatment of Survey Data

6.3.4.1 Rapid Visual Assessment Surveys

Species lists and estimated relative abundances were compiled for each coral monitoring site. The species lists compiled in the Marine Baseline Program were compared to existing species lists for the North West Shelf, Western Australia and Australia to identify any new taxonomic records.

The following information was recorded for each site:

- Dominant coral species: The dominant coral species, as defined in Schedule 2, Statement No. 800 and Schedule 2, EPBC Reference: 2003/1294 and 2008/4178, is the species with the highest relative percentage cover, where percentage cover is expressed as the proportion of total coral cover. In this study, this equates to the highest abundance scale from the RVA surveys in combination with the percentage cover of families. In the event there were multiple species with equal maximum abundance scales, there was no one dominant species.
- Subdominant coral species: The subdominant coral species, as defined in Schedule 2, Statement No. 800 and Schedule 2, EPBC Reference: 2003/1294 and 2008/4178, are species, excluding dominant coral species, which have ≥5% cover. In this study, this equates to an abundance scale of 3, 4 or 5 from the RVA surveys and there can be numerous subdominant species.
- 'Species of interest': Includes new records for the region or species that were recorded at only one site.

Estimates of percentage cover of hard and soft coral species/taxa from photo-quadrats were used to complement the results from the RVA surveys. Each taxon was expressed as a percentage of the total number of points classified from photo-quadrats (Section 6.3.4.3) and also as a percentage of the total cover of hard corals in accordance with the definitions of dominant and subdominant species.

6.3.4.2 Size-class Frequency Distributions

Coral colony size data were used to produce size-class frequency distribution plots for each of the sites. Genera were grouped into families for data analysis because few genera occurred in sufficient abundance to be analysed separately. In general, families were examined individually when there were data for >20 colonies, or where the family constituted >5% of all the colonies measured at a site. Thus sites at which colony densities were low were not excluded from the analyses and subdominant species were included. The remainder of genera, as well as the small number of unidentified colonies present at each site (0–4.5%), were grouped together as 'Other' corals. The exceptions were the families Acroporidae, Poritidae and Faviidae, which met the criteria for all sites (with the exception of the Acroporidae at Biggada Reef and the Poritidae at MOF1). Size-class frequency distributions were plotted for these two sites despite the low abundance of colonies, thus there were three families for which comparisons could be made across all sites. The faviids were numerically abundant, but due to their small size, they did not contribute as much to the percentage cover of hard corals as the acroporids and poritids. The number of colonies measured at each site within each of the families and the percentage composition of each family at each site are shown in Table 6-9.

Table 6-9 Numbers of Colonies in each Family and Percentage of all Corals at each Coral Monitoring Site Measured for Size-class Frequency Distributions

	Zones of High Impact		Zones of Moderate Impact						Reference						Regionally Significant Area					
	LNG0		MOF1		LNG1		Lone Reef		Ah Chong		Biggada Reef		LNG3		Dugong Reef		Batman Reef		Southern Barrow Shoals	
Family	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Acroporidae	**22**	**7.7**	**122**	**38.7**	**24**	**8.9**	**25**	**11.2**	**24**	**5.2**	**4**	**3.0**	**35**	**10.4**	**71**	**15.8**	**21**	**5.8**	**123**	**35.2**
Agariciidae	1	0.4	8	2.5	11	4.1	3	1.3	2	0.4	0	0.0	2	0.6	**20**	**4.5**	1	0.3	1	0.3
Caryophyllidae	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	0.4	0	0.0	0	0.0
Dendrophyllidae	**17**	**6.0**	8	2.5	**25**	**9.3**	**13**	**5.8**	2	0.4	0	0.0	**27**	**8.0**	11	2.4	4	1.1	4	1.1
Faviidae	**79**	**27.7**	**89**	**28.3**	**49**	**18.2**	**46**	**20.6**	**157**	**33.8**	**96**	**72.2**	**107**	**31.7**	**127**	**28.3**	**154**	**42.8**	**158**	**45.3**
Fungiidae	2	0.7	8	2.5	4	1.5	0	0.0	3	0.6	2	1.5	7	2.1	17	3.8	8	2.2	2	0.6
Merulinidae	2	0.7	**16**	**5.1**	3	1.1	4	1.8	**26**	**5.6**	5	3.8	2	0.6	**28**	**6.2**	**22**	**6.1**	3	0.9
Milleporidae	**15**	**5.3**	0	0.0	1	0.4	6	2.7	1	0.2	0	0.0	0	0.0	0	0.0	5	1.4	6	1.7
Mussidae	**23**	**8.1**	**19**	**6.0**	**19**	**7.1**	2	0.9	**33**	**7.1**	1	0.8	9	2.7	**49**	**10.9**	8	2.2	6	1.7
Oculinidae	1	0.4	5	1.6	0	0.0	4	1.8	**28**	**6.0**	0	0.0	0	0.0	**21**	**4.7**	4	1.1	1	0.3
Pectiniidae	3	1.1	14	4.4	5	1.9	6	2.7	18	3.9	5	3.8	7	2.1	**55**	**12.2**	**41**	**11.4**	1	0.3
Pocilloporidae	1	0.4	1	0.3	10	3.7	11	4.9	19	4.1	6	4.5	3	0.9	3	0.7	12	3.3	11	3.2
Poritidae	**107**	**37.5**	**11**	**3.5**	**107**	**39.8**	**93**	**41.7**	**145**	**31.3**	**13**	**9.8**	**129**	**38.2**	**37**	**8.2**	**71**	**19.7**	**26**	**7.4**
Siderastreidae	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	1	0.8	0	0.0	0	0.0	0	0.0	0	0.0
Unidentified species	11	3.9	14	4.4	11	4.1	10	4.5	6	1.3	0	0.0	10	3.0	8	1.8	9	2.5	7	2.0
Total	285	100	315	100	269	100	223	100	464	100	133	100	338	100	449	100	360	100	349	100

Notes: Families in bold are those for which histograms are presented for every site; numbers in bold are sites at which each family is presented individually; non-bold type represents families grouped into 'Others' at each site due to low abundances.

The total percentage of corals at each coral monitoring site is 100%; however, the contribution of each family in each site may not sum exactly to 100% as a result of rounding.

Several statistical measures were used to describe the size-class frequency distributions of the coral populations at each site (Table 6-10). These will be used in future comparisons to evaluate changes in the coral size-class frequency distributions at sites over time (Bak and Meesters 1998, 1999).

Table 6-10 Statistical Measures of Change in Size-class Frequency Distribution

Resolution	Data Type	Statistical Measure	Population Structure Attribute
Site and Family Level	Count Data	Mode	Represents most frequently occurring colony diameter at a site
		Skewness	Describes the shape of the distribution of the diameter of colonies at a site
Transect and Genus/Family Level		Number of Corals	Mean colony density at a site
		Mean number of juveniles ≤5 cm	Estimates the number of small (presumed newly recruited) colonies at a site
		Mean number of colonies >200 cm	Estimates the number of large (presumably older) colonies at a site
Transect and Genus/Family Level	Size Data	Arithmetic mean	Mean diameter of colonies at a site
		Standard deviation	Measure of variance in the diameter of colonies at a site
		Coefficient of Variation	Describes variation in colony diameter, standardised by the mean diameter of colonies at a site; allowing a comparison of the relative variation in colony diameter among sites with different mean diameters

Mode and skewness were calculated for colonies grouped at the site and family level to ensure there were sufficient numbers of replicates to implement the measure. Mode was calculated as the size-class with the greatest number of colonies; skew was calculated on the raw data distributions. In general, if the distribution is symmetric, skewness will be close to zero. A negative value indicates skew to the left, where there are relatively few values in the lower size-classes; and a positive value indicates skew to the right where there are relatively few values in the upper size-classes. A measure of the standard error (SE) of skewness was calculated according to the number of replicates used to calculate the distribution: standard error = $\sqrt{(6/n)}$ (Tabachnick and Fidell 1996). If the skewness was more than twice this value, it is indicative that the distribution of the data was non-symmetric.

More detailed information relating to further statistical measures of coral genera or families are included in the discussion of the results where the data are presented as the mean variation for corals within transects (Section 6.4.3). These measures were calculated at the genus level where possible (31 genera and four family level taxa were examined) and the means of transects were calculated with standard errors so that statistical tests can be undertaken between time periods when the measures are recalculated. The mean number of corals was calculated as an average density over the mean of five transects. The mean number of small (≤5 cm) and large (≥200 cm) colonies and the mean size of colonies were calculated over the mean of the number of transects where each genus/family were recorded. Total values were calculated for all colonies, as well as for both small and large colonies separately, by pooling counts of colonies of all taxa per transect and averaging this value over the five transects. The standard deviation and coefficient of variation were calculated over the mean of the number of transects containing more than one colony for each genus/family because the value of these was zero for transects where there was only one colony of a particular taxa. Total values were calculated by pooling sizes from colonies of all taxa per transect and averaging these values over the five transects.

6.3.4.3 Photo-quadrats – Live Coral Cover and Survival

Digital images of the 1 m^2 quadrats were analysed by randomly allocating 30 points to each image and then classifying the substrate or organism beneath each point. Thirty points per quadrat was selected on the basis that similar studies have demonstrated that while there is a substantial increase in precision from 5 to 10 points per frame and from 10 to 25 points per frame, the increase in precision from 25 to 50 points per frame is marginal (Stoddart *et al.* 2005). The program Coral Point Count with Excel extensions (CPCe) was used to automate the random point count analysis process (Kohler and Gill 2006). Note that photo-quadrats with random point counts have been shown to produce higher estimates of coral cover than point intercept transects for the same area (Brown *et al.* 2004).

The substrate (e.g. sand, rock, rubble) or organism (e.g. coral, macroalgae, sponge) beneath each point was recorded. Points where it was unclear what was beneath a point were classified as 'Unknown' and excluded from any estimates. Organisms were classified to the greatest taxonomic resolution possible. The categories were adapted from the life form categories for classifying benthic communities used by the Australian Institute of Marine Science (English *et al.* 1997), but all corals were identified to family level and the other categories were grouped together. Count data were exported to Microsoft Excel from the CPCe program and each scleractinian family, *Millepora* spp. and the total of both the soft corals and the scleractinian corals, were expressed as a percentage of the total number of points classified from the photo-quadrats. Coral taxa were also expressed as a percentage of the total cover of hard corals in accordance with the definition of dominant and subdominant species.

The mean percentage cover of the major taxonomic groups (each scleractinian family, bleached coral, *Millepora* spp., soft corals, other sessile benthic macro-invertebrates, macroalgae, turfing algae, coralline algae, as well as hard substratum and sand) within the random transects is presented for each site/time. Percentage covers were calculated as the number of points in each category over the total of all classified points. Quadrats within transects were summed before calculating the average and standard errors of the five transect means for each site/time.

Plots of the change in the percentage of live coral cover (expressed as a percentage of total hard substratum; i.e. sum of all points classified excluding sand) within random transects, through time at each site are presented. Coral survival was measured as the change in the percentage of live coral over at each site through time.[2] Site averages and standard errors were based on the mean of the five transects within each site (with all quadrats summed for each transect). Analysis of Variance (ANOVA) was used to test for differences in the percentage of live coral cover among sampling times for each site. Data were arcsine transformed prior to analysis to correct variances for upper and lower limits inherent in percentage data.

Plots of the change in the percentage of live coral cover (expressed as a percentage of total hard substratum; i.e. sum of all points classified excluding sand) between time intervals for fixed transects at each site are also presented. Site averages used to calculate the change in cover between each survey and the initial survey were based on the mean of five transects within each site (with all quadrats summed for each transect). Quadrats within transects were located at approximately similar positions along each transect on each survey occasion, while transects remained fixed.

6.3.4.4 Tagged Colonies – Coral Growth and Coral Survival

Growth was measured as the increase in area of individual tagged tabular, corymbose and massive colonies and as the linear extension of branching colonies, over time (English *et al.* 1997). The area of tabular and corymbose colonies was calculated from digital photographs of each colony using CPCe (Kohler and Gill 2006). The outline of the colony was traced and the area calculated on a scaled photograph (Plate 6-4). Means and standard errors were calculated for

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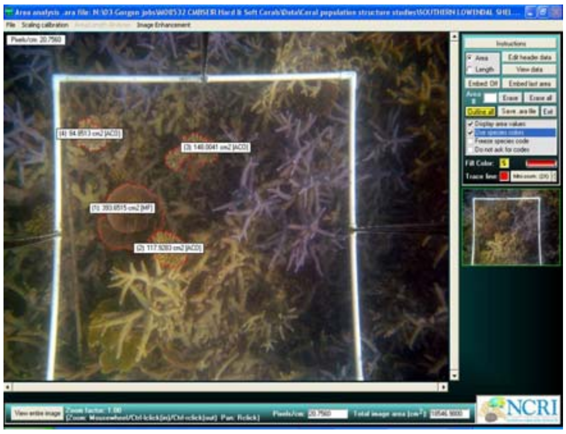
[2] Note that this measure represents the change in the overall live coral cover, which is not strictly survival but *loss - (growth + recruitment)*, rather than the survival of individual colonies (see Section 6.3.4.4).

each genus pooled across sites, each site with genera pooled and for each genus at each site. Data are presented as change in size per month for each six-month period (Time 1 and Time 2), as well as for the whole 12 months. Where tags on branching colonies were replaced at Time 1, branch growth measurements were recorded for the six-month period, not the overall 12-month period because different branches were measured at Time 0 and Time 2. Branches were treated as independent units.

Survival was measured as the change in the proportion of live coral (partial mortality) of individually tagged colonies; note that branching corals were not suitable for survival measurements. For measurement of partial mortality, 60 randomly allocated points were overlaid over a digital image of each colony using CPCe (Kohler and Gill 2006) and each point was classified as live coral, bleached coral, dead coral or ‘other’ (if the point was outside the colony or could not clearly be classified). Count data were exported to Microsoft Excel from the CPCe program and the percentage of live tissue was calculated from the total number of points scored as live coral, bleached coral and dead coral (the ‘other’ points were excluded). Estimates of colony survival were measured as the change in average percentage of live tissue of colonies between time intervals for each site with genera/families pooled, each coral genus/family pooled across sites and for each genus/family within each site.

Screen capture from CPCe showing the traced outline of an *Acropora divaricata* colony and the area calculation



Screen capture from CPCe showing the traced outlines and area calculations of several colonies from a permanent photo-quadrat

Plate 6-4 Measurement of Coral Colony Area

Regression analysis was undertaken on the first six months of growth data to test for a relationship between the proportion of growth and the initial size of the colony. Analyses were undertaken for each family at each site, and, out of 14 analyses, only three were significant (Table 6-11). In addition to this, the r^2 values for these significant differences were low indicating that there was not a strong overall relationship between the initial size of the colony and coral growth, thus colony size was not used as a covariate of growth.

Table 6-11 Summary of Tests for Relationships between Coral Growth and Initial Colony Size Across Sites and Genus/Family

Site	Family	Coefficient	r^2	F-ratio	MS (residual)	*p*
LNG0	Acroporidae	0.0009	0.2423	$F_{1,7}$ = 2.2382	0.0392	0.178
MOF1	Acroporidae	0.0005	0.2299	$F_{1,5}$ = 1.4929	0.0172	0.276
	Mussidae	0.0005	0.1151	$F_{1,5}$ = 0.6502	0.0011	0.457
LNG1	Acroporidae	0.0003	0.0487	$F_{1,5}$ = 0.2557	0.0190	0.635
	Mussidae	0.0014	0.5663	$F_{1,4}$ = 5.2231	0.0762	0.084
Lone Reef	Acroporidae	0.0003	0.2154	$F_{1,12}$ = 3.2949	0.0260	0.095
Ant Point Reef	Acroporidae	0.0007	0.5265	$F_{1,14}$ = 15.567	0.4783	**0.001**
Ah Chong	Acroporidae	-0.0001	0.0084	$F_{1,8}$ = 0.0678	0.0211	0.801
	Mussidae	-0.0002	0.0664	$F_{1,8}$ = 0.5687	0.0134	0.472
Biggada Reef	Acroporidae	-0.0034	0.6251	$F_{1,10}$ = 16.4204	0.1201	**0.002**
	Faviidae	0.0016	0.7409	$F_{1,1}$ = 2.8591	0.0076	0.340
LNG3	Acroporidae	0.0012	0.0841	$F_{1,8}$ = 0.7344	0.5415	0.416
	Mussidae	0.00004	0.0011	$F_{1,7}$ = 0.0076	0.0280	0.933
Southern Barrow Shoals	Acroporidae	0.0011	0.4460	$F_{1,18}$ = 14.4923	0.0927	**0.001**

Note: Regressions undertaken separately for each family at each site.

The sampling error associated with the measurement of the growth of non-branching colonies of *Acropora* and *Lobophyllia* was tested at three levels:

1. The difference in colony area when a photograph of Colony A was measured in CPCe by the same scorer on two different occasions.
2. The difference in colony area when a photograph of Colony A was measured in CPCe by two different scorers.
3. The difference in colony area when Colony A was photographed by two different divers and each photograph measured in CPCe by the same scorer. All the colonies at three sites (MOF1, LNG1 and Southern Barrow Shoals) were photographed by one diver, then a sub-sample of colonies were photographed by a second diver. For those colonies that were photographed twice, the colony area was measured from each photograph by the same scorer.

For each level of sampling error, the error was calculated as the mean coefficient of variation. The results are presented in Table 6-12 and these results indicate that the greatest source of error occurred in photographing the colonies. This error may have arisen because of differences between photographers, or there may be inherent differences that arise from two different photographs. This error should be taken into account in future comparisons of growth rates.

Table 6-12 Error Analysis of Coral Growth Measurement Methods

Error Type	n (colonies)	Mean Coefficient of Variation (%) ± SE
1	21	0.7 ± 0.1
2	18	3.1 ± 0.6
3	20	5.4 ± 1.5

6.3.4.5 Coral Recruitment

Counts of coral recruits were averaged across all tiles from each site over each deployment period. One-way Analysis of Variance (ANOVA) was used to compare the numbers of recruits among deployment periods at each site. Sites were analysed separately because deployment times were different for each site.

6.4 Results

6.4.1 Mapping

6.4.1.1 Description and Maps of Coral Assemblages at Sites in the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.1.1.1 Coral Assemblages at Sites in the Vicinity of the MOF and Causeway

Within the vicinity of the MOF, coral was quantitatively mapped and classified at the coral monitoring site MOF1 (Figure 6-5). The site was dominated by Coral Bombora—Non *Porites* Assemblages, characterised by *Diploastrea heliopora* (faviid) bombora, covering an area of 10–50%. There were three subdominant assemblage types identified: a Mixed Coral Assemblage of 10–50% cover; a Mixed Turfing Algae Assemblage of 5–25% cover; and non-coral benthic macro-invertebrates, including taxa such as ascidians and sponges, of 5–25% cover.

6.4.1.1.2 Coral Assemblages at Sites in the Vicinity of the LNG Jetty Access Channel

The two coral monitoring sites (LNG0 and LNG1) in the vicinity of the Access Channel have been quantitatively mapped and classified (Figure 6-6). The dominant assemblage type at both sites was Coral Bombora—*Porites* with a percentage cover of 10–50%. At both sites, the high-profile *Porites* bombora included: *P. australiensis*, *P. cylindrica*, *P. lichen*, *P. lutea*, *P. nigrescens* and *P. rus*. Similarly to MOF1, there were three subdominant assemblage types identified: a Mixed Coral Assemblage of 10–50% cover; a Mixed Turfing Algae Assemblage of 5–25% cover; and non-coral benthic macro-invertebrates of 5–25% cover.

6.4.1.1.3 Coral Assemblages at Sites in the Vicinity of the Dredge Spoil Disposal Ground

The majority of the Dredge Spoil Disposal Ground was characterised by 'Soft Sediment with Sparse Sessile Taxa'. There was one area of coral, Lone Reef (LONE), bordering the Zone of Moderate Impact associated with the Dredge Spoil Disposal Ground (Figure 6-7).

The dominant assemblage type at Lone Reef was Coral Bombora—*Porites* with a percentage cover of 51–75%. Lone Reef was highly rugose with many channels and crevices and a relatively high percentage of live coral cover (~60%). The Coral Assemblage was dominated by large *Porites* bombora including: *P. cylindrica*, *P. lutea*, *P. australiensis* and *P. rus*, some of which were up to 10 m across and 3 m high. The largest *Porites* colonies were located on the eastern edge of the reef. There were three subdominant assemblage types identified: a Mixed Coral Assemblage of 10–50% cover; a Mixed Turfing Algae Assemblage of 5–25% cover; and non-coral benthic macro-invertebrates of 5–25% cover.

6.4.1.2 Description of Coral Assemblages at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

No Coral Assemblages were observed in the WAPET Landing area and thus no Coral Assemblages were at risk of Material or Serious Environmental Harm (Section 2.3.4) due to the marine upgrade of the existing WAPET Landing. The shallow seabed in the vicinity of the existing WAPET Landing was comprised of sand of various depths over limestone pavement. Exposed pavement reef was dominated by macroalgae and supported only a very sparse coral cover (<5%) (Figure 6-8) (RPS 2009a). In these areas, occasional scattered small corals were present, mainly faviids and some *Euphyllia* sp. Occasional small bombora in the deeper areas around the WAPET Landing supported very low coral cover (<5%).

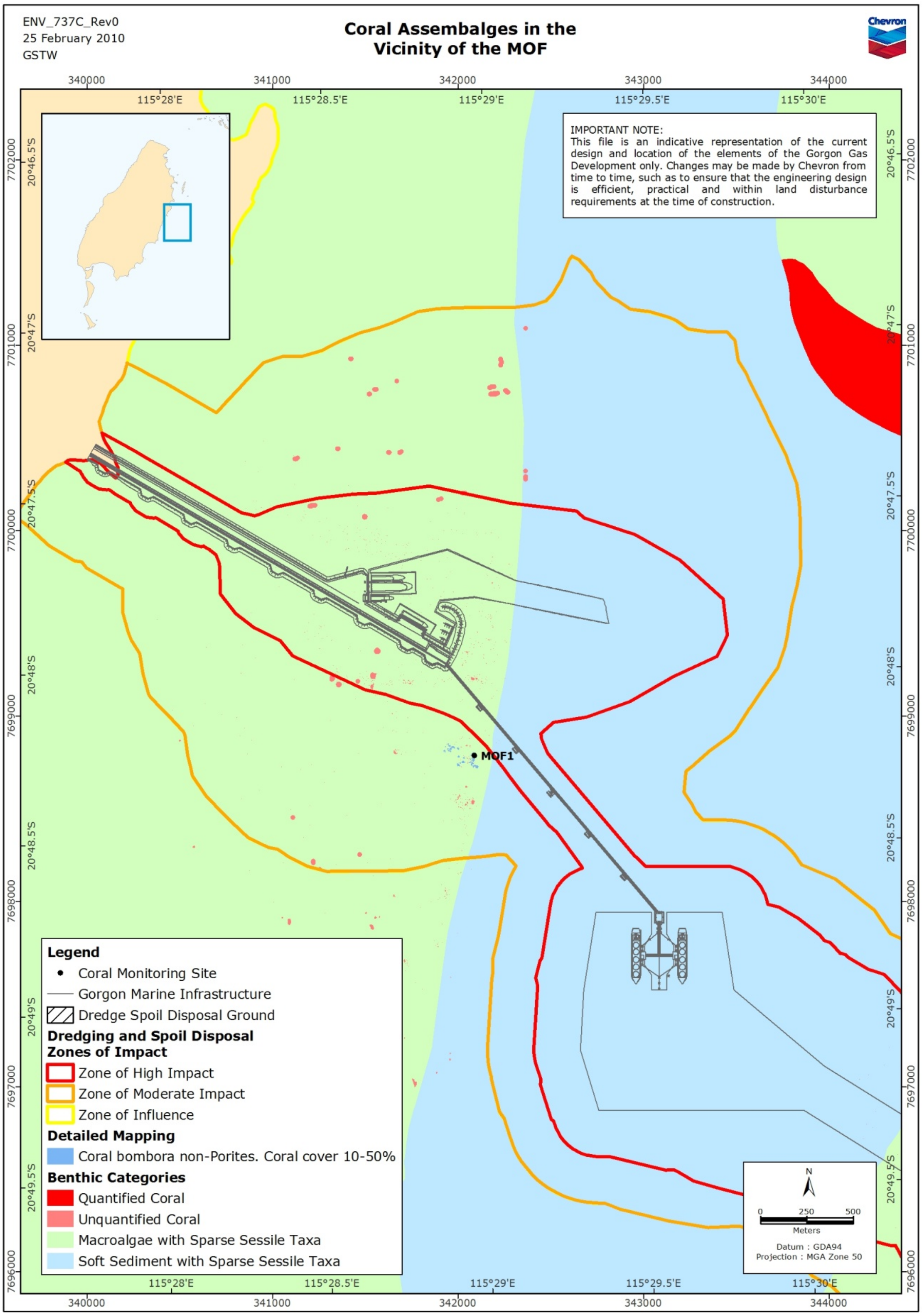


Figure 6-5 Coral Assemblages in the Vicinity of the MOF

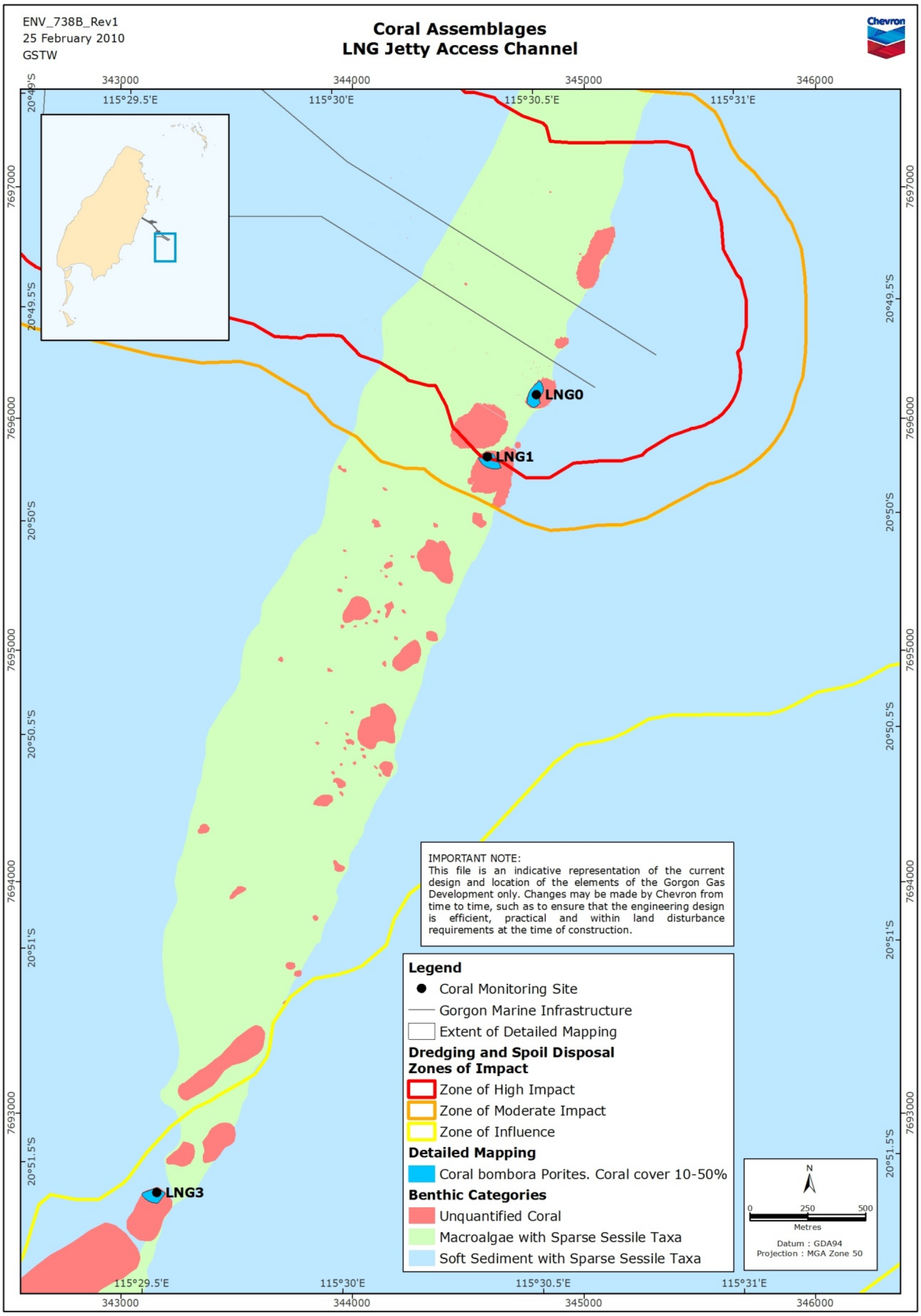


Figure 6-6 Coral Assemblages on East Barrow Ridge in the Vicinity of the LNG Jetty Access Channel

Note: LNG3 is a Reference Site

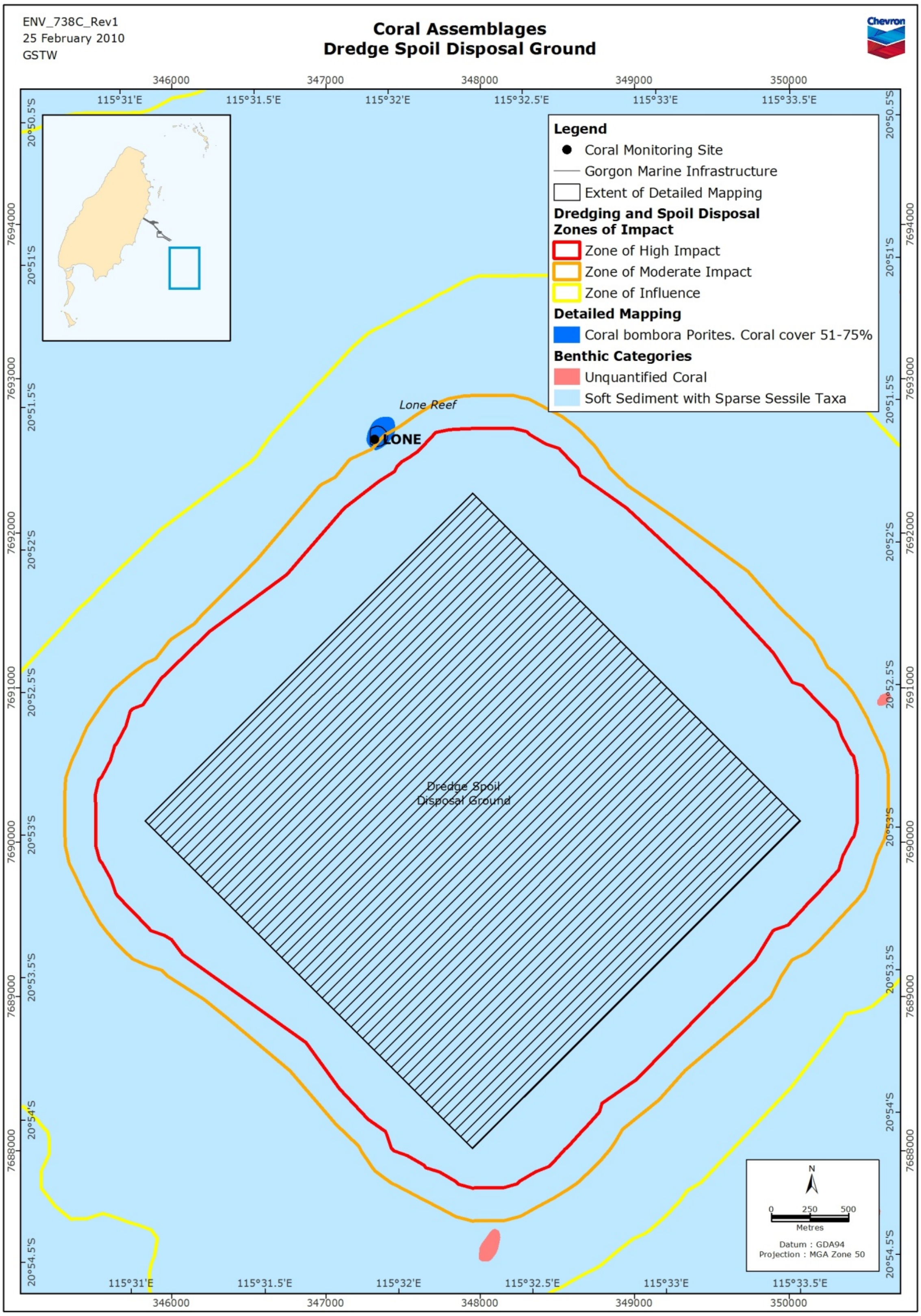


Figure 6-7 Coral Assemblages in the Vicinity of the Dredge Spoil Disposal Ground

6.4.1.3 Description and Maps of Coral Assemblages at Representative Areas in the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.1.3.1 Ant Point Reef (ANT)

Ant Point Reef on the north-east side of Barrow Island is an elongated reef running in a north–south orientation surrounded by 'Macroalgae with Sparse Sessile Taxa' (Figure 6-8). To the north and east of the monitoring site (ANT) were large areas of 'Unquantified Coral'. Large (>10 m in diameter), isolated *Porites* spp. bomboras (most likely *P. lutea*) (Plate 6-5) were evident on aerial photographs and have been observed opportunistically. Other genera reported on these bombora include *Acropora* and *Favia*. These areas remain mapped as 'Unquantified Coral' as they have not been extensively ground-truthed and the dominant benthic assemblage types have not been classified in accordance with the Benthic Habitat Classification Scheme (Section 5.2; Appendix 2).

Plate 6-5 *Porites lutea* Bombora with *Acropora* spp. at Ant Point Reef

The area of the reef at Ant Point around the monitoring site (ANT) was quantitatively ground-truthed and the dominant assemblage type identified as branching *Acropora* thicket including: *A. austera*, *A. intermedia*, *A. muricata*, *A.* cf. *arafura*, *A. florida*, *A. hyacinthus*, *A. nasuta* and *A. spicifera*. The live coral cover in the thickets ranged between 10–50%. Within the *Acropora* thickets, there were also subdominant Mixed Coral Assemblages (10–50% cover) and Mixed Turfing Algae Assemblages (25–75% cover) mostly found on the dead bases of *Acropora* branches.

Monitoring of percentage live coral cover at the Ant Point Reef site over the duration of the Marine Baseline Program indicates that there has been a decline in the estimates of percentage cover of live corals at this site, primarily due to a reduction in the cover of acroporids (Section 6.4.4.3.1).

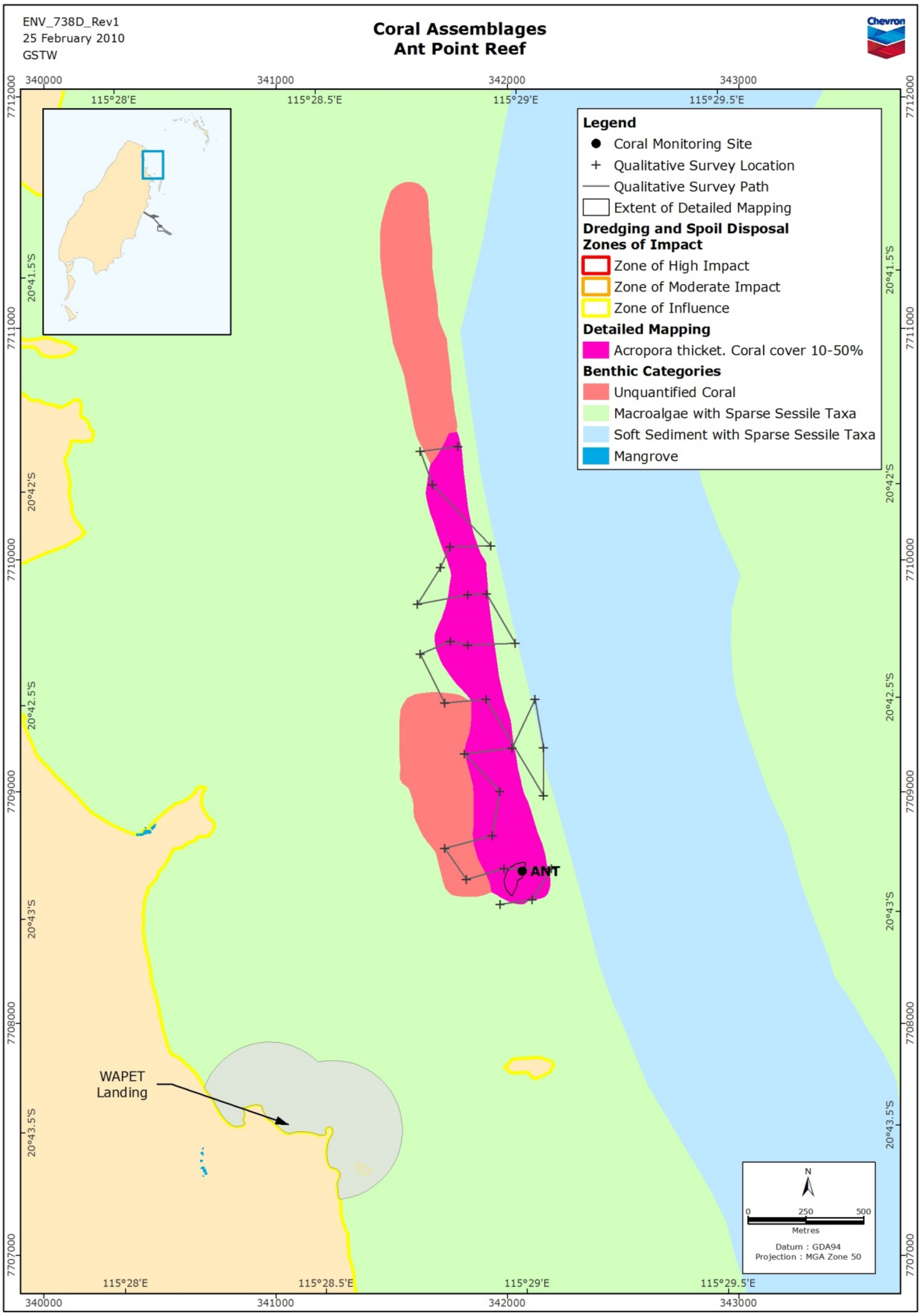


Figure 6-8 Coral Assemblages at Ant Point Reef

6.4.1.3.2 Southern Lowendal Shelf (LOW)

The Lowendal Shelf is a continuous limestone area extending towards the Montebello Islands. The monitoring site (LOW) is located on the south-west corner of the shelf and the mapped area extends to the west and east of the site along the boundary between areas of ‘Macroalgae with Sparse Sessile Taxa’ and ‘Soft Sediment with Sparse Sessile Taxa’ (Figure 6-9). There is also a large area mapped as ‘Unquantified Coral’. The LADS data indicates that there are large bombora in this area, which was confirmed during ground-truthing; however, additional ground-truthing would be required and the dominant benthic assemblage types would need to be classified in accordance with the Benthic Habitat Classification Scheme (Section 5.2; Appendix 2).

Three dominant assemblage types were identified at the Lowendal Shelf (Figure 6-9):

- *Acropora* Thicket—Coral cover 10–50%

  The monitoring site (LOW) is located in a shallow (2 m deep) *Acropora* thicket with 10–50% live coral cover (Plate 6-6). The most abundant *Acropora* species included: *A. austera*, *A. intermedia* and *A. millepora*. The subdominant assemblage type was Mixed Turfing Algae (25–75%), which was present on the dead bases of the *Acropora* branches.

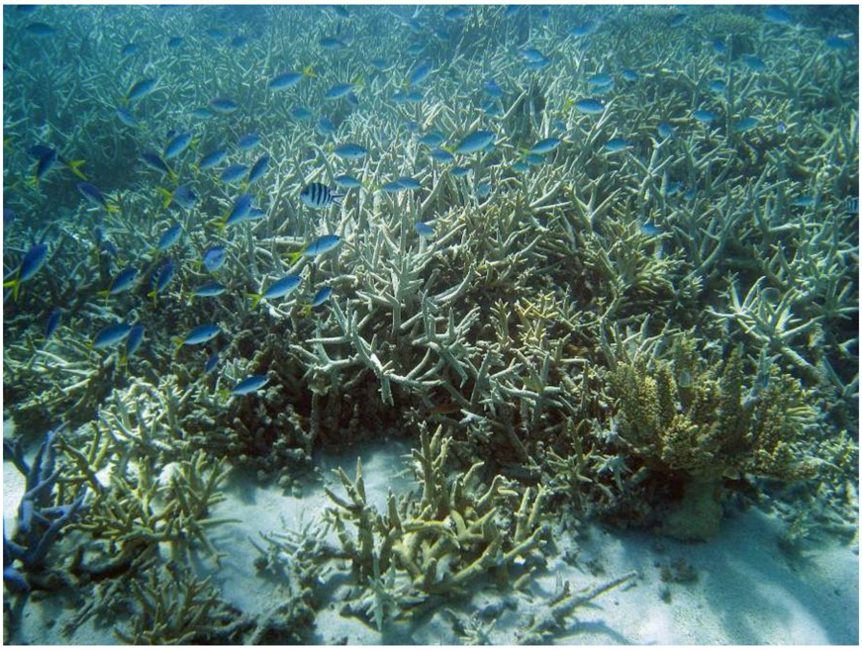


Plate 6-6 *Acropora* Thicket at Southern Lowendal Shelf

- Mixed Coral Assemblage—Coral cover 10–50%

  To the south of the coral monitoring site was a Mixed Coral Assemblage in deeper (3–4 m) water. The coral cover was relatively consistent around the monitoring site; however, coral was more scattered in areas to the west. Coral taxa included: *Acropora*, *Porites*, *Hydnophora*, *Lobophyllia* and faviids. The subdominant assemblage types included a medium coverage (25–75%) of Mixed Turfing Algae Assemblage and non-coral benthic macro-invertebrates.

- Mixed Turfing Algae assemblage—Algal cover 5–25%; Coral cover <10%

  Ground-truthing to the east of the area mapped as ‘Unquantified Coral’ identified assemblages of Mixed Turfing Algae on limestone structures scattered over areas of unvegetated sand. The subdominant assemblages included sparse cover (5–25%) of non-coral benthic macro-invertebrates. Coral cover throughout the area was <10%.

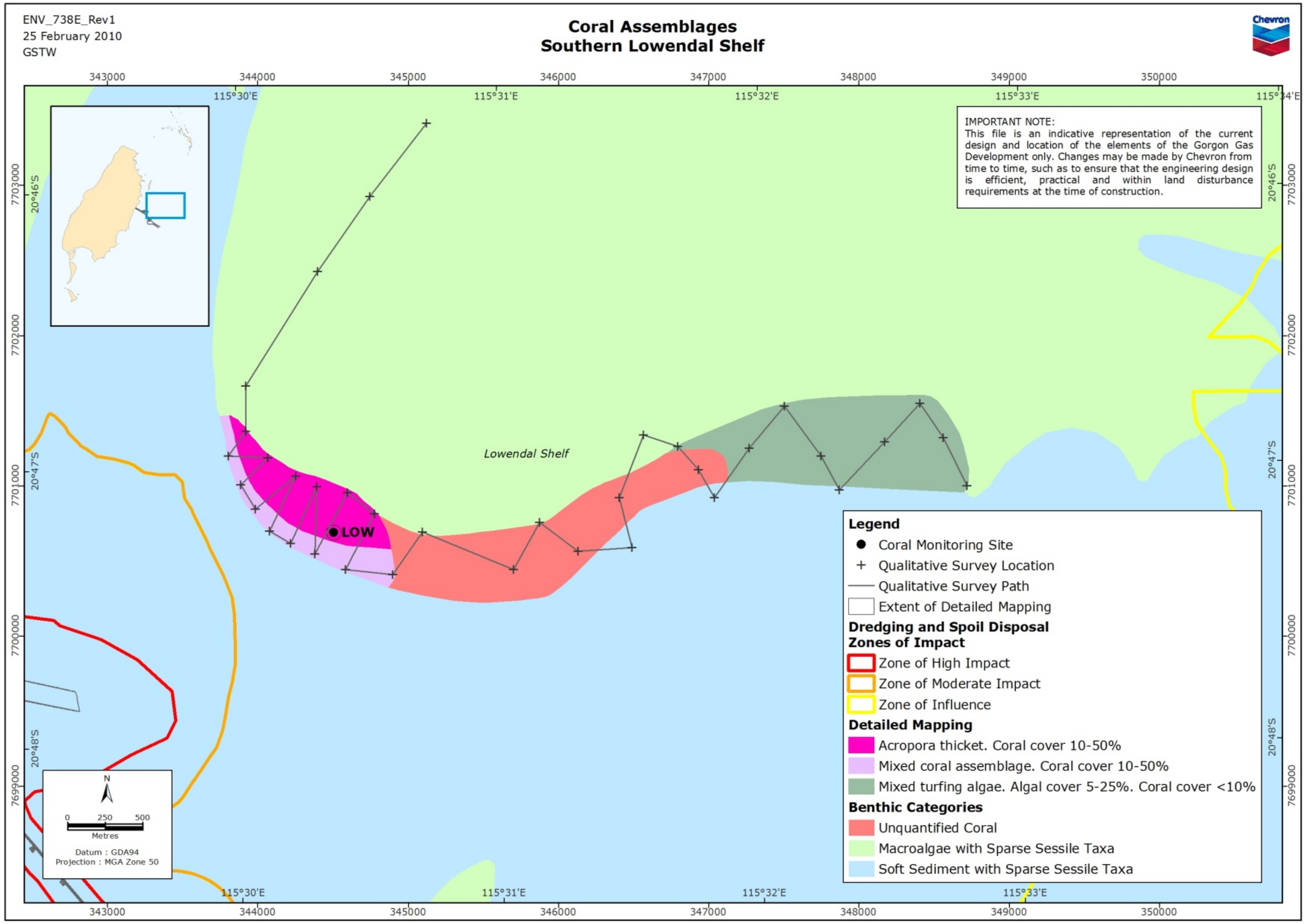


Figure 6-9 Coral Assemblages at Southern Lowendal Shelf

6.4.1.4 Description and Maps of Coral Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

6.4.1.4.1 Ah Chong (AHC)

The coral reef in the vicinity of Ah Chong Island is a mostly continuous feature associated with a deep limestone ridge running parallel to the Montebello Islands in a north–south orientation. The only remote imagery available for the Ah Chong area was aerial photography. It was not possible to define the coral reef boundaries using remote imagery because of the water depth (up to 25 m) along the ridge and these areas were also not accessible for spot diving for ground-truthing. Nevertheless, snorkel surveys identified a mostly continuous area of ‘Unconfirmed Coral’ overlying the ridge between large areas of ‘Macroalgae with Sparse Sessile Taxa’ (Figure 6-10).

The area around the monitoring site (AHC) was ground-truthed and was dominated by Coral Bombora—*Porites* of 51–75% cover. The monitoring site was part of a continuous high profile reef with a high abundance of *P. lutea*, *P. australiensis* and *P. cylindrica* and moderately high abundance of *P. lichen* and *P. nigrescens* (Section 6.4.2.4.1). Between and associated with the bombora, three subdominant assemblage types were identified: a Mixed Coral Assemblage of 51–75% cover; a Mixed Turfing Algae Assemblage of 5–25% cover; and non-coral benthic macro-invertebrates of 5–25% cover.

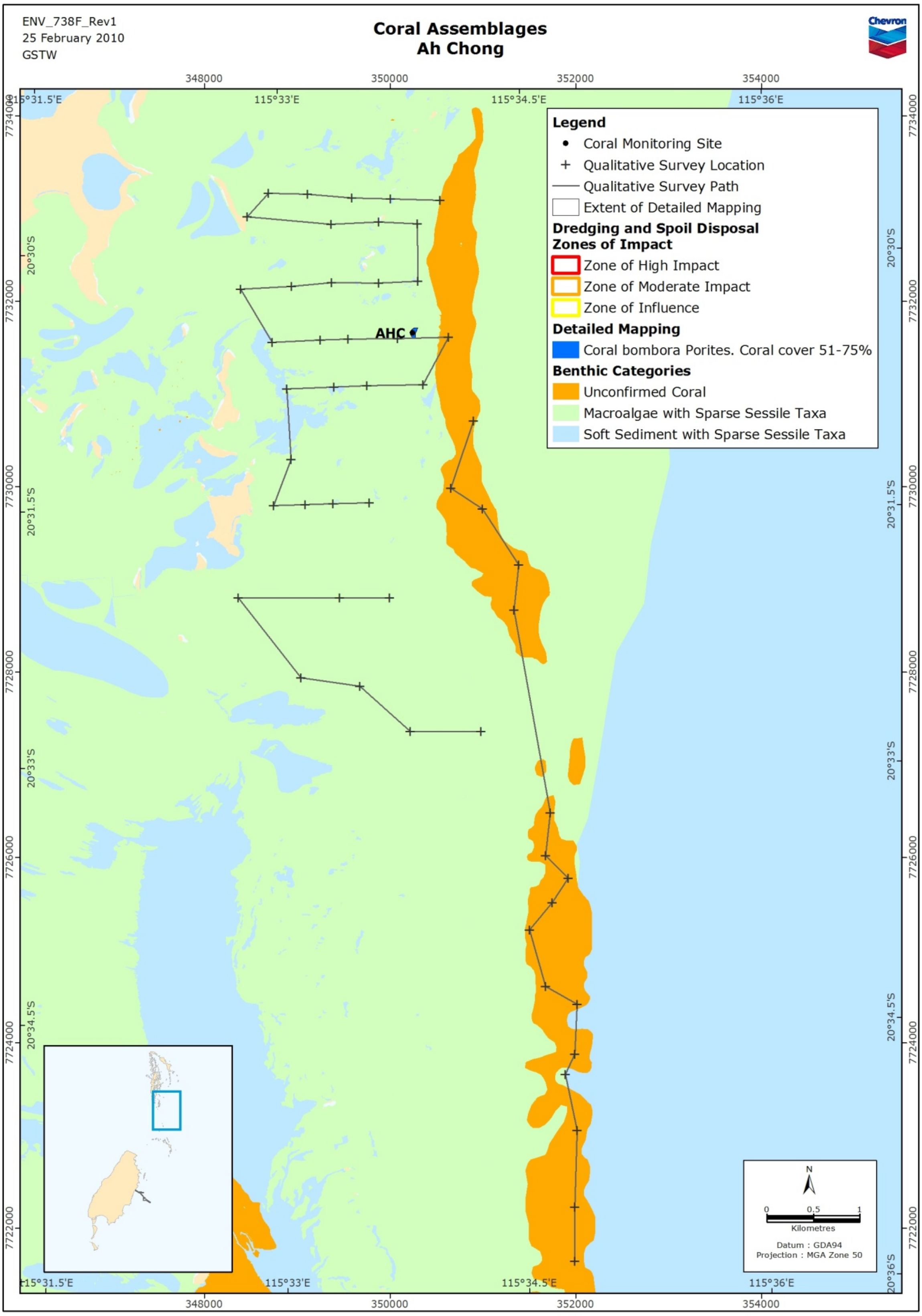


Figure 6-10 Coral Assemblages at Ah Chong (Reference Site)

6.4.1.4.2 Biggada Reef (BIG)

Biggada Reef is a roughly oval-shaped area of reef adjacent to the western side of Barrow Island. Biggada Reef was mapped as intertidal or shallow/limestone and subtidal coral reef communities by the DEC (2007).

Additional ground-truthing is required and the dominant benthic assemblage types need to be classified in accordance with the Benthic Habitat Classification Scheme (Section 5.2; Appendix 2). The 'Unconfirmed Coral' is surrounded by 'Macroalgae with Sparse Sessile Taxa', which changes to 'Soft Sediment with Sparse Sessile Taxa' further offshore (Figure 6-11). The dominant assemblage type identified in the vicinity of the monitoring site (BIG) was a Mixed Coral Assemblage (10–50% cover). The most abundant species were *Acropora nasuta* and *Goniastrea retiformis*, with faviids also generally abundant. Biggada Reef was one of the few sites with an abundance of soft corals, predominantly *Sarcophyton* spp. There was a subdominant assemblage type of Mixed Turfing Algae at medium density (25–75% cover) within the Mixed Coral Assemblage.

6.4.1.4.3 LNG3

LNG3, located on the southern end of the East Barrow Ridge, was one of the larger raised benthic features that occurs along the Ridge, on which two sites (LNG0 and LNG1) in the Zone of High Impact and the Zone of Moderate Impact, respectively, are also located (Figure 6-6). The dominant assemblage type at the monitoring site was Coral Bombora—*Porites* (predominantly *P. lutea* and *P. australiensis*) with a percentage cover of 10–50%. Some *Porites* colonies at this site were very large (up to 20 m across and 7 m high) and are estimated to be between 700 and 1000 years old (Chornesky and Peters 1987). A Mixed Coral Assemblage (10–50% cover) consisting of small corals (<30 cm) of genera such as *Lobophyllia* and *Pocillopora* were observed growing on the top of the bombora (Plate 6-7). Other subdominant assemblage types present were sparse (5–25% cover) Mixed Turfing Algae Assemblage and non-coral benthic macro-invertebrates.

Plate 6-7 *Porites lutea* and Other Corals (e.g. Pocillopora and Lobophyllia) at LNG3

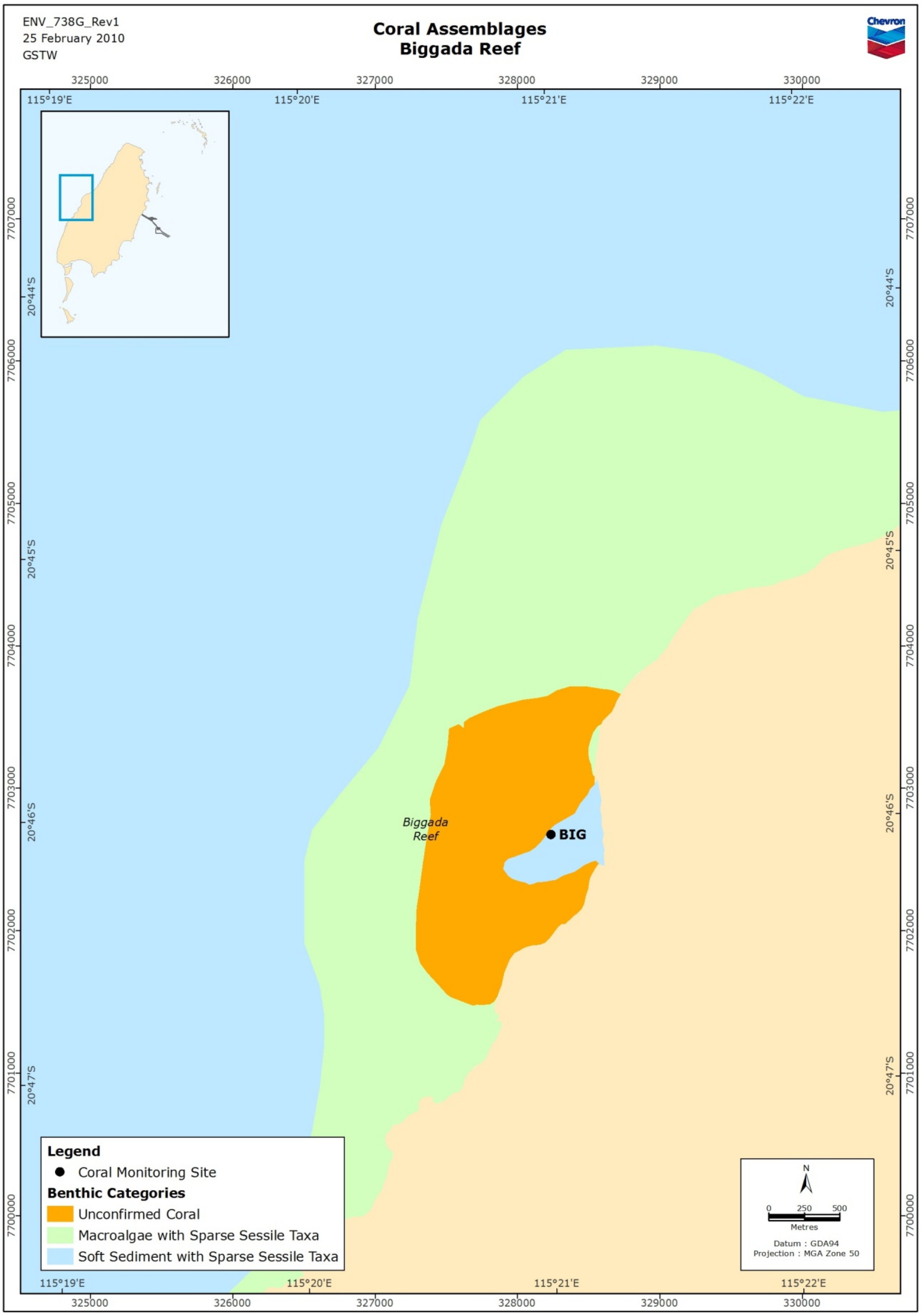


Figure 6-11 Coral Assemblages at Biggada Reef as Mapped by DEC (2007) (Reference Site)

6.4.1.5 Description and Maps of Coral Assemblages at Sites in Regionally Significant Areas Outside the Zones of Influence

6.4.1.5.1 Dugong Reef (DUG)

Dugong Reef on the south-eastern side of Barrow Island is a limestone structure surrounded by ‘Macroalgae with Sparse Sessile Taxa’ on the north, west and southern boundaries, with a deeper channel of ‘Soft Sediment with Sparse Sessile Taxa’ on the eastern boundary (Figure 6-12). Dugong Reef was mapped as intertidal or shallow/limestone and subtidal coral reef communities by the DEC (2007).

In the surveys undertaken for the Marine Baseline Program, four dominant assemblage types were identified at Dugong Reef (Figure 6-12):

- Mixed Coral Assemblage—Coral cover 51–75%

  The eastern area of Dugong Reef, where the monitoring site (DUG) is located, was a high profile reef characterised by high coral percentage cover and diversity, with acroporids, faviids, oculinids, pectiniids and poritids occurring in relatively high abundances. There were also shallower areas of high coral cover dominated by *Acropora* and *Montipora* plates (Plate 6-8). The subdominant assemblage types were sparse (5–25%) Mixed Turfing Algae Assemblage and non-coral benthic macro-invertebrates.

Plate 6-8 Large *Acropora spicifera* Plates at Dugong Reef

- Mixed Coral Assemblage—Coral cover 10–50%

  On the northern boundary of the extent of detailed mapping for Dugong Reef there was a Mixed Coral Assemblage with 10–50% cover that was bounded by ‘Unconfirmed Coral‘ and Mixed Turfing Algae Assemblages. This area was slightly deeper than the higher cover area to the south-east; however, species composition was similar in both areas.

- Mixed Turfing Algae—Algal cover 25–75%; Coral cover <10%

  Previous reports indicate the majority of Dugong Reef was characterised by live coral (LeProvost *et al.* 1990). During the present survey, extensive areas of coral rubble and limestone reef covered with Mixed Turfing Algae (25–75%) were recorded. Coral cover was <10%.

- Mixed Phaeophyceae—Algal cover 25–75%; Coral cover <10%

  The southern part of Dugong Reef was characterised by a medium cover (25–75%) of brown macroalgae with low coral cover (<10%).

The areas of Dugong Reef presently dominated by Mixed Turfing Algae and Phaeophyceae were reported to support live coral cover in the early 1990s (LeProvost *et al.* 1990). High levels of bleaching and coral mortality were reported on Dugong Reef in March 1991, which were presumed to have been caused by anoxia associated with slicks of decomposing coral spawn, in conjunction with elevated water temperatures during a period of very calm weather (LeProvost Environmental Consultants 1992).

Note that there were three areas of Dugong Reef that were not ground-truthed due to depth limitations on spot-diving. These areas are mapped as ‘Unconfirmed Coral’ in Figure 6-12. There is also a large area mapped as ‘Unquantified Coral’.

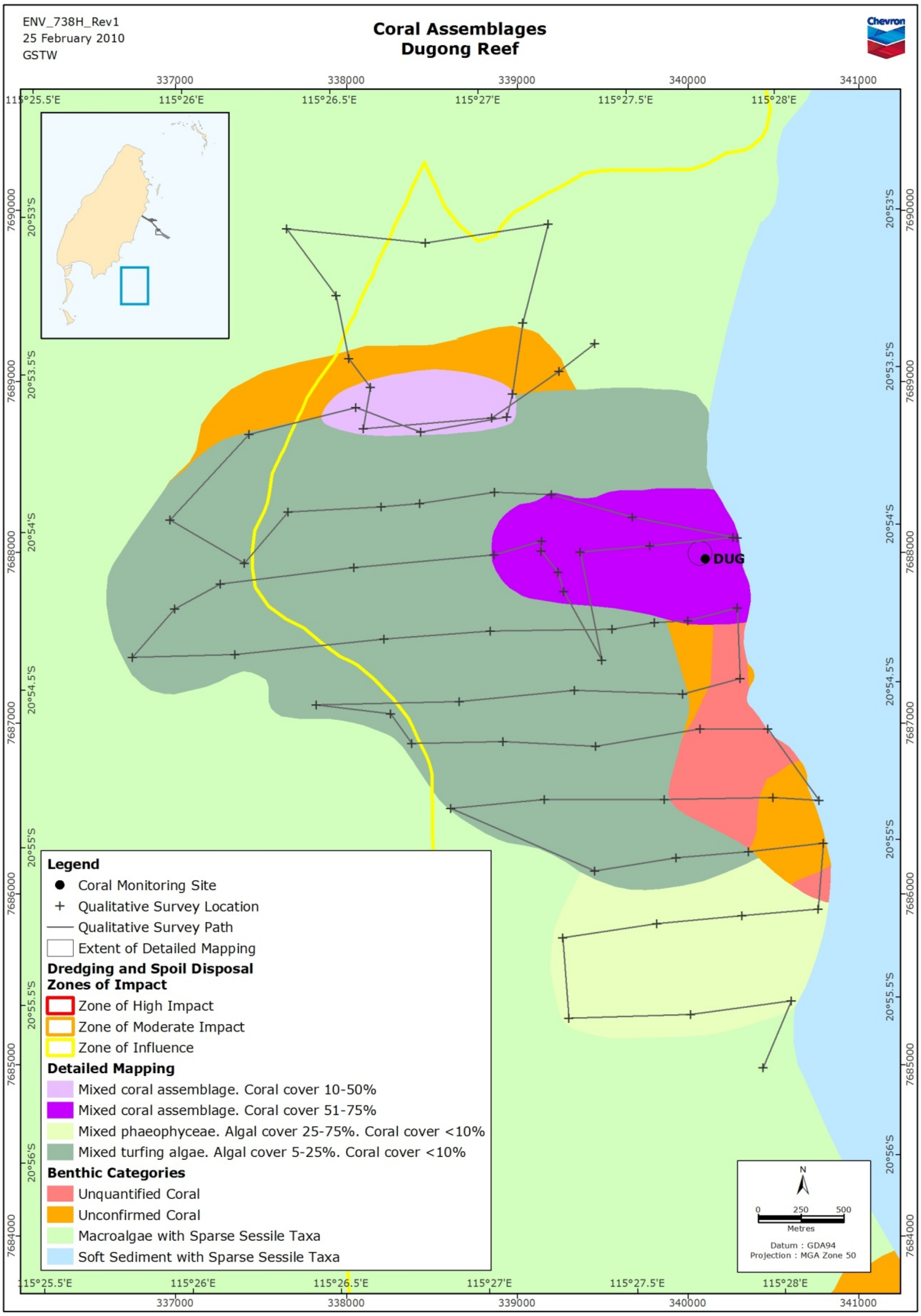


Figure 6-12 Coral Assemblages at Dugong Reef (Regionally Significant Area)

6.4.1.5.2 Batman Reef (BAT)

Batman Reef is a relatively shallow limestone feature surrounded on three sides by 'Macroalgae with Sparse Sessile Taxa' (Figure 6-13). To the north-east is a deeper channel characterised by 'Soft Sediments with Sparse Sessile Taxa'. Batman Reef was mapped as intertidal or shallow/limestone and subtidal coral reef communities by the DEC (2007).

In the surveys undertaken for the Marine Baseline Program, five dominant assemblage types were identified at Batman Reef (Figure 6-13):

- Mixed Coral Assemblage—Coral cover 51–75%

  The monitoring site (BAT) is located in an area of high percentage live coral cover and high diversity. Genera abundant in this area were from a diverse range of coral families and included *Merulina*, *Pectinia*, *Echinopora* and *Porites* (Plate 6-9). Subdominant assemblage types included Mixed Turfing Algae Assemblage (5–25% cover) and non-coral benthic macro-invertebrates (5–25% cover).

Plate 6-9 Mixed Coral Assemblage (High Cover 50–75%) at Batman Reef showing *Merulina* and *Lobophyllia* Among Other Genera

- Mixed Coral Assemblage—Coral cover 10–50%

  This assemblage was found over a large crescent-shaped area of limestone on the western edge of Batman Reef and was mainly comprised of *Porites* spp. and faviids. Subdominant assemblage types included Mixed Turfing Algae Assemblage (5–25% cover) and non-coral benthic macro-invertebrates (5–25% cover), which were present between the areas of live coral cover.

- Coral Bombora—Porites—Coral cover 10–50%

  Scattered *Porites* bombora occurred on unvegetated sand in deeper water away from the shallow limestone structures. Live coral cover in this area was only found on the bombora.

- Mixed Turfing Algae—Algal cover 5–25%; Coral cover <10%

  A large part of the western area of Batman Reef is a shallow old limestone base that was probably once coral, but now has a sparse cover of Mixed Turfing Algae (5–25%). Live coral cover in this area was <10%.

- Mixed Phaeophyceae—Algal cover 25–75%; Coral cover <10%

  A large portion of the north-eastern area of Batman Reef also consists of an old limestone base that was probably once coral, but now has a medium cover of mixed brown algae (25–75%) and scattered corals (<10%).

The areas of Batman Reef currently dominated by mixed turfing algae and Phaeophyceae were reported to have live coral cover in the early 1990s (LeProvost *et al.* 1990). Observations of slicks of decomposing coral spawn to the south-west of Dugong Reef, in the vicinity of Batman Reef in 1991 (LeProvost Environmental Consultants 1992), suggest that the present low coral cover at Batman Reef could be the result of the same anoxic event believed to have resulted in high levels of bleaching and coral mortality at Dugong Reef (Section 6.4.1.5.1).

There were three areas mapped as 'Unconfirmed Coral' in the vicinity of Batman Reef: along the north-western side; an elongated area extending southwards from the south-eastern corner along the deeper channel; and a small area to the west adjacent to the Mixed Coral Assemblage (Figure 6-13).

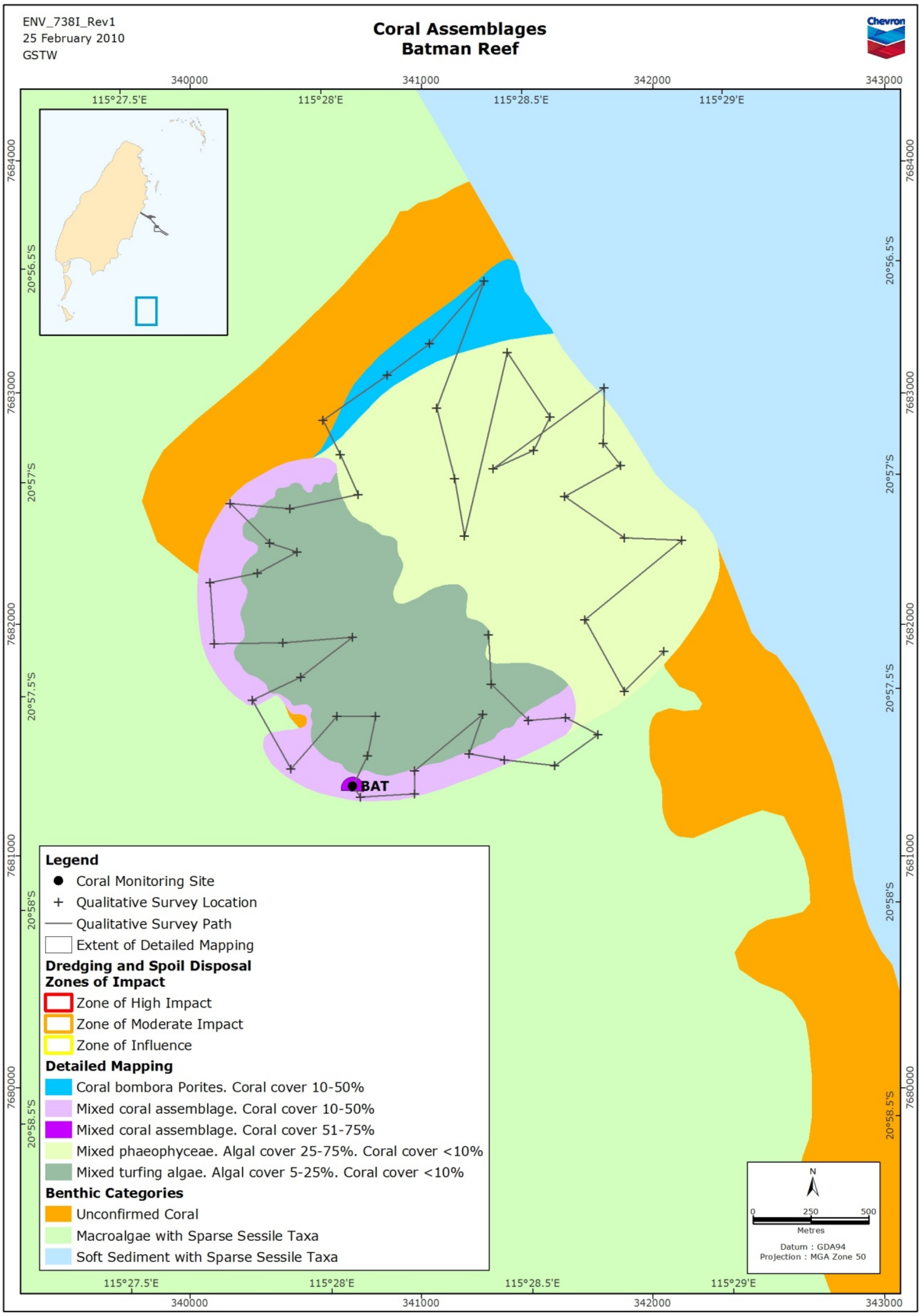


Figure 6-13 Coral Assemblages at Batman Reef (Regionally Significant Area)

6.4.1.5.3 Southern Barrow Shoals (SBS)

Southern Barrow Shoals is a large kidney-shaped area of coral reef overlying an area of limestone covered by 'Macroalgae with Sparse Sessile Taxa' (Figure 6-14). A small area of the south-eastern edge of the reef is adjacent to deeper water characterised by 'Soft Sediment with Sparse Sessile Taxa'. Southern Barrow Shoals was mapped as intertidal or shallow/limestone and subtidal coral reef communities by the DEC (2007).

In the surveys undertaken for the Marine Baseline Program, three dominant assemblage types were identified at Southern Barrow Shoals (Figure 6-14):

- Mixed Coral Assemblage—Coral cover 10–50%

  A small eastern area of Southern Barrow Shoals, where the monitoring site (SBS) is located, was dominated by a Mixed Coral Assemblage of 10–50% cover (Plate 6-10). Corals were mostly acroporids and faviids. Subdominant assemblage types included a sparse coverage (5–25%) of Mixed Turfing Algae Assemblage and non-coral benthic macro-invertebrates.

- Mixed Coral Assemblage—Coral cover 10–50% and Mixed Phaeophyceae—Algal cover 25–75%

  The northern area of Southern Barrow Shoals, characterised by low rugosity, was dominated by an assemblage type that was not observed at any other reef. The assemblage was comprised approximately equally of Mixed Coral Assemblage of medium cover (10–50%) and Mixed Phaeophyceae of medium cover (25–75%). Corals recorded in this area were mostly faviids.

- Mixed Phaeophyceae—Algal cover 25-75%; Coral cover <10%

  The southern part of Southern Barrow Shoals was dominated by a medium cover (25–75%) of Mixed Phaeophyceae. Coral cover was <10% and predominantly comprised of *Turbinaria* spp.

Plate 6-10 Mixed Assemblage of Corals on Limestone Pavement at Southern Barrow Shoals

Several areas at Southern Barrow Shoals were too deep for ground-truthing and remain mapped as 'Unconfirmed Coral'. Additional ground-truthing is required and the dominant benthic assemblage types need to be classified in accordance with the Benthic Habitat Classification Scheme (Section 5.2; Appendix 2).

6.4.1.6 Distribution of Different Assemblage Types Across Coral Monitoring Sites

Using the Benthic Habitat Classification Scheme developed for Barrow Island waters (Section 5.2; Appendix 2), a variety of different dominant assemblage types were recorded within the mapped reefs (Table 6-13; Table 6-14). All four reefs located within the Zones of High Impact and the Zones of Moderate Impact, were dominated by coral bombora. All other assemblage types were subdominant. In contrast, a diversity of dominant coral assemblage types characterised the sites in the Zones of Influence, the Reference Sites and sites in the Regionally Significant Areas, including *Porites* bombora assemblages (Ah Chong, LNG3), *Acropora* thicket assemblages (Ant Point Reef), and mixed coral dominant assemblages (Biggada Reef). Other sites were characterised by a number of dominant assemblage types, including both coral and/or macroalgal assemblages (Southern Lowendal Shelf, Batman Reef, Dugong Reef and Southern Barrow Shoals).

Medium density *Porites* spp. coral bombora mainly occurred along East Barrow Ridge at LNG0, LNG1 and LNG3, but a small patch was also identified at Batman Reef. This assemblage type also occurred at Lone Reef and Ah Chong at a higher percentage cover. At MOF1, bombora were mostly *Diploastrea heliopora* from the family Faviidae and this was the only site where a dominant non-*Porites* bombora assemblage was recorded.

Corals other than bombora-forming species also formed dominant assemblage types. *Acropora* thickets at medium percentage cover were present at Ant Point Reef and Southern Lowendal Shelf. Mixed Coral Assemblages were present at all sites either as dominant or subdominant assemblage types. Mostly these were of medium percentage cover (10–50%); however, Mixed Coral Assemblages of higher percentage cover (51–75%) were recorded at Ah Chong, Batman Reef and Dugong Reef.

In areas where coral cover was <10%, algae formed the dominant assemblage types. Mixed Turfing Algae Assemblages occurred on limestone features that had low (i.e. <10%) coral cover, usually between outcrops of coral. Mixed Turfing Algae was a subdominant assemblage type at all sites and was also a dominant assemblage type at Southern Lowendal Shelf, Dugong Reef and Batman Reef. At most sites, the cover of turfing algae was sparse; however, medium cover was recorded at Biggada Reef, Ant Point Reef, Southern Lowendal Shelf and Dugong Reef. Medium cover of mixed Phaeophyceae (primarily *Sargassum* and *Dictyopteris*) was a dominant assemblage type at Dugong Reef, Batman Reef and Southern Barrow Shoals. The brown macroalgal assemblage type generally occurred in areas of sand and old limestone features. However, at Southern Barrow Shoals it occurred as a mixed assemblage with corals.

Non-coral benthic macro-invertebrates such as sponges and ascidians were a subdominant assemblage type at all reef areas except Biggada Reef (which requires further mapping) and Ant Point Reef, which was dominated by *Acropora* thicket.

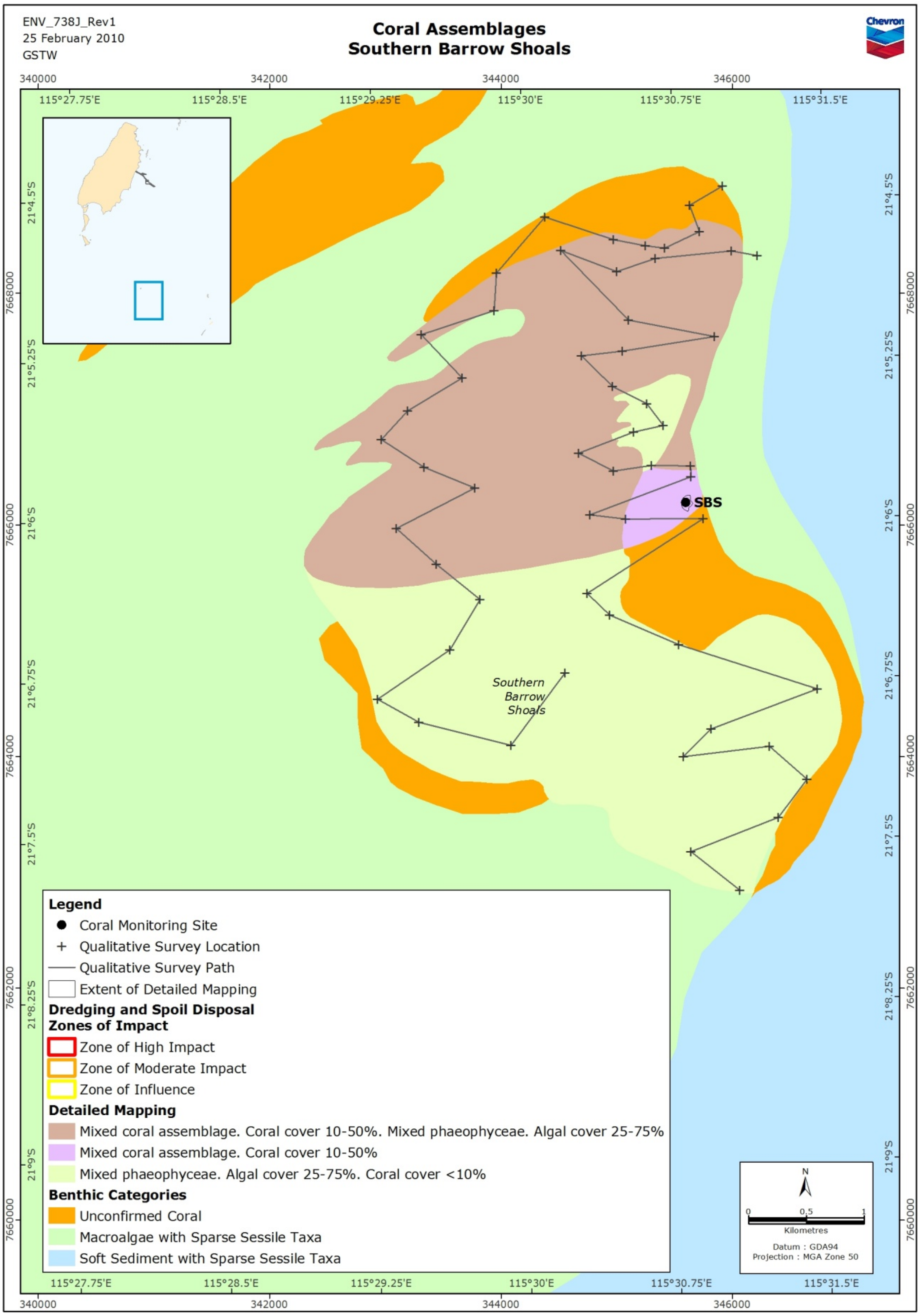


Figure 6-14 Coral Assemblages at Southern Barrow Shoals (Regionally Significant Area)

Table 6-13 Distribution of Assemblage Types in the Mapped Areas at the Coral Monitoring Sites

Assemblage	Assemblage Type	% Cover	Zones of High and Moderate Impact and Areas at Risk of Material or Serious Environmental Harm				Zones of Influence		Reference Sites			Regionally Significant Areas		
			LNG0	MOF1	LNG1	Lone Reef	Ant Point Reef	Southern Lowendal Shelf	Ah Chong	LNG3	Biggada Reef	Dugong Reef	Batman Reef	Southern Barrow Shoals
Coral Assemblages (>10%)	Coral Bombora – *Porites*	Medium (10-50%)	D	-	D	-	-	-	-	D	-	-	D	-
		Dense (51-75%)	-	-	-	D	-	-	D	-	-	-	-	-
	Coral Bombora – Non *Porites*	Medium (10-50%)	-	D	-	-	-	-	-	-	-	-	-	-
		Dense (51-75%)	-	-	-	-	-	-	-	-	-	-	-	-
	Acropora thicket	Medium (10-50%)	-	-	-	-	D	D	-	-	-	-	-	-
		Dense (51-75%)	-	-	-	-	-	-	-	-	-	-	-	-
	Mixed Coral Assemblages	Medium (10-50%)	S	S	S	S	S	D	-	S	D	D	D	D, M
		Dense (51-75%)	-	-	-	-	-	-	S	-	-	D	D	-
Other Assemblages (>5%)	Mixed Turfing Algae	Sparse (5-25%)	S	S	S	S	-	D	S	S	-	S	D, S	S
		Medium (25-75%)	-	-	-	-	S	S	-	-	S	D	-	-
	Mixed Phaeophyceae	Sparse (5-25%)	-	-	-	-	-	-	-	-	-	-	-	-
		Medium (25-75%)	-	-	-	-	-	-	-	-	-	D	D	D, M
	Non-coral Benthic Macro-invertebrates	Sparse (5-25%)	S	S	S	S	-	S	S	S	-	S	S	S
		Medium (25-75%)	-	-	-	-	-	S	-	-	-	-	-	-

Notes: D = Dominant, S = Subdominant, M = Mixed Dominance.

Table 6-14 Approximate Area (ha) of Coral Assemblage Types in the Areas of Detailed Mapping at the Coral Monitoring Sites

Assemblage	Assemblage Type	% Cover	Zones of High and Moderate Impact and Areas at Risk of Material or Serious Environmental Harm				Zones of Influence		Reference Sites		Regionally Significant Areas		
			LNG0	MOF1	LNG1	Lone Reef	Ant Point Reef	Southern Lowendal Shelf	Ah Chong	LNG3	Dugong Reef	Batman Reef	Southern Barrow Shoals
Coral Assemblages (>10%)	**Coral Bombora – *Porites***	**Medium (10-50%)**	0.5	-	0.4	-	-	-	-	0.4	-	20.2	-
		Dense (51-75%)	-	-	-	2.8	-	-	0.6	-	-	-	-
	Coral Bombora – Non-*Porites*	**Medium (10-50%)**	-	0.1	-	-	-	-	-	-	-	-	-
		Dense (51-75%)	-	-	-	-	-	-	-	-	-	-	-
	Acropora thicket	**Medium (10-50%)**	-	-	-	-	39.8	34.7	-	-	-	-	-
		Dense (51-75%)	-	-	-	-	-	-	-	-	-	-	-
	Mixed Coral Assemblages	**Medium (10-50%)**	-	-	-	-	-	21.3	-	-	35.2	39.5	32.1*
		Dense (51-75%)	-	-	-	-	-	-	-	-	96.0	0.5	-

*Note: * = Mixed Coral Assemblage Coral Cover 10-50%, Mixed Phaeophyceae Algal Cover 25-75% 696.4 ha.*

6.4.2 Dominant and Subdominant Species of Hard and Soft Coral

6.4.2.1 All Reefs Surveyed

RVA surveys identified 196 species of hard coral in 48 genera from the order Scleractinia and seven soft coral genera from the suborder Alcyoniina (refer to Appendix 3 for species list). There were 18 new taxonomic records identified during the RVA surveys. These included six new records for Australia (although unpublished information indicates *Platygyra acuta* has been previously recorded in Western Australia), nine new records for Western Australia, and three new records for the North West Shelf (Simpson 1988; Veron and Marsh 1988; Hoeksema 1989; Veron 1993, 2000; Marsh 2000; Blakeway and Radford 2005; Griffith 2004) (Table 6-15).

Table 6-15 New Coral Species Records Recorded During RVA Surveys at Barrow Island

Species	Site(s) Where Species Were Recorded
New records for Australia	
Acanthastrea subechinata Veron, 2000	Batman Reef
Favites acuticollis (Ortmann, 1889)	Biggada Reef
Goniopora burgosi Nemenzo, 1955	Batman Reef
Platygyra acuta Veron 2000	LNG0, MOF1, LNG1, Ah Chong, Biggada Reef, Dugong Reef, Batman Reef, Southern Barrow Shoals
Platygyra yaeyamaensis Eguchi and Shirai, 1977	Ah Chong
Stylophora subseriata (Ehrenberg, 1834)	Ah Chong
New records for Western Australia	
Acanthastrea hemprichii (Ehrenberg, 1834)	MOF1, Ant Point Reef
Favia maritima (Nemenzo, 1971)	MOF1, Southern Barrow Shoals
Fungia corona Döderlein, 1901	Batman Reef
Halomitra pileus (Linnaeus, 1758)	Batman Reef
Hydnophora grandis Gardiner, 1904	Lone Reef, Ah Chong, LNG3, Dugong Reef
Lobophyllia robusta Yabe and Sugiyama, 1936	MOF1, Dugong Reef, Southern Barrow Shoals
Montastrea colemani Veron, 2000	Ah Chong, LNG3
Montastrea salebrosa (Nemenzo, 1959)	Ah Chong
Psammocora obtusangula (Lamarck, 1816)	Ah Chong
New records for the North West Shelf	
Pavona duerdeni Vaughan, 1907	Dugong Reef
Scolymia australis (Milne Edwards and Haime, 1849)	Ah Chong
Acropora cf. *arafura* (new species discovered in the Kimberley in 2008 by Dr C. Wallace, yet to be published)	Southern Barrow Shoals, LNG1, Batman Reef, Ant Point Reef, LNG3, Southern Lowendal Shelf, Ah Chong

Note: Unpublished information indicates Platygryra acuta *has been recorded previously in Western Australia.*

The coral monitoring sites were varied and covered a range of coral assemblage types that could be classified into three broad groups according to species composition:

- Sites dominated by *Acropora* species, including *A. austera*, *A. intermedia*, *A.* cf. *arafura*, *A. florida*, *A. muricata* and *A. nasuta* in high abundance: Ant Point Reef and Southern Lowendal Shelf

- Sites dominated by *Porites* species, mostly *P. lutea*, *P. australiensis* and *P. cylindrica* and also including *P. lichen*, *P. rus* and *P. nigrescens*: LNG0, LNG1, Lone Reef, Ah Chong and LNG3
- Sites with no one obvious dominant genus and the most abundant coral species were from several coral families, including *Diploastrea heliopora* (Faviidae), *Pachyseris speciosa* (Agariciidae) and *Porites australiensis* (Poritidae) at MOF1; *Goniastrea retiformis* (Faviidae) and *Acropora nasuta* (Acroporidae) at Biggada Reef; *Acropora* spp. (Acroporidae), *Porites* spp. (Poritidae), *Montipora aequituberculata* (Acroporidae), *Galaxea astreata* (Oculinidae), *Pectinia lactuca* (Pectiniidae) and *Goniastrea pectinata* (Faviidae) at Dugong Reef; and *Echinopora lamellosa* (Faviidae), *Merulina ampliata* (Merulinidae) and *Pectinia lactuca* (Pectiniidae) at Batman Reef.

Soft corals covered >5% of the substratum at only one site. Three genera, *Lobophytum*, *Sarcophyton*, and *Sinularia*, together comprised ~15% of the hard substratum present at Biggada Reef in June 2009 before reducing to ~5% in October 2009.The site with the greatest coral species diversity was Ah Chong (108 species) and the site with the lowest species diversity was LNG0 (46 species) (Figure 6-15).

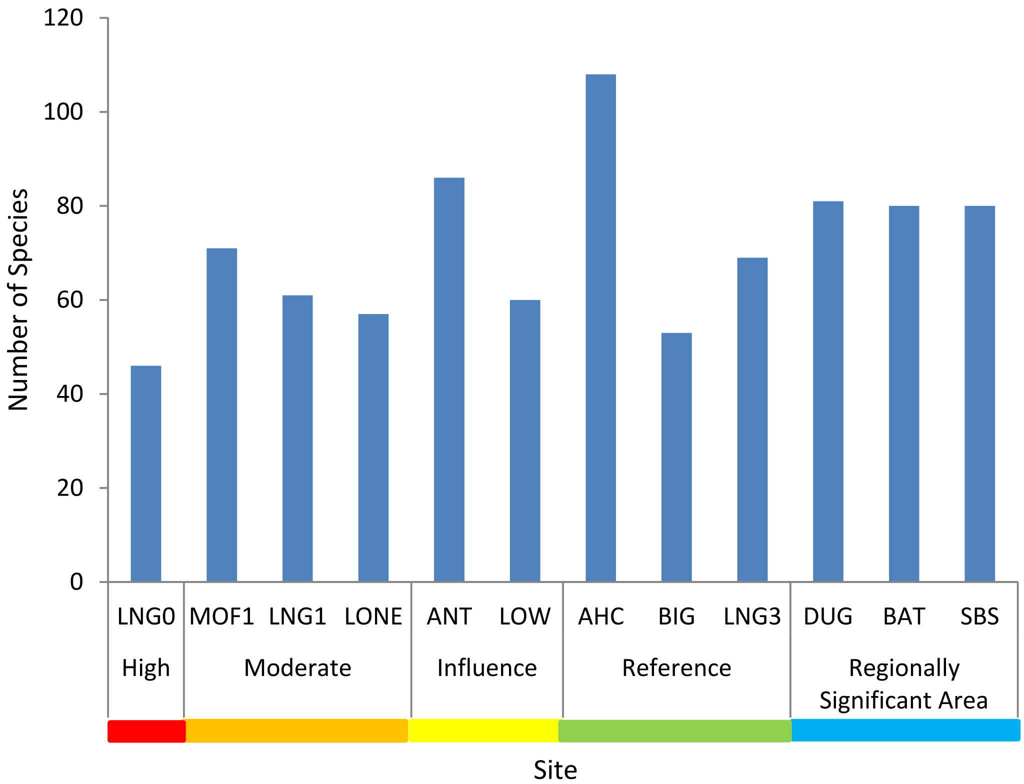


Figure 6-15 Number of Hard and Soft Coral Species Recorded at each Site During RVA Surveys at Barrow Island

6.4.2.2 Dominant and Subdominant Corals at Sites in the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.2.2.1 Dominant and Subdominant Corals at Sites in the Vicinity of the MOF and Causeway

At the MOF1 monitoring site, *Diploastrea heliopora*, *Pachyseris speciosa* and *Porites australiensis* were the most commonly recorded hard corals (Table 6-16). *Porites australiensis* was common on the west and south-west bombora, while *D. heliopora* was common on the bomboras to the east. *Pachyseris speciosa* was common among many of the bombora.

Acropora listeri, *Favia maxima* and *Moseleya latistellata* were recorded only at MOF1. *Favia maritima*, a new record for Western Australia, was recorded only at MOF1 and Southern Barrow Shoals (Table 6-15). *Acanthastrea hemprichii*, also a new record for Western Australia, was recorded only at MOF1 and Ant Point Reef (Table 6-15). The attached fungiid species, *Lithophyllon undulatum* and *Podobacia crustacea*, were also recorded at MOF1. These species are usually rare and their presence at this site is noteworthy considering other free-living fungiid species were absent.

Table 6-16 Relative Abundance of Hard Coral Species at MOF1

Coral Family	Coral Species	Abundance Scale
Faviidae	*Diploastrea heliopora*	4
Agariciidae	*Pachyseris speciosa*	4
Poritidae	*Porites australiensis*	4
Acroporidae	*Acropora divaricata*	3
Mussidae	*Lobophyllia diminuta*	3

Note: 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.2.2 Dominant and Subdominant Corals at Sites in the Vicinity of the LNG Jetty Access Channel

Porites lutea and the non-scleractinian coral *Millepora* sp. were the most commonly recorded taxa at the LNG0 monitoring site located in the Zone of High Impact (Table 6-17).

Table 6-17 Relative Abundance of Hard Coral Species at LNG0

Coral Family	Coral Species	Abundance Scale
Milleporidae	*Millepora* sp.	5
Poritidae	*Porites lutea*	5
Poritidae	*Porites cylindrica*	4
Acroporidae	*Acropora divaricata*	3
Faviidae	*Platygyra pini*	3
Poritidae	*Porites lichen*	3
Poritidae	*Porites nigrescens*	3
Poritidae	*Porites rus*	3
Dendrophylliidae	*Turbinaria reniformis*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

The most commonly recorded species at LNG1, located in the Zone of Moderate Impact, was *Porites lutea* (Table 6-18). *Acropora aculeus* was recorded only at LNG1.

Table 6-18 Relative Abundance of Hard Coral Species at LNG1

Coral Family	Coral Species	Abundance Scale
Poritidae	*Porites lutea*	5
Poritidae	*Porites australiensis*	4
Acroporidae	*Acropora divaricata*	3
Faviidae	*Favia pallida*	3
Faviidae	*Favia speciosa*	3
Mussidae	*Lobophyllia hemprichii*	3
Faviidae	*Platygyra pini*	3
Poritidae	*Porites cylindrica*	3
Poritidae	*Porites nigrescens*	3
Pocilloporidae	*Seriatopora caliendrum*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.2.3 Dominant and Subdominant Corals at Sites in the Vicinity of the Dredge Spoil Disposal Ground

The most commonly recorded species at the Lone Reef (LONE) monitoring site was *Porites lutea* (Table 6-19). *Acropora anthocercis* and *Pavona venosa* were recorded only at Lone Reef.

Table 6-19 Relative Abundance of Hard Coral Species at Lone Reef

Coral Family	Coral Species	Abundance Scale
Poritidae	*Porites lutea*	5
Poritidae	*Porites australiensis*	4
Poritidae	*Porites cylindrica*	4
Acroporidae	*Acropora divaricata*	3
Oculinidae	*Galaxea astreata*	3
Mussidae	*Lobophyllia hemprichii*	3
Faviidae	*Platygyra pini*	3
Siderastreidae	*Psammocora contigua*	3
Dendrophylliidae	*Turbinaria mesenterina*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.3 Dominant and Subdominant Corals at Representative Areas in the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.2.3.1 Ant Point Reef (ANT)

Ant Point Reef was characterised by an *Acropora* thicket comprised predominantly of three species: *A. austera*, *A. intermedia* and *A. muricata*. *Acropora austera* was the most commonly recorded species (Table 6-20). Interspersed among the *Acropora* thicket were colonies from genera such as *Astreopora*, *Favia*, *Galaxea*, *Hydnophora* and large *Porites* bomboras (both live and dead), often covered by small digitate and plate *Acropora* colonies (such *as A. hyacinthus* and *A. nasuta*).

One species of particular interest not recorded at any other coral monitoring site was *Acropora palmerae*. This is one of only two known encrusting *Acropora* species (Veron 2000). Other *Acropora* not recorded at any other sites were *A. horrida*, *A. sarmentosa*, *A. verweyi* and *A. yongei*. *Favia laxa* was also only recorded at Ant Point Reef. *Acanthastrea hemprichii*, which is a new record for Western Australia, was recorded only at Ant Point Reef and MOF1 (Table 6-15).

Table 6-20 Relative Abundance of Hard Coral Species at Ant Point Reef

Coral Family	Coral Species	Abundance Scale
Acroporidae	*Acropora austera*	5
Acroporidae	*Acropora intermedia*	4
Acroporidae	*Acropora muricata*	4
Acroporidae	*Acropora cf. arafura*	3
Acroporidae	*Acropora florida*	3
Acroporidae	*Acropora hyacinthus*	3
Acroporidae	*Acropora nasuta*	3
Acroporidae	*Acropora spicifera*	3
Poritidae	*Porites lutea*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.3.2 Southern Lowendal Shelf (LOW)

Southern Lowendal Shelf was characterised by an *Acropora* thicket interspersed with numerous small colonies of corymbose *Acropora* and colonies from genera such as *Astreopora*, *Favites*, *Galaxea*, and *Hydnophora*. The two most commonly recorded species were *A. austera* and *A. intermedia* (Table 6-21). Species that were not recorded at any other sites were *A. cytherea*, *A. microclados*, *Leptastrea pruinosa* and *Montipora foliosa*. *Mycedium robokaki*, a new record for Australia, *Hydnophora grandis* and *Lobophyllia robusta*, both new records for Western Australia, were observed outside of the RVA survey area at the Southern Lowendal Shelf site.

Table 6-21 Relative Abundance of Hard Coral Species at Southern Lowendal Shelf

Coral Family	Coral Species	Abundance Scale
Acroporidae	*Acropora austera*	5
Acroporidae	*Acropora intermedia*	5
Acroporidae	*Acropora millepora*	4
Acroporidae	*Isopora (Acropora) brueggemanni*	3
Acroporidae	*Acropora* cf. *arafura*	3
Acroporidae	*Acropora florida*	3
Acroporidae	*Acropora muricata*	3
Acroporidae	*Acropora nasuta*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.4 Dominant and Subdominant Corals at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

6.4.2.4.1 Ah Chong (AHC)

The most common species recorded at the Ah Chong monitoring site was *Porites lutea* (Table 6-22). The soft coral *Sinularia* sp. was recorded as 'frequent' at this site.

Species not reported at the other sites and which represent new records were: *Platygyra yaeyamaensis*, *Stylophora subseriata*, *Montastrea salebrosa*, *Psammocora obtusangula* and *Scolymia australis* (Table 6-15). *Montastrea colemani*, a new record for Western Australia, was recorded only at Ah Chong and LNG3 (Table 6-15). Species not recorded at the other sites were *Euphyllia glabrescens*, *Leptoseris explanata*, *L. mycetoseroides*, *Pavona maldivensis* and *Psammocora nierstraszi*.

Table 6-22 Relative Abundance of Hard and Soft Coral Species at Ah Chong

Coral Family	Coral Species	Abundance Scale
Poritidae	*Porites lutea*	5
Poritidae	*Porites australiensis*	4
Poritidae	*Porites cylindrica*	4
Acroporidae	*Acropora* cf. *arafura*	3
Acroporidae	*Acropora divaricata*	3
Faviidae	*Cyphastrea microphthalma*	3
Oculinidae	*Galaxea fasicularis*	3
Merulinidae	*Hydnophora pilosa*	3
Merulinidae	*Merulina ampliata*	3
Pectiniidae	*Oxypora glabra*	3
Agariciidae	*Pachyseris speciosa*	3
Fungiidae	*Podabacia crustacea*	3
Poritidae	*Porites lichen*	3
Poritidae	*Porites nigrescens*	3
Pocilloporidae	*Seriatopora caliendrum*	3
Alcyoniidae	*Sinularia* sp.	3
Dendrophylliidae	*Turbinaria reniformis*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies). Scleractinians in black font, Alcyoniinans in blue font.

6.4.2.4.2 Biggada Reef (BIG)

The two most commonly recorded species at the Biggada Reef monitoring site were *Acropora nasuta* and *Goniastrea retiformis* (Table 6-23). There were three genera of soft coral recorded as 'frequent'. *Favites acuticollis*, a new record for Australia, was recorded only at Biggada Reef (Table 6-15).

Table 6-23 Relative Abundance of Hard and Soft Coral Species at Biggada Reef

Coral Family	Coral Species	Abundance Scale
Acroporidae	*Acropora nasuta*	4
Faviidae	*Goniastrea retiformis*	4
Acroporidae	*Acropora digitifera*	3
Faviidae	*Cyphastrea microphthalma*	3
Faviidae	*Echinopora lamellosa*	3
Faviidae	*Favia pallida*	3
Faviidae	*Favites halicora*	3
Fungiidae	*Fungia repanda*	3
Faviidae	*Goniastrea aspera*	3
Faviidae	*Goniastrea favulus*	3
Merulinidae	*Hydnophora pilosa*	3
Alcyoniidae	*Lobophytum sp.*	3
Merulinidae	*Merulina ampliata*	3
Faviidae	*Platygyra pini*	3
Pocilloporidae	*Pocillopora damicornis*	3
Poritidae	*Porites rus*	3
Alcyoniidae	*Sarcophyton* sp.	3
Alcyoniidae	*Sinularia* sp.	3

Note: 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies). Scleractinians in black font, Alcyoniinans in blue font.

6.4.2.4.3 LNG3

The most commonly recorded species at the LNG3 monitoring site was *Porites lutea* (Table 6-24). *Montastrea colemani*, a new record for Western Australia, was recorded only at LNG3 and Ah Chong (Table 6-15).

Table 6-24 Relative Abundance of Hard Coral Species at LNG3

Coral Family	Coral Species	Abundance Scale
Poritidae	*Porites lutea*	5
Acroporidae	*Acropora divaricata*	3
Oculinidae	*Galaxea astreata*	3
Mussidae	*Lobophyllia hemprichii*	3
Faviidae	*Platygyra pini*	3
Poritidae	*Porites australiensis*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.5 Dominant and Subdominant Corals at Sites in Regionally Significant Areas Outside the Zones of Influence

6.4.2.5.1 Dugong Reef (DUG)

Galaxea astreata and *Porites rus* formed large stands in some parts of the reef. There were eight hard coral species all recorded as 'frequent' at the Dugong Reef monitoring site (Table 6-25). *Pavona duerdeni* was a new record for the North West Shelf recorded only at Dugong Reef (Table 6-15). Other species recorded only at Dugong Reef were *Montipora informis* and *M. turtlensis*. *Acropora* cf. *arafura*, a new record for the North West Shelf, was observed outside of the RVA survey area at the Dugong Reef site.

Table 6-25 Relative Abundance of Hard Coral Species at Dugong Reef

Coral Family	Coral Species	Abundance Scale
Acroporidae	*Acropora florida*	3
Acroporidae	*Acropora muricata*	3
Oculinidae	*Galaxea astreata*	3
Faviidae	*Goniastrea pectinata*	3
Acroporidae	*Montipora aequituberculata*	3
Pectiniidae	*Pectinia lactuca*	3
Poritidae	*Porites lutea*	3
Poritidae	*Porites rus*	3

Note: 3 = Frequent (6–20 colonies).

6.4.2.5.2 Batman Reef (BAT)

The three most commonly recorded species at the Batman Reef monitoring site were *Echinopora lamellosa*, *Merulina ampliata* and *Pectinia lactuca* (Table 6-26). In contrast to all other coral monitoring sites, *Acropora* occurred in low in abundance and diversity at Batman Reef. *Acanthastrea subechinata* and *Goniopora burgosi* were new records for Australia recorded only at Batman Reef (Table 6-15). Species not recorded at the other sites were *Fungia fungites*, *F. corona* and *Halomitra pileus*; these last two were new records for Western Australia (Table 6-15).

Table 6-26 Relative Abundance of Hard Coral Species at Batman Reef

Coral Family	Coral Species	Abundance Scale
Faviidae	*Echinopora lamellosa*	5
Merulinidae	*Merulina ampliata*	5
Pectiniidae	*Pectinia lactuca*	5
Pectiniidae	*Pectinia paeonia*	4
Faviidae	*Echinopora ashmorensis*	3
Faviidae	*Favia speciosa*	3
Favites	*Favites halicora*	3
Fungiidae	*Fungia fungites*	3
Fungiidae	*Fungia repanda*	3

Coral Family	Coral Species	Abundance Scale
Oculinidae	*Galaxea astreata*	3
Faviidae	*Goniastrea pectinata*	3
Faviidae	*Goniastrea retiformis*	3
Merulinidae	*Merulina scabricula*	3
Pectiniidae	*Oxypora lacera*	3
Faviidae	*Platygyra daedalea*	3
Faviidae	*Platygyra pini*	3
Pocilloporidae	*Pocillopora damicornis*	3
Poritidae	*Porites cylindrica*	3
Poritidae	*Porites lutea*	3
Poritidae	*Porites nigrescens*	3

Note: 5 = Most Common (51+ colonies); 4 = Common (21–50 colonies); 3 = Frequent (6–20 colonies).

6.4.2.5.3 Southern Barrow Shoals (SBS)

There were 15 species recorded as ‘frequent’ at the Southern Barrow Shoals monitoring site (Table 6-27). *Astreopora gracilis* was recorded only at the Southern Barrow Shoals. *Favia maritima*, a new record for Western Australia, was recorded only at Southern Barrow Shoals and MOF1 (Table 6-15).

Table 6-27 Relative Abundance of Hard Coral Species at Southern Barrow Shoals

Coral Family	Coral Species	Abundance Scale
Acroporidae	*Acropora divaricata*	3
Acroporidae	*Acropora florida*	3
Acroporidae	*Acropora millepora*	3
Acroporidae	*Astreopora myriophthalma*	3
Faviidae	*Caulastrea curvata*	3
Faviidae	*Echinopora lamellosa*	3
Faviidae	*Goniastrea pectinata*	3
Mussidae	*Lobophyllia hemprichii*	3
Acroporidae	*Montipora aequituberculata*	3
Acroporidae	*Montipora digitata*	3
Acroporidae	*Montipora hispida*	3
Pocilloporidae	*Pocillopora damicornis*	3
Poritidae	*Porites lutea*	3
Siderastreidae	*Psammocora contigua*	3
Pocilloporidae	*Stylophora pistillata*	3

Note: 3 = Frequent (6–20 colonies).

6.4.2.6 Percentage Cover of Coral Families

The percentage cover of hard corals within sampled quadrats ranged from 11.1 ± 1.7% at Biggada Reef to 76.4 ± 2.9% at Ant Point Reef (Table 6-28). Hard corals from 13 families were reported in Barrow Island waters. Of these, seven (Acroporidae, Agariciidae, Faviidae, Merulinidae, Oculinidae, Pectiniidae and Poritidae) covered >5% of sampled quadrats at one or more sites. Soft coral cover was much lower, ranging from zero cover at eight sites to a maximum of 8.0 ± 1.8% at Biggada Reef, which was the only site where soft corals covered >5% of sampled quadrats and as such could be considered a subdominant species (Table 6-28).

Two families (Poritidae and Acroporidae) were recorded at all 12 coral monitoring sites and one family (Faviidae) at 10, and all three families covered >5% of hard substratum at a number of these sites (Table 6-28). The Poritidae covered >5% of the substratum at eight sites, where they comprised between 19% and 87% of the cover of all hard corals and covered between 10.7 ± 2.4 at Southern Barrow Shoals (SBS) and 48.5 ± 4.4% of sampled quadrats at Lone Reef (LONE) (Table 6-28). The hard coral cover at five sites (LNG0, LNG1, Lone Reef [LONE], Ah Chong [AHC] and LNG3) was dominated (>70%) by corals in this family.

The Acroporidae were dominant by percentage cover only at Southern Lowendal Shelf (47.2 ± 2.8%) and at Ant Point Reef (72.9 ± 3.3%) (Table 6-28); at both these sites the Acroporidae contributed to >95% of the cover of all hard corals. At three other sites, MOF1, Dugong Reef, and Southern Barrow Shoals, the Acroporidae contributed to >5% of the sampled quadrats (5.3 ± 1.3%, 7.6 ± 1.7%, and 6.0 ± 1.2%, respectively) and comprised 12% to 28% of the cover of all hard corals at these sites.

The Faviidae contributed to >5% cover of sampled quadrats at four sites: Biggada Reef (8.1 ± 1.3%) where they comprised 73% of the cover of all hard corals, as well as at MOF1, Dugong Reef and Batman Reef, where they comprised between 10% and 42% of the cover of all hard corals and covered 6.5 ± 1.3% to 14.9 ± 2.5% of the sampled quadrats (Table 6-28).

Four families (Merulinidae, Oculinidae, Agariciidae and Pectiniidae) were absent from a number of sites, recorded at low percentage cover at most sites where they occurred, but were dominant or subdominant at one or two sites (Table 6-28). The Merulinidae (mostly *Merulina*) contributed to >5% cover of hard corals at Batman Reef (12.2 ± 2.4%) and comprised 21% of the cover of all hard corals at this site. The Oculinidae (mostly *Galaxea*) covered 14.7 ± 2.8% of the sampled quadrats at Dugong Reef and comprised 22% of the cover of all hard corals at this site. The Agariciidae (*Pachyseris* and *Pavona*) contributed to 7.5 ± 2.9% of the sampled quadrats at Dugong Reef and 11% of the cover of all hard corals at this site. The Pectiniidae (mostly *Pectinia*) were subdominant at two sites (Batman Reef: 9.6 ± 2.5%; Dugong Reef: 9.4 ± 1.9%) where they contributed to 14% to 16% of the cover of hard corals.

Corals from the six other families found in Barrow Island waters covered only a small percentage of the substratum (Table 6-28). Corals from some families were found at many sites (e.g. Pocilloporidae at nine sites, Mussidae at seven sites, Dendrophylliidae at six sites and Fungiidae at four sites) but each only covered a small percentage of the hard substratum. Corals from two families, the Caryophyllidae and Siderastreidae, were recorded only at one site each (Dugong Reef) and contributed to <1% of cover at this site.

Table 6-28 Average Percentage Cover of Hard and Soft Corals ± SE at the 12 Coral Monitoring Sites

Zone of Impact	High			Moderate			Influence			Reference		
Site	**LNG0**	**LNG1**	**Lone Reef**	**MOF1**	**Ant Point Reef**	**Southern Lowendal Shelf**	**Ah Chong**	**Batman Reef**	**Biggada Reef**	**Dugong Reef**	**LNG3**	**Southern Barrow Shoals**
Total Scleractinia	33.3 ± 4.4	27.9 ± 3.6	59.2 ± 4.3	19.1 ± 3.0	76.4 ± 2.9	48.1 ± 2.8	51.9 ± 3.8	58.8 ± 2.9	11.1 ± 1.7	66.0 ± 3.0	15.7 ± 3.6	25.8 ± 2.9
Acroporidae	1.0 ± 0.4	0.2 ± 0.2	3.0 ± 1.1	5.3 ± 1.3	72.9 ± 3.3	47.2 ± 2.8	0.9 ± 0.4	2.3 ± 0.8	1.6 ± 1.0	7.6 ± 1.7	0.2 ± 0.1	6.0 ± 1.2
Agariciidae	0.3 ± 0.3	0.5 ± 0.4	0.5 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	7.5 ± 2.9	0.3 ± 0.2	0.1 ± 0.1
Caryophylliidae	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Dendrophylliidae	0.2 ± 0.2	0.4 ± 0.4	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.3	0.3 ± 0.3	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Faviidae	0.2 ± 0.1	1.4 ± 0.5	2.7 ± 1.8	8.0 ± 2.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.5	14.9 ± 2.5	8.1 ± 1.3	6.5 ± 1.3	1.1 ± 0.4	3.5 ± 0.8
Fungiidae	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	0.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Merulinidae	1.7 ± 1.2	0.0 ± 0.0	0.1 ± 0.1	0.9 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	12.2 ± 2.4	0.2 ± 0.2	0.5 ± 0.3	0.0 ± 0.0	0.1 ± 0.1
Mussidae	0.0 ± 0.0	0.7 ± 0.3	0.0 ± 0.0	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	0.5 ± 0.3	0.0 ± 0.0	2.8 ± 0.7	0.1 ± 0.1	2.3 ± 1.2
Oculinidae	0.0 ± 0.0	0.4 ± 0.4	2.6 ± 1.8	0.2 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	0.3 ± 0.2	1.7 ± 0.7	0.0 ± 0.0	14.7 ± 2.8	0.0 ± 0.0	0.1 ± 0.1
Pectiniidae	0.0 ± 0.0	0.4 ± 0.4	0.0 ± 0.0	1.3 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	9.6 ± 2.5	0.0 ± 0.0	9.4 ± 1.9	0.0 ± 0.0	0.3 ± 0.2
Pocilloporidae	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.6 ± 0.3	0.5 ± 0.2	0.1 ± 0.1	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Poritidae	29.1 ± 4.0	21.2 ± 3.6	48.5 ± 4.4	1.0 ± 0.5	3.1 ± 1.9	0.2 ± 0.1	42.8 ± 4.3	14.2 ± 2.9	0.1 ± 0.1	12.3 ± 2.6	11.6 ± 3.6	10.7 ± 2.4
Siderastreidae	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Unidentified Coral	0.7 ± 0.4	2.8 ± 0.9	1.2 ± 0.3	1.5 ± 0.6	0.1 ± 0.1	0.0 ± 0.0	4.8 ± 0.8	1.7 ± 0.6	0.7 ± 0.3	3.1 ± 0.7	2.3 ± 0.6	2.8 ± 0.7
Bleached Coral	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Alcyoniidae	0.0 ± 0.0	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.8	0.0 ± 0.0	8.0 ± 1.8	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Milleporidae	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Notes: Table denotes average percentage cover of hard and soft corals at Time 0. Families in bold type covered >5% of sampled quadrats at one or more sites.

6.4.3 Size-Class Frequency Distributions of Hard Coral Species/Taxa

6.4.3.1 Mode and Skew

The most abundant coral colony size-class (mode) varied among families within sites and also among sites within families, but was never the smallest size-class (<2 cm) or the larger size-classes (>1 m) (Table 6-29). The modal size-classes for the acroporids, faviids, mussids and 'Others' varied between 2.1–5 cm and 20.1–50 cm; and between 2.1–5 cm and 50.1–100 cm for the merulinds and poritids, respectively. The modal size-class for the dendrophylliids (predominantly *Turbinaria*) was 5.1–10 cm or 10.1–20 cm and for the oculinids (predominantly *Galaxea*) was 10.1–20 cm and 20.1–50 cm. The modal size-class for the agariciids, pectiniids and the hydrocoral *Millepora* was 20.1–50 cm. The largest modal size-classes were generally recorded at Dugong Reef and Batman Reef.

For all families at all sites, skewness was generally positive, indicating that there were greater numbers of colonies in the smaller size-classes and relatively few colonies in the larger size-classes (Table 6-30). Negative skewness, indicating relatively few colonies in the smaller size-classes, was only recorded for the acroporids at Biggada Reef (only four colonies recorded) and the dendrophylliids at LNG3.

Table 6-29 Modal Size-Class (cm) for Families at each Coral Monitoring Site

	Zones of High Impact	Zones of Moderate Impact			Reference			Regionally Significant Area		
Family	**LNG0**	**MOF1**	**LNG1**	**Lone Reef**	**Ah Chong**	**Biggada Reef**	**LNG3**	**Dugong Reef**	**Batman Reef**	**Southern Barrow Shoals**
Acroporidae	2.1–5	20.1–50	2.1–5	5.1–10	10.1–20	10.1–20	2.1–5, 5.1–10	20.1–50	20.1–50	20.1–50
Agariciidae	-	-	-	-	-	-	-	20.1–50	-	-
Dendrophylliidae	5.1–10	-	5.1–10	10.1–20	-	-	10.1–20	-	-	-
Faviidae	2.1–5	10.1–20	2.1–5	10.1–20	10.1–20	20.1–50	5.1–10	10.1–20	20.1–50	10.1–20
Merulinidae	-	10.1–20, 20.1–50	-	-	2.1–5	-	-	20.1–50	50.1–100	-
Milleporidae	20.1–50	-	-	-	-	-	-	-	-	-
Mussidae	2.1–5	10.1–20	2.1–5, 5.1–10	-	2.1–5	-	-	20.1–50	-	-
Oculinidae	-	-	-	-	10.1–20	-	-	20.1–50	-	-
Pectiniidae	-	-	-	-	-	-	-	20.1–50	20.1–50	
Poritidae	20.1–50	20.1–50	20.1–50	50.1–100	20.1–50	10.1–20	2.1–5	20.1–50	20.1–50	20.1–50
Other	2.1–5	10.1–20, 20.1–50	10.1–20	20.1–50	10.1–20	20.1–50	10.1-20	2.1–5	20.1–50	10.1–20

Note: Values separated by a comma indicate equal abundances in two size-classes.

Table 6-30 Skew for Coral Colonies at each Coral Monitoring Site

	Zones of High Impact	Zones of Moderate Impact			Reference			Regionally Significant Area		
Family	**LNG0**	**MOF1**	**LNG1**	**Lone Reef**	**Ah Chong**	**Biggada Reef**	**LNG3**	**Dugong Reef**	**Batman Reef**	**Southern Barrow Shoals**
Acroporidae	2.1	2.3	1.5	2.2	1.0	-1.5	0.8	1.8	0.9	1.8
Agariciidae	-	-	-	-	-	-	-	1.7	-	-
Dendrophylliidae	2.3	-	2.2	1.2	-	-	-0.2	-	-	-
Faviidae	1.6	2.7	3.0	0.5	0.8	1.7	1.4	4.1	1.8	5.1
Merulinidae	-	1.0	-	-	0.8	-	-	2.3	1.0	-
Milleporidae	2.3	-	-	-	-	-	-	-	-	-
Mussidae	1.9	2.0	1.7	-	1.6	-	-	0.4	-	-
Oculinidae	-	-	-	-	1.2	-	-	4.2	-	-
Pectiniidae	-	-	-	-	-	-	-	1.3	0.5	-
Poritidae	3.8	2.0	4.5	3.1	3.8	0.6	6.8	3.1	3.4	2.4
Other	2.5	5.2	3.5	1.0	2.3	1.1	2.9	1.6	2.0	3.4

Note: Positive values indicate a skew to the right (relatively few values in larger size-classes); negative values indicate a skew to the left (relatively few values in smaller size-classes) Skew calculated on raw size distributions.

6.4.3.2 Size-Class Frequency Distributions of Hard Coral Species/Taxa at Sites in the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.3.2.1 Size-class Frequency Distributions of Hard Coral Species/Taxa at Sites in the Vicinity of the MOF and Causeway

A total of 315 colonies were measured at the MOF1 monitoring site, with a mean number per transect of 63.0 ± 12.7 (Table 6-31). The most abundant colonies were *Acropora* (19.2 ± 3.1) and unidentified faviids (15.0 ± 4.0). All other taxa were recorded at densities of ≤5 colonies per transect.

The overall average colony size was 32.1cm, which varied between a mean of 12.8 cm ± 5.0 for the unidentified fungiids and 160.9 ± 27.3 cm for *Diploastrea* (Table 6-31). The standard deviation varied between 8.0 (*Goniastrea*) to 90.5 (*Diploastrea*) and the coefficient of variation between 0.3 (*Goniastrea*) to 1.4 (*Pachyseris*). The only colonies >200 cm in size were *Diploastrea*, massive *Porites*, and *Pachyseris*, with counts of 5, 1, and 1 respectively. There were a total of eight small, <5 cm in size, colonies in four taxonomic groups. *Acropora* and unidentified *Faviidae* and *Fungiidae* each had counts of two whilst the remaining genera had counts of one small colony in total. Hard corals unidentified at family and genus level were not included in counts of taxonomic groups in each of the <5 and >200 cm categories.

The majority (72%) of the colonies measured at MOF1 were in the 10.1–20.0 and 20.1–50.0 cm size-classes, with this value varying from 64% to 87% among families (Figure 6-16). There were small numbers of acroporids, faviids and 'Others' <5 cm in size; and small numbers of acroporids, faviids, poritids and 'Others' were >1 m.

Table 6-31 Size-Class Frequency Count and Size Statistics of Hard Corals at MOF1

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	19.2	3.1	2	0	29.5	96	24.8	2.5	0.8
	Astreopora	0.2	0.2	0	0	26.0	1	-	-	-
	Montipora	5.0	1.9	1	0	28.4	25	21.2	4.2	0.7
Agariciidae	Pachyseris	1.6	0.9	0	1	56.4	8	79.9	28.2	1.4
Faviidae	Diploastrea	2.2	0.9	0	5	160.9	11	90.5	27.3	0.6
	Faviidae Unidentified	15.0	4.0	2	0	23.0	75	18.6	2.1	0.8
	Goniastrea	0.6	0.4	0	0	23.3	3	8.0	4.6	0.3
Merulinidae	Hydnophora	0.2	0.2	0	0	48.0	1	-	-	-
	Merulina	3.0	1.0	0	0	24.4	15	13.0	3.3	0.5
Mussidae	Lobophyllia	3.8	1.0	0	0	22.3	19	17.1	3.9	0.8
Pectiniidae	Oxypora	2.6	0.9	0	0	33.1	13	18.3	5.1	0.6
	Pectinia	0.2	0.2	0	0	20.0	1	-	-	-
Poritidae	Porites	2.0	0.5	0	1	60.5	10	72.9	23.1	1.2
	Porites Branching	0.2	0.2	0	0	23.0	1	-	-	-
Dendrophyllidae	Turbinaria	1.6	0.9	0	0	14.4	8	8.3	2.9	0.6
Fungiidae	Fungiidae Unidentified	1.6	0.8	2	0	12.8	8	14.1	5.0	1.1
Oculinidae	Galaxea	1.0	0.5	0	0	20.2	5	9.6	4.3	0.5
Pocilloporidae	Stylophora	0.2	0.2	0	0	16.0	1	-	-	-
Unidentified Family	Unidentified Genus	2.8	1.0	1	0	20.4	14	18.2	4.9	0.9
TOTAL		**63.0**[1]	**12.7**[1]	**8**	**7**	**32.1**[2]	**315**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects;2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present)

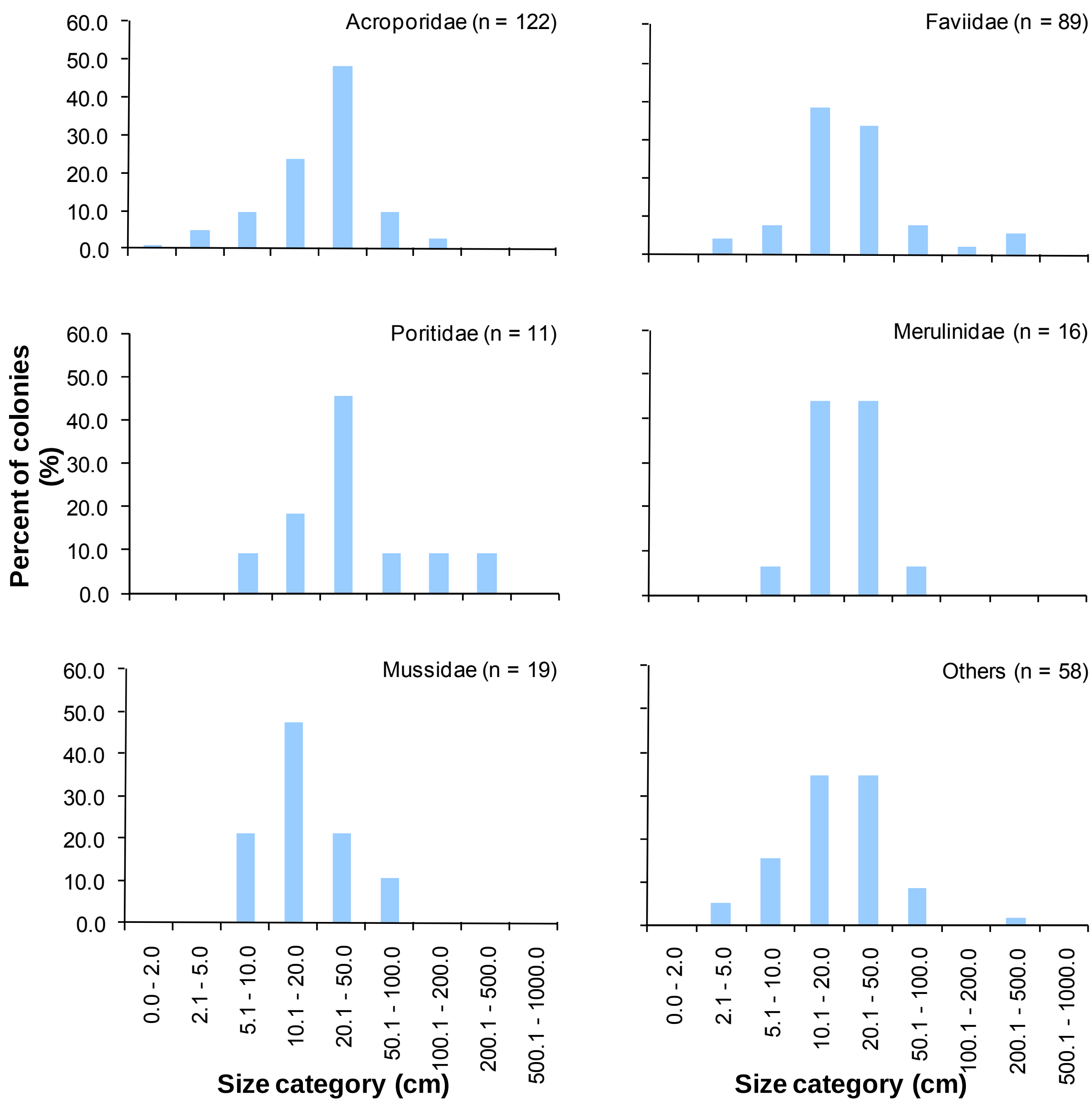


Figure 6-16 Size-class Frequency Distribution of Hard Corals at MOF1

6.4.3.2.2 Size-class Frequency Distributions of Hard Coral Species/Taxa at Sites in the Vicinity of the LNG Jetty Access Channel

A total of 285 colonies were measured at the LNG0 monitoring site, with a mean number per transect of 57.0 ± 6.2 (Table 6-32). The most abundant colonies were massive *Porites* (20.4 ± 2.5) and unidentified faviids (14.8 ± 3.5). All other taxa were recorded at densities of ≤4 colonies per transect.

The overall average colony size was 23.0 cm, which varied between a mean of 2.0 ± 0.0 cm for *Merulina* to 112.0 ± 0.0 cm for *Hydnophora* (Table 6-32). The standard deviation varied between 1.0 (*Symphyllia*) to 47.5 (massive *Porites*) and the coefficient of variation between 0.2 (branching *Porites*) to 1.1 (massive *Porites, Montipora,* and *Millepora*). The only colonies >200 cm in size were massive *Porites*, with a count of one colony in total. There was a total of 76 small, <5 cm in size, colonies in ten taxonomic groups. The greatest in number were unidentified faviids (28) and *Lobophyllia* (14).

Size-class frequency distributions of acroporids, mussids and 'Others' were skewed towards the smaller size-classes, with 41–59% of the colonies in the 2.1–5.0 cm size-class (Figure 6-17). The largest size-class reported for the mussids was 10.1–20.0 cm and 20.1–50 cm in the acroporids, colonies >1 m were reported in 'Others'. In the case of the poritids and milleporids, 39% and 33% of colonies respectively, were between 20.1–50 cm; however, colonies >1 m in size were reported for both families. The faviids exhibited a bi-modal size-class frequency distribution and ranged from <2 cm to 20.1–50 cm. Over 75% of the dendrophylliids were 2.1–10 cm in size, with the remaining colonies between 10.1 and 50 cm.

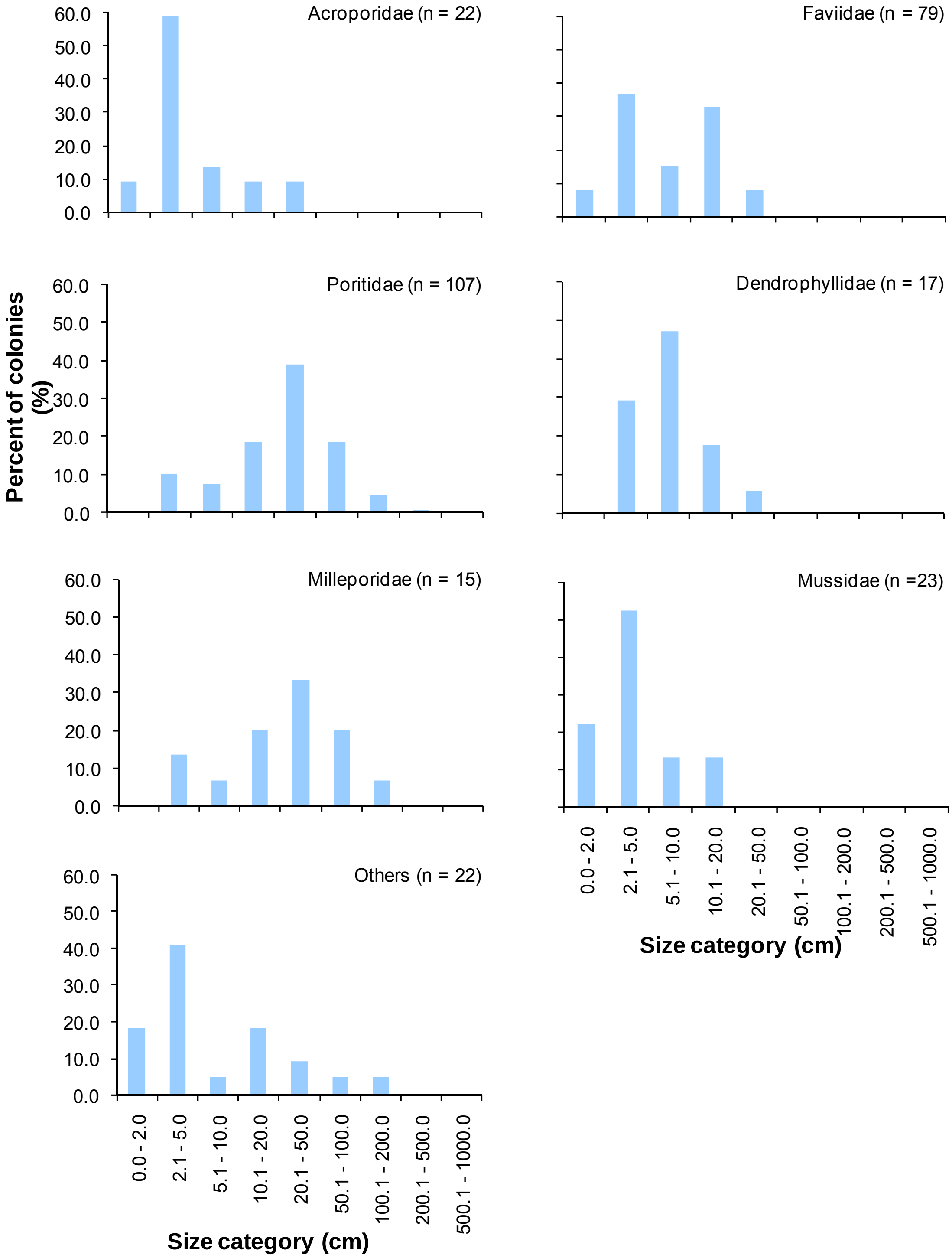


Figure 6-17 Size-Class Frequency Distribution of Hard Corals at LNG0

Table 6-32 Size-Class Frequency Count and Size Statistics of Hard Corals at LNG0

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	2.6	1.1	6	0	5.5	13	4.7	1.3	0.8
	Montipora	1.8	1.0	5	0	10.6	9	11.1	3.7	1.1
Agariciidae	Pachyseris	0.2	0.2	0	0	43.0	1	-	-	-
Faviidae	Echinopora	1.0	0.4	1	0	11.8	5	11.7	5.2	1.0
	Faviidae Unidentified	14.8	3.5	28	0	9.3	74	7.4	0.9	0.8
Merulinidae	Hydnophora	0.2	0.2	0	0	112.0	1	-	-	-
	Merulina	0.2	0.2	1	0	2.0	1	-	-	-
Milleporidae	Millepora	3.0	1.1	0	0	38.8	15	42.6	11.0	1.1
Mussidae	Lobophyllia	4.0	1.0	14	0	5.2	20	4.2	0.9	0.8
	Symphyllia	0.6	0.4	3	0	3.0	3	1.0	0.6	0.3
Pectiniidae	Echinophyllia	0.2	0.2	0	0	18.0	1	-	-	-
	Mycedium	0.2	0.2	0	0	5.0	1	-	-	-
	Pectinia	0.2	0.2	0	0	100.0	1	-	-	-
Poritidae	Goniopora	0.2	0.2	0	0	5.0	1	-	-	-
	Porites	20.4	2.5	7	1	41.5	102	47.5	4.7	1.1
	Porites Branching	0.8	0.5	0	0	31.8	4	7.7	3.8	0.2
Dendrophyllidae	Turbinaria	3.4	1.1	2	0	9.5	17	7.2	1.7	0.8

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Fungiidae	Fungiidae Unidentified	0.2	0.2	0	0	17.0	1	-	-	-
	Herpolitha	0.2	0.2	0	0	33.0	1	-	-	-
Oculinidae	Galaxea	0.2	0.2	1	0	3.0	1	-	-	-
Pocilloporidae	Pocillopora	0.2	0.2	0	0	16.0	1	-	-	-
Siderastreidae	Coscinaraea	0.2	0.2	0	0	16.0	1	-	-	-
Unidentified Family	Unidentified Genus	2.2	0.6	8	0	3.4	11	1.6	0.5	0.5
TOTAL		**57.0**[1]	**6.2**[1]	**76**	**1**	**23.0**[2]	**285**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects;2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

A total of 269 colonies were measured at the LNG1 monitoring site, with a mean number per transect of 53.8 ± 9.1 (Table 6-33). The most abundant colonies were massive *Porites* (14.2 ± 5.0), unidentified faviids (9.6 ± 2.5) and branching *Porites* (6.8 ± 5.1). All other taxa were recorded at densities of ≤5 colonies per transect.

The overall average colony size was 30.7 cm, which varied between a mean of 7.0 ± 0.0 cm for *Symphyllia* and 200.0 ± 0.0 cm for *Millepora* (Table 6-33). The standard deviation varied between 2.1 (*Echinophyllia*) to 100.4 (*Hydnophora*) and the coefficient of variation between 0.1 (*Goniopora*) to 1.3 (*Hydnophora*, massive and branching *Porites*). The only colonies >200 cm in size were massive and branching *Porites*, with counts of two and one colony respectively. There were a total of 31 small, <5 cm in size, colonies, in seven taxonomic groups. The greatest numbers were unidentified faviids (11) in addition to *Montipora* and *Lobophyllia* (5).

The acroporids and faviids had similar size-class frequency distributions, with colonies generally ranging in size from <2 cm to 50 cm and a modal size-class of 2.1–5.0 cm (Figure 6-18). The majority of the colonies (83 and 86%, respectively) were 2.1–20 cm in size. There were similar numbers of mussids (32%) in the 2.1–5.0 cm and 5.1–10.0 cm size-classes. None of the acroporids or mussids were >50 cm in size. The modal size-class of the dendrophylliids was 5.1–10.0 cm, 'Others' 10.1–20.0 cm and poritids 20.1–50.0 cm. The distribution of colony sizes were centred around these modal classes with 84% of the dendrophylliids between 2.1 and 20 cm, 82% of 'Others' between 5.1 and 50 cm and 83% of the poritids between 10.1 and 100 cm in size.

Table 6-33 Size-Class Frequency Count and Size Statistics of Hard Corals at LNG1

Family	Genera	# colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	2.2	1.1	2	0	13.1	11	7.2	2.2	0.6
	Montipora	2.6	1.2	5	0	8.5	13	9.8	2.7	1.2
Agariciidae	Pachyseris	1.4	1.2	0	0	30.9	7	16.3	6.1	0.5
	Pavona	0.8	0.4	0	0	21.8	4	9.5	4.8	0.4
Faviidae	Echinopora	0.2	0.2	0	0	59.0	1	-	-	-
	Faviidae Unidentified	9.6	2.5	11	0	9.4	48	6.4	0.9	0.7
Merulinidae	Hydnophora	0.4	0.2	0	0	79.0	2	100.4	71.0	1.3
	Merulina	0.2	0.2	0	0	57.0	1	-	-	-
Milleporidae	Millepora	0.2	0.2	0	0	200.0	1	-	-	-
Mussidae	Lobophyllia	3.6	1.0	5	0	12.7	18	12.1	2.9	1.0
	Symphyllia	0.2	0.2	0	0	7.0	1	-	-	-
Pectiniidae	Echinophyllia	0.4	0.2	0	0	13.5	2	2.1	1.5	0.2
	Oxypora	0.2	0.2	0	0	15.0	1	-	-	-
	Pectinia	0.4	0.2	0	0	41.0	2	39.6	28.0	1.0
Poritidae	Goniopora	0.4	0.4	0	0	32.0	2	2.8	2.0	0.1
	Porites	14.2	5.0	2	2	59.3	71	76.7	9.1	1.3
	Porites Branching	6.8	5.1	1	1	40.8	34	52.9	9.1	1.3
Dendrophyllidae	Turbinaria	5.0	1.4	3	0	15.0	25	15.2	3.0	1.0
Fungiidae	Fungiidae Unidentified	0.8	0.6	0	0	14.5	4	15.7	7.8	1.1
Pocilloporidae	Pocillopora	0.2	0.2	0	0	15.0	1	-	-	-
	Stylophora	1.8	1.4	0	0	22.1	9	11.4	3.8	0.5
Unidentified Family	Unidentified Genus	2.2	0.7	2	0	10.2	11	8.5	2.6	0.8
TOTAL		**53.8**[1]	**9.1**[1]	**31**	**3**	**30.7**[2]	**269**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present)

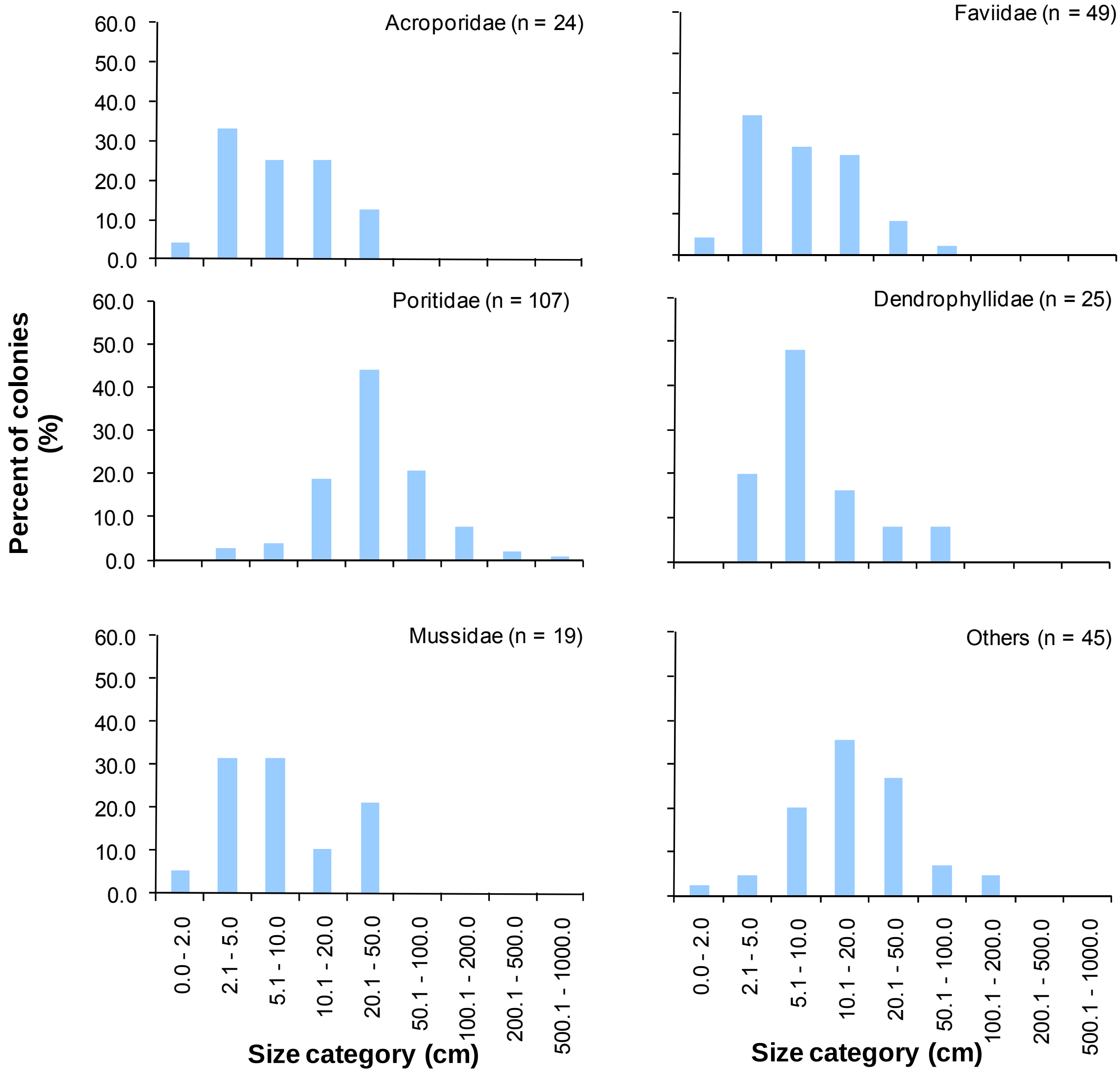


Figure 6-18 Size-Class Frequency Distribution of Hard Corals at LNG1

6.4.3.2.3 Size-class Frequency Distributions of Hard Coral Species/Taxa at Sites in the Vicinity of the Dredge Spoil Disposal Ground

A total of 223 colonies were measured at the Lone Reef (LONE) monitoring site, with a mean number per transect of 55.8 ± 6.4 (Table 6-34). The most abundant colonies were massive *Porites* (17.0 ± 2.1), unidentified faviids (11.3 ± 3.7) and branching *Porites* (6.3 ± 1.3). All other taxa were recorded at densities of ≤4 colonies per transect.

The overall average colony size was 42.7 cm, which varied between 5.0 ± 0.0 cm (*Stylophora*) and 91.0 ± 10.5 cm (massive *Porites*) (Table 6-34). The standard deviation varied between 1.6 (*Pectinia*) and 86.8 (massive *Porites*) and the coefficient of variation between 0.2 (*Pectinia*) and 1.3 (*Pachyseris*). The only colonies >200 cm in size were massive *Porites*, with a total count of four colonies. There were a total of 28 small, <5 cm in size, colonies, in six taxonomic groups. The greatest in number were unidentified faviids (13) and all other taxonomic groups were ≤4 small colonies per transect.

The faviids ranged in size from <2 cm to 50 cm, with the majority of colonies (76%) within the three size-classes 2.1–5.0, 5.1–10.0, and 10.1–20.0 cm (Figure 6-19). The size-class frequency distributions of the faviids at Lone Reef were very similar to those at LNG1 and LNG3. The modal size-class of the dendrophylliids was 10.1–20.0 cm, with the majority of colonies (92%) 5.1–50 cm in size. The size-class frequency distribution of the dendrophylliids was also similar at Lone Reef to LNG1 and LNG3. However, in contrast to these sites, there were no dendrophylliids in the 2.1–5.0 cm size-class at Lone Reef. Colonies <2 cm in size were recorded at Lone Reef, but not at LNG1 or LNG3. Acroporids (84%), poritids (90%) and 'Others' (89%) were predominantly within four size-classes; the acroporids and 'Others' were mostly between 2.1 and 50 cm in size, while the poritids were larger, between 10.1 cm and 2 m in size.

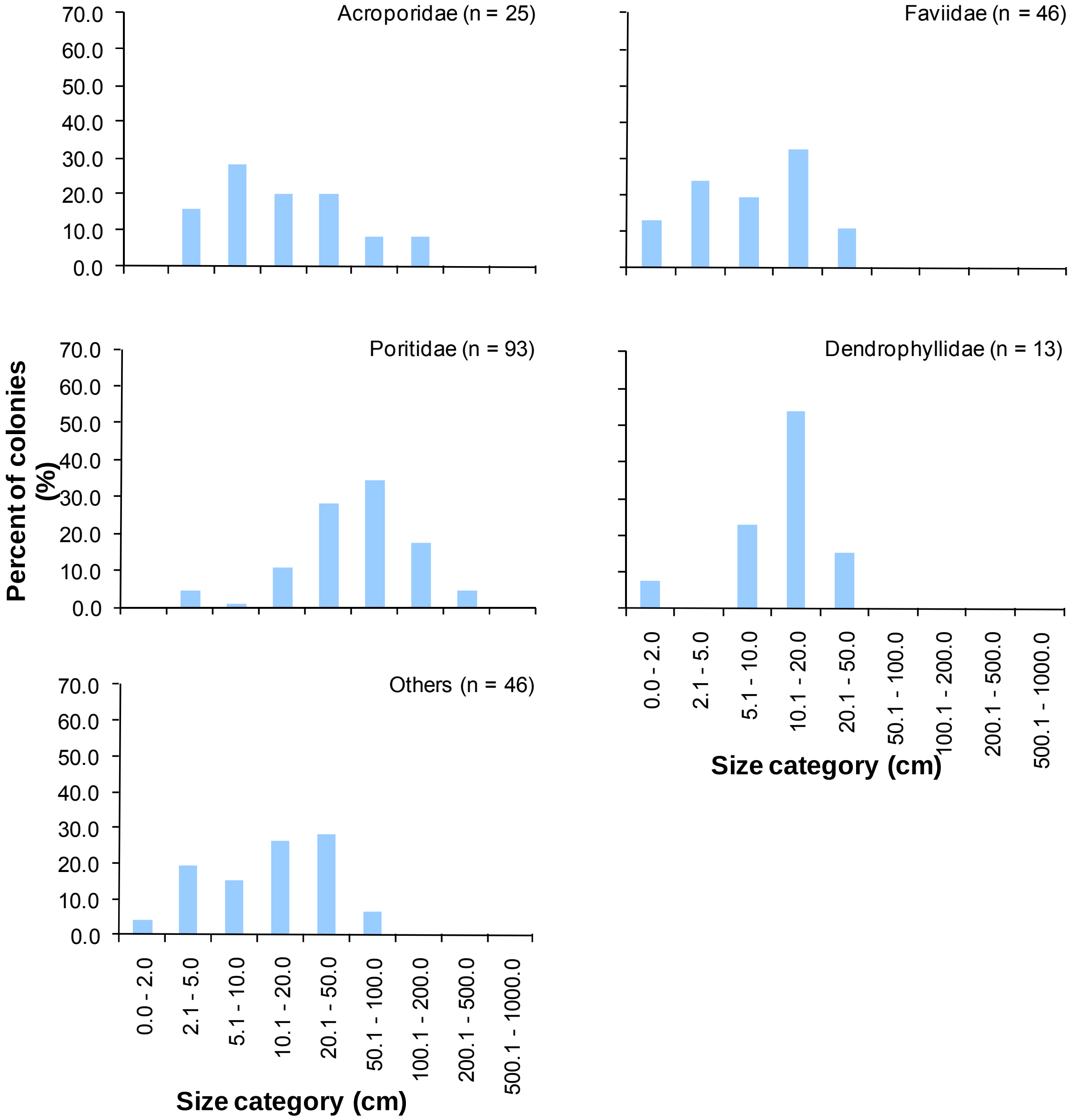


Figure 6-19 Size-Class Frequency Distribution of Hard Corals at Lone Reef

Table 6-34 Size-Class Frequency Count and Size Statistics of Hard Corals at Lone Reef

Family	Genera	Number of colonies per transect (n=4)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	3.5	1.2	4	0	16.9	14	16.2	4.3	1.0
	Montipora	2.8	1.5	0	0	46.3	11	55.0	16.6	1.2
Agariciidae	Agariciidae Unidentified	0.3	0.3	0	0	11.0	1	-	-	-
	Pachyseris	0.5	0.3	1	0	32.5	2	41.7	29.5	1.3
Faviidae	Caulastrea	0.3	0.3	0	0	13.0	1	-	-	-
	Faviidae Unidentified	11.3	3.7	13	0	10.1	45	6.8	1.0	0.7
Merulinidae	Merulina	1.0	0.4	0	0	21.3	4	18.7	9.4	0.9
Milleporidae	Millepora	1.5	1.0	0	0	37.7	6	19.6	8.0	0.5
Mussidae	Lobophyllia	0.5	0.3	0	0	11.5	2	6.4	4.5	0.6
Pectiniidae	Oxypora	0.3	0.3	0	0	23.0	1	-	-	-
	Pectinia	1.3	0.8	0	0	7.2	5	1.6	0.7	0.2
Poritidae	Porites	17.0	2.1	2	4	91.0	68	86.8	10.5	1.0
	Porites Branching	6.3	1.3	0	0	38.3	25	24.5	4.9	0.6
Dendrophyllidae	Turbinaria	3.3	0.6	1	0	14.7	13	9.0	2.5	0.6
Oculinidae	Galaxea	1.0	0.7	2	0	10.0	4	7.5	3.8	0.8
Pocilloporidae	Pocillopora	2.5	0.9	0	0	33.2	10	14.3	4.5	0.4
	Stylophora	0.3	0.3	0	0	5.0	1	-	-	-
Unidentified Family	Unidentified Genus	2.5	0.6	5	0	11.8	10	14.0	4.4	1.2
TOTAL		**55.8**[1]	**6.4**[1]	**28**	**4**	**42.7**[2]	**223**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over four transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

6.4.3.3 Size-Class Frequency Distributions of Hard Coral Species/Taxa at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

6.4.3.3.1 Ah Chong (AHC)

A total of 464 colonies were measured at the Ah Chong monitoring site, with a mean number per transect of 92.8 ± 7.8 (Table 6-35). The most abundant colonies were massive *Porites* (28.0 ± 3.0) and unidentified faviids (14.8 ± 3.3). All other taxa were recorded at densities of ≤7 colonies per transect.

The overall average colony size was 20.5 cm, which varied between a mean of 6.8 ± 1.0 cm for *Cyphastrea* and 90.0 ± 0.0 cm for *Millepora* (Table 6-35). The standard deviation varied between 0.7 (*Pachyseris*) and 51.6 (*Oxypora*) and the coefficient of variation between <0.1 ± 0.0 (*Pachyseris*) and 1.2 (*Oxypora* and *Porites*). The only colonies >200 cm in size were massive *Porites*, with two colonies in total. There were a total of 56 small, <5 cm in size, colonies, in 13 taxonomic groups. The greatest numbers were unidentified faviids (15) and *Merulina* (7).

Coral colonies ranged from <2 cm to >2 m in size, with 80–100% of the colonies from all the families between 2.1 and 50 cm in size (Figure 6-20). The majority (64–78%) of the poritids, oculinids and ‘Others’ were 10.1–50 cm in size. The only corals >1 m in size were the poritids, while the only corals <2 cm were the faviids, oculinids and ‘Others’.

Table 6-35 Size-Class Frequency Count and Size Statistics of Hard Corals at Ah Chong

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	2.0	0.7	2	0	14.7	10	11.1	3.5	0.8
	Astreopora	1.0	0.8	0	0	10.4	5	4.2	1.9	0.4
	Montipora	1.8	0.7	1	0	12.1	9	7.2	2.4	0.6
Agariciidae	Pachyseris	0.4	0.4	0	0	34.5	2	0.7	0.5	0.0
Faviidae	Cyphastrea	2.2	1.0	3	0	6.8	11	3.3	1.0	0.5
	Echinopora	2.4	0.8	0	0	13.1	12	4.7	1.4	0.4
	Faviidae Unidentified	14.8	3.3	15	0	10.1	74	6.2	0.7	0.6
	Goniastrea	4.6	1.3	9	0	8.9	23	6.2	1.3	0.7
	Leptastrea	0.8	0.4	0	0	12.8	4	6.5	3.3	0.5
	Platygyra	6.6	1.0	0	0	14.4	33	4.4	0.8	0.3
Merulinidae	Merulina	5.2	1.0	7	0	8.5	26	5.3	1.0	0.6
Milleporidae	Millepora	0.2	0.2	0	0	90.0	1	-	-	-
Mussidae	Lobophyllia	5.8	1.2	6	0	17.8	29	18.1	3.4	1.0
	Symphyllia	0.8	0.4	0	0	9.5	4	2.4	1.2	0.3
Pectiniidae	Echinophyllia	2.0	0.6	0	0	15.3	10	9.3	2.9	0.6
	Mycedium	1.0	0.5	1	0	14.4	5	11.1	5.0	0.8
	Oxypora	0.4	0.4	0	0	43.5	2	51.6	36.5	1.2
	Pectinia	0.2	0.2	0	0	11.0	1	-	-	-
Poritidae	Goniopora	1.0	0.8	0	0	14.6	5	4.7	2.1	0.3
	Porites	28.0	3.0	5	2	35.9	140	44.7	3.8	1.2
Dendrophyllidae	Turbinaria	0.4	0.2	0	0	21.5	2	6.4	4.5	0.3
Fungiidae	Fungiidae Unidentified	0.6	0.2	1	0	11.3	3	6.4	3.7	0.6
Oculinidae	Galaxea	5.6	1.1	1	0	18.6	28	11.6	2.2	0.6
Pocilloporidae	Pocillopora	1.0	0.4	1	0	13.0	5	9.1	4.1	0.7

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
	Seriatopora	2.6	0.7	1	0	24.7	13	11.9	3.3	0.5
	Stylophora	0.2	0.2	0	0	11.0	1	-	-	-
Unidentified Family	Unidentified Genus	1.2	0.4	3	0	19.8	6	39.3	16.0	2.0
TOTAL		**92.8**[1]	**7.8**[1]	**56**	**2**	**20.5**[2]	**464**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

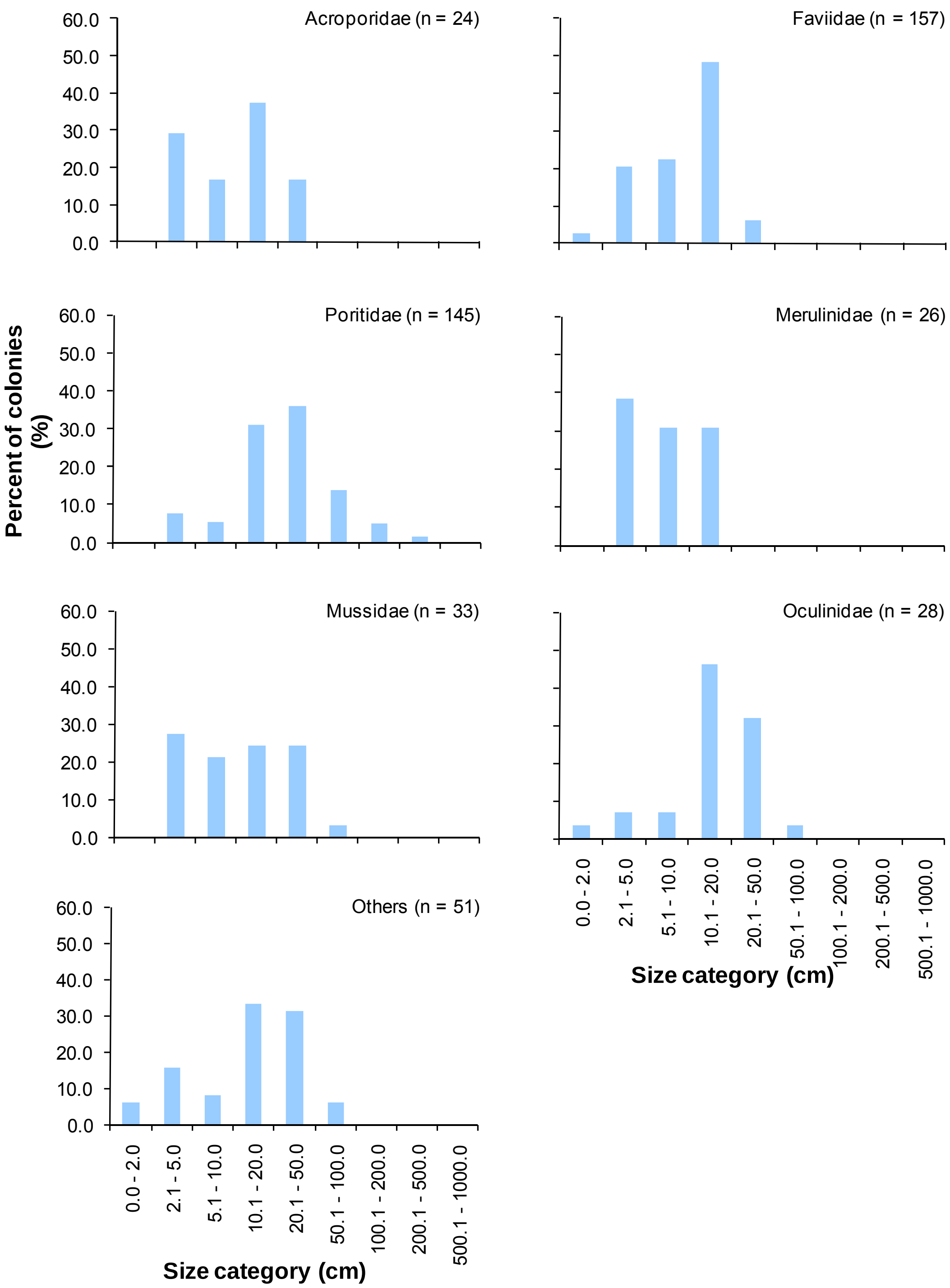


Figure 6-20 Size-Class Frequency Distribution of Hard Corals at Ah Chong

6.4.3.3.2 Biggada Reef (BIG)

A total of 133 colonies were measured at the Biggada Reef monitoring site, with a mean number per transect of 26.6 ± 4.0 (Table 6-36). The most abundant colonies were *Goniastrea* (9.2 ± 2.4). All other taxa were recorded at densities of ≤4 colonies per transect.

The overall average colony size was 42.2 cm, which varied between a mean of 4.0 ± 0.0 cm for *Goniopora* and 71.6 ± 7.8 cm for *Goniastrea* (Table 6-36). The standard deviation varied between 0.0 (*Goniopora*) and 53.2 (*Goniastrea*) and the coefficient of variation between <0.1 (*Goniopora*) and 1.3 (*Hydnophora*). The only colonies >200 cm in size were Goniastrea, which numbered one colony in total. There were a total of ten small, <5 cm in size, colonies, in seven taxonomic groups. The greatest in number were *Goniopora, Cyphastrea,* and *Pocillopora* (two colonies each) and all other taxonomic groups were ≤1 small colony per transect.

Colonies were recorded across all size-classes between <2 cm and 5 m (Figure 6-21). The majority of the acroporids and poritids were in the 10.1–20.0 cm size-class and the majority of the faviids and 'Others' were in the 20.1–50.0 cm size-class. The faviids represented 72% of the colonies measured and was the only family where colonies were >100 cm in size.

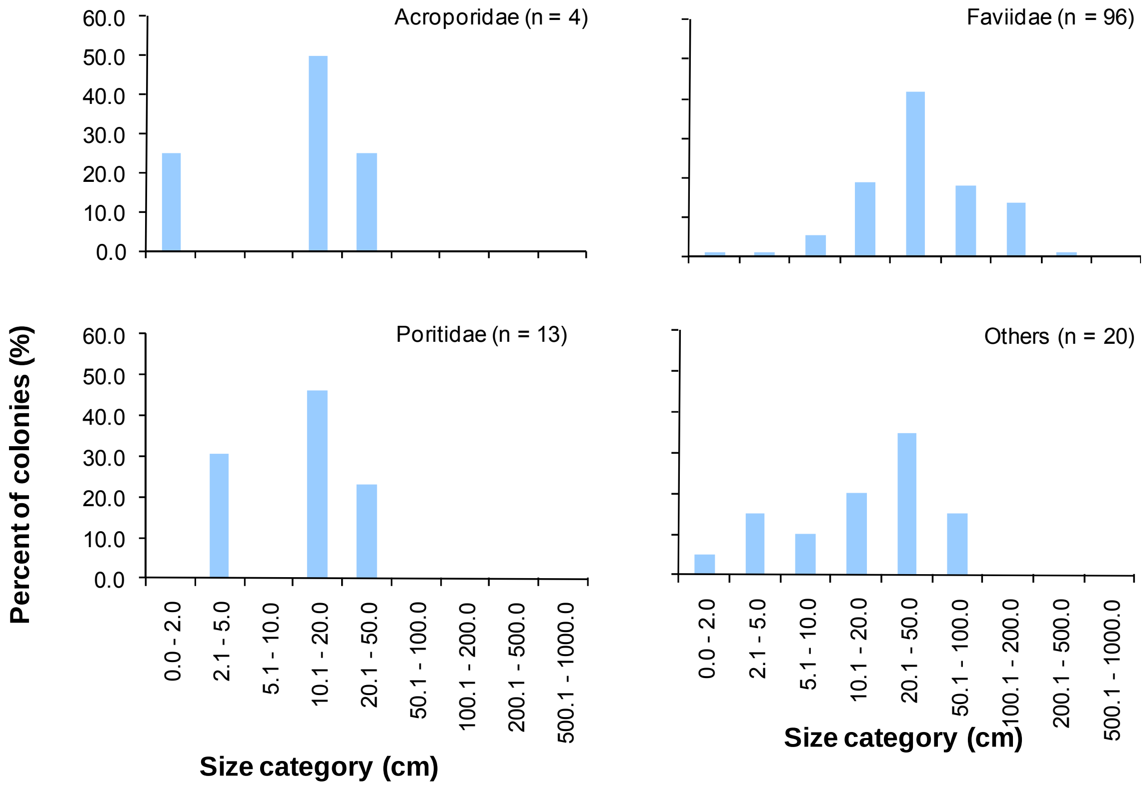


Figure 6-21 Size-Class Frequency Distribution of Hard Corals at Biggada Reef

Table 6-36 Size-Class Frequency Count and Size Statistics of Hard Corals at Biggada Reef

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	0.8	0.5	1	0	15.9	4	10.7	5.3	0.7
Faviidae	Cyphastrea	4.0	1.5	2	0	22.7	20	15.1	3.4	0.7
	Echinopora	1.4	0.7	0	0	61.7	7	28.5	10.8	0.5
	Faviidae Unidentified	4.0	1.5	0	0	28.9	20	11.4	2.5	0.4
	Goniastrea	9.2	2.4	0	1	71.6	46	53.2	7.8	0.7
	Leptastrea	0.6	0.4	0	0	39.3	3	13.5	7.8	0.3
Merulinidae	Hydnophora	0.4	0.4	1	0	36.0	2	48.1	34.0	1.3
	Merulina	0.6	0.6	1	0	17.0	3	11.5	6.7	0.7
Mussidae	Lobophyllia	0.2	0.2	0	0	50.0	1	-	-	-
Pectiniidae	Echinophyllia	0.2	0.2	0	0	67.0	1	-	-	-
	Mycedium	0.6	0.4	0	0	31.0	3	22.3	12.9	0.7
	Pectinia	0.2	0.2	0	0	9.0	1	-	-	-
Poritidae	Goniopora	0.4	0.4	2	0	4.0	2	0.0	0.0	0.0
	Porites	2.2	0.5	1	0	16.5	11	8.8	2.7	0.5
Fungiidae	Fungiidae Unidentified	0.4	0.2	0	0	11.0	2	1.4	1.0	0.1
Pocilloporidae	Pocillopora	1.2	0.6	2	0	17.0	6	12.6	5.1	0.7
Siderastreidae	Psammocora	0.2	0.2	0	0	17.0	1	-	-	-
TOTAL		**26.6**[1]	**4.0**[1]	**10**	**1**	**42.2**[2]	**133**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

6.4.3.3.3 LNG3

A total of 338 colonies were measured at the LNG3 monitoring site, with a mean number per transect of 67.6 ± 16.7 (Table 6-37). The most abundant colonies were massive *Porites* (23.4 ± 9.3) and unidentified faviids (21.2 ± 6.1). All other taxa were recorded at densities of <6 colonies per transect.

The overall average colony size was 16 cm, which varied between a mean of 3.7 ± 0.3 cm for unidentified mussids and 72.5 ± 18.5 cm for *Hydnophora* (Table 6-37). The standard deviation varied between 0.6 (unidentified mussids) and 69.5 (massive *Porites*) and the coefficient of variation between 0.2 (unidentified mussids) and 2.9 (massive *Porites*). The only colonies >200 cm in size were massive *Porites*, which numbered two colonies in total. There were a total of 82 small, <5 cm in size, colonies, in five taxonomic groups. The greatest in number were massive *Porites* (39), unidentified faviids (22), and *Acropora* (10).

There were very few large colonies, with 324 (97%) <50 cm in diameter (Figure 6-22). The acroporids and faviids had similar size-class frequency distributions at LNG3 to those recorded at LNG1, with colonies ranging in size from <2 cm to 50 cm. The majority of colonies (80% and 87% respectively) were 2.1–20 cm in size. The exception was that faviids >50 cm in size were recorded at LNG1, but not LNG3. The dendrophylliid modal size-class was one size-class greater (10.1–20 cm) at LNG3 compared to LNG1. The majority (93%) of poritid colonies were <50 cm in size; however, the only colonies >1 m in size at LNG3 were poritids. The majority (85%) of corals in the ‘Other’ families were <20 cm in size. There were two colonies of *Hydnophora* (Merulinidae) that were >50 cm.

Table 6-37 Size-Class Frequency Count and Size Statistics of Hard Corals at LNG3

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of variation
		Mean	SE							
Acroporidae	Acropora	5.2	1.2	10	0	6.2	26	4.7	0.9	0.8
	Montipora	1.8	0.7	0	0	18.6	9	4.9	1.6	0.3
Agariciidae	Pachyseris	0.4	0.2	0	0	12.0	2	7.1	5.0	0.6
Faviidae	Echinopora	0.2	0.2	0	0	11.0	1	-	-	-
	Faviidae Unidentified	21.2	6.1	22	0	9.3	106	5.9	0.6	0.6
Merulinidae	Hydnophora	0.4	0.2	0	0	72.5	2	26.2	18.5	0.4
Mussidae	Lobophyllia	1.2	0.4	0	0	9.0	6	2.6	1.1	0.3
	Mussidae Unidentified	0.6	0.2	3	0	3.7	3	0.6	0.3	0.2
Pectiniidae	Echinophyllia	0.4	0.2	0	0	14.0	2	11.3	8.0	0.8
	Oxypora	0.6	0.4	0	0	8.7	3	2.9	1.7	0.3
	Pectinia	0.4	0.4	0	0	29.0	2	15.6	11.0	0.5
Poritidae	Porites	23.4	9.3	39	2	24.1	117	69.5	6.4	2.9
	Porites Branching	2.4	1.1	0	0	29.1	12	14.6	4.2	0.5
Dendrophyllidae	Turbinaria	5.4	1.2	0	0	13.4	27	4.9	1.0	0.4
Fungiidae	Fungiidae Unidentified	1.4	0.4	4	0	6.9	7	7.4	2.8	1.1
Pocilloporidae	Pocillopora	0.6	0.2	0	0	22.3	3	21.2	12.3	1.0
Unidentified Family	Unidentified Genus	2.0	1.0	4	0	10.4	10	8.9	2.8	0.9
TOTAL		**67.6**[1]	**16.7**[1]	**82**	**2**	**16.0**[2]	**338**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).;

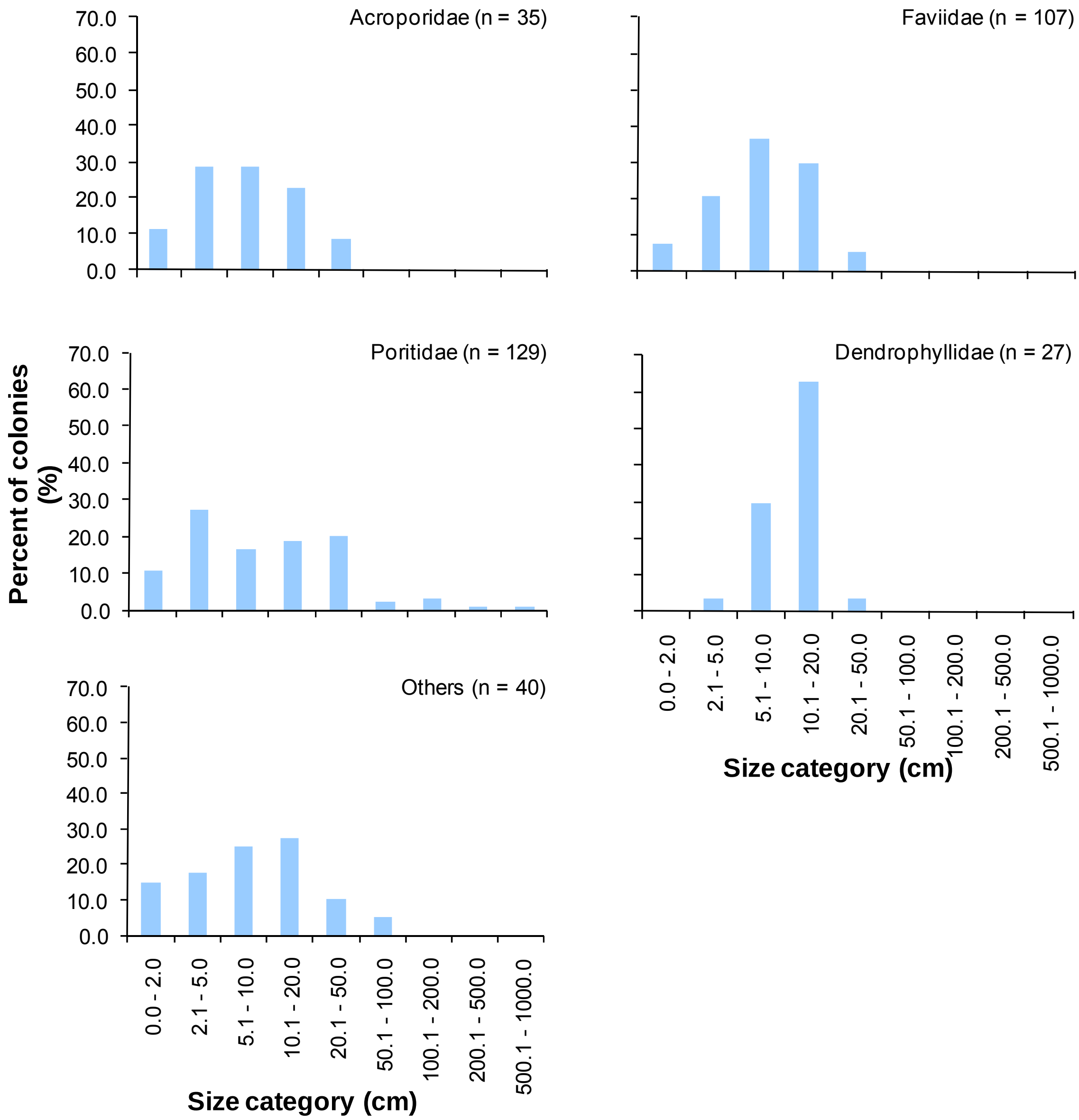


Figure 6-22 Size-Class Frequency Distribution of Hard Corals at LNG3

6.4.3.4 Size-Class Frequency Distributions of Hard Coral Species/Taxa at Sites in Regionally Significant Areas Outside the Zones of Influence

6.4.3.4.1 Dugong Reef (DUG)

A total of 449 colonies were measured at the Dugong Reef monitoring site, with a mean number per transect of 89.8 ± 11.7 (Table 6-38). The most abundant colonies were unidentified faviids (22.4 ± 3.1), *Montipora* (10.4 ± 2.4), and *Lobophyllia* (7.6 ± 1.2). All other taxa were recorded at densities of ≤5 colonies per transect.

The overall average colony size was 35.7 cm, which varied between a mean of 3.4 ± 0.9 cm for unidentified mussids and 120.9 ± 5.1 cm for massive *Porites* (Table 6-38). The standard deviation varied between 2.9 (unidentified mussids) and 192 (massive *Porites*) and the coefficient of variation between 0.5 (*Pocillopora* and *Lobophyllia*) and 2.1 (*Galaxea*). The only colonies >200 cm in size were massive *Porites* and Galaxea, with four and one colony in total respectively. There were a total of 45 small, <5 cm in size, colonies, in nine taxonomic groups. The greatest numbers were unidentified fungiids (12) and unidentified faviids (10) and all other taxonomic groups contained ≤7 small colonies

Corals ranged from <2 cm to >5 m in size (the latter including a stand of the oculinid *Galaxea*) (Figure 6-23). The most common (38–57%) size-class across all families, with the exception of the faviids and 'Others', was 20.1–50.0 cm. In contrast, >73% of the faviids were 10.1–50 cm in size, while the 'Others' were between <2 cm and 1 m in size.

Table 6-38 Size-Class Frequency Count and Size Statistics of Hard Corals at Dugong Reef

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	3.8	1.1	5	0	26.1	19	35.2	8.1	1.3
	Montipora	10.4	2.4	0	0	32.9	52	20.9	2.9	0.6
Agariciidae	Pachyseris	2.2	0.7	0	0	60.4	11	61.1	18.4	1.0
	Pavona	1.8	0.4	0	0	51.6	9	35.1	11.7	0.7
Faviidae	Cyphastrea	0.2	0.2	0	0	16.0	1	-	-	-
	Echinopora	1.4	1.0	0	0	30.7	7	18.3	6.9	0.6
	Faviidae Unidentified	22.4	3.1	10	0	21.8	112	23.1	2.2	1.1
	Goniastrea	1.2	0.7	0	0	56.2	6	73.3	29.9	1.3
	Oulophyllia/Oulastrea	0.2	0.2	0	0	37.0	1	-	-	-
Merulinidae	Hydnophora	2.6	1.1	0	0	70.2	13	55.2	15.3	0.8
	Merulina	3.0	0.9	2	0	26.9	15	24.2	6.2	0.9
Mussidae	Lobophyllia	7.6	1.2	0	0	26.4	38	12.5	2.0	0.5
	Mussidae Unidentified	2.2	0.6	7	0	3.4	11	2.9	0.9	0.9
Pectiniidae	Echinophyllia	3.4	0.8	0	0	24.8	17	21.0	5.1	0.8
	Mycedium	0.2	0.2	0	0	13.0	1	-	-	-
	Oxypora	3.4	1.1	0	0	33.3	17	19.4	4.7	0.6
	Pectinia	4.0	1.4	1	0	26.6	20	23.7	5.3	0.9
Poritidae	Goniopora	0.2	0.2	0	0	38.0	1	-	-	-
	Porites	5.0	1.6	1	4	120.9	25	192.0	5.1	1.6
	Porites Branching	2.2	0.5	1	0	45.3	11	33.1	10.0	0.7
Caryophyllidae	Euphyllia	0.4	0.2	0	0	12.5	2	10.6	4.7	0.8
Dendrophyllidae	Turbinaria	2.2	0.9	0	0	14.2	11	9.0	5.3	0.6
Fungiidae	Fungiidae Unidentified	3.2	1.7	12	0	4.7	16	4.9	10.4	1.0
	Herpolitha	0.2	0.2	0	0	30.0	1	-	-	-

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Oculinidae	Galaxea	4.2	0.6	1	1	80.8	21	169.1	38.4	2.1
Pocilloporidae	Pocillopora	0.6	0.4	0	0	34.0	3	18.0	10.0	0.5
Unidentified Family	Unidentified Genus	1.6	0.9	5	0	5.9	8	5.0	1.8	0.8
TOTAL		**89.8**[1]	**11.7**[1]	**45**	**5**	**35.7**[2]	**449**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

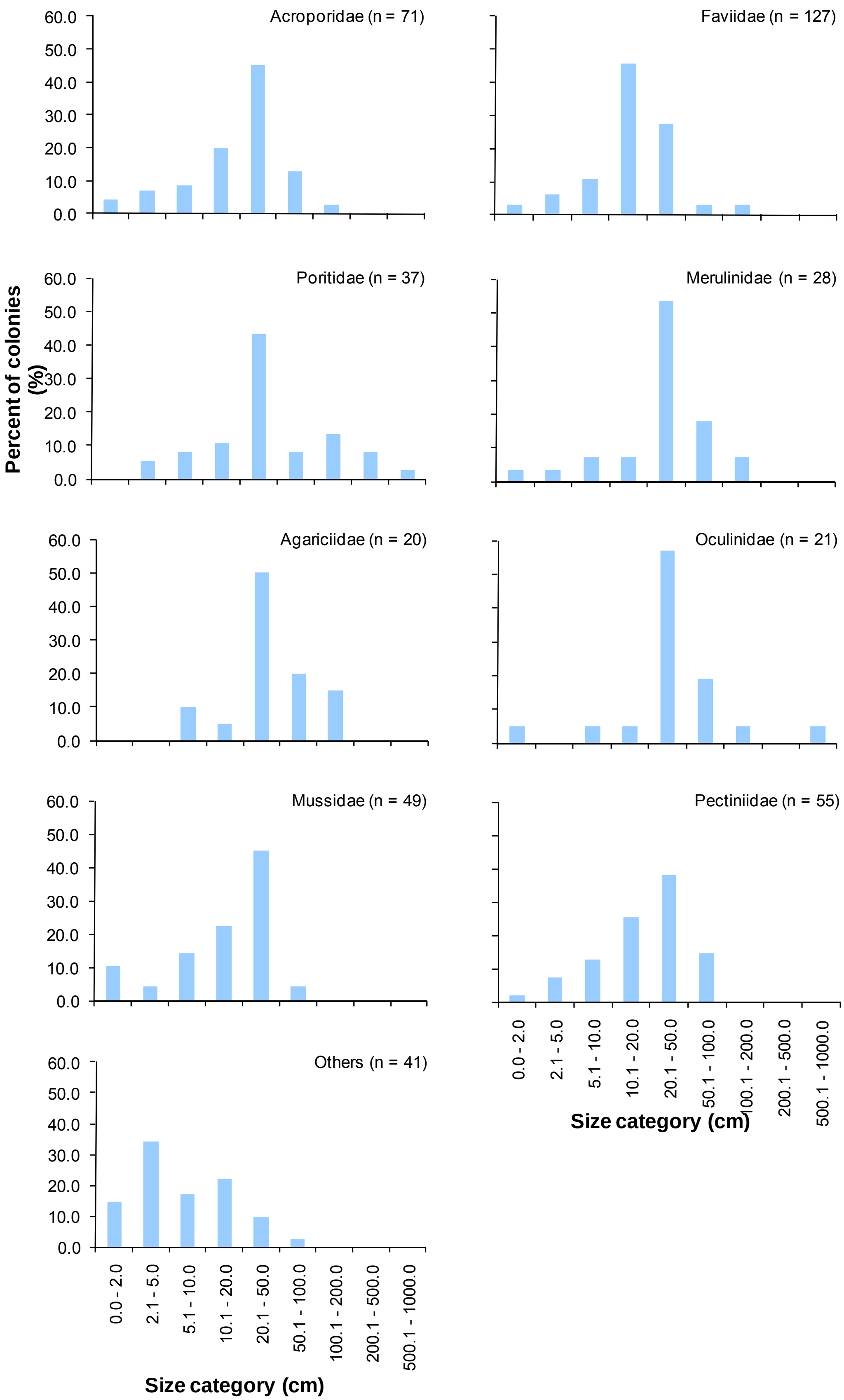


Figure 6-23 Size-Class Frequency Distribution of Hard Corals at Dugong Reef

6.4.3.4.2 Batman Reef (BAT)

A total of 360 colonies were measured at the Batman Reef monitoring site, with a mean number per transect of 72.0 ± 6.4 (Table 6-39). The most abundant colonies were unidentified faviids (26.0 ± 1.9) and branching *Porites* (12.4 ± 3.4). All other taxa were recorded at densities of ≤4 colonies per transect.

The overall average colony size was 31.9 cm, which varied between a mean of 6.0 cm for *Caulastrea* and 104.0 cm for *Pavona* (Table 6-39). The standard deviation varied between 6.8 (unidentified genus), 8.0 (unidentified fungiids), and 81.0 (massive *Porites*) and the coefficient of variation between 0.4 (*Millepora, Oxypora,* and *Pectinia*) and 1.6 (massive *Porites*). The only colonies >200 cm in size were massive *Porites*, with one colony in total. There were a total of 17 small, <5 cm in size, colonies in seven taxonomic groups. The greatest in number were unidentified faviids (6) and all the other taxonomic groups were <1 small colony in total.

Colonies ranged in size from <2 cm to >2 m (Figure 6-24), but only poritids were recorded in all these size-classes. Between 88% and 95% of the acroporids, poritids, merulinids, and pectiniids were 10.1–100 cm in size, slightly larger than at Ah Chong. The majority of the faviids and ‘Others’ (89 and 88%, respectively) were 2.1–50 cm in size.

Table 6-39 Size-Class Frequency Count and Size Statistics of Hard Corals at Batman Reef

Family	Genera	# Colonies per transect		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	0.2	0.2	0	0	30.0	1	-	-	-
	Montipora	4.0	0.9	0	0	42.8	20	24.9	5.6	0.6
Agariciidae	Pavona	0.2	0.2	0	0	104.0	1	-	-	-
Faviidae	Caulastrea	0.2	0.2	0	0	6.0	1	-	-	-
	Cyphastrea	0.4	0.4	0	0	25.5	2	19.1	13.5	0.7
	Echinopora	4.0	1.3	0	0	47.7	20	24.0	5.4	0.5
	Faviidae Unidentified	26.0	1.9	6	0	19.9	130	13.7	1.2	0.7
	Goniastrea	0.2	0.2	0	0	18.0	1	-	-	-
Merulinidae	Hydnophora	0.4	0.4	0	0	58.5	2	31.8	22.5	0.5
	Merulina	4.0	0.3	0	0	59.2	20	31.2	7.0	0.5
Milleporidae	Millepora	1.0	0.4	0	0	44.4	5	16.4	7.4	0.4
Mussidae	Lobophyllia	1.6	0.4	1	0	23.3	8	14.4	5.1	0.6
Pectiniidae	Echinophyllia	2.0	0.9	1	0	27.4	10	16.2	5.1	0.6
	Oxypora	2.2	1.3	0	0	37.6	11	16.6	5.0	0.4
	Pectinia	4.0	1.5	0	0	47.3	20	20.6	4.6	0.4
Poritidae	Porites	1.8	0.4	1	1	50.3	9	81.0	27.0	1.6
	Porites Branching	12.4	3.4	1	0	40.0	62	24.1	3.1	0.6
Dendrophyllidae	Turbinaria	0.8	0.4	0	0	16.5	4	14.7	7.4	0.9
Fungiidae	Fungiidae Unidentified	1.4	0.5	1	0	12.7	7	8.0	3.0	0.6
	Herpolitha	0.2	0.2	0	0	13.0	1	-	-	-
Oculinidae	Galaxea	0.8	0.5	0	0	32.5	4	21.7	10.9	0.7
Pocilloporidae	Pocillopora	1.0	0.5	1	0	22.8	5	15.8	7.1	0.7
	Stylophora	1.4	0.4	0	0	15.9	7	8.3	3.1	0.5
Unidentified Family	Unidentified Genus	1.8	1.0	5	0	7.7	9	6.8	2.3	0.9
TOTAL		**72.0**[1]	**6.4**[1]	**17**	**1**	**31.9**[2]	**360**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

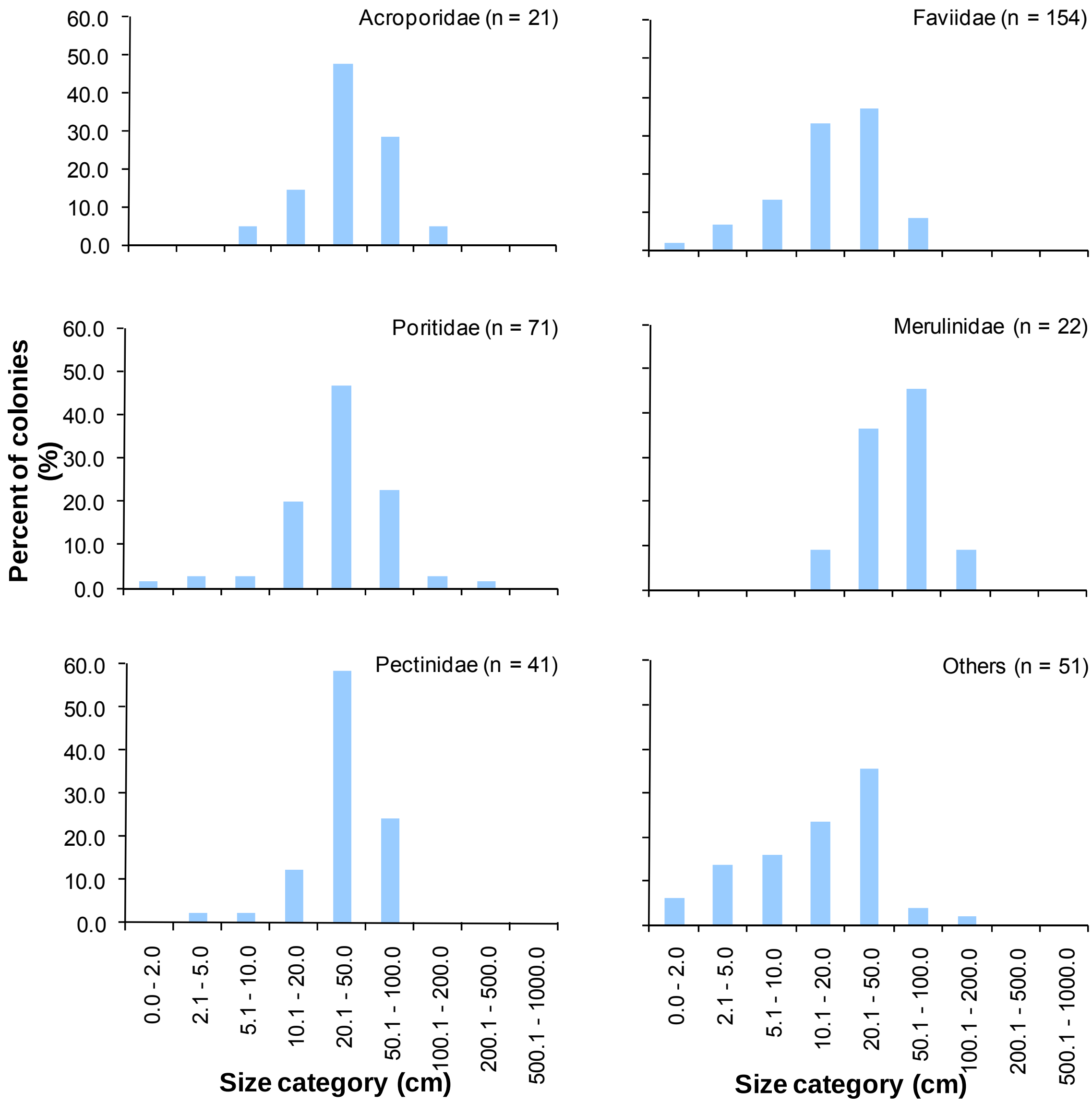


Figure 6-24 Size-Class Frequency Distribution of Hard Corals at Batman Reef

6.4.3.4.3 Southern Barrow Shoals (SBS)

A total of 349 colonies were measured at the Southern Barrow Shoals monitoring site, with a mean number per transect of 69.8 ± 14.8 (Table 6-40). The most abundant colonies were unidentified faviids (30.6 ± 7.1) and *Montipora* (19.2 ± 2.1). All other taxa were recorded at densities of ≤4 colonies per transect.

The overall average colony size was 24.8 cm, which varied between a mean of 15.3 ± 2.5 cm for *Stylophora* and 59.0 ± 0.0 cm for *Echinopora* (Table 6-40). The standard deviation varied between 0.7 (*Podobacia*) and 67.6 (massive *Porites*) and the coefficient of variation between 0.0 (*Podobacia*) and 1.2 (massive *Porites*). The only colonies >200 cm in size were massive *Porites*, which numbered one colony in total. There were a total of 17 small, <5 cm in size, colonies, in three taxonomic groups. The greatest numbers were unidentified faviids (13) and all the other taxonomic groups were <2 small colonies in total.

The majority (80%) of the colonies measured at Southern Barrow Shoals were in the 10.1–20.0 cm and 20.1–50.0 cm size-classes (Figure 6-25). Corals of these sizes contributed between 75–93% of the acroporid, faviid, poritid, and 'Others' colonies; colonies of <5 cm in size and >1 m were reported for all four families.

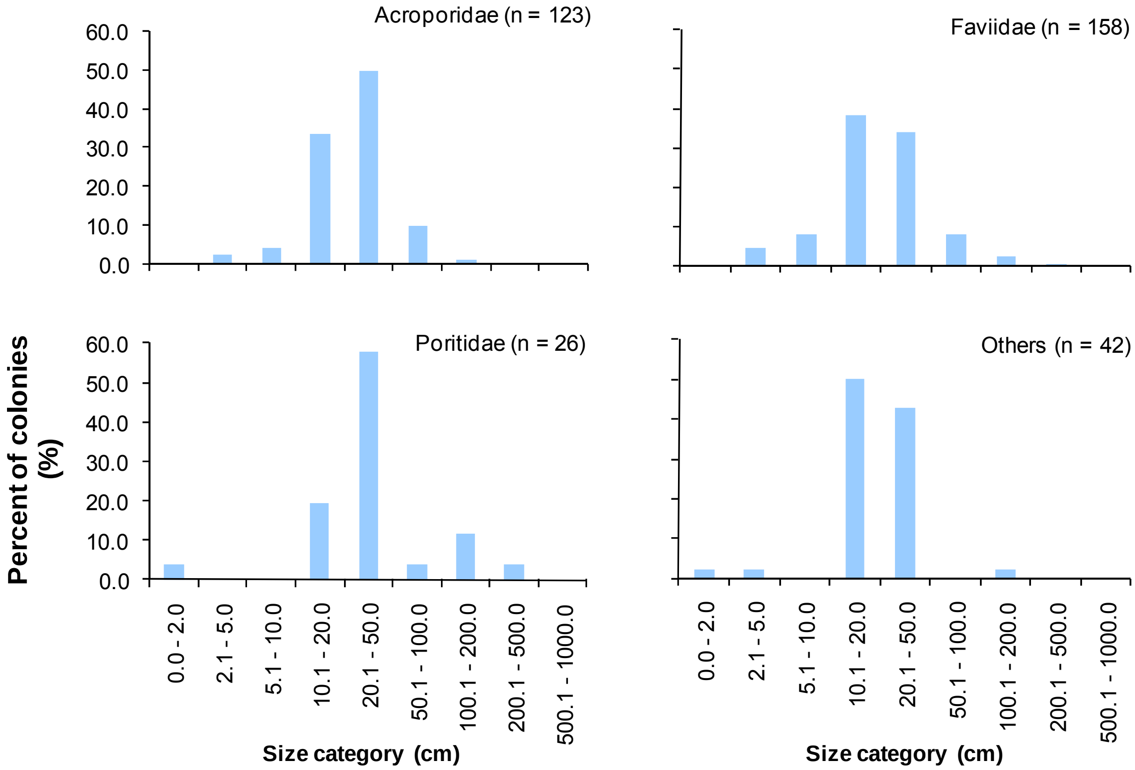


Figure 6-25 Size Class-Frequency Distribution of Hard Corals at Southern Barrow Shoals

Table 6-40 Size-Class Frequency Count and Size Statistics of Hard Corals at Southern Barrow Shoals

Family	Genera	Number of colonies per transect (n=5)		# Colonies <5 cm	# Colonies >200 cm	Average size (cm)	# Colonies Sampled	Standard Deviation	Standard Error	Coefficient of Variation
		Mean	SE							
Acroporidae	Acropora	3.0	1.0	0	0	28.3	15	13.7	3.5	0.5
	Astreopora	2.4	0.4	0	0	32.2	12	21.0	6.1	0.7
	Montipora	19.2	2.1	2	0	27.7	96	18.7	1.9	0.7
Agariciidae	Pavona	0.2	0.2	0	0	22.0	1	-	-	-
Faviidae	Cyphastrea	0.6	0.4	0	0	23.7	3	8.5	4.9	0.4
	Echinopora	0.2	0.2	0	0	59.0	1	-	-	-
	Faviidae Unidentified	30.6	7.1	13	0	18.2	153	16.7	1.4	0.9
	Goniastrea	0.2	0.2	0	0	30.0	1	-	-	-
Merulinidae	Hydnophora	0.4	0.2	0	0	26.0	2	15.6	11.0	0.6
	Merulina	0.2	0.2	0	0	38.0	1	-	-	-
Milleporidae	Millepora	1.2	0.7	0	0	36.2	6	35.8	14.6	1.0
Mussidae	Lobophyllia	1.2	0.6	0	0	15.5	6	3.4	1.4	0.2
Pectiniidae	Pectinia	0.2	0.2	0	0	32.0	1	-	-	-
Poritidae	Porites	4.0	1.9	0	1	56.9	20	67.6	15.1	1.2
	Porites Branching	1.2	0.6	1	0	26.5	6	16.6	6.8	0.6
Dendrophylliidae	Turbinaria	0.8	0.5	0	0	17.5	4	11.0	5.5	0.6
Fungiidae	Podobacia	0.4	0.4	0	0	34.5	2	0.7	0.5	0.0
Oculinidae	Galaxea	0.2	0.2	0	0	37.0	1	-	-	-
Pocilloporidae	Pocillopora	0.6	0.4	0	0	22.0	3	6.2	3.6	0.3
	Stylophora	1.6	0.4	0	0	15.3	8	7.0	2.5	0.5
Unidentified Family	Unidentified Genus	1.4	1.2	1	0	18.6	7	9.4	3.6	0.5
TOTAL		**69.8**[1]	**14.8**[1]	**17**	**1**	**24.8**[2]	**349**	**-**	**-**	**-**

Notes: n = number of transects for which mean is calculated; 1 = total value calculated by pooling counts of all taxa per transect and averaging over five transects; 2 = mean colony size (cm) across the site (the sum of all colony sizes averaged by the total number of colonies present).

6.4.4 Survival of Dominant Hard Coral Species/Taxa

6.4.4.1 Percentage Live Cover of Coral Families

Live coral percentage cover and composition measured from random transects was variable among the coral monitoring sites, with coral cover ranging from <20% to ~80% on the first survey. Coral cover was >50% at five sites: Ah Chong, Ant Point Reef, Lone Reef, Dugong Reef and Batman Reef. Ant Point Reef and Southern Lowendal Shelf were characterised by dense *Acropora* thickets; Dugong Reef, Batman Reef and Southern Barrow Shoals were characterised by a mixture of different coral families (e.g. acroporids, faviids, merulinids and poritids); while Ah Chong and Lone Reef were dominated by *Porites* bomboras. Large *Porites* bombora also dominated LNG0, LNG1, LNG3; at these sites live coral cover was <40%. Two of the sites with the lowest cover (<20%), MOF1 and Biggada Reef, were characterised predominantly by faviids.

6.4.4.2 Percentage Live Cover at Sites in the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.4.2.1 Percentage Live Cover at Sites in the Vicinity of the MOF and Causeway

Hard corals covered ~20% of the substratum at the MOF1 monitoring site, with faviids representing ~50% and acroporids ~25% of the cover (Table 6-41; Figure 6-26). Hard coral cover and percentage composition of hard corals were consistent over the 12 months of sampling. The sample mean of turfing algae cover, which comprised ~40% of the live cover in October 2008, decreased between the two surveys, with ~25% cover recorded in April 2009; but increased again in October 2009 to ~40%. There were corresponding changes in the estimates of percentage cover of sediment.

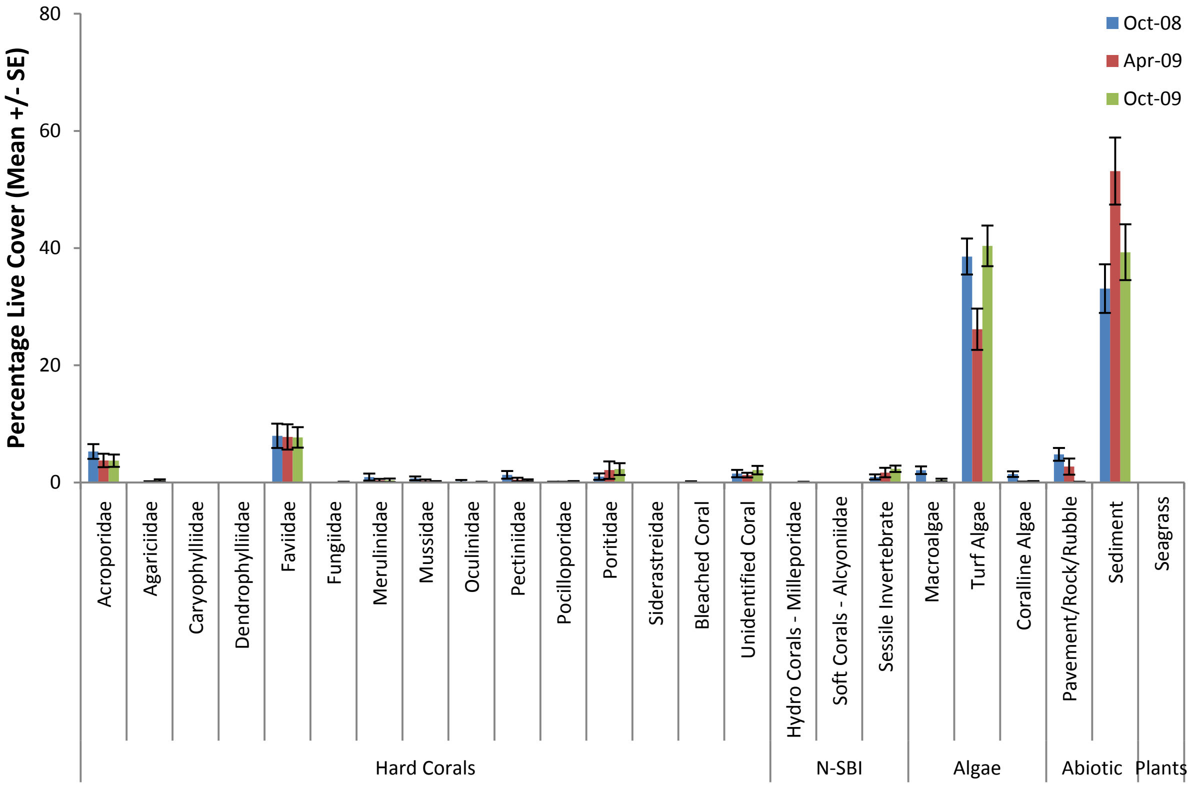


Figure 6-26 Mean Percentage Cover (± SE) and Composition of Corals at MOF1

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-41 Mean Percentage Cover ± SE Data and Composition of Corals at MOF1

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Oct 2008	Mean	5.3	0.0	0.0	0.0	8.0	0.0	0.9	0.7	0.2	1.3	0.1	1.0	0.0	0.1	1.5	0.0	0.0	0.9	2.1	38.6	1.4	4.8	33.1	0.0
	SE	1.3	0.0	0.0	0.0	2.1	0.0	0.6	0.3	0.2	0.7	0.1	0.5	0.0	0.1	0.6	0.0	0.0	0.4	0.6	3.1	0.5	1.1	4.2	0.0
Apr 2009	Mean	3.8	0.1	0.0	0.0	7.8	0.0	0.4	0.3	0.0	0.5	0.1	2.1	0.0	0.0	1.3	0.0	0.0	1.7	0.0	26.1	0.1	2.7	53.1	0.0
	SE	1.1	0.1	0.0	0.0	2.2	0.0	0.3	0.2	0.0	0.3	0.1	1.5	0.0	0.0	0.4	0.0	0.0	0.8	0.0	3.5	0.1	1.4	5.7	0.0
Oct 2009	Mean	3.7	0.3	0.0	0.0	7.7	0.1	0.4	0.1	0.1	0.3	0.1	2.3	0.0	0.0	2.1	0.1	0.0	2.3	0.4	40.4	0.1	0.1	39.3	0.0
	SE	1.0	0.2	0.0	0.0	1.8	0.1	0.3	0.1	0.1	0.2	0.1	1.0	0.0	0.0	0.7	0.1	0.0	0.5	0.2	3.5	0.1	0.1	4.8	0.0

6.4.4.2.2 Percentage Live Cover at Sites in the Vicinity of the LNG Jetty Access Channel

At the LNG0 monitoring site, the live cover of hard corals ranged from ~20–30% over the period January–November 2009 (Table 6-42; Figure 6-27). Poritids represented the largest percentage of live hard coral cover (~85%), with a smaller proportion (5%) represented by merulinids. All other families comprised <3% of the hard coral assemblage. Soft corals covered <1% of the substratum. Cover of the sessile invertebrates was 24% in January 2009 and decreased to <3% by November 2009. The majority of the substratum at this site was covered by turfing algae. Turfing algae cover increased from ~40% in January 2009 to ~60% in August and November 2009. There was a corresponding decline in the estimates of mean percentage cover of poritids and sessile invertebrates over the same time period.

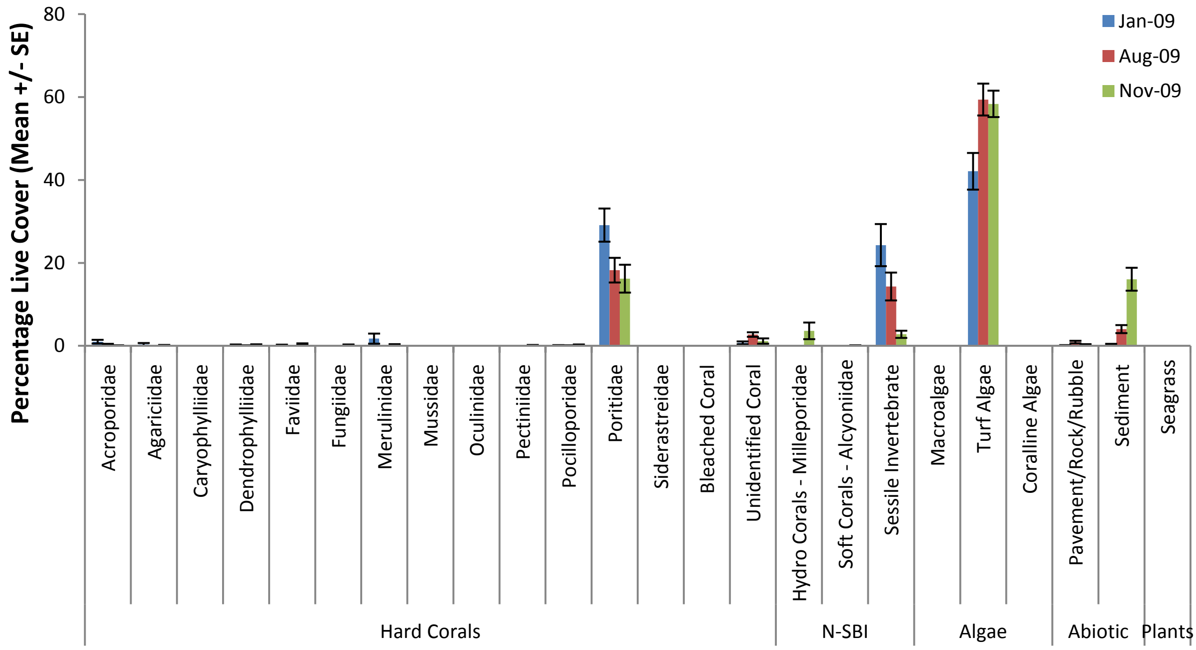


Figure 6-27 Mean Percentage Cover (± SE) and Composition of Corals at LNG0

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-42 Mean Percentage Cover ± SE Data and Composition of Corals at LNG0

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Jan 2009	Mean	1.0	0.3	0.0	0.2	0.2	0.0	1.7	0.0	0.0	0.0	0.1	29.1	0.0	0.0	0.7	0.0	0.0	24.3	0.0	42.1	0.0	0.1	0.2	0.0
	SE	0.4	0.3	0.0	0.2	0.1	0.0	1.2	0.0	0.0	0.0	0.1	4.0	0.0	0.0	0.4	0.0	0.0	5.1	0.0	4.4	0.0	0.1	0.2	0.0
Aug 2009	Mean	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	18.2	0.0	0.0	2.7	0.0	0.0	14.3	0.0	59.4	0.0	0.9	4.0	0.0
	SE	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	0.0	0.0	0.5	0.0	0.0	3.4	0.0	3.8	0.0	0.3	1.0	0.0
Nov 2009	Mean	0.1	0.1	0.0	0.2	0.4	0.2	0.3	0.0	0.0	0.1	0.2	16.2	0.0	0.0	1.2	3.6	0.1	2.8	0.0	58.4	0.0	0.2	16.1	0.0
	SE	0.1	0.1	0.0	0.1	0.2	0.1	0.2	0.0	0.0	0.1	0.1	3.4	0.0	0.0	0.6	2.0	0.1	0.9	0.0	3.2	0.0	0.1	2.7	0.0

Hard corals covered ~28% of the hard substratum at the LNG1 monitoring site in October 2008 (Table 6-43; Figure 6-28). Similarly to LNG0, the poritids contributed the greatest (76%) to the percentage of live hard coral cover at this time, with little cover of any of the other coral families. Soft corals were also recorded at the site, but contributed little (<1%) to percentage cover. The sample means of percentage cover of live corals generally did not change markedly between October 2008 and April 2009, but there was a decrease in the estimates of cover of poritids between April and August 2009 (~9%), and August and November 2009 (<9%). There was a corresponding increase in the sample means of cover of turfing algae over the period October 2008 to August 2009 when turfing algae comprised ~68% of the live cover at this site, with a decline in sample means of percentage cover to ~30% in November 2009.

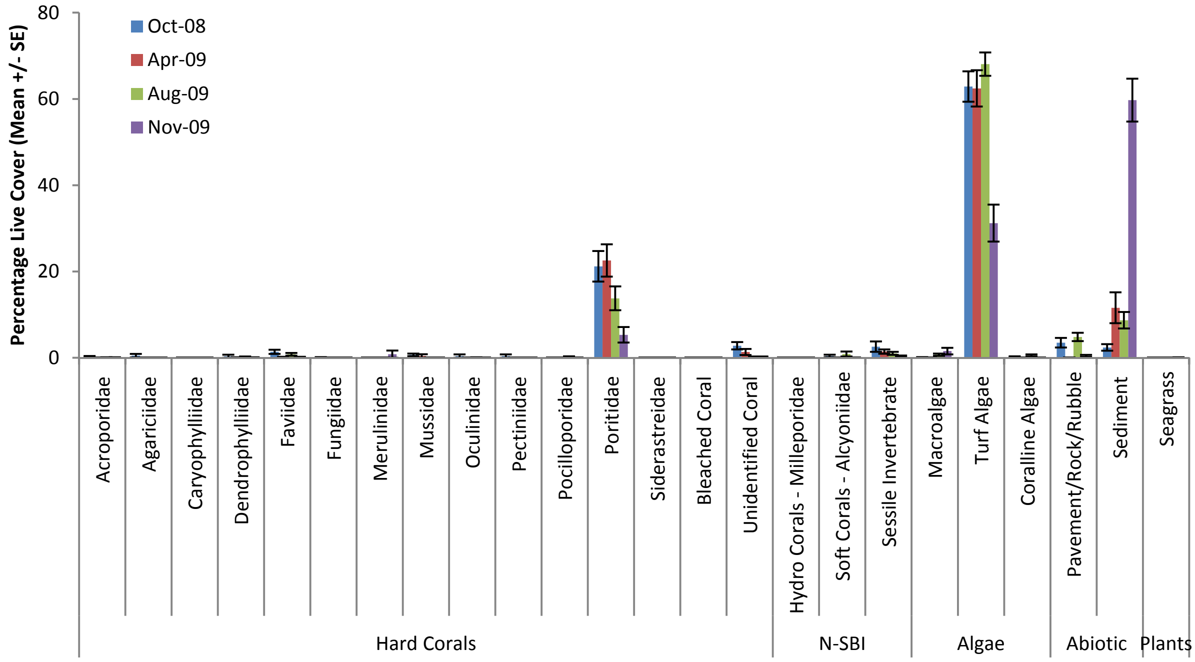


Figure 6-28 Mean Percentage Cover (± SE) and Composition of Corals at LNG1

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-43 Mean Percentage Cover ± SE Data and Composition of Corals at LNG1

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Oct 2008	Mean	0.2	0.5	0.0	0.4	1.4	0.1	0.0	0.7	0.4	0.4	0.0	21.2	0.0	0.0	2.8	0.0	0.4	2.6	0.1	62.9	0.2	3.5	2.4	0.0
	SE	0.2	0.4	0.0	0.4	0.5	0.1	0.0	0.3	0.4	0.4	0.0	3.6	0.0	0.0	0.9	0.0	0.3	1.2	0.1	3.5	0.1	1.1	0.8	0.0
Apr 2009	Mean	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.4	0.0	0.0	0.0	22.6	0.0	0.0	1.3	0.0	0.0	1.4	0.0	62.4	0.0	0.0	11.6	0.0
	SE	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.4	0.0	0.0	0.0	3.8	0.0	0.0	0.7	0.0	0.0	0.5	0.0	4.2	0.0	0.0	3.6	0.0
Aug 2009	Mean	0.1	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.1	0.0	0.2	13.8	0.0	0.0	0.2	0.0	0.9	1.0	0.7	68.1	0.5	4.8	8.7	0.0
	SE	0.1	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.1	2.8	0.0	0.0	0.1	0.0	0.6	0.4	0.3	2.7	0.2	1.0	1.9	0.0
Nov 2009	Mean	0.1	0.0	0.0	0.1	0.1	0.0	0.8	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.2	0.0	0.0	0.4	1.6	31.2	0.0	0.4	59.7	0.1
	SE	0.1	0.0	0.0	0.1	0.1	0.0	0.8	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.1	0.0	0.0	0.1	0.8	4.3	0.0	0.2	5.0	0.1

6.4.4.2.3 Percentage Live Cover at Sites in the Vicinity of the Dredge Spoil Disposal Ground

Live hard corals covered >50% of the substratum at the Lone Reef (LONE) monitoring site and the poritids represented the majority (>80%) of hard coral cover (Table 6-44; Figure 6-29). The sample means of percentage cover of live hard corals did not change markedly between the four surveys. Turfing algae were the second most abundant live cover, occupying ~35% of the substratum.

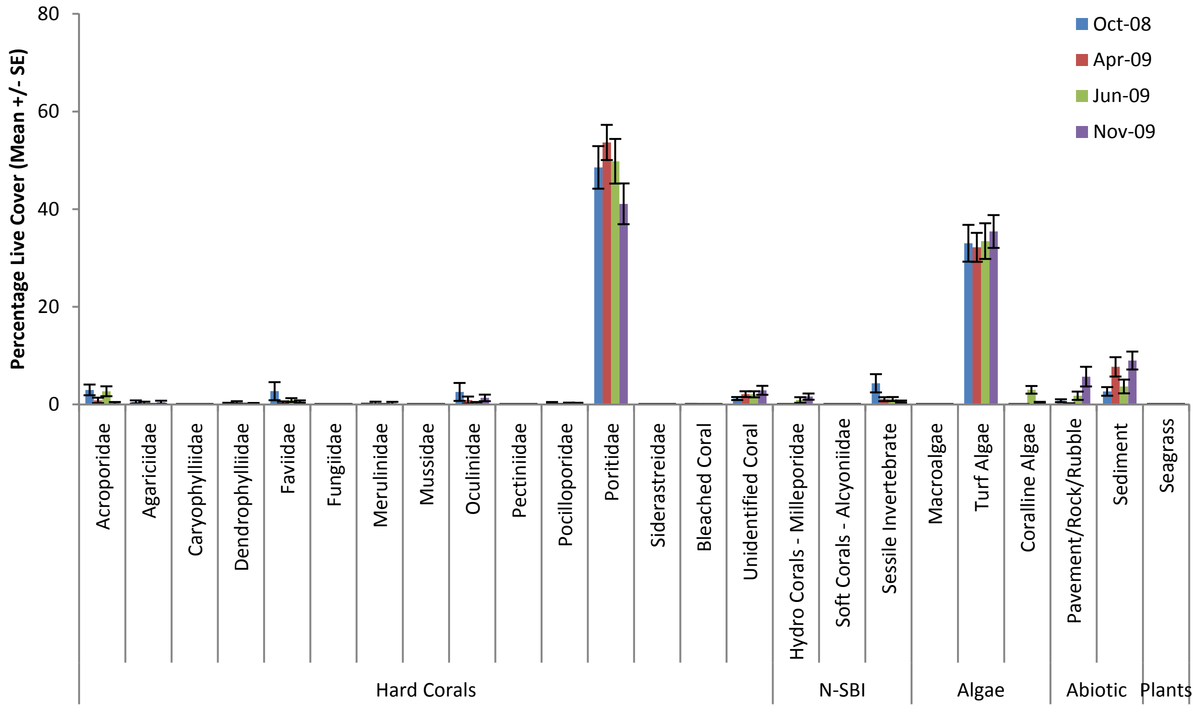


Figure 6-29 Mean Percentage Cover (± SE) and Composition of Corals at Lone Reef

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-44 Mean Percentage Cover ± SE Data and Composition of Corals at Lone Reef

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Oct 2008	Mean	3.0	0.5	0.0	0.2	2.7	0.0	0.1	0.0	2.6	0.0	0.3	48.5	0.0	0.1	1.2	0.0	0.0	4.4	0.0	33.0	0.0	0.8	2.7	0.0
	SE	1.1	0.3	0.0	0.1	1.8	0.0	0.1	0.0	1.8	0.0	0.2	4.4	0.0	0.1	0.3	0.0	0.0	1.9	0.0	3.8	0.0	0.3	0.9	0.0
Apr 2009	Mean	0.8	0.3	0.0	0.4	0.4	0.0	0.3	0.0	0.9	0.0	0.0	53.6	0.0	0.0	2.1	0.0	0.0	1.1	0.0	32.2	0.0	0.1	7.7	0.0
	SE	0.6	0.3	0.0	0.3	0.2	0.0	0.3	0.0	0.7	0.0	0.0	3.6	0.0	0.0	0.6	0.0	0.0	0.4	0.0	3.0	0.0	0.1	2.0	0.0
Jun 2009	Mean	2.7	0.0	0.0	0.1	0.9	0.0	0.0	0.0	0.3	0.0	0.2	49.8	0.0	0.0	2.1	0.9	0.0	1.1	0.0	33.5	3.0	1.8	3.7	0.0
	SE	1.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.2	0.0	0.2	4.6	0.0	0.0	0.6	0.6	0.0	0.4	0.0	3.6	0.8	0.8	1.4	0.0
Nov 2009	Mean	0.3	0.4	0.0	0.2	0.6	0.0	0.3	0.0	1.3	0.0	0.2	41.1	0.0	0.0	2.9	1.6	0.0	0.6	0.0	35.4	0.4	5.7	9.0	0.0
	SE	0.2	0.3	0.0	0.1	0.2	0.0	0.3	0.0	0.7	0.0	0.1	4.2	0.0	0.0	0.9	0.6	0.0	0.2	0.0	3.4	0.2	2.0	1.8	0.0

6.4.4.3 Percentage Live Cover at Representative Areas in the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

6.4.4.3.1 Ant Point Reef (ANT)

The monitoring site at Ant Point Reef had the highest percentage cover of live coral compared with other monitoring sites (>75%) in May 2008 (Table 6-45; Figure 6-30). The acroporids represented the greatest live cover of all hard corals (95%). Sample means of coral cover declined between the surveys, to ~15% in March 2009 and ~8% in August 2009. The decline in estimates of percentage cover of live corals was primarily due to a reduction in the cover of acroporids. The decline in sample means of live coral cover between May 2008 and November 2008 coincided with an increase in the sample means of macroalgal cover from <1% to ~25%. By March 2009, there were further declines in the estimates of live cover of acroporids and the substratum was predominantly covered by turfing algae (~75%).

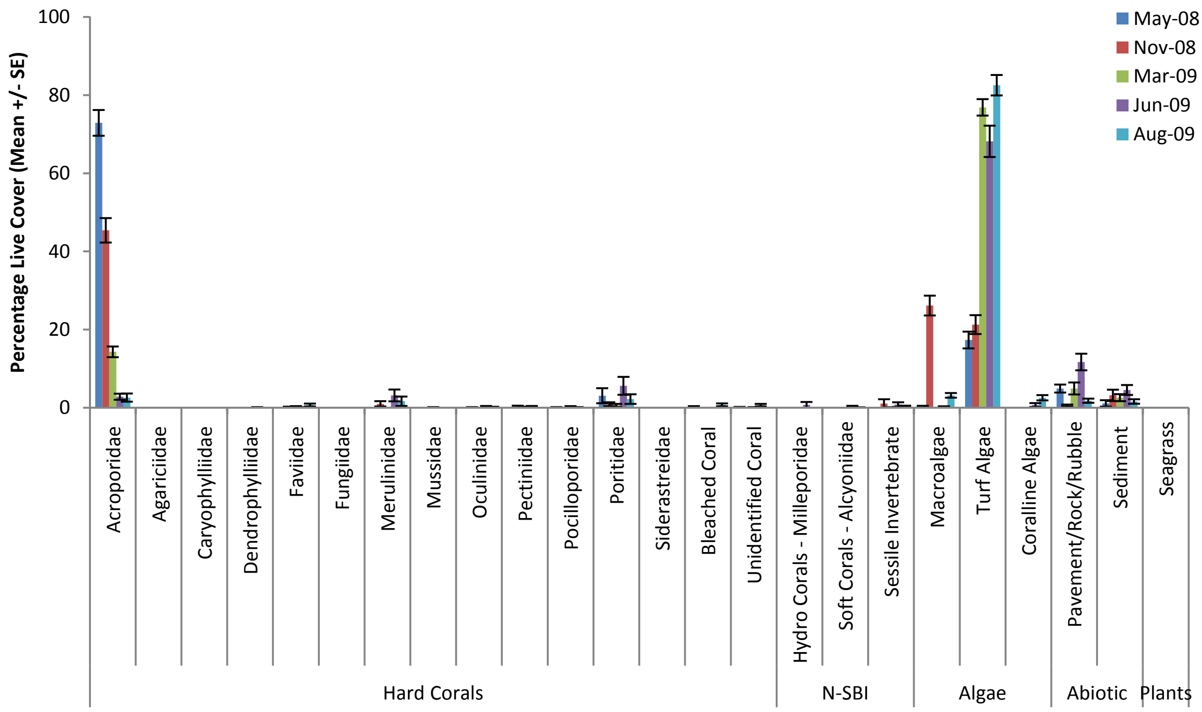


Figure 6-30 Mean Percentage Cover (± SE) and Composition of Corals at Ant Point Reef

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

High densities of the corallivorous snail *Drupella* sp. were observed at Ant Point Reef, and it is considered that these are likely to have been one of the potential causes of the observed coral mortality at this site. These snails prey almost exclusively on living coral tissue but are rarely present in sufficient numbers to cause significant coral mortality. However, when the abundance of snails is high, extensive loss of coral tissue and colony mortality has been recorded (Turner 1994). The reasons for outbreaks of *Drupella* remain unclear (DEC 2009). Attributing the ultimate cause of recent coral mortality to specific causes is often difficult without detailed experimentation/field studies and it is likely that coral loss at any given location is a consequence of one or more factors.

Table 6-45 Mean Percentage Cover ± SE Data and Composition of Corals at Ant Point Reef

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
May 2008	Mean	72.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.1	0.0	0.2	0.1	0.0	0.0	0.0	0.3	17.3	0.0	4.9	1.1	0.0
	SE	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	0.0	0.2	0.1	0.0	0.0	0.0	0.2	2.1	0.0	1.0	0.8	0.0
Nov 2008	Mean	45.4	0.0	0.0	0.0	0.2	0.0	1.0	0.0	0.1	0.3	0.0	0.9	0.0	0.0	0.0	0.0	0.0	1.1	26.1	21.3	0.0	0.6	3.2	0.0
	SE	3.1	0.0	0.0	0.0	0.1	0.0	0.7	0.0	0.1	0.3	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.1	2.5	2.4	0.0	0.3	1.5	0.0
Mar 2009	Mean	14.3	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.2	0.6	0.0	0.0	0.1	0.0	0.0	0.1	0.0	76.9	0.0	4.9	2.6	0.0
	SE	1.4	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.2	0.4	0.0	0.0	0.1	0.0	0.0	0.1	0.0	2.1	0.0	1.5	0.9	0.0
June 2009	Mean	2.8	0.0	0.0	0.1	0.1	0.0	3.2	0.0	0.2	0.2	0.1	5.6	0.0	0.0	0.6	0.7	0.3	0.8	0.2	68.2	0.7	11.7	4.5	0.0
	SE	0.8	0.0	0.0	0.1	0.1	0.0	1.5	0.0	0.2	0.2	0.1	2.3	0.0	0.0	0.3	0.7	0.2	0.6	0.1	4.0	0.5	2.1	1.3	0.0
Aug 2009	Mean	2.6	0.0	0.0	0.0	0.7	0.0	1.7	0.0	0.1	0.0	0.0	2.2	0.0	0.7	0.0	0.0	0.1	0.3	3.2	82.5	2.5	1.8	1.6	0.0
	SE	1.0	0.0	0.0	0.0	0.4	0.0	1.2	0.0	0.1	0.0	0.0	1.2	0.0	0.4	0.0	0.0	0.1	0.2	0.6	2.6	0.7	0.5	0.6	0.0

6.4.4.3.2 Southern Lowendal Shelf (LOW)

Approximately 50% of the hard substratum at the Southern Lowendal Shelf monitoring site was covered with live hard coral, with the acroporids representing almost all (98%) of the live cover (Table 6-46; Figure 6-31). There was no marked change in the sample means of live coral cover over the 12-month period between May 2008 and May 2009. The remainder of live cover of the substratum at this site was predominantly turfing algae (~40–45%).

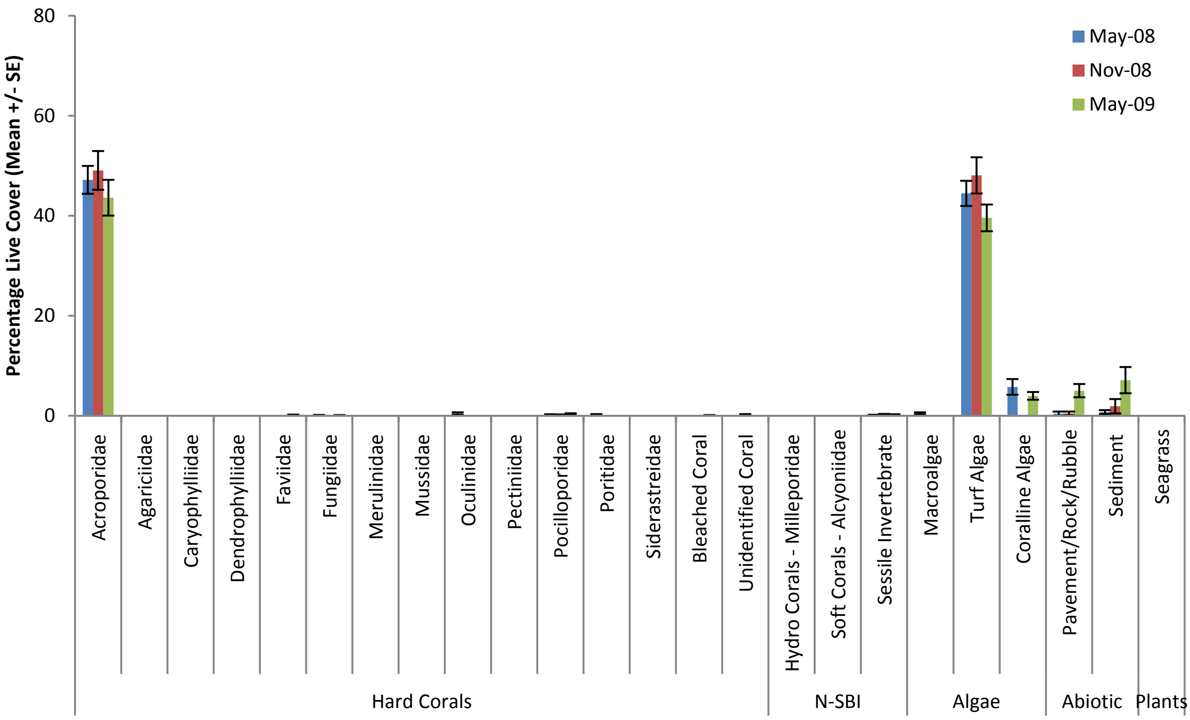


Figure 6-31 Mean Percentage Cover (± SE) and Composition of Corals at Southern Lowendal Shelf

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

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Table 6-46 Mean Percentage Cover ± SE Data and Composition of Corals at Southern Lowendal Shelf

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
May 2008	Mean	47.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.5	44.5	5.8	0.4	0.7	0.0
	SE	2.8	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	2.5	1.6	0.4	0.4	0.0
Nov 2008	Mean	49.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	48.1	0.0	0.5	1.9	0.0
	SE	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	3.6	0.0	0.4	1.4	0.0
May 2009	Mean	43.6	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	39.6	4.0	5.0	7.1	0.0
	SE	3.6	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	2.7	0.8	1.3	2.6	0.0

6.4.4.4 Percentage Live Cover at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

6.4.4.4.1 Ah Chong (AHC)

Approximately 50% of the hard substratum at the Ah Chong monitoring site was covered by hard corals and <2% by soft corals in September 2008 (Table 6-47; Figure 6-32). Poritids represented the majority (~82%) of the live hard coral cover at this time, with faviids ~4%. There was a decline of ~13% in the sample means of live cover of poritids between September 2008 and March 2009, with the estimates of live cover of poritids increasing (~7%) between March and June 2009. The remainder of the substratum was comprised of turfing algae (~40%) and sediment (~10%).

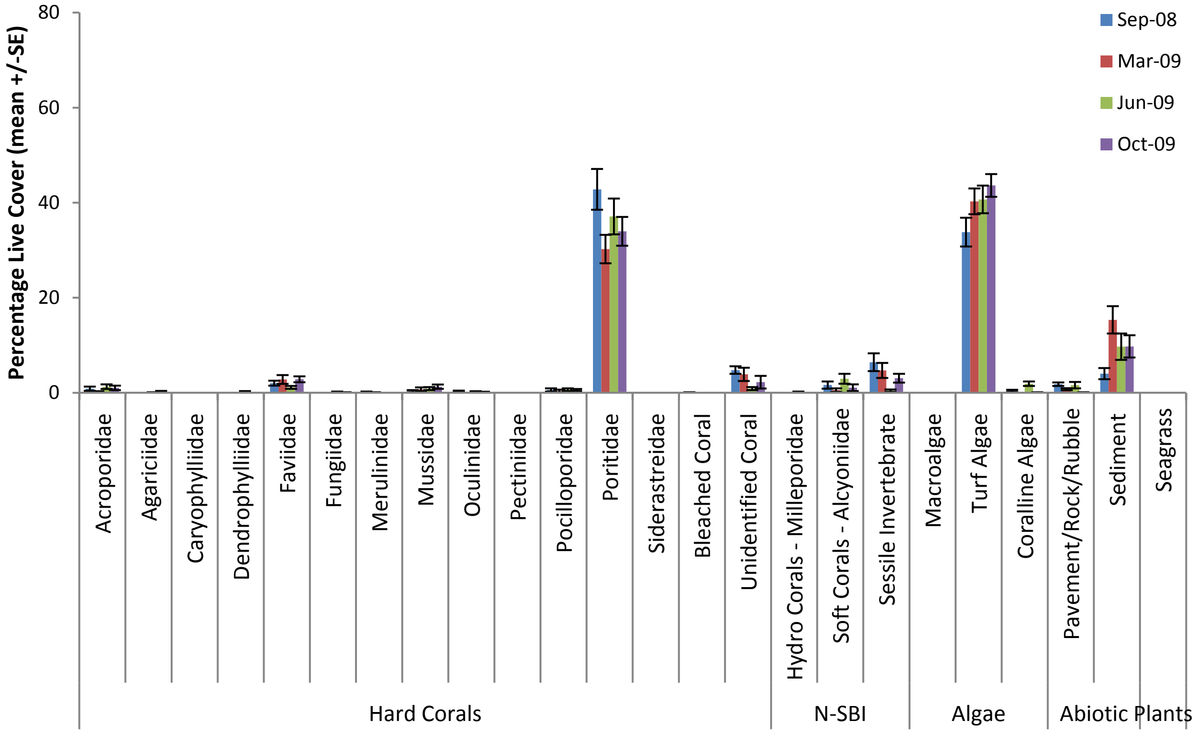


Figure 6-32 Mean Percentage Cover (± SE) and Composition of Corals at Ah Chong

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-47 Mean Percentage Cover ± SE Data and Composition of Corals at Ah Chong

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Sep 2008	Mean	0.9	0.0	0.0	0.0	2.0	0.0	0.1	0.3	0.3	0.0	0.6	42.8	0.0	0.1	4.8	0.0	1.6	6.4	0.0	33.8	0.4	1.8	4.0	0.0
	SE	0.4	0.0	0.0	0.0	0.5	0.0	0.1	0.2	0.2	0.0	0.3	4.3	0.0	0.1	0.8	0.0	0.8	1.9	0.0	3.0	0.2	0.4	1.2	0.0
Mar 2009	Mean	0.2	0.0	0.0	0.0	2.8	0.0	0.1	0.7	0.0	0.0	0.4	30.2	0.0	0.0	3.9	0.0	0.6	4.7	0.0	40.3	0.0	0.8	15.3	0.0
	SE	0.1	0.0	0.0	0.0	0.9	0.0	0.1	0.4	0.0	0.0	0.3	3.0	0.0	0.0	1.4	0.0	0.4	1.6	0.0	2.7	0.0	0.2	2.9	0.0
June 2009	Mean	1.3	0.1	0.0	0.2	1.1	0.1	0.0	0.9	0.2	0.0	0.7	37.1	0.0	0.0	0.9	0.1	3.0	0.5	0.0	40.7	1.9	1.6	9.7	0.0
	SE	0.5	0.1	0.0	0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.3	3.8	0.0	0.0	0.3	0.1	1.0	0.3	0.0	2.9	0.5	0.7	2.8	0.0
Oct 2009	Mean	1.0	0.2	0.0	0.0	2.8	0.1	0.0	1.3	0.1	0.0	0.6	34.0	0.0	0.0	2.2	0.0	1.1	3.1	0.0	43.6	0.1	0.1	9.8	0.0
	SE	0.5	0.2	0.0	0.0	0.6	0.1	0.0	0.5	0.1	0.0	0.2	3.0	0.0	0.0	1.3	0.0	0.7	0.9	0.0	2.4	0.1	0.1	2.3	0.0

6.4.4.4.2 Biggada Reef (BIG)

Live hard coral cover at the Biggada Reef monitoring site was relatively low (~10%) compared to the other monitoring sites (Table 6-48; Figure 6-33). Faviids represented the majority (~80%) of hard coral cover. There was an increase in the sample means of percentage live cover of soft corals between March and June 2009 to ~16%, at which point soft corals contributed a higher percentage live cover than hard corals. However, between June and October 2009 the sample means of the percentage of the substratum covered by soft corals reduced to 5%. Turfing algae covered the greatest proportion of the substratum on all the sampling occasions (~45–65%).

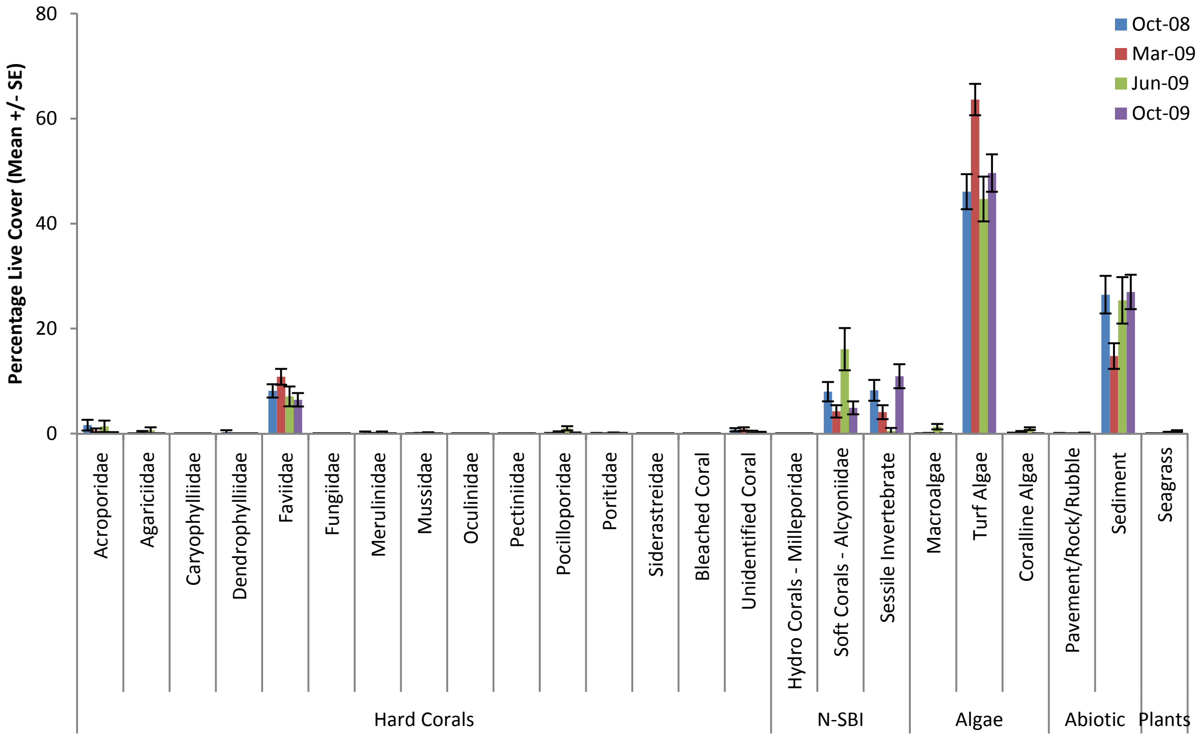


Figure 6-33 Mean Percentage Cover (± SE) and Composition of Corals at Biggada Reef

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-48 Mean Percentage Cover ± SE Data and Composition of Corals at Biggada Reef

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Oct 2008	Mean	1.6	0.0	0.0	0.3	8.1	0.0	0.2	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.7	0.0	8.0	8.2	0.0	46.1	0.1	0.1	26.5	0.0
	SE	1.0	0.0	0.0	0.3	1.3	0.0	0.2	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0	1.8	2.0	0.0	3.3	0.1	0.1	3.6	0.0
Mar 2009	Mean	0.6	0.3	0.0	0.0	10.8	0.0	0.1	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.9	0.0	4.2	4.1	0.1	63.6	0.3	0.0	14.8	0.0
	SE	0.4	0.2	0.0	0.0	1.5	0.0	0.1	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	1.2	1.3	0.1	3.0	0.2	0.0	2.5	0.0
June 2009	Mean	1.4	0.6	0.0	0.0	7.1	0.0	0.2	0.1	0.0	0.0	1.0	0.1	0.0	0.0	0.3	0.0	16.1	0.5	1.3	44.7	0.9	0.0	25.4	0.2
	SE	1.1	0.6	0.0	0.0	1.9	0.0	0.2	0.1	0.0	0.0	0.4	0.1	0.0	0.0	0.2	0.0	4.0	0.5	0.5	4.3	0.3	0.0	4.4	0.1
Oct 2009	Mean	0.2	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.0	4.9	10.9	0.0	49.6	0.0	0.1	27.0	0.5
	SE	0.1	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	1.2	2.3	0.0	3.6	0.0	0.1	3.3	0.2

6.4.4.4.3 LNG3

The live cover and composition of hard corals at the LNG3 monitoring site was very similar to that at LNG1 and, with the exception of Biggada Reef, live coral cover was lower (16% in September 2008) than at other monitoring sites (Table 6-49; Figure 6-34). Poritids represented the greatest cover of hard corals (~73%) followed by faviids (7%) at this time. The majority (>60%) of the substratum was covered by turfing algae; the sample means of the percentage cover of turfing algae increased over the 12-month sampling period.

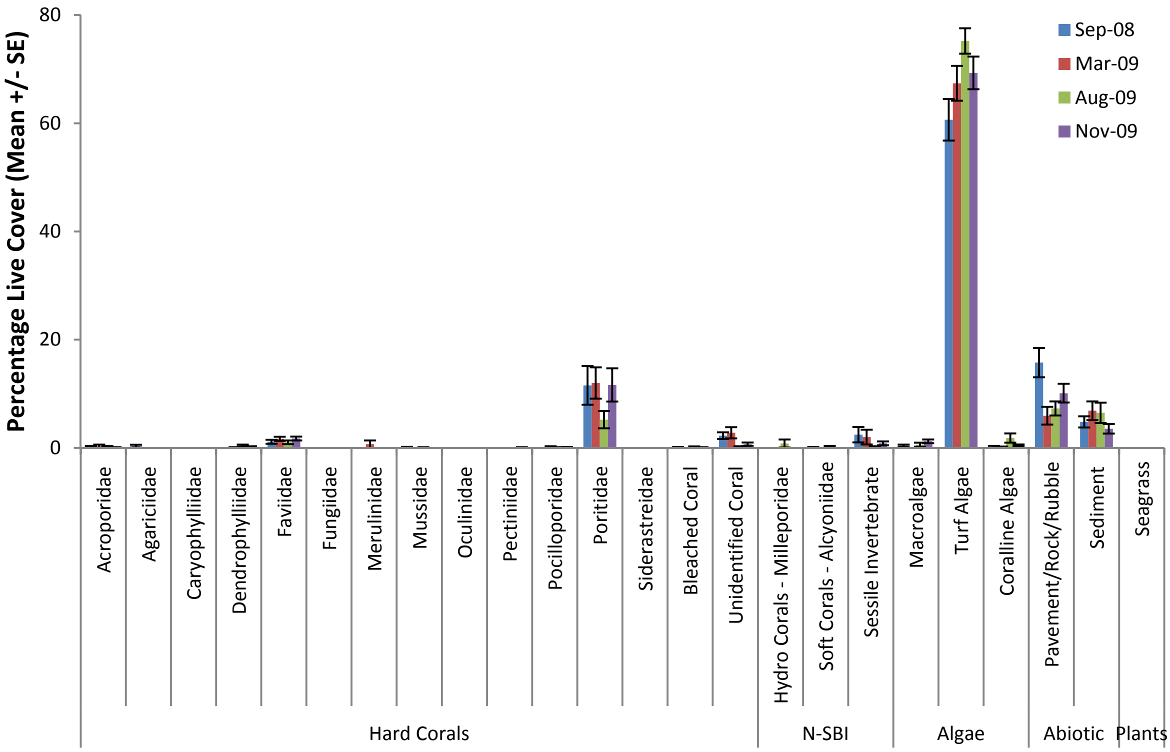


Figure 6-34 Mean Percentage Cover (± SE) and Composition of Corals at LNG3

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-49 Mean Percentage Cover ± SE Data and Composition of Corals at LNG3

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Sep 2008	Mean	0.2	0.3	0.0	0.0	1.1	0.0	0.0	0.1	0.0	0.0	0.0	11.6	0.0	0.1	2.3	0.0	0.1	2.4	0.4	60.6	0.2	15.8	4.8	0.0
	SE	0.1	0.2	0.0	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	3.6	0.0	0.1	0.6	0.0	0.1	1.4	0.2	3.8	0.2	2.7	1.0	0.0
Mar 2009	Mean	0.3	0.0	0.0	0.1	1.7	0.0	0.7	0.0	0.0	0.0	0.2	12.0	0.0	0.0	2.8	0.0	0.0	2.0	0.0	67.4	0.1	5.9	6.9	0.0
	SE	0.3	0.0	0.0	0.1	0.4	0.0	0.7	0.0	0.0	0.0	0.2	2.9	0.0	0.0	1.0	0.0	0.0	1.4	0.0	3.2	0.1	1.6	1.7	0.0
Aug 2009	Mean	0.2	0.0	0.0	0.4	1.0	0.0	0.0	0.1	0.0	0.0	0.1	5.2	0.0	0.1	0.2	0.8	0.2	0.2	0.6	75.2	1.8	7.3	6.5	0.0
	SE	0.1	0.0	0.0	0.2	0.3	0.0	0.0	0.1	0.0	0.0	0.1	1.6	0.0	0.1	0.1	0.7	0.2	0.1	0.4	2.4	0.9	1.3	1.9	0.0
Nov 2009	Mean	0.1	0.0	0.0	0.2	1.7	0.0	0.0	0.0	0.0	0.1	0.1	11.6	0.0	0.1	0.7	0.0	0.0	0.9	1.2	69.3	0.5	10.1	3.5	0.0
	SE	0.1	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.1	0.1	3.1	0.0	0.1	0.3	0.0	0.0	0.4	0.3	3.0	0.2	1.7	0.9	0.0

6.4.4.5 Percentage Live Cover at Sites in Regionally Significant Areas Outside the Zones of Influence

6.4.4.5.1 Dugong Reef (DUG)

Similarly to Ah Chong, Ant Point Reef and Batman Reefs, the percentage of substratum covered by live corals was relatively high (~65–70%) at the Dugong Reef monitoring site (Table 6-50; Figure 6-35). Similar to the monitoring site at Batman Reef, there was no one dominant family and corals from several families, including the Acroporidae, Agariciidae, Faviidae, Oculinidae, Pectiniidae and Poritidae, contributed ~5–15% each to the percentage of live cover during all three surveys. Turfing algae covered ~30% of the hard substratum over the 12-month sampling period.

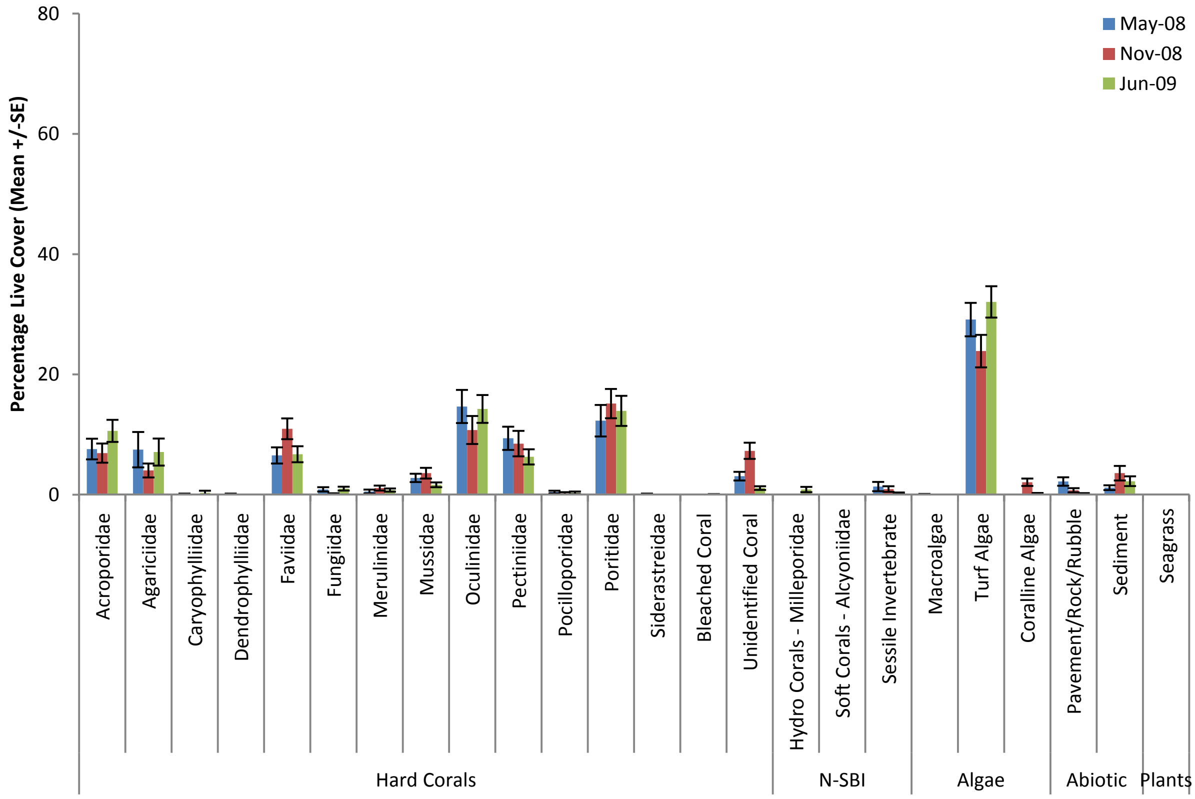


Figure 6-35 Mean Percentage Cover (± SE) and Composition of Corals at Dugong Reef

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-50 Mean Percentage Cover ± SE Data and Composition of Corals at Dugong Reef

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
May 2008	Mean	7.6	7.5	0.1	0.1	6.5	0.9	0.5	2.8	14.7	9.4	0.4	12.3	0.1	0.0	3.1	0.0	0.0	1.4	0.1	29.1	0.0	2.2	1.2	0.0
	SE	1.7	2.9	0.1	0.1	1.3	0.4	0.3	0.7	2.8	1.9	0.2	2.6	0.1	0.0	0.7	0.0	0.0	0.8	0.1	2.8	0.0	0.7	0.4	0.0
Nov 2008	Mean	6.9	4.0	0.0	0.0	11.0	0.2	1.1	3.6	10.8	8.5	0.2	15.2	0.0	0.0	7.3	0.0	0.0	0.9	0.0	23.9	2.1	0.7	3.6	0.0
	SE	1.6	1.2	0.0	0.0	1.7	0.1	0.4	0.9	2.3	2.1	0.2	2.4	0.0	0.0	1.3	0.0	0.0	0.5	0.0	2.7	0.6	0.3	1.2	0.0
June 2009	Mean	10.6	7.1	0.3	0.0	6.7	1.0	0.8	1.7	14.3	6.3	0.3	13.9	0.0	0.1	1.1	0.9	0.0	0.3	0.0	32.1	0.2	0.1	2.3	0.0
	SE	1.8	2.3	0.3	0.0	1.3	0.3	0.3	0.4	2.3	1.3	0.2	2.5	0.0	0.1	0.3	0.4	0.0	0.1	0.0	2.6	0.1	0.1	0.8	0.0

6.4.4.5.2 Batman Reef (BAT)

Approximately 50-60% of the hard substratum at the Batman Reef monitoring site was covered by live corals; however, there was no one dominant family (Table 6-51; Figure 6-36). Live cover of each of three families (the Faviidae, Merulinidae, and Poritidae) was ~15% and cover of Pectiniidae was ~10%. With the exception of the poritids, which increased from ~15% to 20% cover in October 2008, the estimates of percentage live cover of coral did not vary markedly between June 2008 and August 2009. Turfing algae represented ~30–45% of the live cover of the substratum.

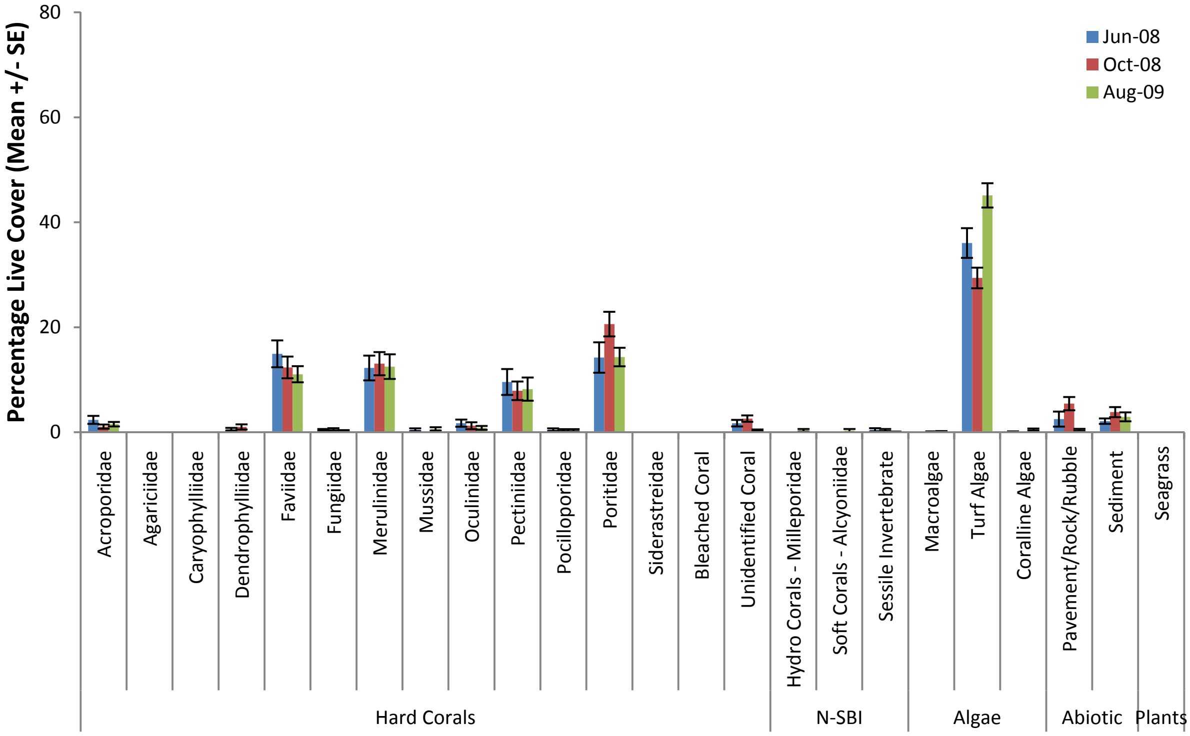


Figure 6-36 Mean Percentage Cover (± SE) and Composition of Corals at Batman Reef

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-51 Mean Percentage Cover ± SE Data and Composition of Corals at Batman Reef

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
June 2008	Mean	2.3	0.0	0.0	0.6	14.9	0.4	12.2	0.5	1.7	9.6	0.5	14.2	0.0	0.0	1.7	0.0	0.0	0.5	0.0	36.1	0.1	2.5	2.1	0.0
	SE	0.8	0.0	0.0	0.3	2.5	0.2	2.4	0.3	0.7	2.5	0.2	2.9	0.0	0.0	0.6	0.0	0.0	0.3	0.0	2.8	0.1	1.4	0.5	0.0
Oct 2008	Mean	1.1	0.0	0.0	1.0	12.4	0.6	13.1	0.0	1.2	7.9	0.4	20.6	0.0	0.0	2.6	0.0	0.0	0.4	0.1	29.4	0.0	5.5	3.8	0.0
	SE	0.4	0.0	0.0	0.5	2.1	0.2	2.2	0.0	0.6	1.8	0.2	2.4	0.0	0.0	0.6	0.0	0.0	0.2	0.1	2.0	0.0	1.3	1.0	0.0
Aug 2009	Mean	1.5	0.0	0.0	0.0	11.0	0.3	12.5	0.6	0.8	8.2	0.4	14.3	0.0	0.0	0.4	0.4	0.3	0.1	0.1	45.1	0.5	0.4	2.9	0.0
	SE	0.4	0.0	0.0	0.0	1.5	0.1	2.4	0.3	0.4	2.2	0.2	1.8	0.0	0.0	0.2	0.3	0.3	0.1	0.1	2.3	0.2	0.2	0.9	0.0

6.4.4.5.3 Southern Barrow Shoals (SBS)

Approximately 20–25% of the hard substratum at the Southern Barrow Shoals monitoring site was comprised of live hard corals. Approximately 40% of the hard coral cover was represented by poritids, ~20% by acroporids, and ~13% by faviids in October 2008 (Table 6-52; Figure 6-37). The majority (~50% in October 2008; ~45% in April 2009; ~35% in June 2009; ~60% in October 2009) of the substratum was covered with turfing algae.

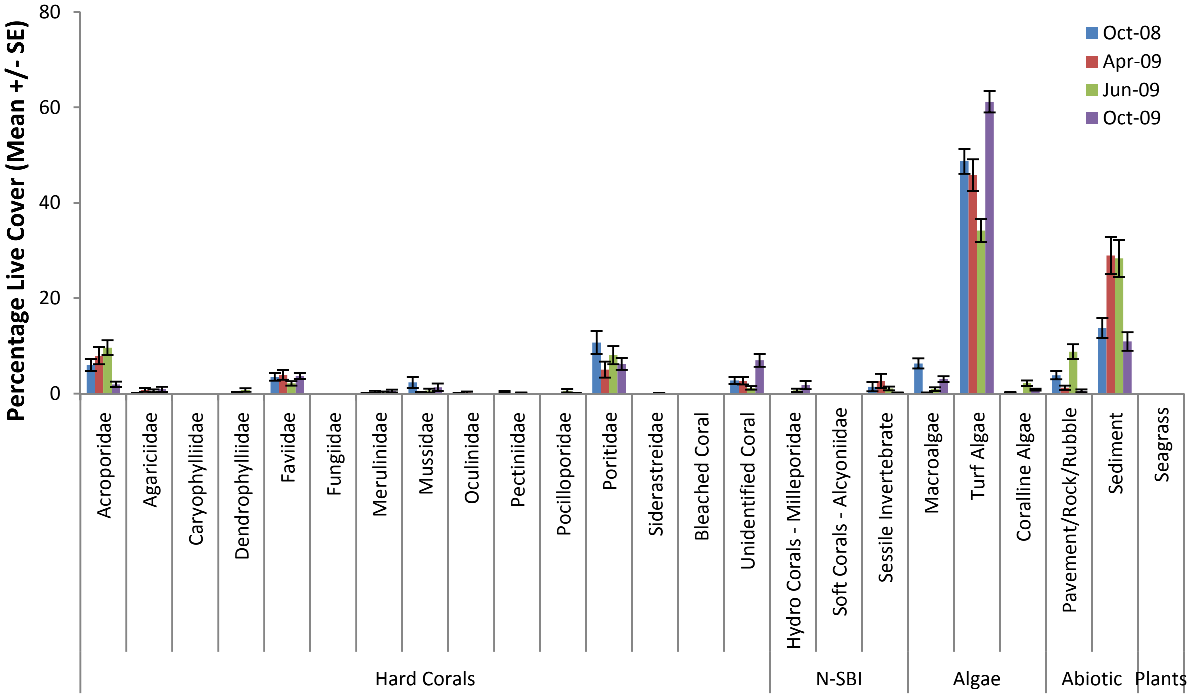


Figure 6-37 Mean Percentage Cover (± SE) and Composition of Corals at Southern Barrow Shoals

Note: N-SBI: Non-scleractinian Benthic Invertebrates.

Table 6-52 Mean Percentage Cover ± SE Data and Composition of Corals at Southern Barrow Shoals

Survey Date	% Cover	Acroporidae	Agariciidae	Caryophylliidae	Dendrophylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae	Bleached Coral	Unidentified Coral	Hydro Corals - Milleporidae	Soft Corals - Alcyoniidae	Sessile Invertebrates	Macroalgae	Turf Algae	Coralline Algae	Pavement/Rock/Rubble	Sediment	Seagrass
Oct 2008	Mean	6.0	0.1	0.0	0.0	3.5	0.0	0.1	2.3	0.1	0.3	0.0	10.7	0.0	0.0	2.8	0.0	0.0	1.4	6.3	48.7	0.2	3.8	13.7	0.0
	SE	1.2	0.1	0.0	0.0	0.8	0.0	0.1	1.2	0.1	0.2	0.0	2.4	0.0	0.0	0.7	0.0	0.0	1.0	1.1	2.6	0.1	0.9	2.1	0.0
Apr 2009	Mean	7.9	0.8	0.0	0.1	3.9	0.0	0.3	0.2	0.2	0.0	0.0	5.0	0.0	0.0	2.7	0.0	0.0	2.7	0.1	45.8	0.0	1.2	28.9	0.0
	SE	1.8	0.4	0.0	0.1	1.0	0.0	0.2	0.2	0.2	0.0	0.0	1.7	0.0	0.0	0.8	0.0	0.0	1.5	0.1	3.3	0.0	0.4	3.9	0.0
Jun 2009	Mean	9.6	0.6	0.0	0.7	2.1	0.0	0.2	0.6	0.0	0.1	0.6	8.0	0.1	0.0	1.2	0.7	0.0	1.1	0.9	34.2	2.2	8.8	28.3	0.0
	SE	1.5	0.3	0.0	0.3	0.4	0.0	0.2	0.4	0.0	0.1	0.4	1.9	0.1	0.0	0.4	0.4	0.0	0.4	0.4	2.4	0.6	1.5	3.9	0.0
Oct 2009	Mean	1.9	0.9	0.0	0.0	3.7	0.0	0.5	1.3	0.0	0.0	0.1	6.2	0.0	0.0	7.0	1.8	0.0	0.1	3.0	61.2	0.8	0.6	10.9	0.0
	SE	0.6	0.5	0.0	0.0	0.7	0.0	0.3	0.8	0.0	0.0	0.1	1.2	0.0	0.0	1.3	0.9	0.0	0.1	0.6	2.3	0.2	0.3	1.9	0.0

6.4.4.6 Temporal Changes in Live Coral Cover Across all Sites as Measured from Random Transects

There was a significant temporal change in the cover of live coral within random transects at the monitoring sites, LNG1, Ant Point Reef, Ah Chong, Biggada Reef, and Batman Reef(Table 6-53). The cover of live corals at Ant Point Reef decreased by almost 70% between the first and last sampling occasions, from 76.2 ± 2.9% in May 2008 (the highest recorded at any of the monitoring sites), to 47.8 ± 3.2% in November 2008, 15.6 ± 1.5% in March 2009, and 7.3 ± 2.2% in August 2009 (Figure 6-38). The cover of live corals at LNG1 decreased by ~20% between the first and last sampling occasions, from 28.3 ± 3.7% in October 2008, to 24.5 ± 3.9% in April 2009, to 16.2 ± 2.8% in August 2009, and 6.6 ± 2.1% in November 2009 (Figure 6-38). The cover of live corals at Ah Chong decreased by 10% between the first and last sampling occasions, from 53.5 ± 3.8% in September 2008 to 38.9 ± 3.2% in March 2009 and 43.4 ± 3.1% in October 2009 (Figure 6-38). Live coral cover at Biggada Reef slightly decreased between the initial survey in October 2008 (19.1 ± 2.4%) to the final survey in October 2009 (11.9 ± 1.8%); however, during this time live coral cover was as much as 26.9 ± 4.0% in June 2009 (Figure 6-38). The cover of live corals at Batman Reef decreased by 8% between the first and last survey from 58.8 ± 2.9% in June 2008 to 50.8 ± 2.6% in August 2009 (Figure 6-38). While the difference in percentage live coral cover as a proportion of hard substratum at other sites between the first and last surveys ranged between <1% and 10.7%, these differences were not significant (Table 6-53).

Table 6-53 Summary of ANOVA Tests for Changes in the Cover of Live Coral among Sampling Times

Location	Site	*Pseudo-F*	$MS_{(residual)}$	*p*
Zones of High Impact	LNG0	$F_{2,152} = 1.93$	0.267	0.150
Zones of Moderate Impact	MOF1	$F_{2,150} = 0.41$	0.044	0.670
	LNG1	$F_{3,207} = 14.30$	1.454	**<0.001**
	Lone Reef	$F_{3,207} = 1.56$	0.218	0.204
Zones of Influence	Ant Point Reef	$F_{4,243} = 114.40$	7.348	**<0.001**
	Southern Lowendal Shelf	$F_{2,148} = 1.17$	0.103	0.319
Reference	Ah Chong	$F_{3,210} = 3.36$	0.291	**0.018**
	Biggada Reef	$F_{3,205} = 3.61$	0.287	**0.012**
	LNG3	$F_{3,200} = 1.30$	0.123	0.276
Regionally Significant Areas	Dugong Reef	$F_{2,152} = 0.68$	0.043	0.502
	Batman Reef	$F_{2,149} = 4.29$	0.183	**0.017**
	Southern Barrow Shoals	$F_{3,202} = 0.40$	0.028	0.747

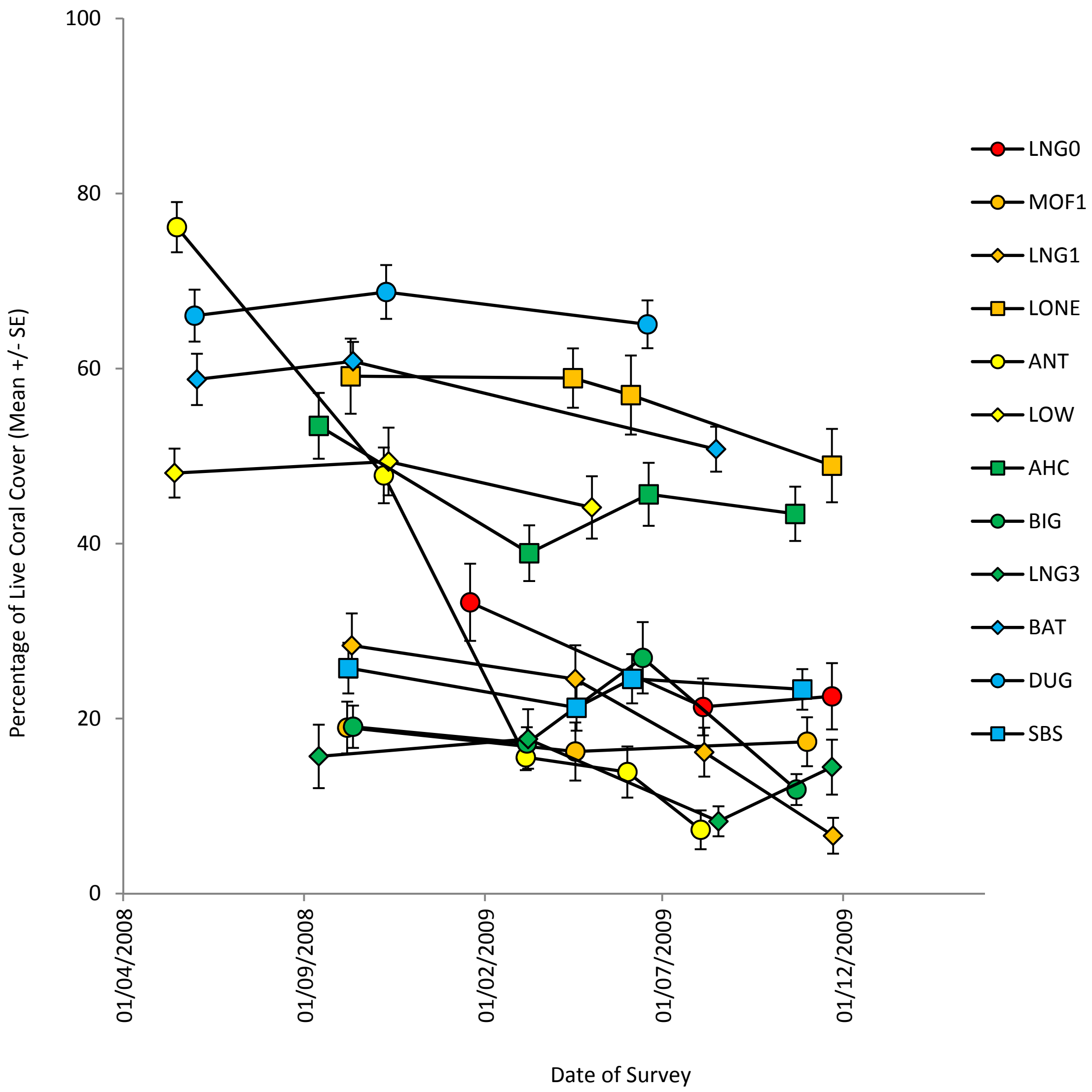


Figure 6-38 Temporal Changes in the Cover of Live Corals. Mean (± SE) Cover Based on the Mean of 5 Random Transects at Each Monitoring Site/Time

Note: Coloured symbols denote; red: Zone of High Impact, orange: Zone of Moderate Impact, yellow: Zone of Influence, green: Reference, blue: Regionally Significant Area.

6.4.4.7 Temporal Changes in Live Coral Cover as Measured from Fixed Transects

There was little change in the estimates of percentage cover of live coral within fixed transects at Dugong Reef and Batman Reef over the 12-month Marine Baseline Program (Figure 6-39; Figure 6-40). Percentage cover of live coral varied from ~60–90% at Dugong Reef and ~50–70% at Batman Reef. Estimates of percentage cover of corals within fixed transects at Ant Point Reef varied from ~55–80% in mid-2008 and decreased to <10% by mid-2009, representing a decrease in percentage live coral cover of ~70% (Figure 6-39; Figure 6-40). At Southern Lowendal Shelf estimates of percentage cover varied from ~35–60% in mid-2008 and increased to ~45–70% in mid-2009, an average increase of ~15%.

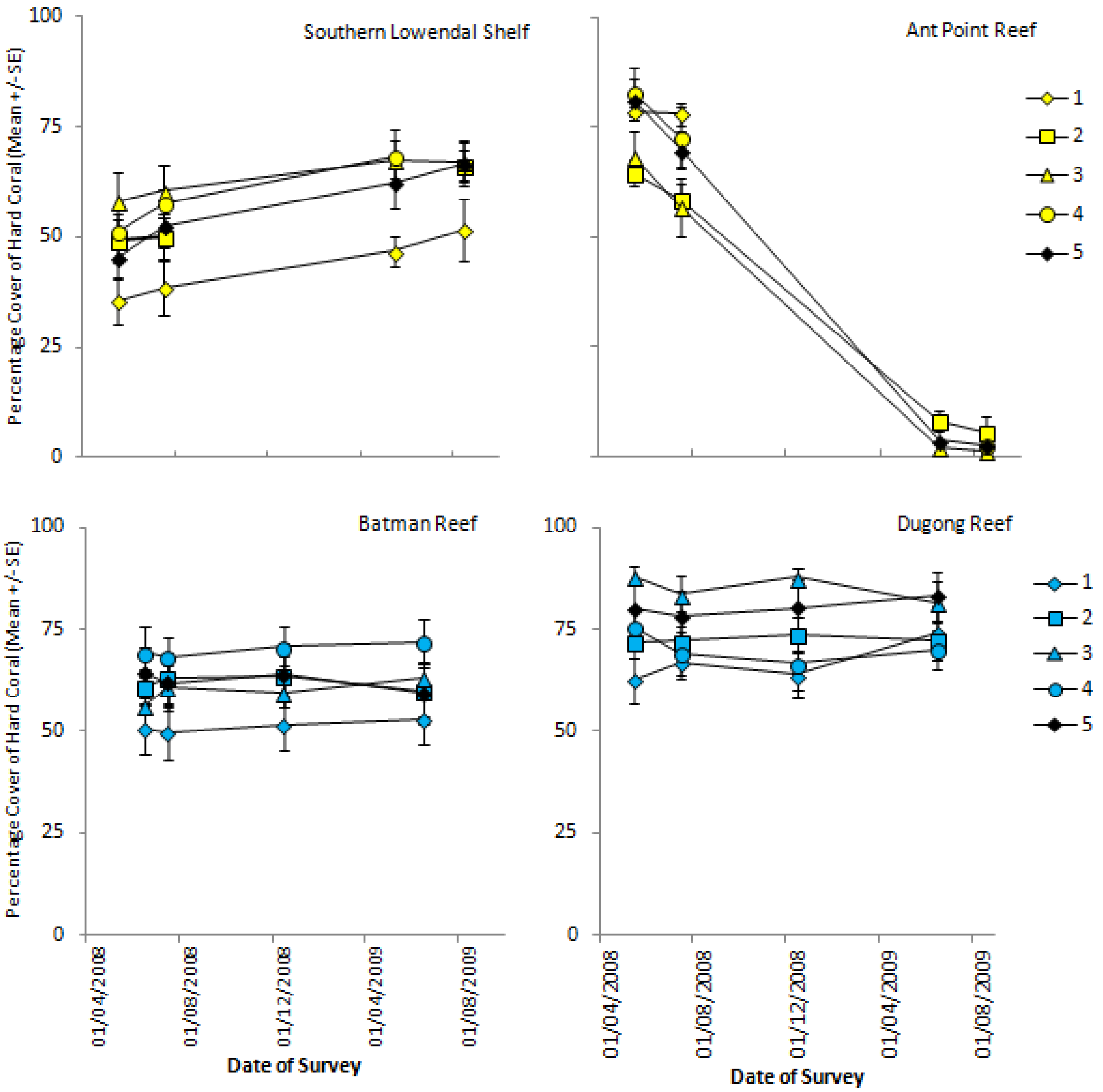


Figure 6-39 Percentage Cover of Live Coral over 12 months within each Fixed Transect (Mean ± SE) at Four Monitoring Sites

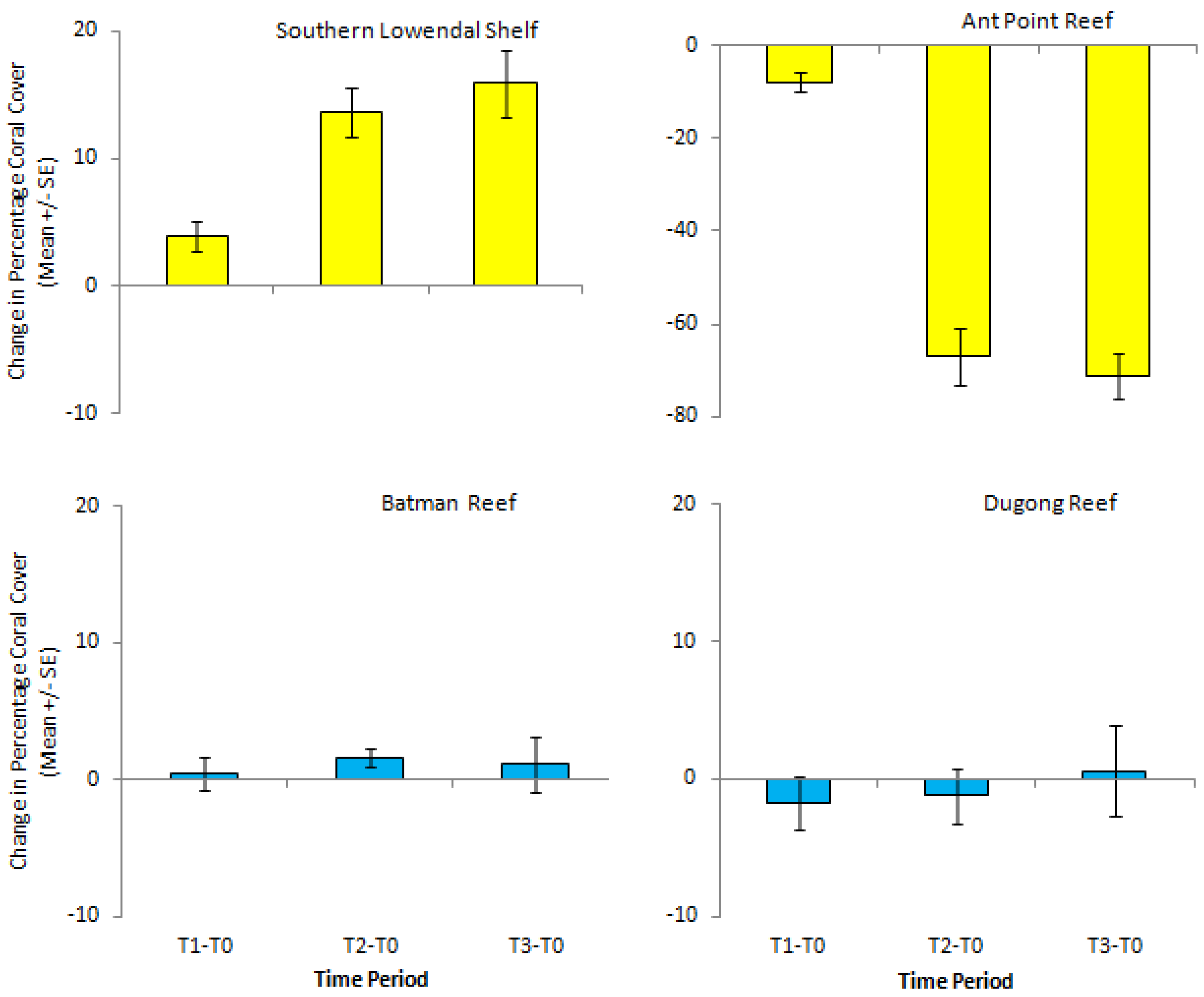


Figure 6-40 Change in Percentage Cover of Live Coral at each Monitoring Site between each Survey Period (Mean ± SE)

6.4.4.8 Temporal Changes in Live Coral Tissue as measured from Tagged Corals

Estimates of the percentage of live tissue of tagged colonies (genera pooled for each site) showed little to no change, or decreased between Time 0 and Time 1 and between Time 0 and Time 2. The greatest changes between Time 0 and Time 1 were recorded at LNG1, Lone Reef and Batman Reef, where live tissue decreased by 8.3 ± 7.1%, 8.5 ± 5.2% and 7.1 ± 5.7%, respectively (Figure 6-41). At Southern Lowendal Shelf, Biggada Reef, MOF1, Dugong Reef, and Southern Barrow Shoals, average decreases in live tissue were ≤5%. At Ah Chong, Ant Point Reef, LNG0 and LNG3, there was <1% change in live tissue between Time 0 and Time 1.

Between Time 0 and Time 2, the greatest decreases in the estimates of the percentage of live tissue of tagged colonies were reported at Biggada Reef and Ant Point Reef where live tissue decreased by 35.1 ± 14.5% and 13.1 ± 11.4%, respectively (Figure 6-41). At Ant Point Reef this reflected the decrease in percentage of live coral cover measured using both random and fixed transects. At LNG1, live tissue of tagged colonies decreased by ~10%, by ~9% at Southern Lowendal Shelf, and by ~6% at Lone, Batman, and Dugong Reefs. At LNG0, MOF1, LNG3 and Southern Barrow Shoals live tissue decreased by <5%; while at Ah Chong, decreases in live tissue were <1%.

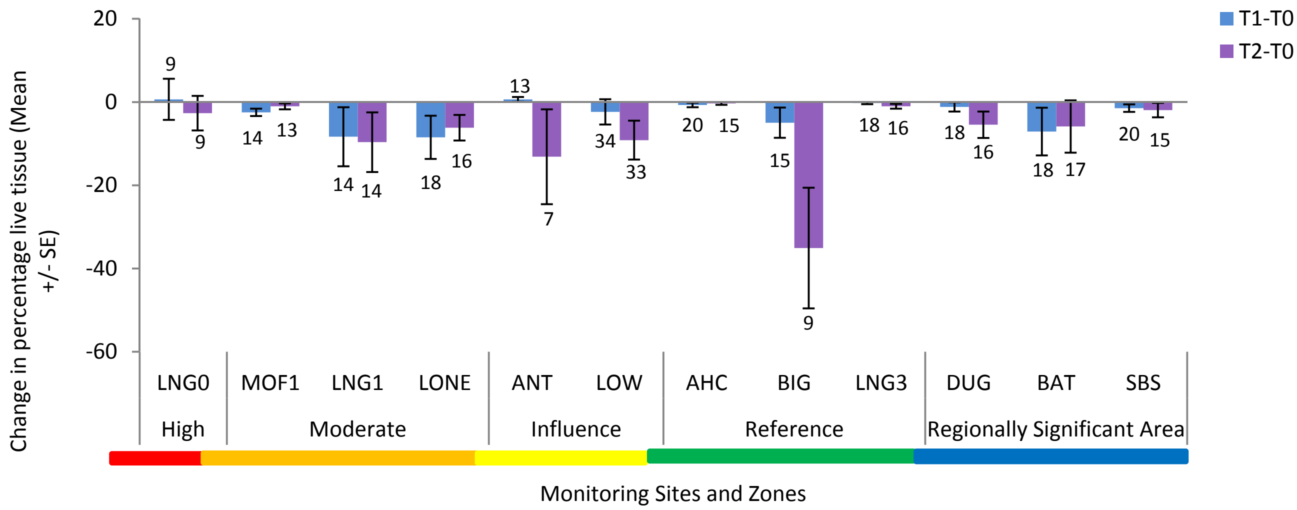


Figure 6-41 Change in Percentage of Live Tissue of Tagged Colonies at each Monitoring Site

Note: n values are provided within the figure against each site's measure of change. .

At a genus/family level, faviids and *Acropora* showed the greatest decrease in live tissue of tagged colonies between both Time 0 and Time 1 (~9% and ~3%, respectively) and Time 0 and Time 2 (~15% and ~8%, respectively) (Figure 6-42). Live tissue varied by <5% for both time periods in *Lobophyllia*, *Montipora*, and *Pectinia*.

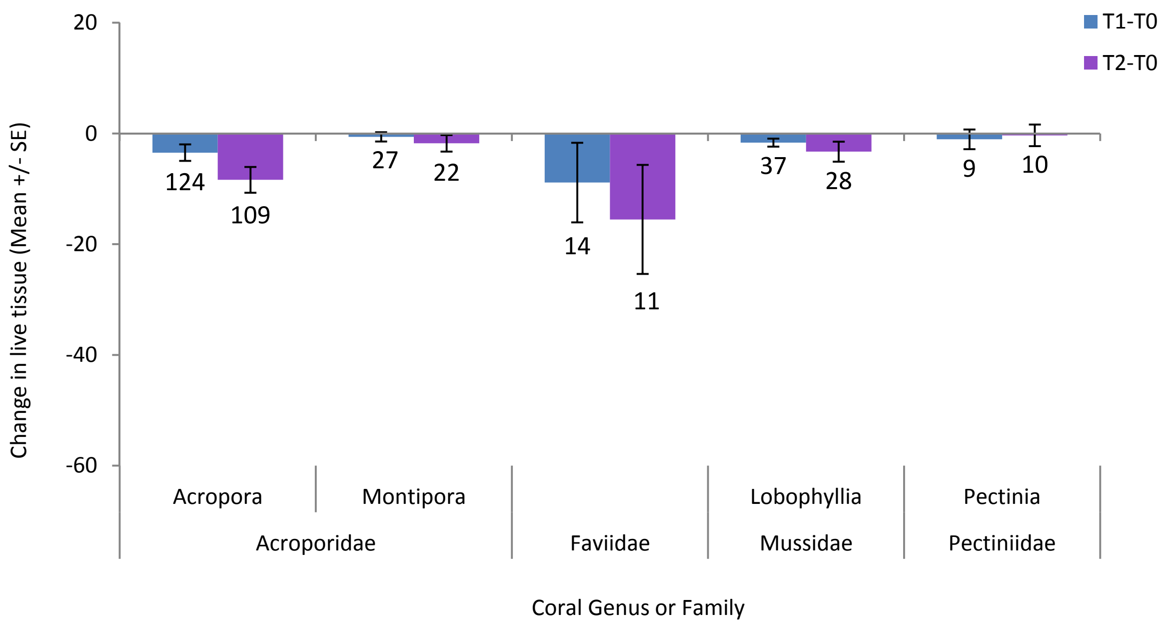


Figure 6-42 Change in Percentage of Live Tissue of Tagged Colonies at Genus/Family Level

Note: n values are provided within the figure against each site's measure of change. .

Patterns in the change of live tissue on colonies varied among genera/families within individual sites and among sites for different genera. Out of the 25 genera/families and site combinations, there were two instances where genera/families within sites showed zero change in live tissue, two where live tissue increased by ≤6%, and nine where live tissue decreased by <2.5% between Time 0 and Time 2 (Table 6-54). The greatest decreases in the estimates of the percentage of live tissue of tagged colonies were recorded for colonies of *Acropora* at Biggada Reef (-37.5 ± 18.2%), LNG1 (-15.5 ± 12.4%), Southern Lowendal Shelf (-11.3 ± 5.8%) and Ant Point Reef (-13.1 ± 11.4%); faviids at Batman Reef (-13.1 ± 11.4%) and Biggada Reef (-26.5 ± 22.2%); and *Lobophyllia* at Dugong Reef (-28.4 ± 19.8%). The greatest tissue loss was observed in colonies of *Acropora* at Biggada Reef, where there was a decrease of 37.5 ± 18.2% in live tissue cover between Time 0 and Time 2.

Table 6-54 Change in Live Tissue (%) in each Genus/Family in Tagged Colonies at Monitoring Sites

Site	Genus/Family	Mean ± SE change in live tissue (%) Time 0-Time 1	n (T1-T0)	Mean ± SE change in live tissue (%) Time 0-Time 2	n (T2-T0)
LNG0	*Acropora*	0.7 ± 4.9	9	-2.7 ± 4.2	9
MOF1	*Acropora*	-2.1 ± 1.4	7	-0.2 ± 0.9	7
	Lobophyllia	-2.9 ± 1.1	7	-2.0 ± 1.1	6
LNG1	*Acropora*	-12.9 ± 12.5	8	-15.5 ± 12.4	8
	Lobophyllia	-2.3 ± 1.7	6	-1.8 ± 1.4	6
Lone Reef	*Acropora*	-9.9 ± 5.7	16	-6.4 ± 3.3	15
	Lobophyllia	2.9 ± 2.9	2	-1.9	1
Ant Point Reef	*Acropora*	0.6 ± 0.6	13	-13.1 ± 11.4	7
Ah Chong	*Acropora*	-0.6 ± 0.6	10	0.0 ± 0.0	10
	Lobophyllia	-0.8 ± 0.9	10	-1.0 ± 1.0	5
Biggada Reef	*Acropora*	-5.8 ± 4.5	12	-37.5 ± 18.2	7
	Faviidae	-1.7 ± 1.0	3	-26.5 ± 22.2	2
LNG3	*Acropora*	0.0 ± 0.0	10	0.0 ± 0.0	10
	Lobophyllia	-0.6 ± 0.6	8	-2.7 ± 1.3	6
Southern Lowendal Shelf	*Acropora*	-3.2 ± 4.0	26	-11.3 ± 5.8	26
	Montipora	0.4 ± 1.2	8	-1.1 ± 1.8	7
Dugong Reef	*Acropora*	0.0 ± 0.0	4	-0.1 ± 0.1	3
	Lobophyllia	-9.4 ± 4.2	2	-28.4 ± 19.8	2
	Montipora	0.0 ± 1.8	8	-2.8 ± 2.9	7
	Pectinia	-0.7 ± 0.7	4	-2.7 ± 1.6	4
Batman Reef	Faviidae	-10.8 ± 9.2	11	-13.1 ± 11.4	9
	Lobophyllia	-0.9 ± 10.9	2	5.3 ± 5.3	2
	Pectinia	-1.4 ± 3.3	5	1.2 ± 3.0	6
Southern Barrow Shoals	*Acropora*	-1.1 ± 1.1	9	-2.4 ± 1.6	7
	Montipora	-1.8 ± 1.4	11	-1.5 ± 3.1	8

6.4.5 Growth of Hard Coral Species/Taxa

6.4.5.1 Non-branching Colonies

Sites Dugong Reef, Batman Reef, and Southern Lowendal Shelf were excluded from analysis of coral growth as photo-quadrats did not contain a scale bar required for colony growth measurements.

Coral growth was variable among genera, sites and seasons. Over the first six months, the lowest estimates of positive mean monthly growth rates were recorded for *Lobophyllia* at LNG1 (0.2 ± 1.5%) and the highest were recorded for *Acropora* at LNG3 (7.0 ± 2.2%) (Table 6-55). Across all sites, sample means of monthly growth rates, both positive and negative over the first six months were 2.1% and 5.9% for *Montipora* and *Faviidae* respectively, and ranged from, -0.1 to 7.0% for *Acropora*, and -1.7 to 2.3% for *Lobophyllia*.

The lowest estimates of positive mean monthly growth rates over the second six months were recorded for *Acropora* at Lone Reef (0.8 ± 14.0%) and *Lobophyllia* at LNG3 (0.8 ± 5.0%) whilst the highest were recorded for *Lobophyllia* at Ah Chong (10.0 ± 5.0%), and *Acropora* (5.1 ± 7.0%) at LNG1 (Table 6-55). Across all sites, sample means of monthly growth rates both positive and negative over the second six months were 2.5% and 2.4% for *Montipora* and *Faviidae* respectively, and ranged from -3.6 to 5.1% for *Acropora* and -2.8 to 10.0% for *Lobophyllia*. Negative growth was recorded for some colonies of *Lobophyllia* and *Acropora*. This is normal in studies of growth in colonial organisms over short time periods (i.e. several months to a few years) as colony growth can be interrupted or reversed by competition, predation or injury (Hughes 1985). Note, however, that this negative growth was <1% for all genera and variation in measurements was often greater than the reduction in size (Figure 6-43).

At family and genus level growth rates of non-branching corals were highest in the faviids (4.5 ± 3.2% per month over 12 months) and *Acropora* (3.3 ± 4.7% per month over 12 months); and lowest in *Mussidae* (1.0 ± 1.9% per month over 12 months) (Figure 6-43).

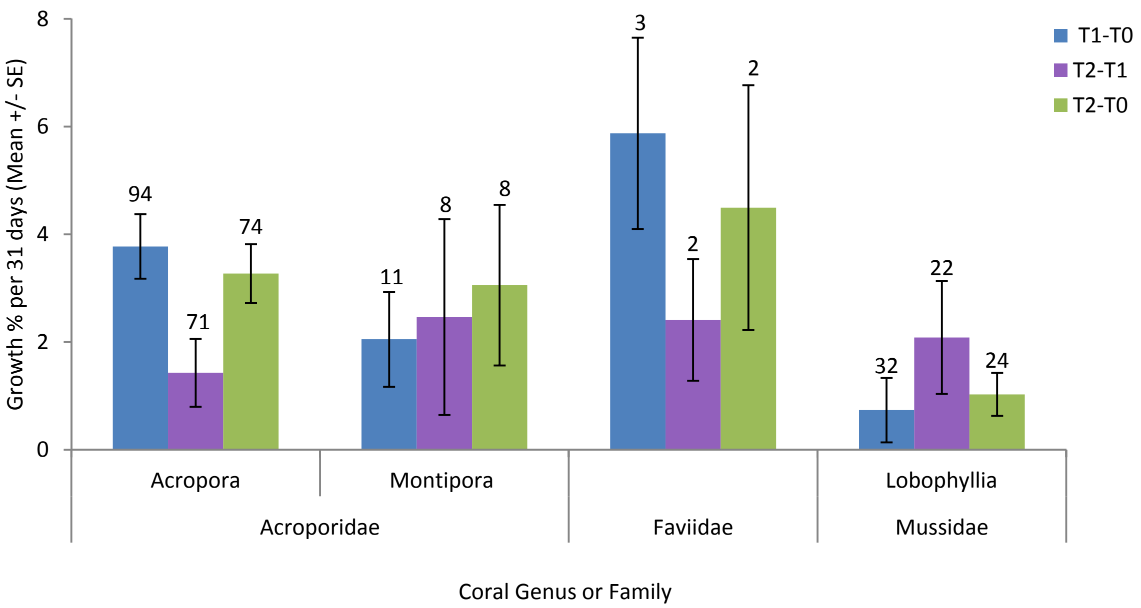


Figure 6-43 Growth Rates per Month (Mean ± SE) of Non-branching Corals per Genus or Family

Note: n values are provided within the figure against each site's measure of change. .

Coral growth among sites was often variable within genera, although 10% was the upper limit of growth per month across all genera and all sites. Positive monthly growth rates over the 12-month period were 3.1 ± 1.5% at Southern Barrow Shoals for *Montipora* and 4.5 ± 2.3% at Biggada Reef for faviids, whilst growth rates ranged from <1% at Biggada Reef to 7.6 ± 3.0% at LNG1 for *Acropora* (Table 6-55). In the case of *Lobophyllia*, the range between sites was lower than recorded for the other genera, with mean monthly growth rates both positive and negative over the 12-month period ranging from -0.3% at Lone Reef to 1.3 ± 0.8% at LNG3. Growth also varied within a site between times for most of the genera (Table 6-55). The results indicate that, given the slow growth rate of some species and the error margin associated with determining colony area, it is difficult to monitor colony growth over a 12-month period in slow-growing genera/families (e.g. *Lobophyllia* and faviids).

Table 6-55 Growth Rates (%) per Month of Non-branching Colonies at Coral Monitoring Sites at Time 1 (T1) and Time 2 (T2)

Site	Genus/ Family	Average Growth Rate (%) ± SE per 31 days at Time 1 (first six months)	n (T1-T0)	Average Growth Rate (%) ± SE per 31 days at Time 2 (second six months)	n (T2-T1)	Average of Growth Rate (%) ± SE per 31 days over 12 months	n (T2-T0)
Non-branching Tagged Colonies							
LNG0	*Acropora*	3.5 ± 1.1	9	-0.9 ± 9.0	9	1.8 ± 0.7	9
MOF1	*Acropora*	2.0 ± 0.7	7	1.5 ± 5.0	5	2.4 ± 0.5	7
	Lobophyllia	-1.7 ± 0.8	7	4.0 ± 6.0	6	1.0 ± 1.3	6
LNG1	*Acropora*	6.3 ± 2.9	7	5.1 ± 7.0	7	7.6 ± 3.0	7
	Lobophyllia	0.2 ± 1.5	6	3.2 ± 5.0	5	1.1 ± 0.4	6
Lone Reef	*Acropora*	3.3 ± 0.8	14	0.8 ± 14.0	14	2.1 ± 0.7	15
	Lobophyllia	1.6 ± 1.7	2	-2.8	1	-0.3	1
Ant Point Reef	*Acropora*	-0.1 ± 0.5	16	3.7 ± 5.0	5	1.7 ± 2.9	5
Ah Chong	*Acropora*	6.8 ± 1.1	10	2.8 ± 10.0	10	5.3 ± 1.0	10
	Lobophyllia	1.5 ± 0.9	10	10.0 ± 5.0	5	1.0 ± 0.9	5
Biggada Reef	*Acropora*	3.8 ± 3.2	12	-3.6 ± 7.0	7	0.7 ± 2.8	7
	Faviidae	5.9 ± 1.8	3	2.4 ± 2.0	2	4.5 ± 2.3	2
LNG3	*Acropora*	7.0 ± 2.2	10	1.9 ± 9.0	9	4.2 ± 1.3	9
	Lobophyllia	2.3 ± 1.6	7	0.8 ± 5.0	5	1.3 ± 0.8	6
Southern Barrow Shoals	*Acropora*	4.2 ± 1.0	9	3.3 ± 5.0	5	3.7 ± 1.7	5
	Montipora	2.1 ± 0.9	11	2.5 ± 8.0	8	3.1 ± 1.5	8

Note: No SE value calculated for site LONE for family Lobophyllia for T1-T2 and T2-T0 due to n value of 1.

For genera pooled within sites, growth over the 12-month period was highest at LNG1 and lowest at Biggada Reef (Figure 6-44).

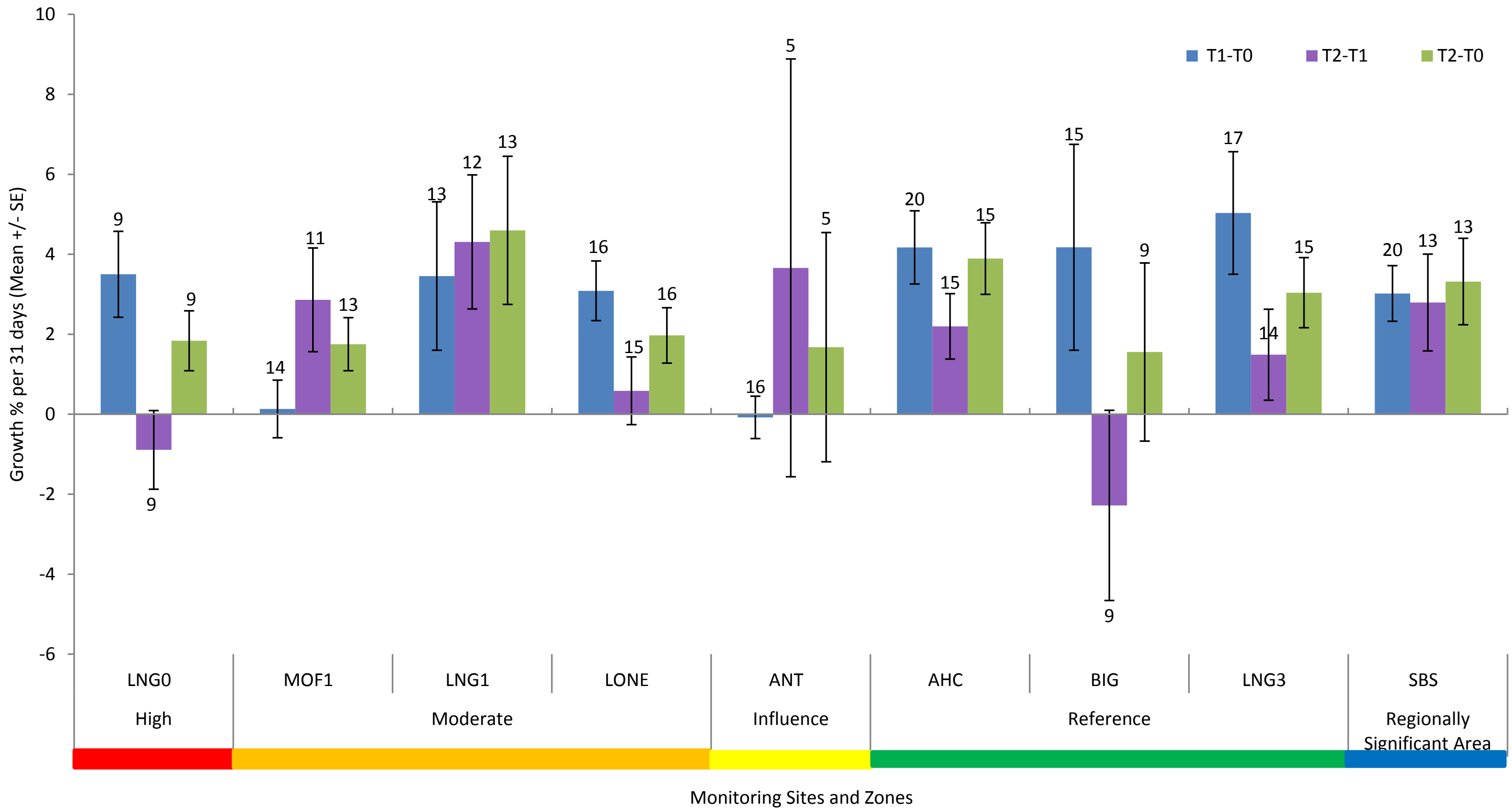


Figure 6-44 Growth Rates (Mean ± SE) per Month of Non-branching Corals Across Sites and Genera

Note: n values are provided within the figure against each site's measure of change.

6.4.5.2 Branching Colonies

Over the first six months (summer), sample means of monthly linear extension rates of branching *Acropora* colonies ranged from 2.0 ± 0.7 mm to 5.4 ± 1.0 mm (Table 6-56). Estimates of mean monthly growth rates of branching *Acropora* colonies were highest at Southern Lowendal Shelf and lowest at Ant Point Reef; note that the highest growth rates over the first six months for non-branching *Acropora* were also recorded at Southern Lowendal Shelf. Sample means of monthly linear extension rates of branching *Porites* colonies ranged from 1.4 ± 0.2 mm at Batman Reef to 2.1 ± 0.2 mm at Ah Chong, which is faster (i.e. 1.6 to 2.5 cm per year) than the published growth rates for massive *Porites* of 1 cm per year (Chornesky and Peters 1987). Given these growth rates, branching *Porites* colonies could potentially be used in future studies of coral growth where this species is dominant.

Over the second six months (winter), the growth of branching *Porites* at Ah Chong was lower (1.6 ± 0.2 mm per month) than recorded over the summer period at this site (Table 6-56). Mean monthly linear extension rates over 12 months were 2.0 ± 0.2 mm per month.

Growth rates of *Acropora* colonies were 1–3 mm per month lower at Southern Lowendal Shelf and Southern Barrow Shoals over the winter period compared to the summer period (Table 6-56). Mean monthly linear extension rates of *Acropora* colonies were negative over the winter period at Ant Point Reef, where the majority of the tagged colonies were dead at the time of re-measurement. Mean monthly linear extension rates over 12 months ranged between 1.0 ± 0.3 mm per month at Ant Point Reef and 3.8 ± 1.2 mm per month at Southern Lowendal Shelf.

Table 6-56 Linear Extension Rates (mm) per Month and Range of Branching *Acropora* and *Porites* Colonies at Coral Monitoring Sites

Site	Genus	Average Linear Extension (mm) ± SE per 31 days at Time 1 (first six months)	n (colonies)	Average Linear Extension (mm) ± SE per 31 days at Time 2 (second six months)	n (colonies)	Average Linear Extension (mm) ± SE per 31 days calculated over 12 months	n (colonies)
Ant Point Reef	*Acropora*	2.0 ± 0.7	10	-0.4 ± 0.2	10	1.0 ± 0.3	2
Southern Lowendal Shelf	*Acropora*	5.4 ± 1.0	10	2.0 ± 0.7	7	3.8 ± 1.2	7
Ah Chong	*Porites*	2.1 ± 0.2	10	1.6 ± 0.2	10	2.0 ± 0.2	9
Batman Reef	*Porites*	1.4 ± 0.2	9	-	-	-	-
Southern Barrow Shoals	*Acropora*	3.0 ± 0.6	9	1.6 ± 0.4	6	3.7 ± 0.9	6

6.4.6 Recruitment of Hard Coral Species

6.4.6.1 Temporal Patterns of Coral Recruitment

The numbers of coral recruits recorded on recruitment tiles indicated two distinct spawning periods at Barrow Island, in autumn and spring (Table 6-57 and Table 6-58; Figure 6-45). In autumn 2008, the mean number of recruits per tile across all sites was 13.7 ± 2.4, which equates to ~490 per m^2. In autumn 2009, recruitment was more than three times higher, with a mean number of recruits per tile of 43.5 ± 5.1 (~1555 per m^2). The lower number of recruits in autumn 2008 was likely a reflection that mass coral spawning was split between February and March 2008 and the recruitment tile deployment only captured the late autumn spawning event in March. In contrast, in 2009 the predominant month of mass spawning was March, reflected in the high number of recruits recorded in this month. On average, 12.1 ± 1.6 recruits were recorded per tile (~430 per m^2) in spring 2008, compared to 19.9 ± 2.7 recruits per tile (~710 per m^2) in summer 2008–2009. Recruitment was generally lower in winter, with a mean of 0.5 ± 0.1 recruits per tile (~18 recruits per m^2) in 2008 and 1.7 ± 0.3 (~60 recruits per m^2) in 2009.

Table 6-57 Summary of ANOVA Tests for Variation in Coral Recruitment Among Sampling Times

Location	Site	*F*-ratio	MS(residual)	*p*
Zone of High Impact	LNG0	$F_{2,32}$ = 23.6	0.187	**<0.001**
Zones of Moderate Impact	MOF1	$F_{5,72}$ = 13.5	0.004	**<0.001**
	LNG1	$F_{5,69}$ = 67.2	0.018	**<0.001**
	Lone Reef	$F_{5,72}$ = 110.5	0.015	**<0.001**
Zones of Influence	Ant Point Reef	$F_{6,86}$ = 9.3	0.000	**<0.001**
	Southern Lowendal Shelf	$F_{6,86}$ = 15.4	0.016	**<0.001**
Reference	Biggada Reef	$F_{6,87}$ = 10.6	0.004	**<0.001**
	LNG3	$F_{5,71}$ = 34.0	0.032	**<0.001**
Regionally Significant Areas	Dugong Reef	$F_{6,84}$ = 17.9	0.042	**<0.001**
	Batman Reef	$F_{5,72}$ = 29.1	0.013	**<0.001**
	Southern Barrow Shoals	$F_{5,71}$ = 42.6	0.002	**<0.001**

Note: Data were log(x+1) transformed.

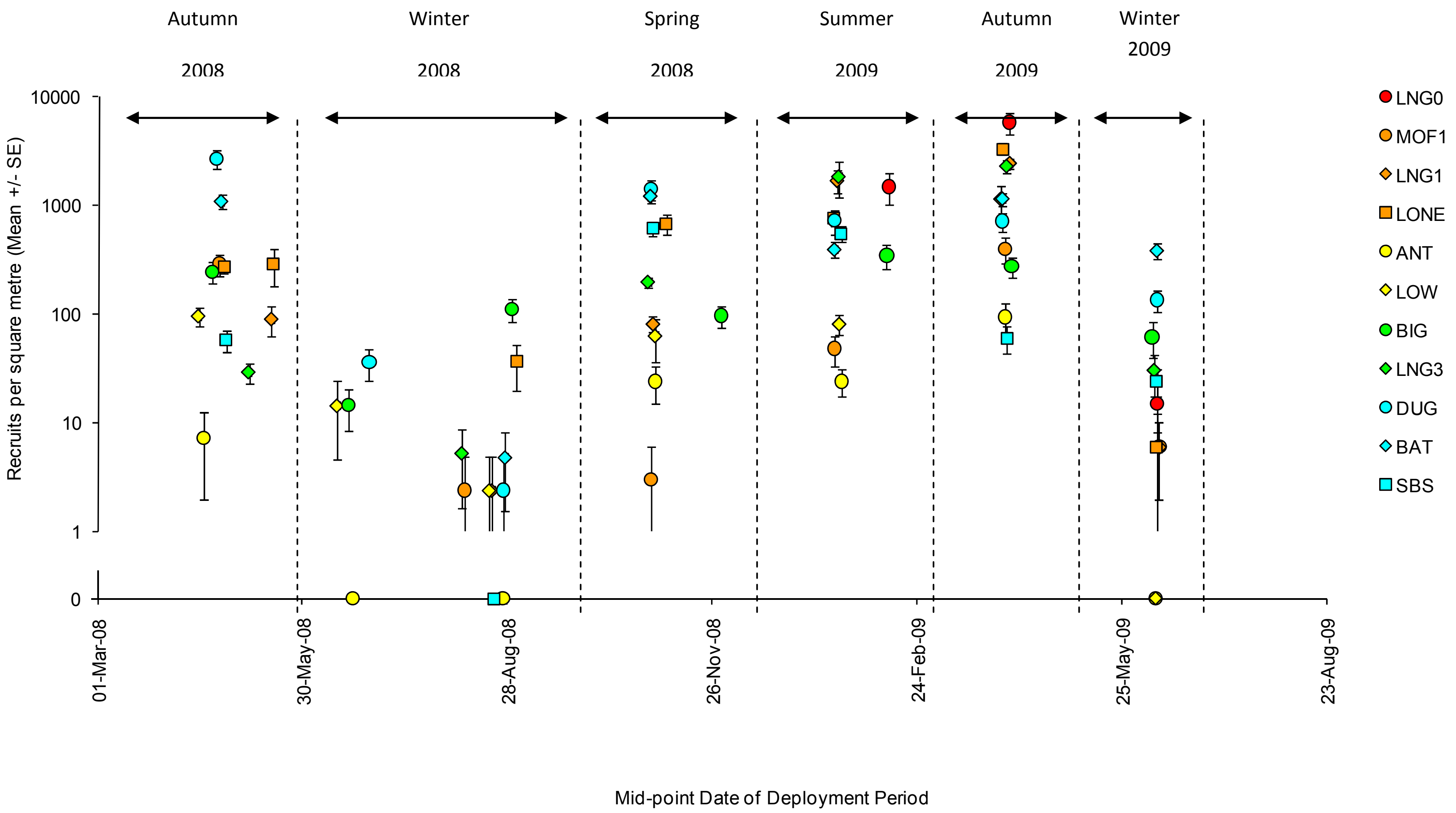


Figure 6-45 Mean Number of Recruits (± SE) per Square Metre from March 2008 to July 2009

Notes: Log scale on y-axis. Red = Site in the Zone of High Impact; Orange = Sites in the Zones of Moderate Impact; Yellow = Sites in the Zones of Influence; Green = Reference Sites; Blue = Sites in Regionally Significant Areas.

Table 6-58 Mean Number of Coral Recruits ± SE Per Tile and Number of Days Tiles were Deployed

Site		LNG0	MOF1	LNG1	Lone Reef	Ant Point Reef	Southern Lowendal Shelf	Biggada Reef	LNG3	Dugong Reef	Batman Reef	Southern Barrow Shoals
Mar 2008	No. of recruits	-	8.0 ± 1.8	2.5 ± 0.8	7.6 ± 1.0	0.2 ± 0.1	2.7 ± 0.5	6.8 ± 1.5	0.8 ± 0.2	74.5 ± 14.6	30.0 ± 4.1	1.6 ± 0.4
	Days deployed	-	72	119	76 & 121*	60	57	73	99	74	78	77
May 2008	No. of recruits	-	-	-	-	0.0 ± 0.0	0.4 ± 0.3	0.4 ± 0.2	-	1.0 ± 0.3	-	-
	Days deployed	-	-	-	-	73	64	47	-	61	-	-
Jun 2008	No. of recruits	-	0.1 ± 0.1	-	-	-	-	-	0.1 ± 0.1	-	-	-
	Days deployed	-	89	-	-	-	-	-	89	-	-	-
Jul 2008	No. of recruits	-	-	0.1 ± 0.1	1.0 ± 0.5	0.0 ± 0.0	0.1 ± 0.1	3.1 ± 0.8	-	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
	Days deployed	-	-	75	78	59	71	88	-	57	56	70
Sep 2008	No. of recruits	-	0.1 ± 0.1	2.3 ± 0.4	-	0.7 ± 0.3	1.8 ± 0.8	-	5.4 ± 0.6	39.0 ± 8.1	33.5 ± 4.8	17.1 ± 2.5
	Days deployed	-	74	67	-	75	75	-	75	72	72	70
Oct 2008	No. of recruits	-	-	-	18.8 ± 3.9	-	-	2.7 ± 0.6	-	-	-	-
	Days deployed	-	-	-	54	-	-	96	-	-	-	-
Dec 2008	No. of recruits	-	1.3 ± 0.4	46.6 ± 11.0	20.9 ± 3.2	0.7 ± 0.2	2.3 ± 0.5	-	50.6 ± 18.1	19.9 ± 5.1	10.8 ± 1.7	15.5 ± 2.2
	Days deployed	-	89	95	94	88	86	-	93	91	91	96
Jan 2009	No. of recruits	40.8 ±13.1	-	-	-	-	-	9.6 ± 2.5	-	-	-	-
	Days deployed	49	-	-	-	-	-	50	-	-	-	-
Mar 2009	No. of recruits	159.2 ± 34.2	11.0 ± 2.9	67.4 ± 7.3	90.8 ± 10.7	2.6± 0.8	31.7 ± 9.4	7.6 ± 1.6	63.3 ± 9.3	19.7 ± 3.9	31.8 ± 4.2	1.7 ± 0.5
	Days deployed	56	60	56	54	57	57	60	55	57	57	51
May 2009	No. of recruits	0.4 ±0.2	0.2 ±0.1	0.2 ±0.1	0.2 ±0.2	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.6	0.8 ± 0.3	3.8 ± 0.8	10.6 ± 1.7	0.7 ± 0.2
	Days deployed	75	76	74	82	74	78	69	75	78	79	80

Note: Where cells do not contain data, tiles were in the water but no collection and redeployment occurred during that month. Tiles were installed at LNG0 in January 2009.

** Of 15 tiles in total, 11 were deployed for 76 days and four were deployed for 121 days.*

6.4.6.2 Spatial Patterns of Coral Recruitment

Recruitment of coral larvae is spatially variable (Harrison and Wallace 1990) and coral recruitment varied significantly among the 11 monitoring sites (Table 6-58) During the autumn 2008 spawning period, the highest number of coral recruits were recorded at Dugong Reef (74.5 ± 14.6 recruits per tile; ~2660 per m^2) and Batman Reef (30.0 ± 4.1; ~1070 per m^2). The lowest number of coral recruits was recorded at Ant Point Reef (0.2 ± 0.1 recruits per tile; ~7 per m^2). With the exception of Dugong Reef and Batman Reef, all the sites had ≤8 recruits per tile (~285 recruits per m^2). This variation in recruitment was similar (<1 to approximately 100 recruits per panel) to that reported in the largest study of recruitment documented in the literature, which was undertaken on the Great Barrier Reef (Hughes *et al.* 2000).

Different sites recorded the highest recruitment in autumn 2009. The highest recruitment was recorded at LNG0 (159.2 ± 34.2 recruits per tile; ~5680 per m^2), Lone Reef (90.8 ± 10.7 recruits per tile; ~3245 per m^2), LNG1 (67.4 ± 7.3 recruits per tile; ~2410 per m^2) and LNG3 (63.3 ± 9.3 recruits per tile; ~2660 per m^2) (Table 6-58). The lowest number of recruits was recorded at Ant Point Reef and Southern Barrow Shoals (<3 recruits per tile) in autumn 2008 and 2009.

The spring 2008 spawning event was less significant than the autumn spawning event; only four sites recorded an increased coral recruitment (>15 recruits per tile; ~540 per m^2), these being Lone Reef, Dugong Reef, Batman Reef and Southern Barrow Shoals (Table 6-58). The other sites had <6 recruits per tile (~215 per m^2). The lowest number of recruits was recorded at MOF1 (0.1 ± 0.1 recruits per tile; ~5 per m^2) and the highest at Dugong Reef (39.0 ± 8.1; ~1395 per m^2).

The greatest recruitment in summer 2008 occurred at LNG1 (46.6 ± 11.0 recruits per tile; ~1665 per m^2) and LNG3 (50.6 ± 18.1 recruits per tile; ~1810 per m^2).

At other times of the year, lower numbers of recruits were generally recorded (<1 recruit per tile; ~35 per m^2) and at several sites no coral recruits were recorded. Sites which consistently recorded low recruitment throughout 2008 and 2009 were Ant Point Reef (<3 recruits per tile; ~105 per m^2), Biggada Reef (<10 recruits per tile; ~355 per m^2), and MOF 1 (<11 recruits per tile; ~395 per m^2). Similar to the autumn recruitment period, sites where there was high recruitment recorded during one winter did not necessarily have high recruitment during the subsequent winter. In winter 2008, recruitment was highest at Biggada Reef (3.1 ± 0.8 recruits per tile; ~110 per m^2), while in winter 2009, recruitment was highest at Batman Reef (10.6 ± 1.7 recruits per tile; ~380 per m^2).

6.4.6.3 Composition of Coral Recruits

The composition of coral recruits was generally variable through time, with different patterns in different seasons as well as inter-annual variation, although some clear patterns were evident. There was no indication that recruits from particular families primarily recruited to a specific site.

In late autumn 2008, the total number of recruits ranged from three at Ant Point Reef to 1118 at Dugong Reef. There was a mixed composition of coral recruits with varying numbers of poritid (up to 70% composition), pocilloporid (up to 50% composition) and acroporid (<5–65% composition) recruits, as well as a large number (<5–95% composition) of ‘Unidentified’ recruits (possibly faviids) (Figure 6-46). The greatest numbers of ‘Unidentified’ recruits were recorded at Dugong Reef. These results are indicative of a multi-specific spawning event of non-acroporid species in March 2008, consistent with the results from coral gravidity assessments.

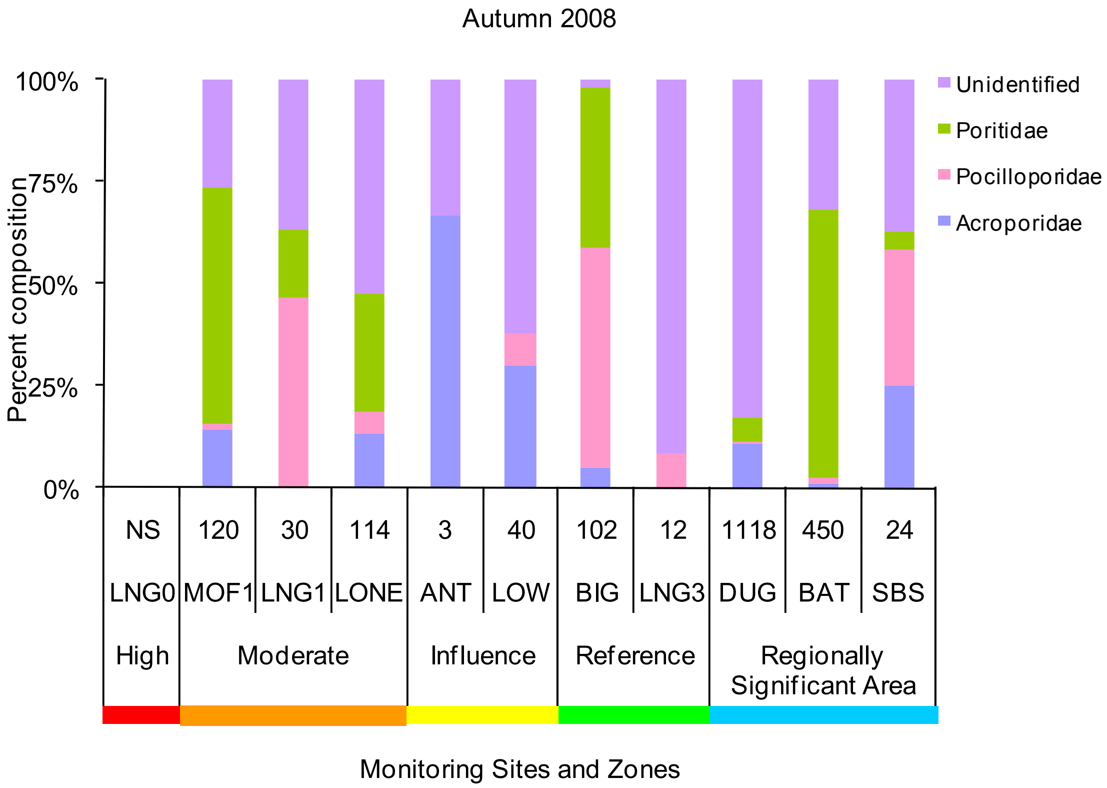


Figure 6-46 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Autumn 2008 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site is recorded below the x-axis; NS denotes there was no sampling over this time period.

In winter 2008, the total number of recruits ranged from zero at Ant Point Reef to 52 at Biggada Reef. The majority (65–100% composition) of recruits at all sites were pocilloporids, some species of which are planular brooders (Figure 6-47). Brooding corals spawn several times each year, unlike broadcast spawners that typically spawn annually (Harrison and Wallace 1990). Pocilloporids were not abundant at any of the monitoring sites and the consistently low numbers of pocilloporid recruits reflects their low abundance and multiple spawning events. There was almost no recruitment of acroporids. Low numbers (<15%) of 'Unidentified' recruits were recorded at Lone Reef, Biggada Reef and Dugong Reef and low numbers (<20%) of poritid recruits were recorded at Lone Reef and Dugong Reef.

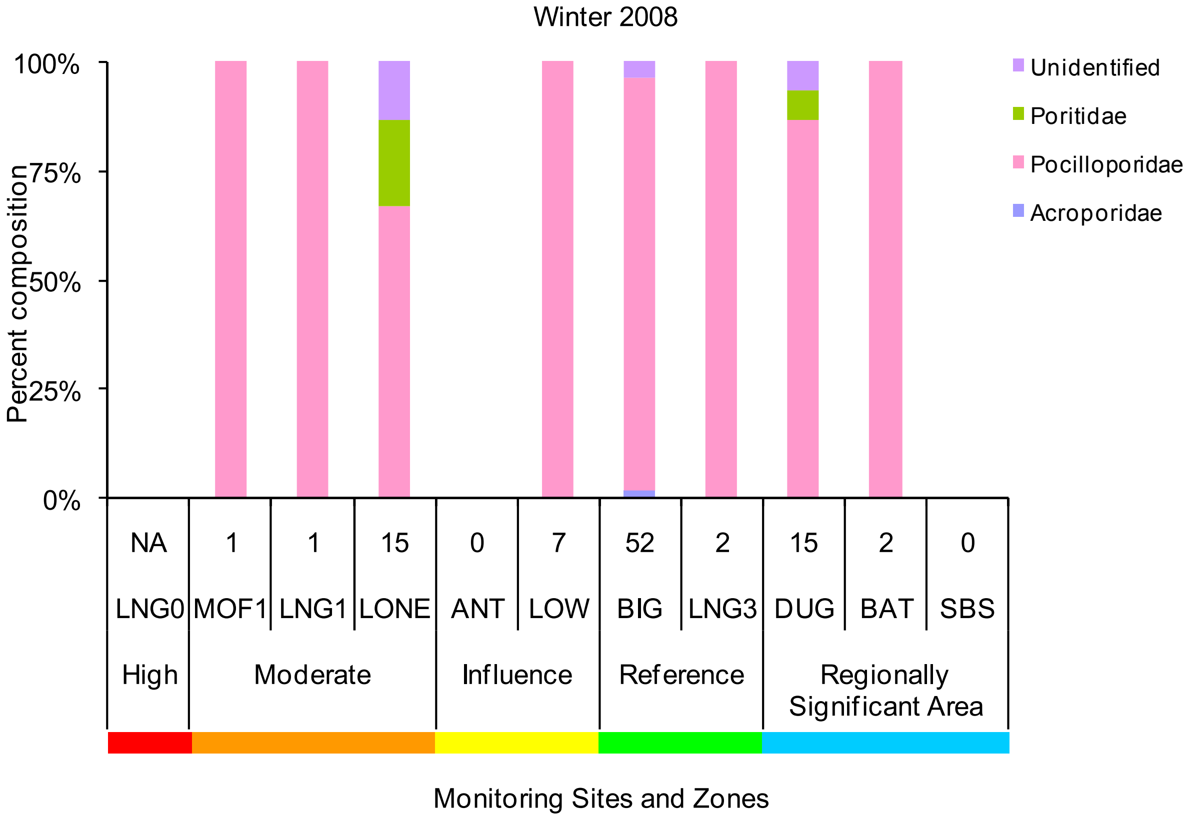


Figure 6-47 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Winter 2008 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site recorded below the x-axis; NA denotes there was no sampling over this time period; 0 denotes no recruits were recorded.

In spring 2008, the total number of recruits ranged from one at MOF1 to 468 at Dugong Reef. Recruitment was again dominated by pocilloporids (50–100% composition), but in much higher numbers than in winter, particularly at Lone Reef, LNG3, Dugong Reef Batman Reef and Southern Barrow Shoals, indicating a seasonal peak in reproduction for these brooding species (Figure 6-48). Poritid recruits were also recorded at this time at eight sites (<5–100%), in particular at Lone Reef, LNG3, Dugong Reef and Batman Reef, as well as one recruit at MOF1. Poritids are generally considered to spawn during the mass spawning period in autumn (Simpson 1985); however, recent observations in the Dampier Archipelago suggest that poritids may spawn there in November and December (J Stoddart, pers. comm. 19 December 2008). The presence of poritid recruits in October/November is also indicative that some species may spawn in spring at Barrow Island.

Acroporids were recorded at LNG3 and Southern Barrow Shoals but comprised <5% of recruits. Secondary spawning events involving *Acropora* have been observed in spring in Western Australia (Stoddart and Gilmour 2005; Rosser and Gilmour 2008). However, the low numbers of acroporid recruits observed in spring is indicative that this may not be an important spawning period for these species on Barrow Island. ‘Unidentified’ recruits ranged in percentage composition from 0–30%.

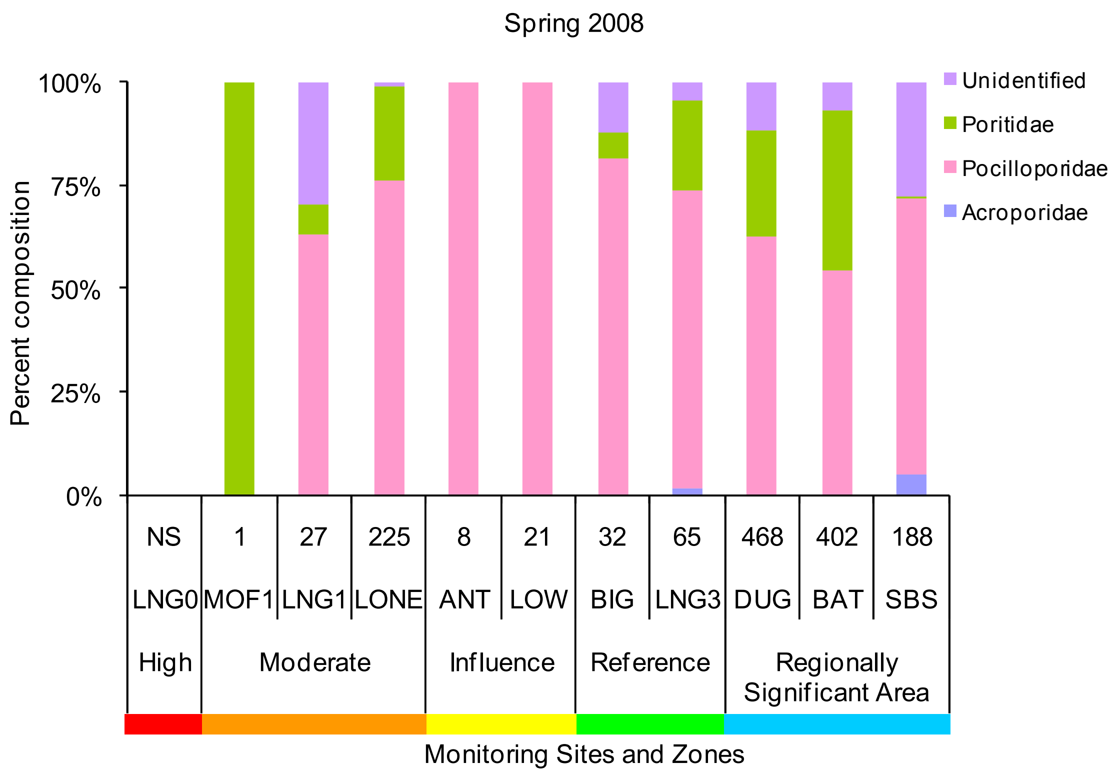


Figure 6-48 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Spring 2008 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site recorded below the x-axis; NS denotes there was no sampling over this time period.

In summer 2008–2009, the total number of recruits ranged from eight at Ant Point Reef to 607 at LNG3. The composition of recruits at the three sites with highest recruitment (LNG0, LNG1 and LNG3, all located in close proximity to each other) was predominantly acroporids (>75% composition) (Figure 6-49). At other sites where recruitment was lower, recruitment was dominated either by poritid (up to 90%) (Lone Reef, Dugong Reef and Batman Reef), or pocilloporid (up to 70%) (Biggada Reef) recruits. This is consistent with a late spring–summer spawning of these families, also supported by coral gravidity assessments.

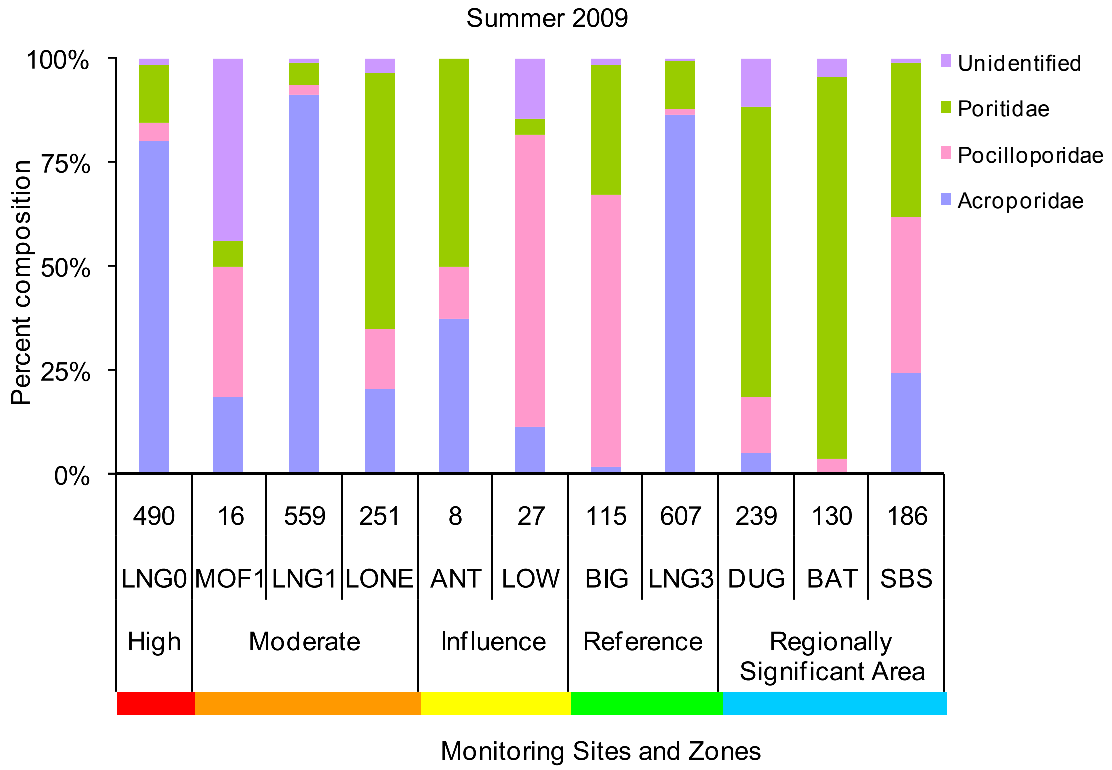


Figure 6-49 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Summer 2009 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site recorded below the x-axis.

In autumn 2009, the total number of recruits ranged from 20 at Southern Barrow Shoals to 1751 at LNG0. Recruitment was dominated by poritids at Batman Reef and Southern Barrow Shoals, by pocilloporids at Biggada Reef and by acroporids (60–95% composition) at the remaining sites (Figure 6-50). Of interest were the large numbers of acroporid recruits at LNG0, LNG1, LNG3 and Lone Reef, given that these sites were dominated by *Porites* colonies with limited *Acropora* growing at these sites. These results indicate that in autumn 2009 these sites served as “sinks” for recruits from other source reefs. The composition of recruits in autumn 2009 was very different to the composition in autumn 2008. In 2009, recruitment tiles were dominated by acroporids, while in 2008 there were relatively few acroporid recruits, suggesting that there was very little spawning of acroporids in autumn 2008, consistent with the assessment of coral gravidity.

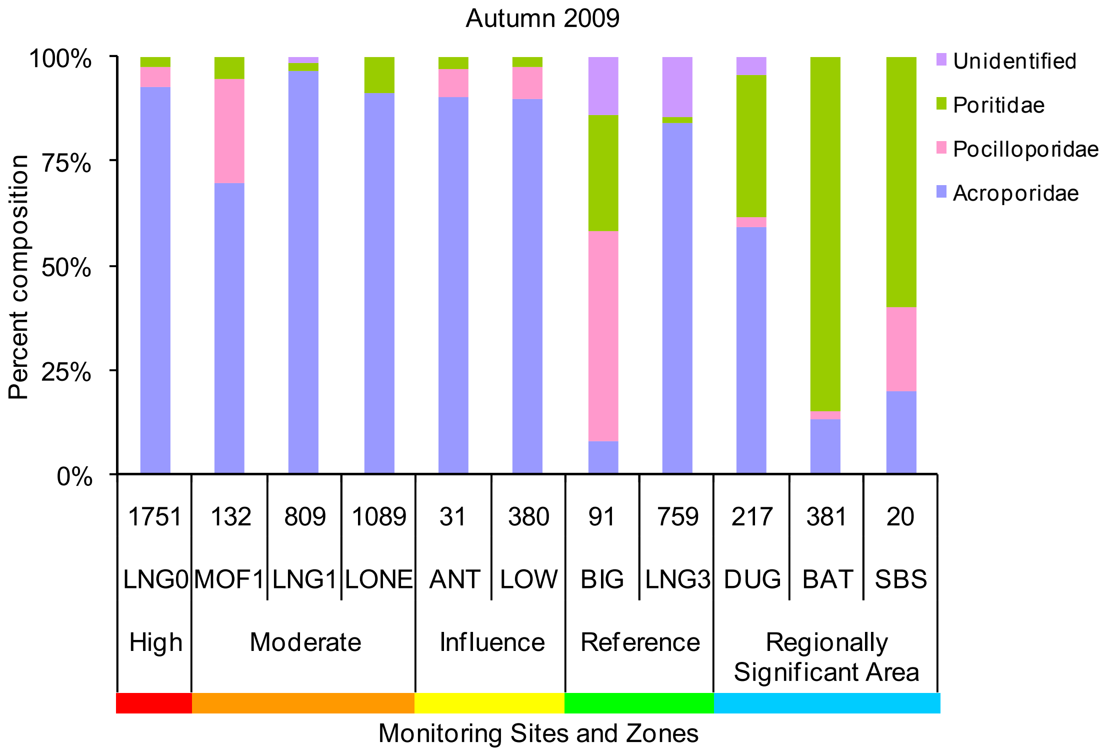


Figure 6-50 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Autumn 2009 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site is recorded below the x-axis.

In winter 2009, the total number of recruits ranged from zero at Ant Point Reef and Southern Lowendal Shelf to 127 at Batman Reef. Recruitment was dominated by poritids and pocilloporids (Figure 6-51). The presence of poritid recruits in winter is indicative that the Poritidae were spawning all year round. This may indicate that some poritid species in Barrow Island waters are brooders, as is the case on the east coast of Australia (Harriott 1983). The composition of recruits in winter 2009 is in contrast to winter 2008, where there were very few poritid recruits, which is consistent with inter-annual variability in the spawning of poritids.

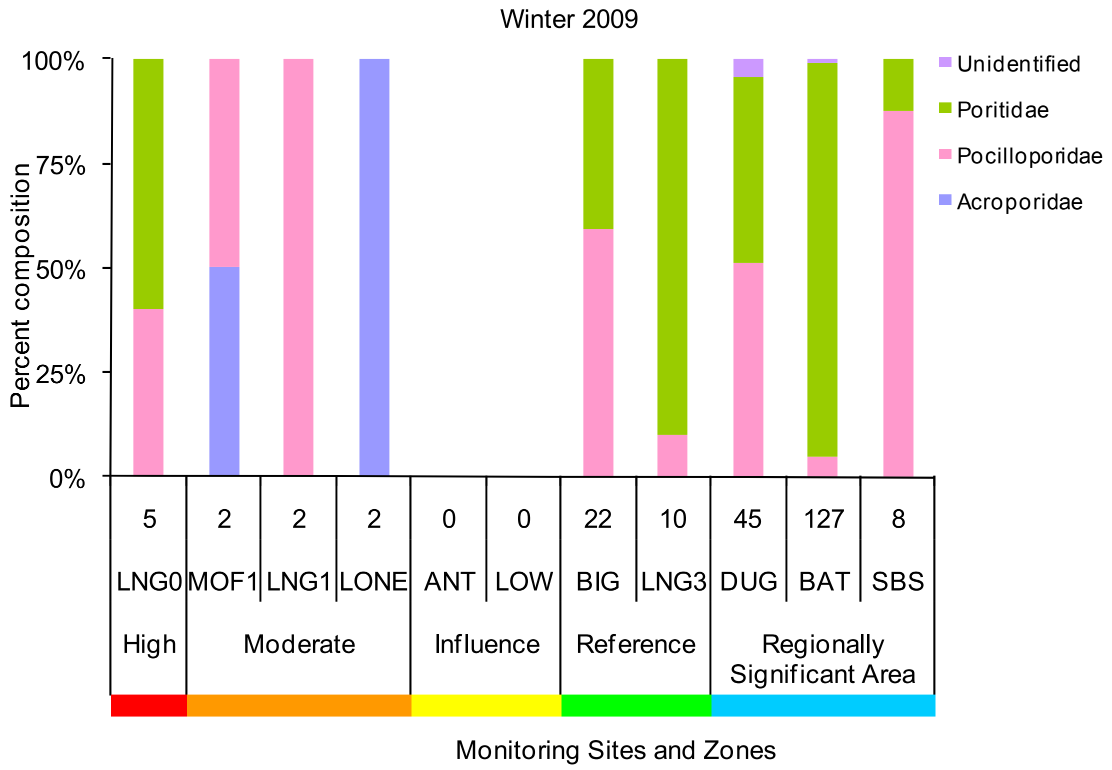


Figure 6-51 Composition of Coral Recruits on Tiles Deployed at Monitoring Sites after the Winter 2009 Spawning Period

Notes: Total number of recruits recorded on all tiles at each site is recorded below the x-axis; 0 = no recruits recorded.

6.4.6.4 Comparison with Other Studies in North-western Australia

An average of 43.5 ± 5.1 recruits (or ~1554 recruits per m^2) was recorded on tiles deployed in autumn 2009 at Barrow Island, which is comparable to the results reported from studies in other locations in Western Australia. Studies of coral recruitment at Scott Reef recorded 36.2 ± 13.7 (95% Confidence Interval per year) acroporid recruits per tile, equivalent to ~1273 recruits per m^2, in autumn 1997 and 1998, 3.4 ± 0.8 recruits per tile (~120 recruits per m^2) in spring and 0.08 ± 0.15, and 0.2 ± 0.5 recruits per tile in winter (~3 and ~7 recruits per m^2) (Gilmour *et al.* 2009). At Ningaloo Reef, recruitment ranged from 2.4 to 43.4 recruits per tile pair (equivalent to ~53 to ~964 recruits per m^2) with acroporids contributing 73% and pocilloporids contributing 18% of recruits (Harriott and Simpson 1997). Recruitment rates of 24.7 ± 24.3 (standard error) (or ~549 recruits per m^2) were recorded in autumn 1994 at Ningaloo Reef. Recruitment rates were considerably lower further south at the Houtman-Abrolhos, where mean rates of 0.77 recruits per tile pair were recorded, which equates to ~17 recruits per m^2. The composition of recruits on tiles deployed at the Houtman-Abrolhos was similar to that at Ningaloo Reef, with acroporids contributing 83% and pocilloporids contributing 15% of recruits.

While direct comparisons between the different studies are not straightforward because of differences in the size of deployed tiles, differences in the types of material used for the tiles, tile orientation and position in the water column and distance above the seafloor, which tile surfaces are recorded, which can all influence recruitment, the results from the Marine Baseline Program indicate that recruitment rates at Barrow Island are more similar to the tropical areas of Ningaloo Reef and Scott Reef than the subtropical Houtman-Abrolhos.

6.5 Discussion

The coral assemblages that are at risk of impacts associated with the generation of turbidity and sediment deposition from dredging and spoil disposal activities occur in the vicinity of the Materials Offloading Facility (MOF) and Causeway, in the Jetty Access Channel and in the vicinity of the Dredge Spoil Disposal Ground (Figure 2-1). These coral assemblages are also at risk of Material or Serious Environmental Harm caused by, for example, the direct placement of infrastructure on the seabed, the permanent removal of substrates suitable for colonisation through dredging, and as a result of vessel movements and anchoring.

The footprint of the Causeway will be located wholly on the limestone pavement adjacent to Barrow Island, extending from the beach cliffs at Town Point, across the intertidal reef platform adjacent to the shore, out to approximately 7 m water depth at the MOF. The intertidal zone is approximately 200 m wide and characterised by mixed turfing algae, with larger macroalgae and sparse seagrass in rock pools. The subtidal platform reef was covered by extensive macroalgal beds with sparse sessile taxa, including sparse assemblages of seagrass on small sand patches scattered across the limestone pavement. Scattered bomboras, generally <2 m in diameter, were present amongst the macroalgal beds in shallow water (0–8 m). Bomboras in the nearshore areas of the platform were generally dominated by macroalgae and benthic macro-invertebrates, whereas bombora on the offshore edge of the platform generally supported more live coral. Patches of unvegetated limestone pavement in the vicinity of the Causeway supported mixed benthic macro-invertebrate assemblages, including ascidians, hydroids, sea whips, small isolated hard corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges.

The footprint of the MOF lies on the deeper subtidal area of the platform adjacent to the east coast of Barrow Island. The dominant ecological element in the area was macroalgae, with subdominant levels of cover of other sparse sessile taxa, including sparse assemblages of seagrass on shallow patches of sand on the limestone pavement. Coral assemblages in the vicinity of the MOF were similar to those of the offshore parts of the Causeway, with higher live coral cover than inshore areas of the platform. While most of the bombora within the MOF Marine Disturbance Footprint were relatively small (<2 m in diameter), there were a number of larger (up to 50 m diameter) coral bombora (non-*Porites*) assemblages in this area. The benthic macro-invertebrate assemblages present in this area were typical of the platform and similar to those in the vicinity of the Causeway, comprising ascidians, hydroids, sea whips, scattered small hard corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges.

The footprint of the LNG Jetty extends across the outer part of the limestone platform adjacent to Barrow Island for 500 m past the end of the MOF and then continues for a further 1200 m across the soft sediment assemblages in deeper water. The outer part of the reef platform within the footprint of the LNG Jetty was dominated by macroalgal assemblages with sparse sessile taxa, similar to those within the footprint of the MOF. Bomboras in this area were similar to bomboras within the footprint of the MOF, which were comprised mostly of *Diploastrea heliopora* (Faviidae) and also *Porites australiensis* (Poritidae) and *Lobophyllia diminuta* (Mussidae). While most bomboras were small, several bombora assemblages 3–10 m in diameter were present. Benthic macro-invertebrate assemblages included ascidians, hydroids, sea whips, scattered small corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges.

The footprint of the Turning Basin lies in 8–11 m of water over limestone pavement with a sand veneer. The sediments within the footprint of the Turning Basin mainly comprised coarse- to fine-grained sand. The dominant benthic category comprised soft sediment (unvegetated sand) with sparse sessile taxa at subdominant levels of cover, including sparse cover of macroalgae and seagrass and benthic macro-invertebrates. Sea whips and sponges were the most abundant of the benthic macro-invertebrates in this area. No coral assemblages were recorded within the footprint of the Turning Basin.

The footprint of the LNG Jetty Access Channel overlies a small section of the East Barrow Ridge (a raised limestone platform in approximately 7 m water depth) and the soft sediment habitats either side of the ridge. The western end of the LNG Jetty Access Channel, to the west of the ridge, is an extension of the Turning Basin and was characterised by the same soft sediment comprised of coarse- to fine-grained sand, with sparse sessile taxa. The area on East Barrow Ridge within the footprint of the LNG Jetty Access Channel was characterised by areas mapped as 'Macroalgae with Sparse Sessile Taxa', coral assemblages and patches of sediment (largely unvegetated bare sand), with subdominant levels of cover of seagrass and benthic macro-invertebrates. The ridge was characterised by sparse coral cover and several large bomboras, some of which had live coral. The biotic cover on the bomboras was variable, with many bombora comprising a mixture of coral, macroalgae and benthic macro-invertebrates. There was one large bombora assemblage (approximately 60 m in diameter) within the LNG Jetty Access Channel Marine Disturbance Footprint that was dominated by *Porites*. The benthic macro-invertebrate assemblages present on the ridge were characterised by sea whips, small hard corals (*Turbinaria* sp.), sponges and soft corals.

The footprint of the Dredge Spoil Disposal Ground lies within an area mapped as 'Soft Sediments with Sparse Sessile Taxa', including benthic macro-invertebrate assemblages in areas where the underlying pavement was exposed, or the sand veneer was shallow. No coral habitats occur within the Dredge Spoil Disposal Ground. There were two patch reefs in the area around the Dredge Spoil Disposal Ground: Lone Reef to the north in the Zone of Moderate Impact, and one to the south in the Zone of Influence. Both reefs were dominated by large (up to 10 m across and 3 m high) *Porites* bombora (predominantly *P. lutea*, *P. australiensis* and *P. rus*).

6.6 Conclusions

The hard and soft coral assemblages within the Zones of High Impact and Zones of Moderate Impact were discontinuous and occurred as scattered *Porites* bombora or Mixed Coral Assemblages within extensive areas of 'Macroalgae with Sparse Sessile Taxa' (seagrass and non-coral benthic macro-invertebrates). There were also a few bombora in areas of soft sediment with sparse non-coral sessile taxa. The density of the bombora, their size, percentage of live coral cover and species composition was variable and the level of impact within these Zones will range from permanent or long-term coral loss, to short-term loss (recovery in less than five years) to negligible impact depending on the specific species/taxa concerned and the type of impact. The ground-truthing of the potential coral features, including the quantitative assessment of live coral cover, identified within the Zones of High Impact and the Zones of Moderate Impact to calculate the Area of Loss of Coral Assemblages, as required under Condition 14.6.ii of Statement No. 800 and Condition 11.6.II of EPBC Reference: 2003/1294 and 2008/4178, was undertaken in November 2009, as close as practicable to the commencement of the dredging and spoil disposal activities and Marine Facilities construction activities, to reduce the risk of natural events confounding the assessment of live Coral Assemblages undertaken prior to the commencement of the dredging and spoil disposal activities and marine construction activities. Quantitative assessment of live coral cover involved the analysis of photo-quadrats along transects using the software program Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006) to assess percentage composition of assemblages. The results are presented in the Coastal and Marine Baseline State and Environmental Impact Report Supplement: Area of Coral Assemblages (Chevron Australia 2010). Note that the maps in the Marine Baseline Report have also been updated to reflect the results from this field assessment.

7.0 Non-Coral Benthic Macro-invertebrates

7.1 Introduction

While the knowledge of the benthic macro-invertebrate assemblages in the Montebello/Barrow Islands region is generally limited to species lists and distributions of taxa, the available information suggests that the assemblages are species-rich (Marsh 1993; Wells *et al.* 1993; Chevron Australia 2005; DEC 2007; RPS Bowman Bishaw Gorham 2007). Invertebrate species richness is considered high in the Montebello Islands region in particular, with 633 species of molluscs and 170 species of echinoderms recorded (Wells *et al.* 1993; Marsh *et al.* 1993b cited in DEC 2007). Deeper limestone reef areas in the region may support benthic macro-invertebrate communities that contain diverse assemblages of tubular, digitate, laminar, branching, globose and encrusting sponges; hydroids; gorgonians (sea fans); soft corals (sea whips); colonial and solitary ascidians; bryozoans and small scleractinian corals (such as *Turbinaria* spp.) (Chevron Australia 2005).

The habitats on the east and west coasts of Barrow Island support different benthic macro-invertebrate assemblages. Of the 316 species of molluscs recorded from Barrow Island, less than one third occur on both coasts (Chevron Australia 2005). The muddier habitats on the east coast support a greater proportion of bivalve species, whilst the west coast supports a greater proportion of coral reef gastropod species (Chevron Australia 2005). The gastropod *Amoria macandrewi*, is endemic to sandbars within the Montebello/Barrow Islands region (Chevron Australia 2005). The macro-invertebrate fauna of the rocky shores and intertidal mudflats on the leeward sides of the offshore islands in the Montebello/Barrow Islands region also have strong affinities with the fauna of the nearshore intertidal areas on the mainland (Chevron Australia 2005).

7.2 Scope

This Section records the dominant species of non-coral benthic macro-invertebrates (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the non-coral benthic macro-invertebrates:

- within the Zones of High Impact and the Zone of Moderate Impact and representative areas with the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

Non-coral benthic macro-invertebrates (hereafter referred to as 'benthic macro-invertebrates') are a broad category of fauna that include sessile, filter-feeding taxa such as sponges, gorgonians and ascidians, as well as motile taxa such as asteroids (starfish), echinoids (sea urchins) and holothurians (sea cucumbers). The Marine Baseline Program has focused on the dominant (most common) benthic macro-invertebrate species among the sessile, habitat-forming groups which characterise the benthic macro-invertebrate assemblages around Barrow Island (Condition 14.8.iii, Statement No. 800; 11.8.III, EPBC Reference: 2003/1294 and 2008/4178).

The soft corals (order Alcyonacea) are commonly observed in benthic macro-invertebrate dominated habitats in Barrow Island waters (outside of coral reef habitats) and represent an important part of the sessile benthic macro-invertebrate assemblages; they are also included in this Section. The hard coral *Turbinaria* spp. is also common in these habitats and has been included as a benthic macro-invertebrate as, from a habitat perspective, it is more like other benthic macro-invertebrates (i.e. solitary with a low profile and low benthic cover) than the hard corals discussed in Section 6.0.

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was approved on 3 November 2009, and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

7.3 Methods

7.3.1 Site Locations

A total of 28 benthic macro-invertebrate survey sites were selected within those areas where benthic macro-invertebrates were identified as being present through broadscale benthic habitat mapping (Section 5.1). Nine sites were located on limestone pavement and 19 in soft sediments. Seven sites were located within the Zones of High Impact and Moderate Impact around the area to be dredged, and two sites were located within the Zone of High Impact at the Dredge Spoil Disposal Ground (Table 7-1; Figure 7-1). Six sites (TP5, TPCI1, TPCI2, LNGI1, DS1 and DS2) were in the area at Risk of Serious Environmental Harm (Section 2.3.4) and three (TP2, TP6 and LNGI2) were within the area at Risk of Material Environmental Harm (Figure 2-5), with all but three of these sites (TP2, DS1 and DS2) within the Marine Disturbance Footprint (Figure 2-3).

Fifteen sites were located within the Zones of Influence, including one adjacent to the Dredge Spoil Disposal Ground (Table 7-1; Figure 7-1). These sites are considered to be Reference Sites because, although located within the Zones of Influence, turbidity and sediment deposition are not expected to impact on benthic macro-invertebrates and no Material or Serious Environmental Harm is expected to affect these sites (see Section 2.3.4). These sites will only be used as Reference Sites in any future analyses if it is determined through the Dredging and Spoil Disposal Monitoring Program that they have not been impacted by dredging and spoil disposal activities. Four sites were located outside the Zone of Influence, in the deeper soft sediments east of the East Barrow Ridge.

In addition, surveys were undertaken at WAPET Landing (RPS Bowman Bishaw Gorham 2006; RPS 2009a).

Table 7-1 Benthic Macro-invertebrate Survey Sites and Dates

Location	Site Code	Easting	Northing	Latitude	Longitude	Habitat	Survey Date		
		(GDA94, MGA Zone 50)		(GDA94)			Nov 2008	Jan 2009	Jul 2009
Zones of High Impact	TP6	342238	7699286	20° 47.978' S	115° 29.050' E	Limestone Pavement	X*		X
	TP5	342085	7699098	20° 48.079' S	115° 28.961' E	Limestone Pavement			X
	TPCI1	342952	7697366	20° 49.022' S	115° 29.451' E	Soft Sediment		X	
	TPCI2	343537	7697097	20° 49.171' S	115° 29.787' E	Soft Sediment		X	
	LNGI1	344397	7696825	20° 49.323' S	115° 30.281' E	Limestone Pavement	X	X	X
	LNGI2	344879	7696121	20° 49.707' S	115° 30.555' E	Limestone Pavement		X	
	DS1	348019	7691926	20° 51.996' S	115° 32.343' E	Soft Sediment		X	X
	DS2	347615	7689533	20° 53.291' S	115° 32.098' E	Soft Sediment		X	
Zones of Moderate Impact	TP2	342234	7700922	20° 47.091' S	115° 29.057' E	Limestone Pavement	X*		X
Zones of Influence	NEBWI2	343137	7713599	20° 40.225' S	115° 29.645' E	Limestone Pavement	X	X	
	DI1	342869	7706775	20° 43.922' S	115° 29.454' E	Limestone Pavement			X**
	TP1	342332	7701483	20° 46.788' S	115° 29.116' E	Soft Sediment	X		
	LC2	344619	7700316	20° 47.432' S	115° 30.428' E	Soft Sediment	X	X	X
	LC1	344931	7700025	20° 47.591' S	115° 30.606' E	Soft Sediment		X	
	LC3	344142	7699047	20° 48.117' S	115° 30.146' E	Soft Sediment	X	X	
	LC4	344832	7698996	20° 48.148' S	115° 30.543' E	Soft Sediment		X	X
	LNGR2	345444	7697787	20° 48.807' S	115° 30.890' E	Soft Sediment		X	
	LNGR3	343604	7694856	20° 50.386' S	115° 29.813' E	Limestone Pavement		X	X
	LNGR1	344321	7694295	20° 50.694' S	115° 30.224' E	Soft Sediment		X	X
	TP9	341069	7695737	20° 49.895' S	115° 28.357' E	Soft sediment	X		
	TP10	337826	7694122	20° 50.754' S	115° 26.478' E	Limestone Pavement	X**		
	TPC3	342101	7694972	20° 50.315' S	115° 28.947' E	Soft Sediment		X	
	TPC1	342628	7694475	20° 50.587' S	115° 29.249' E	Soft Sediment		X	
	DSS1	347316	7687119	20° 54.598' S	115° 31.913' E	Soft Sediment		X	X**
Reference Sites	DSR3	353494	7695109	20° 50.297' S	115° 35.516' E	Soft Sediment		X	
	DSR5	346075	7694125	20° 50.794' S	115° 31.234' E	Soft Sediment		X	X
	DSR6	350774	7693683	20° 51.057' S	115° 33.941' E	Limestone		X**	
	DGI0	342795	7690816	20° 52.571' S	115° 29.325' E	Soft Sediment		X	X

*Note: * = Habitat classified as Soft Sediment at this survey date, ** = Transects fall on both Soft Sediment and Limestone habitat.*

Note that some benthic macro-invertebrate survey sites were also macroalgal and/or seagrass survey sites as these ecological elements commonly occurred together. Macroalgae and benthic macro-invertebrates co-occurred on the inshore limestone pavement, while seagrass and benthic macro-invertebrates often co-occurred in soft sediments.

7.3.2 Methods

At each site, three 30 m long and 0.5 m wide belt transects were filmed using a diver-operated high definition video camera in a waterproof housing, with the lens maintained at a fixed distance of 50 cm from the substratum (RPS 2009). Each transect covered an area of approximately 15 m^2. The first transect was orientated parallel to the anchor line and the two others at 90° to the first. The co-ordinates of the start point of each transect was recorded using GPS. The variability within and among transects was estimated based on the preliminary field data collected in November 2008, to confirm that the proposed sampling design would adequately account for natural variability at these spatial scales.

The dominant benthic macro-invertebrates along each transect were photographed with a digital camera in a waterproof housing and voucher specimens were collected, preserved (frozen or in 70% ethanol) and catalogued.

Qualitative surveys were undertaken at WAPET Landing to record the most common benthic macro-invertebrate species, including photographing 0.25 m^2 quadrats placed on the seabed and the most common benthic macro-invertebrates were recorded and photographed. Note that the digital images were not suitable for CPCe analysis.

The benthic macro-invertebrate assemblages were described at a broad taxonomic level because the identification of soft corals and sponges to species level is often problematic (Hooper 2000; P. Alderslade, pers. comm. RPS November 2008). Nevertheless, this broad level of information is considered appropriate as a baseline to determine the impacts of the disturbance associated with dredging and spoil disposal activities because changes to assemblages will still be detected at this level (Harvey *et al.* 1998; Fabricius and Alderslade 2001).

7.3.3 Timing and Frequency of Sampling

Sampling was undertaken in late spring and summer (November 2008 and January 2009; Table 7-1). Sampling at a subset of 11 sites surveyed in November 2008 and January 2009, as well as two additional sites, was repeated in winter (July 2009). The sites sampled in July 2009 were selected based on their proximity to the proposed Marine Facilities and to include a number of sites in the different Dredge Management Areas.

Surveys at WAPET Landing were undertaken in July–August 2006 and June 2009 (RPS Bowman Bishaw Gorham 2006; RPS 2009a).

7.3.4 Treatment of Survey Data

Video footage of transects was reviewed to:

- identify growth form of the sessile benthic macro-invertebrates
- identify family (where possible) of the sessile benthic macro-invertebrates
- estimate the abundance of the sessile benthic macro-invertebrates (i.e. numbers of individuals of each of the major benthic macro-invertebrates groups along each transect).

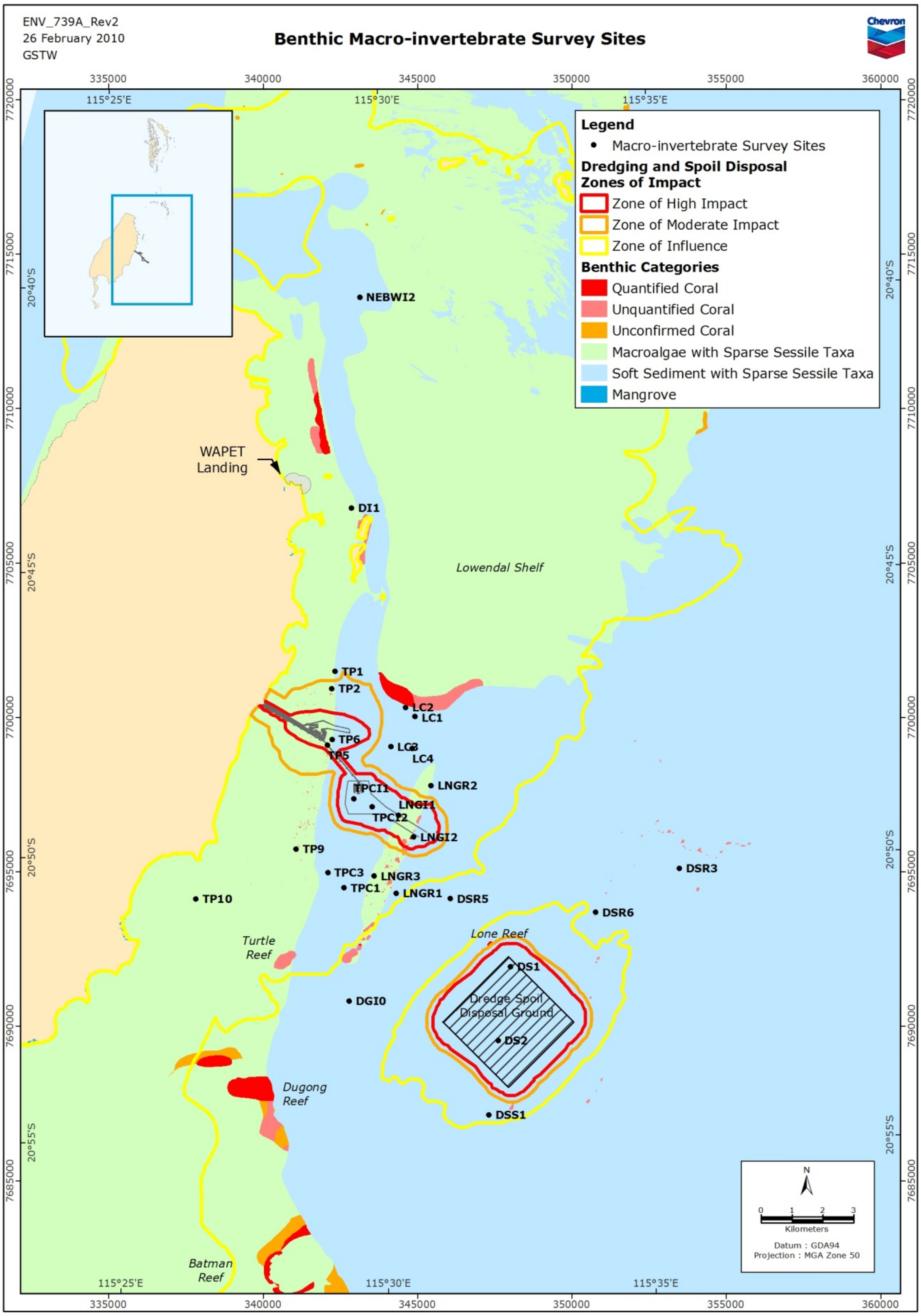


Figure 7-1 Benthic Macro-invertebrate Survey Sites

7.4 Results

7.4.1 Dominant and Subdominant Benthic Macro-invertebrates

The most commonly recorded (dominant) benthic macro-invertebrate taxa during the Marine Baseline Program, were:

- sponges (of varying morphology)
- hydroids
- Alcyoniidae (e.g. *Sarcophyton*, *Lobophytum*)
- sea whips (e.g. *Junceela*, *Rumphella*)
- gorgonians (sea fans)
- hard corals (*Turbinaria*)
- crinoids
- ascidians (e.g. *Atriolum robustum*).

Sponges were relatively common on both limestone pavement and soft sediments. Sponges were classified according to a morphological classification scheme adapted from Bell and Barnes (2001). Sponges were classified as barrel-shaped sponges (*Xestospongia*), digitate sponges, flabellate or fan sponges, arborescent or branching sponges, cup-shaped sponges, tubular sponges, globular sponges, or sponges with variable (irregular) morphologies (Plate 7-1).

Atriolum robustum (family Didemnidae) was the most commonly observed ascidian in Barrow Island waters, occurring on hard substrates such as limestone pavements (Plate 7-1) and the calcified stalks of hydroids.

Soft corals and gorgonians were relatively common in Barrow Island waters. The term ‘gorgonian’ is used in this Report to describe the densely reticulate sea fans growing in a single plane and with a rigid exoskeleton (Plate 7-1). The term ‘sea whip’ is used to describe the fleshy branching and non-branching soft corals such as *Junceela* spp. and *Rumphella* spp. (Plate 7-1). The non-branched, elongate sea whip *Junceela* spp. was commonly observed in soft sediments and less commonly on limestone pavements, with unidentified branching sea whips also relatively common (Plate 7-1). The fleshy, massive soft corals (Alcyoniidae) in the genus *Sarcophyton* and *Lobophytum* were observed in soft sediment and limestone pavement habitats.

The hard coral *Turbinaria* was common on both limestone pavement and soft sediment substrates. Hydroids were commonly observed on hard substrates, occasionally with ascidians attached. Crinoids were often attached to other benthic macro-invertebrates on limestone pavement and soft sediment habitats (Plate 7-1).

Pennatulids (sea pens) were also observed but were not included in the quantitative data. Sea pens were present at a small number of sites (LC1, LC2, DS1 and DS2) and occurred in low abundances in soft sediment habitats (the greatest number recorded on a single transect was three).

Barrel Sponge

Flabellate Sponge

Ascidians (*Atriolum robustum*)

Gorgonian (Sea Fan)

Sea Whip

Crinoid attached to Sea Whip

Plate 7-1 Benthic Macro-invertebrates Found in Waters Around Barrow Island

7.4.2 Distribution of Benthic Macro-invertebrates in Barrow Island Waters

Figure 7-2 shows the spatial distribution of benthic macro-invertebrates in Barrow Island waters as point (presence/absence) observations derived from broadscale mapping and ground-truthing (towed video camera surveys, spot dives and transect surveys). 'Null observations' were recorded where benthic macro-invertebrates were not observed during ground-truthing.

Benthic macro-invertebrate assemblage composition was relatively homogenous across broad areas of similar substrate, and while benthic macro-invertebrates were generally sparsely distributed, the abundance of the different taxa was variable. Distinct assemblages were observed on the different substrate types (sand or soft sediment and limestone pavement). Benthic macro-invertebrates often occurred with macroalgae and the only areas where benthic macro-invertebrates were the most common or abundant benthic biota were in the deeper (>10 m) soft sediment habitats. The results from the qualitative towed video camera surveys indicated that the greatest density of benthic macro-invertebrates occurred at Double Island to the north of the MOF. This area was dominated by sponges and sea whips, which were more common in the deeper sand habitat to the east of the limestone pavement.

The mean abundances of benthic macro-invertebrates recorded in soft sediment and limestone pavement habitats recorded during transect surveys are summarised in Table 7-2, Table 7-3 and Table 7-4. The percentage contribution of the different benthic macro-invertebrate taxa (number of individuals), to the total number of benthic macro-invertebrates on limestone pavement and soft sediment habitats, are presented in Table 7-5.

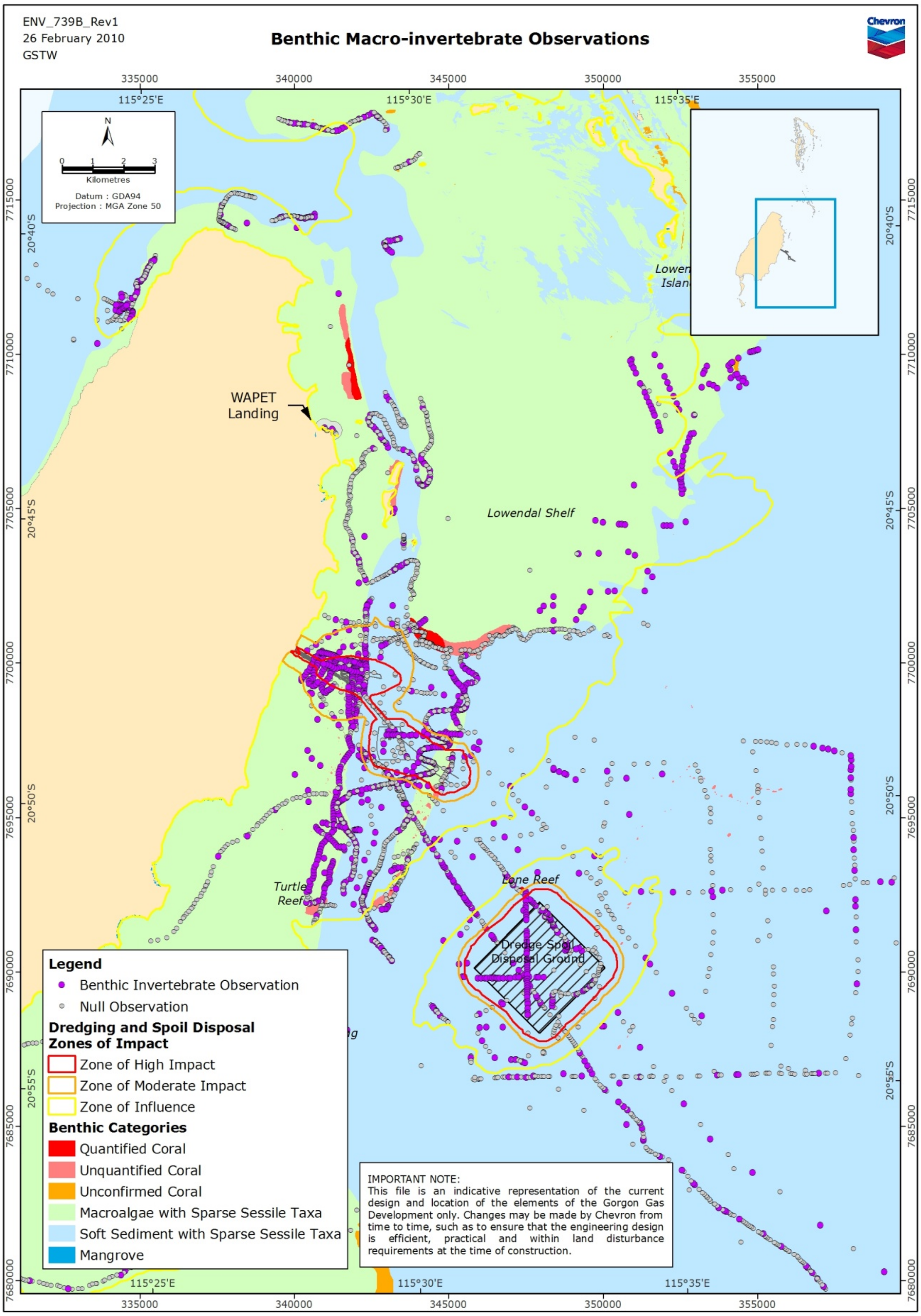


Figure 7-2 Observations of Benthic Macro-invertebrates in Barrow Island Waters

Table 7-2 Mean Benthic Macro-invertebrate Abundance ± SE per 30 m Transect (approximately 15 m^2) at Sites and Sampling Occasions in the Zones of High Impact and the Zones of Moderate Impact

Benthic Macro-invertebrate	TP6		TP5	TPCI1	TPCI2	LNGI1		LNGI2	DS1		DS2	TP2	
	Nov 08	Jul 09	Jul 09	Jan 09	Jan 09	Jan 09	Jul 09	Jan 09	Jan 09	Jul 09	Jan 09	Nov 08	Jul 09
Ascidian colonial	2.3 ± 0.9	2.7 ± 0.9	-	-	-	-	0.3 ± 0.3	1.3 ± 0.7	0.7 ± 0.3	1.3 ± 0.9	0.3 ± 0.3	6.3 ± 1.8	8.0 ± 5.6
Ascidian solitary	-	-	-	-	-	1.0 ± 0.6	0.3 ± 0.3	1.0 ± 0.6	-	-	-	-	-
Crinoid	0.7 ± 0.7	-	0.7 ± 0.7	0.7 ± 0.7	0.7 ± 0.7	-	-	0.7 ± 0.3	-	1.0 ± 0.6	-	0.7 ± 0.3	-
Gastropod	-	-	-	-	-	-	-	-	-	-	-	-	-
Gorgonian	0.3 ± 0.3	-	-	0.3 ± 0.3	-	-	-	-	1.0 ± 0.6	-	-	-	-
Hydroid	1.3 ± 1.3	1.0 ± 0.0	-	-	-	1.0 ± 0.0	-	0.3 ± 0.3	-	0.3 ± 0.3	-	0.3 ± 0.3	5.7 ± 3.2
Nudibranch	-	-	-	-	-	-	-	0.7 ± 0.3	-	-	-	-	-
Other soft coral (e.g. Alcyoniidae)	1.7 ± 1.2	0.7 ± 0.3	0.3 ± 0.3	-	-	1.0 ± 0.6	0.7 ± 0.3	1.3 ± 0.7	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	-
Sea cucumber	0.7 ± 0.3	-	-	-	-	1.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	-	-	0.3 ± 0.3	0.3 ± 0.3	-
Sea star	-	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3	-	-	1.0 ± 1.0	-	-	-
Sea urchin	-	-	-	0.3 ± 0.3	2.0 ± 2.0	-	-	1.3 ± 1.3	-	-	-	-	-
Sea whip	5.0 ± 2.1	4.0 ± 1.2	0.7 ± 0.7	5.3 ± 0.9	3.7 ± 1.5	6.3 ± 2.3	3.3 ± 0.3	0.7 ± 0.7	10.0 ± 1.0	9.3 ± 1.2	2.7 ± 1.5	5.0 ± 1.5	2.3 ± 1.9
Sponge barrel	0.3 ± 0.3	-	-	-	-	-	-	-	-	-	0.3 ± 0.3	-	-
Sponge branching/ arborescent	4.0 ± 1.5	0.3 ± 0.3	-	-	-	-	-	0.3 ± 0.3	0.7 ± 0.7	2.3 ± 1.5	1.0 ± 0.6	1.3 ± 0.3	0.7 ± 0.3
Sponge cup	-	0.3 ± 0.3	0.3 ± 0.3	-	-	0.3 ± 0.3	-	-	-	0.3 ± 0.3	-	-	-
Sponge digitate	-	-	-	-	-	1.0 ± 0.0	0.7 ± 0.7	0.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	-	0.3 ± 0.3	0.3 ± 0.3

Benthic Macro-invertebrate	TP6		TP5	TPCI1	TPCI2	LNGI1		LNGI2	DS1		DS2	TP2	
	Nov 08	Jul 09	Jul 09	Jan 09	Jan 09	Jan 09	Jul 09	Jan 09	Jan 09	Jul 09	Jan 09	Nov 08	Jul 09
Sponge fan / flabellate	1.3 ± 0.9	-	-	-	-	0.7 ± 0.7	0.3 ± 0.3	0.7 ± 0.3	1.0 ± 0.6	1.3 ± 0.9	-	0.7 ± 0.3	0.3 ± 0.3
Sponge globular	-	-	0.3 ± 0.3	-	-	-	-	0.3 ± 0.3	0.7 ± 0.7	-	1.3 ± 0.9	-	-
Sponge tubular	0.7 ± 0.7	-	-	1.0 ± 0.6	-	-	-	-	-	-	-	1.7 ± 0.9	-
Sponge variable	3.0 ± 1.2	1.0 ± 0.0	2.3 ± 0.7	0.7 ± 0.3	-	3.3 ± 0.9	-	10.7 ± 6.7	1.7 ± 0.9	1.0 ± 0.0	2.0 ± 0.6	3.0 ± 1.0	1.3 ± 0.9
Turbinaria	5.3 ± 1.7	0.3 ± 0.3	0.7 ± 0.3	-	-	0.7 ± 0.7	-	1.7 ± 0.9	1.7 ± 1.2	1.3 ± 0.3	1.3 ± 0.7	1.3 ± 0.7	0.7 ± 0.3
Unknown	0.7 ± 0.3	-	-	1.3 ± 0.3	-	0.3 ± 0.3	-	2.3 ± 1.9	-	-	-	0.7 ± 0.7	-

Note: '-' indicates zero invertebrates from that taxa were observed.

Table 7-3 Mean Benthic Macro-invertebrate Abundance ± SE per 30 m Transect (Approximately 15 m^2) at Sites and Sampling Occasions in the Zones of Influence

Benthic Macro-invertebrate	NE BWI 2	DI1	TP1	LC2		LC1	LC3	LC4		LNG R2	LNGR3		LNGR1		TP9	TP10	TPC 3	TPC 1	DSS1	
	Nov 08	Jul 09	Nov 08	Jan 09	Jul 09	Jan 09	Jan 09	Jan 09	Jul 09	Jan 09	Jan 09	Jul 09	Jan 09	Jul 09	Nov 08	Nov 08	Jan 09	Jan 09	Jan 09	Jul 09
Ascidian colonial	-	0.3 ± 0.3	0.3 ± 0.3	-	-	-	-	0.3 ± 0.3	-	-	4.0 ± 1.0	-	0.3 ± 0.3	-	7.3 ± 2.3	3.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.3	0.3 ± 0.3	4.0 ± 0.6
Ascidian solitary	0.3 ± 0.3	-	-	-	-	-	-	-	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	-	-	-	0.7 ± 0.7	1.7 ± 1.2	-	-	-	0.7 ± 0.7
Crinoid	1.0 ± 1.0	-	0.3 ± 0.3	-	0.3 ± 0.3	1.3 ± 0.9	-	2.0 ± 1.0	-	-	-	-	0.7 ± 0.7	1.3 ± 0.9	-	-	1.7 ± 1.2	0.7 ± 0.3	-	-
Gastropod	-	-	-	-	-	-	0.3 ± 0.3	0.3 ± 0.3	-	-	-	-	-	-	-	-	-	-	-	-
Gorgonian	0.3 ± 0.3	-	-	-	-	-	-	1.3 ± 0.3	-	0.3 ± 0.3	-	-	-	-	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3
Hydroid	-	-	0.3 ± 0.3	-	-	0.7 ± 0.3	-	-	-	-	-	-	-	-	1.0 ± 1.0	0.3 ± 0.3	-	-	1.3 ± 1.3	0.3 ± 0.3
Nudibranch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other soft coral (e.g. Alcyoniidae)	-	-	0.3 ± 0.3	-	-	0.3 ± 0.3	-	1.3 ± 0.7	0.3 ± 0.3	-	0.3 ± 0.3	-	-	-	1.0 ± 1.0	4.0 ± 0.6	1.0 ± 1.0	-	-	2.0 ± 0.6
Sea cucumber	-	0.3 ± 0.3	-	-	-	-	-	-	-	-	0.7 ± 0.7	0.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.3	-	0.3 ± 0.3	0.7 ± 0.3	-	-	0.7 ± 0.3
Sea star	0.3 ± 0.3	0.3 ± 0.3	-	-	-	-	-	-	-	-	-	-	-	1.3 ± 1.3	-	-	-	0.3 ± 0.3	-	-
Sea urchin	-	-	-	-	-	-	0.3 ± 0.3	6.0 ± 3.2	-	-	-	-	0.3 ± 0.3	-	-	-	-	-	-	-
Sea whip	0.7 ± 0.3	0.7 ± 0.7	-	-	-	8.3 ± 2.2	11.0 ± 2.0	3.3 ± 1.9	0.7 ± 0.3	3.7 ± 1.9	2.7 ± 0.7	1.7 ± 0.7	2.3 ± 1.9	0.7 ± 0.7	1.0 ± 0.6	3.0 ± 1.5	2.3 ± 0.3	3.0 ± 1.5	10.0 ± 2.5	12.3 ± 0.9

Benthic Macro-invertebrate	NE BWI 2	DI1	TP1	LC2		LC1	LC3	LC4		LNG R2	LNGR3		LNGR1		TP9	TP10	TPC 3	TPC 1	DSS1	
	Nov 08	Jul 09	Nov 08	Jan 09	Jul 09	Jan 09	Jan 09	Jan 09	Jul 09	Jan 09	Jan 09	Jul 09	Jan 09	Jul 09	Nov 08	Nov 08	Jan 09	Jan 09	Jan 09	Jul 09
Sponge barrel	-	0.3 ± 0.3	0.3 ± 0.3	-	-	-	-	-	-	-	-	-	-	-	1.7 ± 0.7	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	-	-
Sponge branching/ arborescent	0.3 ± 0.3	-	-	-	-	1.0 ± 0.6	-	1.0 ± 0.6	1.0 ± 0.6	1.3 ± 0.7	-	-	0.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	1.3 ± 0.9	2.3 ± 0.9	2.7 ± 1.5	2.3 ± 1.5	3.7 ± 0.3
Sponge cup	0.3 ± 0.3	-	-	-	-	-	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3	-	-	-	0.3 ± 0.3	-	-	1.0 ± 0.6	2.7 ± 0.3
Sponge digitate	-	-	-	-	-	-	-	-	-	0.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.3	-	-	-	0.7 ± 0.7	0.7 ± 0.3	0.7 ± 0.3	-	5.7 ± 2.6
Sponge fan / flabellate	2.0 ± 0.6	-	-	-	-	-	-	-	-	1.0 ± 1.0	0.7 ± 0.7	-	0.3 ± 0.3	-	-	1.0 ± 1.0	3.0 ± 0.6	1.3 ± 1.3	3.3 ± 0.9	10.7 ± 2.8
Sponge globular	0.3 ± 0.3	-	-	-	-	-	-	-	-	0.3 ± 0.3	-	-	-	0.3 ± 0.3	-	-	1.0 ± 1.0	-	-	-
Sponge tubular	0.3 ± 0.3	-	-	-	-	-	-	0.3 ± 0.3	-	-	-	-	-	-	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3
Sponge variable	3.3 ± 1.2	-	1.0 ± 0.6	0.3 ± 0.3	-	2.0 ± 1.5	0.3 ± 0.3	3.0 ± 1.5	-	1.7 ± 1.2	2.0 ± 1.0	-	1.7 ± 0.7	1.0 ± 0.6	0.3 ± 0.3	8.7 ± 5.2	4.3 ± 0.3	4.0 ± 1.2	4.3 ± 2.0	2.7 ± 1.2
Turbinaria	3.3 ± 2.3	1.0 ± 1.0	0.3 ± 0.3	-	-	1.0 ± 0.6	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	3.7 ± 2.0	1.0 ± 0.0	-	1.3 ± 0.3	-	1.7 ± 1.2	0.3 ± 0.3	0.7 ± 0.3	1.3 ± 0.9	1.0 ± 0.6	-
Unknown	-	-	-	-	-	1.0 ± 0.6	-	0.7 ± 0.3	-	0.3 ± 0.3	0.7 ± 0.7	-	0.3 ± 0.3	-	0.3 ± 0.3	0.7 ± 0.3	-	-	-	0.3 ± 0.3

Note: '-' indicates zero invertebrates from that taxa were observed.

Table 7-4 Mean Benthic Macro-invertebrate Abundance ± SE per 30 m Transect (Approximately 15 m²) at Reference Sites not at Risk of Material or Serious Environmental Harm

Benthic Macro-invertebrate	DSR3	DSR5		DSR6	DGI0	
	Jan 09	Jan 09	Jul 09	Jan 09	Jan 09	Jul 09
Ascidian colonial	-	-	-	1.7 ± 1.2	-	-
Ascidian solitary	-	-	-	-	-	-
Crinoid	0.7 ± 0.3	-	-	-	0.3 ± 0.3	-
Gastropod	-	-	-	-	-	-
Gorgonian	-	-	-	-	-	-
Hydroid	-	0.3 ± 0.3	-	2.3 ± 0.9	0.3 ± 0.3	-
Nudibranch	-	-	-	-	-	-
Other soft coral (e.g. Alcyoniidae)	-	-	1.3 ± 0.7	2.3 ± 1.5	1.3 ± 0.9	0.3 ± 0.3
Sea cucumber	-	1.0 ± 0.6	0.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.7	3.0 ± 1.7
Sea star	-	-	-	-	-	-
Sea urchin	-	0.7 ± 0.7	-	-	-	-
Sea whip	1.0 ± 1.0	3.0 ± 1.0	0.7 ± 0.3	-	0.7 ± 0.3	-
Sponge barrel	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3
Sponge branching/ arborescent	0.3 ± 0.3	1.3 ± 0.9	0.3 ± 0.3	-	4.3 ± 1.2	-
Sponge cup	-	-	-	-	-	-
Sponge digitate	-	-	-	-	2.7 ± 1.8	0.7 ± 0.7
Sponge fan / flabellate	0.3 ± 0.3	0.3 ± 0.3	1.3 ± 0.3	0.7 ± 0.7	-	1.7 ± 0.3
Sponge globular	-	-	-	0.3 ± 0.3	-	0.3 ± 0.3
Sponge tubular	-	-	-	-	-	0.3 ± 0.3
Sponge variable	-	3.0 ± 1.2	-	1.0 ± 1.0	4.7 ± 0.3	1.0 ± 0.0
Turbinaria	-	1.3 ± 0.3	1.0 ± 0.6	4.7 ± 1.3	1.0 ± 0.6	0.3 ± 0.3
Unknown	0.3 ± 0.3	0.7 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	1.3 ± 0.3	-

Note: '-' indicates zero invertebrates from that taxa were observed.

7.4.2.1 Soft Sediment Habitats

The benthic macro-invertebrate assemblages associated with soft sediment habitats were sparse in most areas, but were the dominant benthic biota in terms of commonality (proportion of sites at which these assemblages were present). The distribution and density of macro-invertebrates in soft sediment habitats is generally limited by the availability of hard substrates for attachment (Fromont 2004). The substrate of those areas mapped as 'Soft Sediment with Sparse Sessile Taxa' (Figure 7-2) comprised a sediment veneer of varying depths overlaying a hard limestone pavement. Rocks and outcrops of limestone pavement in these soft sediment habitats often serve as attachment points for sponges, sea whips and other macro-invertebrate taxa. The most abundant benthic macro-invertebrates on soft sediments were sea whips, sponges (predominantly variable sponges) and turbinaria(Table 7-5). Colonial ascidians were also observed in abundance in November 2008, but more sparsely in subsequent sampling periods.

The abundance of benthic macro-invertebrates determined from transect surveys in soft sediment was highly variable. The highest mean abundances were recorded at DSS1(23.7 ± 3.8/15 m^2 in spring/summer, which equates to ~1.6/m^2; and46.0 ± 2.0/15 m^2 in winter, which equates to ~3.0/m^2) south of the Dredge Spoil Disposal Ground and TP6 (27.3 ± 6.2/15 m^2 in spring/summer, which equates to ~1.8/m^2) adjacent to the MOF and LNG jetty (Figure 7-3). Sea whips were the most abundant taxa at these sites (mean abundances 10.0 ± 2.5/15 m^2 in spring/summer [~0.7/m^2], 12.3 ± 0.9/15 m^2 in winter [~0.8/m^2] and 5.0 ± 2.1/15 m^2 in spring/summer [~0.3/m^2], 4.0± 1.2/15 m^2 in winter [~0.3/m^2] respectively) (Table 7-3). The lowest abundance of benthic macro-invertebrates was recorded at LC2 (0.3 ± 0.3/15 m^2 in spring/summer [~0.02/m^2] and 0.3 ± 0.3/15 m^2 in winter [~0.02/m^2]) and DI1 (1.0 ± 0.0/15 m^2 in winter[~0.07/m^2]).

The highest mean abundance of any benthic macro-invertebrate taxa in soft sediments was 12.5 ± 1.5 sea whips/15 m^2 recorded in winter, which equates to ~0.8/m^2, at DSS1 (along two transects with sediment as the dominant substrate) (Table 7-3). Sea whips and fan/flabellate sponges were the only taxon recorded in abundances >10/15 m^2 (>0.7/m^2) in soft sediment habitats, with the greatest abundances recorded at LC3, DS1 and DSS1.

The highest diversity of benthic macro-invertebrate taxa in habitats dominated by soft sediment was recorded at TP6, TP2 (which had 14 and 13 taxa respectively in spring/summer), and DSS1, which had eight taxa in spring/summer and 14 in winter (Table 7-2; Table 7-3). The lowest diversity was recorded at LC2 in both spring/summer and winter, where one taxon was recorded (Table 7-3). Taxonomic diversity was generally higher in spring/summer than winter and in benthic macro-invertebrate assemblages in soft sediment habitats than on limestone pavements.

7.4.2.2 Limestone Pavement Habitats

Benthic macro-invertebrates were relatively common on the inshore limestone pavement areas growing in mixed assemblages with macroalgae and occasionally seagrass. The most abundant benthic macro-invertebrate associated with hard limestone pavement were ascidians, sea whips and variable sponges (Table 7-5). Macroalgae were generally the most common biota on shallow limestone pavements in Barrow Island waters.

The highest mean abundances of benthic macro-invertebrates on limestone pavements in spring/summer were recorded at TP10 on the inshore limestone pavement (29.5 ± 12.5/15 m^2 or ~2.0/m^2) and LNGI2 on the East Barrow Ridge (24.7 ± 13.3/15 m^2, or ~1.6/$m^{2`}$), and in winter at DSS1 (47.0/15 m^2, or ~3.1/m^2), and TP2 (19.3 ± 11.5/15 m^2 or ~1.3/m^2) adjacent to the dredge spoil disposal ground, and on the inshore limestone pavement respectively (Figure 7-3). Variable sponges were the most abundant benthic macro-invertebrates in spring/summer at TP10 (8.7 ± 5.2/15 m^2 or ~0.6/m^2) and LNGI2 (10.7 ± 6.7/15 m^2 ~0.7/m^2), sea whips at DSS1 in winter (12.3 ± 0.9/15 m^2 or ~0.8/m^2), and ascidians at TP2 in winter (8.0 ± 5.6/15 m^2 or ~0.5/m^2) (Table 7-2; Table 7-3). The lowest abundance of benthic macro-invertebrates was recorded in winter at LNGR3 and TP5 (3.0 ± 0.6/15 m^2 [~0.2/m^2] and 5.3 ± 0.9/15 m^2 [~0.4/m^2], respectively).

The highest mean abundance of any benthic macro-invertebrate taxa on habitat dominated by limestone pavement was 10.7 ± 6.7 variable sponges/15 m^2 (~0.7/m^2) recorded at LNGI2 in spring/summer (Table 7-3). This was also the only occurrence of taxa recorded in abundances >10/15 m^2 (>0.7/m^2) on limestone pavement dominated sites.

The highest diversity of benthic macro-invertebrate taxa on limestone pavements was recorded at LNGI2, which had 16 taxa in spring/summer; and the lowest at LNGR3 where four taxa were recorded in winter (Table 7-2; Table 7-3).

Table 7-5 Percentage Contribution of the Macro-invertebrate Taxa (Total Number) to the Total Number of Macro-invertebrate Individuals found on Limestone Pavement and Soft Sediment in November 2008, January 2009 and July 2009 sampling periods

Macro-invertebrate Taxa	Limestone Pavement			Soft Sediment		
	Nov 08 (3)	Jan 09 (10)	Jul 09 (17)	Nov 08 (21)	Jan 09 (44)	Jul 09 (22)
Ascidian clonial	7.4	5.9	16.8	19.3	1.2	4.3
Ascidian solitary	5.3	2.0	1.3	1.1	0.1	0.4
Crinoid	-	0.6	0.9	3.0	3.5	3.1
Gastropod	-	-	-	-	0.3	-
Gorgonian	-	-	0.4	0.7	1.3	-
Hydroid	1.1	2.5	9.1	3.3	1.3	0.4
Nudibranch	-	0.6	-	-	-	-
Other soft coral (e.g. Alcyoniidae)	9.6	4.2	3.4	5.6	1.9	3.9
Sea cucumber	1.1	2.5	1.3	1.1	1.3	5.4
Sea star	-	-	0.4	0.4	0.3	3.1
Sea urchin	-	1.1	-	-	3.9	-
Sea whip	6.4	5.3	21.6	14.1	29.7	23.0
Sponge barrel	1.1	0.3	0.4	2.6	0.4	0.4
Sponge branching/ arborescent	3.2	0.3	3.0	7.8	7.5	7.4
Sponge cup	2.1	-	2.2	-	0.7	2.7
Sponge digitate	-	1.1	6.5	1.1	2.0	4.7
Sponge fan / flabellate	6.4	1.1	3.0	3.3	4.8	15.6
Sponge globular	1.1	0.3	0.4	-	1.5	0.8
Sponge tubular	1.1	-	-	2.6	0.7	0.8
Sponge variable	28.7	12.0	6.5	11.5	14.7	6.2
Turbinaria	2.1	5.6	3.4	13.0	6.6	3.5
Unknown	1.1	2.5	-	2.2	2.7	0.8

Note: '-' indicates zero invertebrates from that taxa were observed. Numbers in parentheses next to dates indicate the number of transects surveyed.

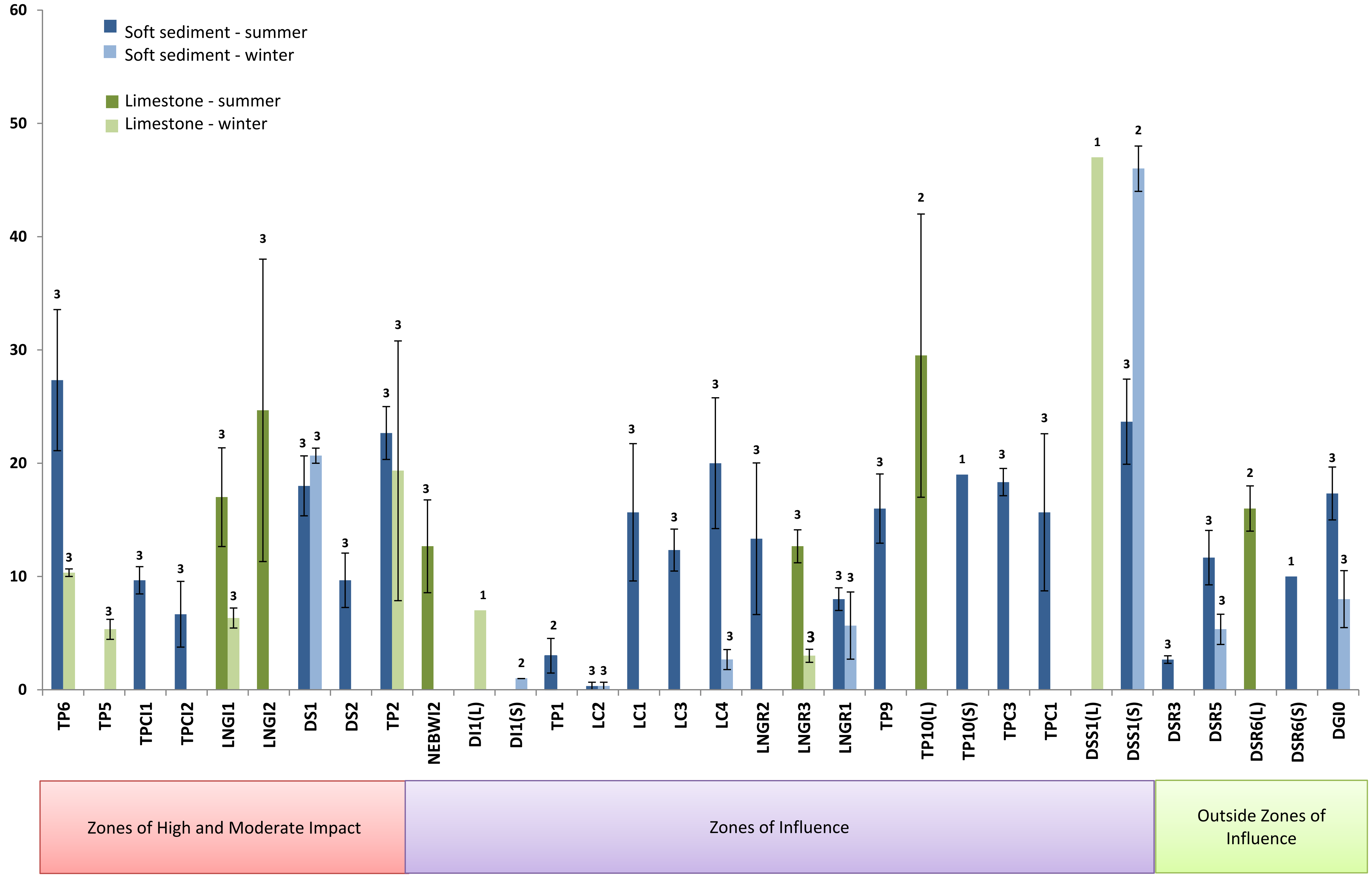


Figure 7-3 Mean Total Number of Sessile Benthic Macro-invertebrates Recorded ± SE per 30 m Transect (approx. 15 m²) at all Survey Sites

Notes:

1. Numbers above error bars indicate the number of transects at the site.

2. Sites with transects falling on both soft sediment and limestone have been separated by habitat type and are further identified by L (limestone) and S (soft sediment) after the site name.

7.4.3 Description of Benthic Macro-invertebrate Assemblages within the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

7.4.3.1 Benthic Macro-invertebrate Assemblages at Sites in the Vicinity of the MOF and Causeway and the LNG Jetty Access Channel

The area of seabed within the Zone of High Impact and the Zone of Moderate Impact associated with the generation of turbidity and sediment deposition from dredging for the construction of the MOF and LNG Jetty encompassed two major substrate types: an extensive area of soft sediments in the deep water east of Barrow Island and a shallow inshore limestone pavement area. These different substrates supported distinct suites of benthic macro-invertebrates.

Sea whips and sponges of various morphologies were the most abundant benthic macro-invertebrates in the soft sediment habitats (TPCI1 and TPCI2; Table 7-2). A mixed assemblage of ascidians, hydroids, sea whips, *Turbinaria* and sponges of various morphologies was recorded on the inshore limestone pavement (TP2, TP5, and TP6; Table 7-2); however, macroalgae were the most common biota on this pavement (Figure 7-2). The most abundant benthic macro-invertebrates recorded on the East Barrow Ridge offshore limestone pavement were sea whips, with *Turbinaria*, sponges of various morphologies, ascidians, and soft corals also common in lower numbers (LNGI1 and LNGI2; Table 7-2).

7.4.3.2 Benthic Macro-invertebrate Assemblages at Sites in the Vicinity of the Dredge Spoil Disposal Ground

The Dredge Spoil Disposal Ground is located on a relatively deep (~16 m), predominantly sandy seabed supporting a sparsely distributed benthic macro-invertebrate assemblage (Figure 7-2). The most common benthic macro-invertebrates in this area were sea whips and sponges of various morphologies (DS1 and DS2; Table 7-2).

7.4.4 Description of Benthic Macro-invertebrate Assemblages at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

The area at risk of Material or Serious Environmental Harm (Section 2.3.4) at WAPET Landing is a limestone pavement covered with a sand veneer of varying depth. This pavement was characterised by a cover of predominantly macroalgae (Figure 7-2), but occasional sponges of branching, cup and digitate morphologies were recorded (RPS Bowman Bishaw Gorham 2006). Large *Xestospongia* sp. were present in low numbers. All benthic macro-invertebrate taxa recorded within the area of WAPET Landing are well represented elsewhere in the Barrow Island region.

7.4.5 Description of Benthic Macro-invertebrate Assemblages at Representative Areas of the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

7.4.5.1 Sites in Representative Areas of the Zone of Influence on the Inshore Limestone Pavement

Sites surveyed on the inshore limestone pavement included areas to the north and south of the MOF. Surveys at sites to the north of the MOF (TP1; Table 7-3) recorded a sparse assemblage of sponges of various morphologies, ascidians, hydroids, and *Turbinaria*. The low numbers of macro-invertebrates at this site may be due to the thick sediment veneer covering the limestone pavement (~30 cm), limiting the potential attachment sites for benthic macro-invertebrates. The most abundant macro-invertebrates at the site at Double Island (DI1) were sea whips and *Turbinaria*, also in relatively low numbers.

Benthic macro-invertebrates were more abundant at sites to the south of the MOF (TP9 and TP10; Table 7-3) where ascidians and sponges of various morphologies were the most abundant taxa, with lower abundances of hydroids, sea whips, and *Turbinaria*. TP10 was one of the few sites on the inshore limestone pavement where soft corals from the Alcyoniidae family were recorded.

7.4.5.2 Sites in Representative Areas of the Zone of Influence in the Sandy Channel East of the Inshore Limestone Pavement

The sites in the sandy channel between the inshore limestone pavement and the East Barrow Ridge generally had a higher number and diversity of benthic macro-invertebrates than sites within the Zones of High and Moderate Impact. LC2, to the north of the Zone of High Impact and Zone of Moderate Impact was the exception, with very low abundances and diversities of benthic macro-invertebrates recorded. Sea whips were the most abundant benthic macro-invertebrate at these sites, in particular LC1 and LC3 (Table 7-3). Sponges of various morphologies were also present at these sites, but in lower numbers.

7.4.5.3 Sites in Representative Areas of the Zone of Influence on the East Barrow Ridge

The benthic macro-invertebrate assemblages at the sites on the East Barrow Ridge were similar to those present within the Zones of High and Moderate Impact in the same habitat. Sea whips were the most abundant benthic macro-invertebrates recorded at LNGR1 and LNGR2, with ascidians more abundant at LNGR3 (Table 7-3). Sponges and *Turbinaria* were also common in low numbers at all three sites.

7.4.5.4 Sites in Representative Areas of the Zone of Influence on the Lowendal Shelf

The site to the north-east of Barrow Island was characterised by sponges of various morphologies that were relatively abundant at this site (NEBWI2; Table 7-3).

7.4.5.5 Sites in Representative Areas of the Zone of Influence Associated with the Dredge Spoil Disposal Ground

DSS1, located to the south of the Dredge Spoil Disposal Ground in the Zone of Influence, supported the greatest abundance and diversity of soft sediment habitat benthic macro-invertebrates (Table 7-3;Figure 7-3). Relatively high numbers of sea whips and sponges of various morphologies were recorded at this site.

7.4.6 Description of Benthic Macro-invertebrate Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

7.4.6.1 Reference Sites in the Deep Soft Sediments east of the East Barrow Ridge

The Reference Sites in the deep soft sediments east of the East Barrow Ridge were generally comparable to the sites on the same substrate within the Dredge Spoil Disposal Ground (Table 7-4; Figure 7-3). The benthic macro-invertebrate assemblages at these sites were sparse; sea whips and sponges of various morphologies were common across these sites, but occurred in low numbers.

7.5 Discussion

Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed, physical removal of the substrate through dredging, or smothering and burial in the Dredge Spoil Disposal Ground, is predicted to affect benthic macro-invertebrates within the Marine Facilities Footprint, the Dredge Spoil Disposal Ground and in some areas of the Marine Disturbance Footprint within the Zones of High and Moderate Impact. The areas at risk of Material Environmental Harm, caused by elevated turbidity from the dredge plume and anchoring damage, include the Zones of Moderate Impact and those areas within the Zones of High Impact that are not within the Marine Facilities Footprint or the Dredge Spoil Disposal Ground.

The Causeway footprint lies across the limestone pavement adjacent to Barrow Island; extending from the beach cliffs at Town Point, across the intertidal reef platform adjacent to the shore, out to approximately 7 m water depth at the Materials Offloading Facility (MOF) (Figure 2-1). The intertidal zone is approximately 200 m wide and characterised by mixed turfing algae, with larger macroalgae and sparse seagrass in rock pools. The subtidal platform reef was covered with around 70% macroalgae with sparse sessile taxa. Scattered bomboras (generally <2 m in diameter) were present amongst the macroalgal beds in shallow water (0-8 m). Bomboras in the nearshore areas of the platform were generally dominated by macroalgae and benthic macro-invertebrates, whereas bomboras on the offshore edge of the platform generally supported more live coral. Patches of unvegetated limestone pavement in the vicinity of the Causeway footprint supported mixed benthic macro-invertebrate assemblages, including ascidians, hydroids, sea whips, small isolated hard corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges.

The MOF footprint lies on the deeper subtidal area of the platform adjacent to the east coast of Barrow Island. The dominant ecological element in the area was macroalgae, with subdominant levels of cover of other sparse sessile taxa. The benthic macro-invertebrate assemblages present were typical of the platform and similar to those in the vicinity of the Causeway footprint, comprising ascidians, hydroids, sea whips, scattered small hard corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges.

The LNG Jetty footprint extends across the outer part of the limestone platform adjacent to Barrow Island for 500 m past the end of the MOF and then continues for a further 1200 m across the soft sediment assemblages in deeper water. The outer part of the reef platform within the footprint of the LNG Jetty was dominated by macroalgal assemblages with sparse sessile taxa, similar to those within the MOF footprint. Benthic macro-invertebrate assemblages included ascidians, hydroids, sea whips, scattered small corals (e.g. *Turbinaria* sp., *Montipora* sp.) and sponges. The majority of the LNG Jetty footprint overlies habitat categorised as 'Soft Sediments with Sparse Sessile Taxa', including benthic macro-invertebrates. Sea whips and sponges were the most abundant of the benthic macro-invertebrates on the sandy substrate in this area.

The Turning Basin footprint lies in 8–11 m of water over limestone pavement with a sand veneer. The dominant benthic category comprised soft sediment (unvegetated sand) with sparse sessile taxa at subdominant levels of cover, including benthic macro-invertebrates. Sea whips and sponges were the most abundant of the benthic macro-invertebrates in this area. The LNGJetty Access Channel footprint overlies a small section of the East Barrow Ridge (a raised limestone platform in approximately 7 m water depth) and the soft sediment habitats either side of the ridge. The area on East Barrow Ridge within the LNG Jetty Access Channel footprint was characterised by areas mapped as 'Macroalgae with Sparse Sessile Taxa', including patches of sediment (largely unvegetated bare sand), with subdominant levels of cover of benthic macro-invertebrates. The benthic macro-invertebrate assemblages present on the ridge were characterised by sea whips, small hard corals (*Turbinaria* sp.), sponges, ascidians, and soft corals.

The Dredge Spoil Disposal Ground footprint lies within an area mapped as 'Soft Sediments with Sparse Sessile Taxa', including benthic macro-invertebrate assemblages in areas where the underlying pavement was exposed, or the sand veneer was shallow. These soft sediments supported benthic macro-invertebrate assemblages characterised by sponges, sea whips, and scattered gorgonians.

The patchy distribution of benthic macro-invertebrates, makes it difficult to estimate the total area of benthic macro-invertebrates that will be impacted as a consequence of the construction of the Marine Facilities at Town Point. The construction of the Marine Facilities on the east coast of Barrow Island will result in the loss of approximately 35.5 ha (0.2%) within the Marine Facilities Footprint, of the total area of 'Macroalgae with Sparse Sessile Taxa' (~16 500 ha) in the Management Units on the east coast of Barrow Island.[3] The Marine Disturbance Footprint

[3] Fourteen Management Units were defined to assess impacts to benthic primary producer habitats associated with the Gorgon Gas Development, 11 on Barrow Island and three on the mainland (Section 11.4, Chevron Australia 2005; Section 8.8, Chevron Australia 2006).

associated with the construction of the Marine Facilities will potentially impact on up to approximately 285 ha (1.7%) of the area of 'Macroalgae with Sparse Sessile Taxa'. The Marine Facilities Footprint will result in the loss of approximately 4.6 ha (0.02%) and the Marine Disturbance Footprint will potentially impact on up to approximately 441 ha (2%), of the total area of 'Soft Sediments with Sparse Sessile Taxa' (~22 400 ha).

7.6 Conclusions

Benthic macro-invertebrates were generally sparsely distributed and relatively homogenous across broad areas of similar substratum. Distinct assemblages were observed on the different substrate types (sand or soft sediment and limestone pavement). Benthic macro-invertebrates often occurred with macroalgae, and the only areas where benthic macro-invertebrates were the most common or abundant benthic biota were in the deeper (>10 m) sand habitats, even though they were generally in lower abundances than on limestone pavements.

There was no indication of marked differences in the mean abundance or diversity of benthic macro-invertebrates at sites in the Zones of High and Moderate Impact compared to sites in the Zones of Influence or at Reference Sites outside the Zones of Influence. Benthic macro-invertebrate taxa recorded at sites in the Zones of High and Moderate Impact were also recorded at sites within the Zones of Influence and at Reference Sites, including: Alyconiidae, ascidians, a variety of different morphological types of sponges, gorgonians, hydroids, sea whips and *Turbinaria*. All benthic macro-invertebrate taxa at risk of Serious or Material Environmental Harm were well represented elsewhere.

8.0 Macroalgae

8.1 Introduction

The macroalgal flora of tropical northern Australia are relatively poorly known compared to temperate regions and there have been few systematic collections undertaken to date (Huisman and Borowitzka 2003) A marine flora checklist for the Dampier Archipelago has recently been published, listing some 210 species (Huisman and Borowitzka 2003). This includes 114 species of red algae (Rhodophyta), 50 species of green algae (Chlorophyta), 32 species of brown algae (Heterokontophyta, Phaeophyceae) and five species of blue-green algae (Cyanophyta). Fifty-seven species were new records for Western Australia and five were new records for Australia.

Macroalgal-dominated limestone reef and subtidal reef platform/sand mosaic are the most extensive habitat types in the Montebello/Barrow Islands region (DEC 2007). The extensive subtidal macroalgae communities are major benthic primary producers, significantly contributing to the productivity of the region, as well as providing refuge areas for fish and invertebrates (DEC 2007). These communities are most commonly found on shallow limestone pavement in depths of 5 to 10 m (DEC 2007). Macroalgal habitats in the Montebello/Barrow Islands region vary seasonally in response to water temperature, day length, reproductive cycles, physical disturbance and regrowth (DEC 2007).

The macroalgal assemblages are typically dominated by species of brown algae, particularly of the genera *Sargassum*, *Turbinaria* and *Padina* (Chevron Australia 2005; DEC 2007). Other common taxa include *Halimeda*, *Dictyopteris*, *Dictyota*, *Cystoseira*, *Codium* and *Laurencia*. Green algae from the genera *Caulerpa* and *Cladophora* and red algae from the genera *Centroceras*, *Ceramium*, *Champia*, *Chondria*, *Gelidiopsis*, and *Hypnea* are dominant or widespread off the east coast of Barrow Island (Chevron Australia 2005; DEC 2007; RPS Bowman Bishaw Gorham 2007). Some species, such as *Avrainvillea* sp. and *Halimeda macroloba*, appear to be restricted to the east coast of Barrow Island (Chevron Australia 2005). One species; *Gracilaria urvillei* is known only from Barrow Island (Chevron Australia 2005).

8.2 Scope

This Section records the dominant species of macroalgae (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the macroalgae:

- within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

8.3 Methods

8.3.1 Site Locations

A total of 20 macroalgal survey sites were selected within those areas where macroalgae were identified as being present through broadscale benthic habitat mapping (Section 5.1). Six sites were located within the Zones of High Impact, one of which was located within the Zone of High Impact at the Dredge Spoil Disposal Ground (Table 8-1; Figure 8-1). Two sites were located in the Zone of Moderate Impact. Three sites (TP5, LNGI1 and DS1) were in the area at Risk of Serious Environmental Harm (Section 2.3.4) and five (TP2, TP4, TP6, TP7 and LNGI2) were within the area at Risk of Material Environmental Harm (Figure 2-5), with all but two of these sites (TP2 and DS1) within the Marine Disturbance Footprint (Figure 2-3).

Eleven sites were located within the Zones of Influence, including one adjacent to the Dredge Spoil Disposal Ground (Table 8-1; Figure 8-1). These sites are considered to be Reference Sites because, although located within the Zones of Influence, turbidity and sediment deposition are not expected to impact on macroalgae and no Material or Serious Environmental Harm is expected to affect these sites (see Section 2.3.4). These sites will only be used as Reference Sites in any future analyses if it is determined through the Dredging and Spoil Disposal Monitoring Program that they have not been impacted by dredging and spoil disposal activities. One site was located outside the Zones of Influence at Biggada Reef on the west coast of Barrow Island.

In addition, surveys were undertaken at the WAPET Landing (RPS Bowman Bishaw Gorham 2006; RPS 2009a).

Table 8-1 Macroalgal Survey Sites and Dates

Location	Site Code	Easting	Northing	Latitude	Longitude	Survey Date		
		(GDA94, MGA Zone 50)		(GDA94)		Nov 2008	Jan 2009	Jul 2009
Zones of High Impact	TP5	342085	7699098	20° 48.079' S	115° 28.961' E	X		X
	TP6	342238	7699286	20° 47.978' S	115° 29.050' E			X
	TP7	344321	7696403	20° 49.551' S	115° 30.235' E	X		
	LNGI1	344397	7696825	20° 49.323' S	115° 30.281' E		X	X
	LNGI2	344879	7696121	20° 49.707' S	115° 30.555' E		X	
	DS1	348019	7691926	20° 51.996' S	115° 32.343' E		X	X
Zones of Moderate Impact	TP2	342235	7700923	20° 47.091' S	115° 29.057' E	X		X
	TP4	342407	7698457	20° 48.428' S	115° 29.143' E	X		X
Zones of Influence	NEBWI1	343959	7716235	20° 38.801' S	115° 30.132' E	X		
	DI1	342869	7706775	20° 43.922' S	115° 29.454' E			X
	LC1	344931	7700025	20° 47.591' S	115° 30.606' E		X	
	LC4	344832	7698996	20° 48.148' S	115° 30.543' E		X	X

Location	Site Code	Easting	Northing	Latitude	Longitude	Survey Date		
		(GDA94, MGA Zone 50)		(GDA94)		Nov 2008	Jan 2009	Jul 2009
	LNGR2	345444	7697787	20° 48.807' S	115° 30.890' E		X	
	LNGR3	343604	7694856	20° 50.386' S	115° 29.813' E		X	X
	TP9	341069	7695738	20° 49.895' S	115° 28.357' E	X		X
	TP10	337827	7694122	20° 50.754' S	115° 26.479' E	X		
	TPC1	342628	7694475	20° 50.587' S	115° 29.249' E		X	
	TPC3	342101	7694972	20° 50.315' S	115° 28.947' E		X	
	DSS1	347316	7687119	20° 54.598' S	115° 31.913' E		X	X
Reference Sites	BR	329234	7705071	20° 44.774' S	115° 21.589' E	X		X

Note: The location of BR was adjusted between the November 2008 and July 2009 surveys because of issues associated with safe access to the site.

Note that some macroalgal survey sites were also seagrass and non-coral benthic macro-invertebrate survey sites where these ecological elements co-occurred in the same area.

8.3.2 Methods

At each site, three 30 m length transects were laid out from a central clump weight (RPS 2009). The first transect was orientated parallel to the anchor line and the two others at approximately 90° to the first. The coordinates of the start point of each transect was recorded using GPS.

Seven 1 m^2 photo-quadrats were positioned at 5 m intervals along the right side of each transect. In the July 2009 survey, each 1 m^2 photo-quadrat was comprised of four sub-quadrats of 0.25 m^2, which were individually photographed to improve image quality and thus increase the precision of percentage cover measurements. In addition, the macroalgae present in the quadrat (or sub-quadrat) were recorded and the percentage cover was estimated in situ by divers (November 2008 and January 2009 only). The macroalgae species present in each quadrat (or sub-quadrat) were identified to the lowest reliable taxonomic level (to genus and species level where possible). Variability in species richness and percentage cover within and among transects was estimated based on the preliminary field data collected in November 2008, to confirm that the proposed sampling design would adequately account for natural variability at these spatial scales.

Voucher samples of those species that could not be reliably identified in the field were collected, preserved and catalogued for identification by Dr John Huisman (Murdoch University, Western Australia).

In the November 2008 and January 2009 surveys, the macroalgae in two 0.25 m^2 quadrats along each transect were collected for total biomass measurement (i.e. a total of six samples per site). A quadrat was located at 10 m and 20 m intervals along the left side of each transect. In the July 2009 survey, the macroalgae in two 0.25 m^2 quadrats were collected from each of the 10 m and 20 m intervals (i.e. a total of 12 samples per site). If the quadrat was on bare sand, no biomass sample was collected. Samples were blot-dried and total wet-weight recorded.

Qualitative surveys were undertaken at WAPET Landing to record the most common macroalgae species, including photographing of 0.25 m^2 quadrats placed on the seabed. Note that the digital images were not suitable for CPCe analysis and measures of percentage cover were based on visual estimates.

8.3.3 Timing and Frequency of Sampling

Sampling was undertaken in late spring and summer (November 2008 and January 2009; Table 8-1) during the period of peak macroalgal growth and biomass. Sampling at a subset of 10 sites surveyed in November 2008 and January 2009, as well as at two additional sites, was repeated in winter (July 2009). The sites sampled in July 2009 were selected on the basis of their proximity to the proposed Marine Facilities and to include a number of sites in the different Dredge Management Areas.

Surveys at WAPET Landing were undertaken in July–August 2006 and June 2009 (Bowman Bishaw Gorham 2006; RPS 2009a).

8.3.4 Treatment of Survey Data

Digital images were analysed using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006). Thirty random points were overlain over the image and each point visually classified into the broad categories of benthic cover (macroalgae, seagrass, coral, non-coral benthic macro-invertebrates, sand, pavement, rubble and unidentified). Estimates of the percentage cover of macroalgae were then calculated.

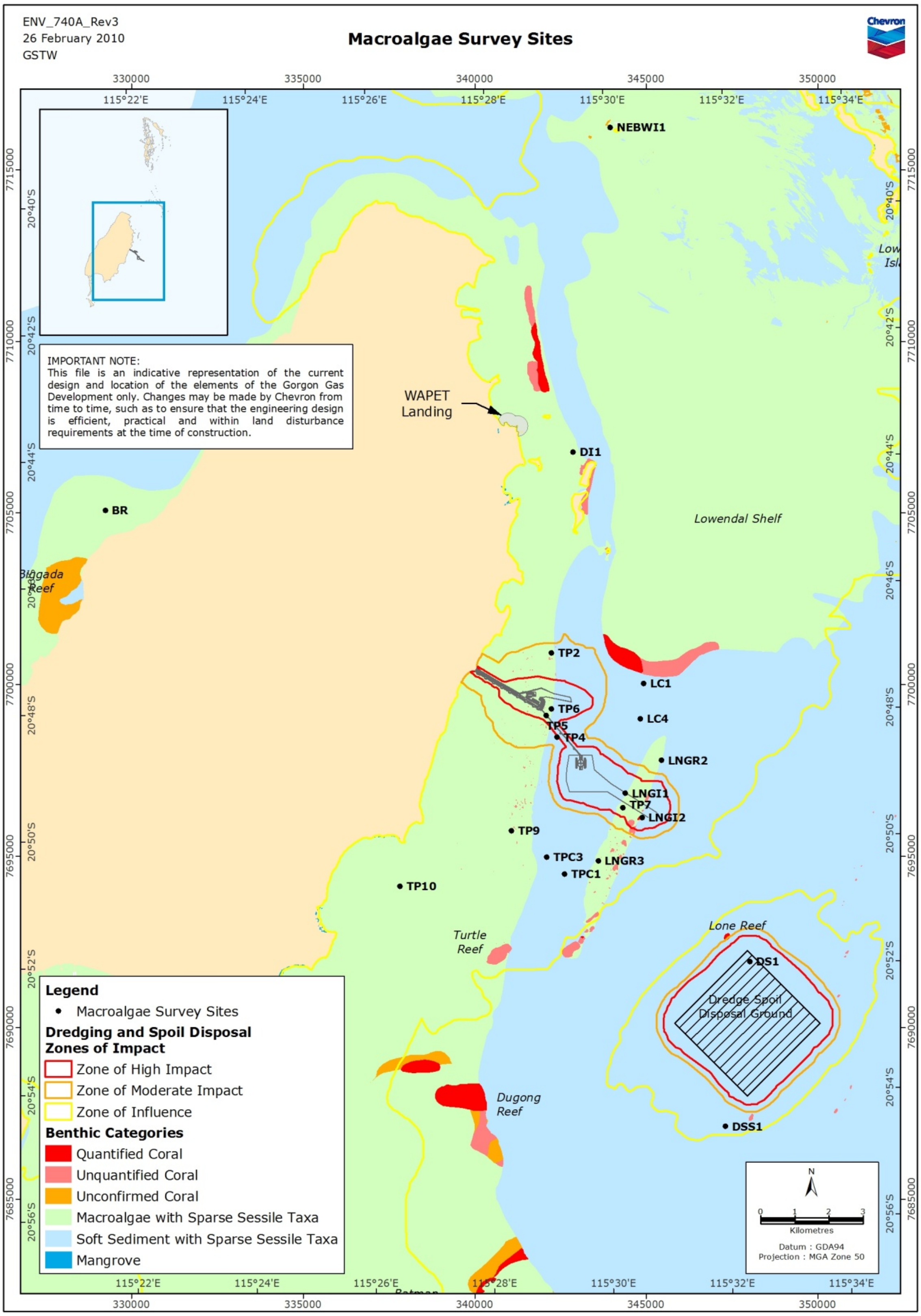


Figure 8-1 Macroalgal Survey Sites

8.4 Results

8.4.1 Macroalgae in Barrow Island Waters

Different survey techniques were used for the various components of the Marine Baseline Program, including broadscale mapping (Section 5.1) and small-scale quantitative sampling. These all contributed to the systematic compilation of the macroalgae reported in Barrow Island waters. Ninety-one species of macroalgae were identified in Barrow Island waters during the Marine Baseline Program (Table 8-2), including 35 species of red algae (Rhodophyta), 27 species of brown algae (Phaeophyta), 28 species of green algae (Chlorophyta) and one blue-green species (Cyanophyta). Many of these species were epiphytic on macroalgae. Refer to Appendix 4 for the full list of macroalgae species recorded at each site.

Table 8-2 Macroalgae Species Identified in the Waters around Barrow Island

Rhodophyta	Phaeophyta	Chlorophyta	Cyanophyta
Acrochaetium sp.	*Sirophysalis trinodis*	*Avrainvillea obscura*	*Calothrix* sp.
Aglaothamnion cordatum	*Dictyopteris australis*	*Bornetella oligospora*	
Amphiroa fragilissima	*Dictyopteris serrata*	*Caulerpa brachypus*	
Anotrichium tenue	*Dictyopteris* sp.	*Caulerpa cactoides*	
Asparagopsis taxiformis	*Dictyopteris woodwardii*	*Caulerpa corynephora*	
Centroceras clavulatum	*Dictyota* sp.	*Caulerpa cupressoides*	
Champia parvula	*Encyothalia cliftoni*	*Caulerpa cupressoides* var. *mamillosa*	
Champia sp.	*Feldmannia* sp.	*Caulerpa lentillifera*	
Chondria sp.	*Hincksia mitchelliae*	*Caulerpa racemosa* var. *lamourouxii*	
Chondrophycus sp.	*Hormophysa cuneiformis*	*Caulerpa serrulata*	
Coelarthrum cliftonii	*Hydroclathrus clathratus*	*Cualerpa* sp.	
Coelothrix irregularis	*Lobophora variegata*	*Cladophora catenata*	
Cottoniella filamentosa	*Padina australis*	*Cladophora vagabunda*	
Crustose coralline algae sp.	*Padina boryana*	*Codium dwarkense*	
Dasya sp.	*Padina* sp.	*Halimeda cuneata*	
Desikacharyella indica	Phaeophyceae sp. (turf)	*Halimeda discoidea*	
Galaxaura rugosa	*Sargassum carpophyllum*	*Halimeda* cf. *cuneata*	
Galaxaura sp.	*Sargassopsis decurrens*	*Halimeda* cf. *discoidea*	
Gayliella flaccida	*Sargassum oligocystum*	*Halimeda lacunalis*	
Griffithsia sp.	*Sargassum peronii*	*Halimeda macroloba*	
Haliptilon roseum	*Sargassum* sp.	*Halimeda* sp.	
Herposiphonia secunda	*Sargassum* sp. 1	*Penicillus nodulosus*	
Heterosiphonia callithamnion	*Sargassum* sp. 2	*Penicillus* sp.	
Heterosiphonia crassipes	*Sargassum* sp. 3	*Udotea argentea*	
Hypnea pannosa	*Spatoglossum macrodontum*	*Udotea flabellum*	
Jania rosea	*Sphacelaria rigidula*	*Udotea glaucescens*	
Jania sp.	*Sporochnus comosus*	*Udotea orientalis*	
Laurencia sp.		*Udotea* sp.	
Leveillea jungermannoides			
Lophocladia sp.			
Placophora binderi			
Platysiphonia delicata			
Polysiphonia sp.			
Spyridia filamentosa			
Tolypiocladia glomerulata			

Dictyopteris sp.

Padina sp.

Sargassopsis decurrens

Halimeda cf. *cuneata*

Caulerpa corynephora

Caulerpa cupressoides

Plate 8-1 Brown and Green Macroalgae Found in Waters around Barrow Island

8.4.2 Dominant and Subdominant Macroalgae

The dominant (or most common) macroalgae in terms of percentage cover recorded in Barrow Island waters were the brown algae and green algae.

The dominant brown algae were *Dictyopteris* spp., including *D. australis*, *D. serrata* and *D. woodwardii*; *Padina* spp., including *P. australis*, *P. boryana* and an unidentified *Padina* sp.; *Sargassopsis decurrens*; and *Sargassum* spp., including *S. oligocystum*, as well as two unidentified *Sargassum* species (*Sargassum* sp.1 and *Sargassum* sp.2) (Plate 8-1). The dominant green algae were *Halimeda* cf. *cuneata*, *Caulerpa corynephora* and *Caulerpa cupressoides* (Plate 8-1). The red algae were numerically dominant but, due to their generally small growth morphology and epiphytic habit, occupied a smaller percentage of the substratum than the other algal divisions.

The less abundant species by percentage cover and occurrence were the brown alga *Encyothalia cliftoni* and the green alga *Udotea argentea*.

8.4.3 Distribution of Macroalgae in Barrow Island Waters

Figure 8-2 shows the spatial distribution of macroalgae in Barrow Island waters as point (presence/absence) observations derived from broadscale mapping and ground-truthing (towed video camera surveys, spot dives and transect surveys). 'Null observations' were recorded where macroalgae were not observed during ground-truthing.

Macroalgal assemblages were commonly recorded on limestone pavement in depths of 5–10 m and were the most common ecological element along the shallow shelf off the east coast of Barrow Island and on the East Barrow Ridge. Macroalgae often co-occurred in lower abundance with seagrass and non-coral benthic macro-invertebrates. Macroalgal assemblages were also common across the shallow limestone pavement of the Southern Lowendal Shelf that extends north towards the Montebello Islands. Mixed coral communities were observed on the Shelf, with sparse macroalgae and seagrass and, to a lesser extent, non-coral benthic macro-invertebrates.

Macroalgae were not common on soft sediments and sparse percentage covers were recorded on substrates comprising a thick sand veneer over limestone pavement and on sand. There were little-to-no macroalgae in the deeper sand area between the broad, shallow limestone platform adjacent to the east coast of Barrow Island and the East Barrow Ridge.

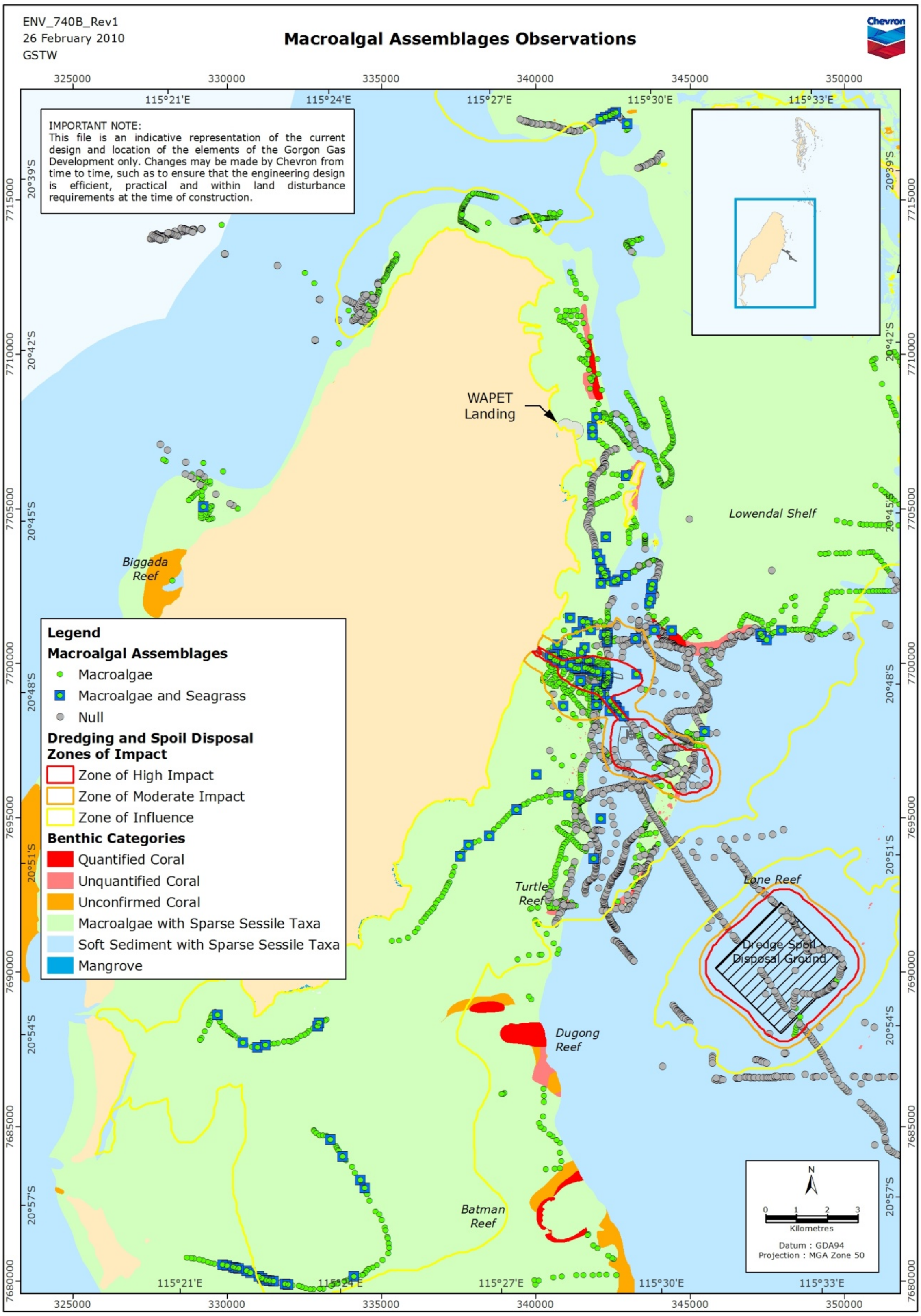


Figure 8-2 Observations of Macroalgal Assemblages in the Waters around Barrow Island

8.4.4 Description of Macroalgal Assemblages within the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

8.4.4.1 Macroalgal Assemblages at Sites in the Vicinity of the MOF and Causeway and the LNG Jetty Access Channel

Mean macroalgal percentage cover at the sites on the limestone pavement adjacent to Town Point (TP2, TP5, TP6) and the East Barrow Ridge (TP7, LNGI1) varied between ~5–26% in spring/summer and ~5–23% in winter (Table 8-3). Mean macroalgal spring/summer biomass varied between ~500 and 700 g wet weight/m^2 at TP5, TP7 and LNGI1, at which there were between three and eight dominant species recorded. Mean biomass was lower in winter, varying from ~115–480 g wet weight/m^2 at TP2, TP5, TP6 and LNGI1, at which there were between four and eight dominant species recorded. The greatest decline in estimates of biomass between spring/summer and winter was recorded at TP5 (~287 g); however, estimates of percentage cover declined by no greater than 3% across sites. An increase in the estimate of percentage cover was recorded at TP2 only.. *Padina australis/P. boryana* and *Sargassum oligocystum* were the most abundant species recorded at TP5 in spring/summer (diver visual estimate ~15% and ~10% cover respectively); and *Dictyopteris australis* was the only species recorded at TP2 in spring/summer (diver visual estimate ~10% cover). *Hormophysa cuneiformis* and *Sargassopsis decurrens* (diver visual estimate ~10% cover) were the most abundant species in spring/summer at the two sites on the East Barrow Ridge. With the exception of TP2, where one species was recorded in spring/summer compared to seven in winter, species diversity and species composition were generally similar in spring/summer and winter at these sites.

Estimates of mean macroalgal percentage cover (<1% in both spring/summer and winter), biomass (no biomass recorded in spring/summer or winter) and total number of species (four) recorded at TP4, were generally lower than at sites located on the adjacent limestone pavements (Table 8-3). TP4 is located in the deeper sand substrates in the channel between the limestone pavement adjacent to Town Point and East Barrow Ridge.

Some other macroalgae species were recorded at the sites, but at very low percentage covers (Table 8-3). For example, there were single observations of *Udotea argentea* and *U. orientalis* recorded at TP4, TP5 and TP7. Occasional *Udotea* spp. and *Caulerpa* spp. were identified from towed video camera footage within the sandy substrate located between the limestone pavement adjacent to Town Point and East Barrow Ridge, and occasionally further east in deeper water (Figure 8-2).

LNGI2, located on the eastern slope of the East Barrow Ridge, was characterised by limestone boulders leading into deeper water. Quantitative estimates of percentage cover were not available for this site in spring/summer, but field observations indicated that the site was characterised by calcareous branching and encrusting red algae (e.g. *Amphiroa fragilissima* [diver visual estimate ~5% cover]; *Laurencia* sp. [diver visual estimate ~1% cover]), turfing brown algae (diver visual estimate 15% cover) and fast-growing *Dictyopteris* spp. and *Dictyota* spp. (Table 8-3). Estimates of macroalgal biomass were low (no macroalgae were recorded in any of the six biomass quadrats sampled at this site) in spring/summer.

8.4.4.2 Macroalgal Assemblages at Sites in the Vicinity of the Dredge Spoil Disposal Ground

Mean macroalgal percentage cover was very low (<1%) at DS1, located in the Dredge Spoil Disposal Ground, and no macroalgae were recorded in the biomass quadrats in either spring/summer or winter (Table 8-3). *Udotea* sp. was the only dominant species recorded at this site on the transects in spring/summer and was only present in a few quadrats (diver visual estimate <1% cover). This area is a relatively deep (<18 m), coarse-to-fine grain sand habitat. *Caulerpa* sp. and *Halimeda* sp. were observed in towed video camera footage (Figure 8-2).

8.4.5 Description of Macroalgal Assemblages at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

The area of seabed at risk of Serious Environmental Harm (Section 2.3.4) associated with the marine upgrade of the existing WAPET Landing comprised limestone pavement with varying depths of overlying sand veneer. Sparse (<25%) to dense (>75%) cover macroalgal assemblages characterised the biotic communities (Figure 8-2) (RPS 2009a). *Sargassaceae*, *Dictyopteris*, *Dictyota*, *Padina* and *Halimeda* were the most abundant macroalgal taxa (RPS Bowman Bishaw Gorham 2006; RPS 2009a). Other taxa recorded included *Caulerpa*, *Codium*, *Champia*, *Euchema* and *Asparagopsis*. The composition of the macroalgal assemblages was similar to that of the broader macroalgae community that dominates the shallow limestone pavement along the east coast of Barrow Island.

The area of seabed at risk of Material Environmental Harm (Section 2.3.4), associated with the WAPET Landing facilities, comprised limestone pavement with varying depths of overlying sand veneer. The biotic assemblages were dominated by sparse-to-medium density macroalgal beds (RPS 2009a).

Table 8-3 Macroalgal Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Sites in the Zones of High Impact and Zones of Moderate Impact

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
TP2	5.1±1.6	21	10.0±1.9	21	No samples collected	-	115.4±64.5	12	*Dictyopteris australis*	*Asparagopsis taxiformis* *Caulerpa brachypus* *Caulerpa cactoides* *Dictyopteris australis* *Galaxaura rugosa* Phaeophyceae spp. *Sargassum* sp.
TP4	0.2±0.2	22	0.3±0.2	21	No samples in quadrats	-	No samples in quadrats	-	*Tolypiocladia glomerulata* *Udotea argentea*	*Caulerpa cactoides* *Phaeophyceae* spp. *Tolypiocladia glomerulata*
TP5	12.0±2.5	18	10.5±2.7	19	528.0±179.1	5	241.9±49.0	10	*Caulerpa cactoides* *Chondrophycus* sp. *Dictyopteris australis* *Galaxaura rugosa* *Padina australis / Padina boryana* *Sargassopsis decurrens* *Sargassum oligocystum* *Udotea orientalis*	*Caulerpa cactoides* *Dictyopteris* sp. *Galaxaura rugosa* *Padina australis / Padina boryana* *Sargassum carpophyllum* *Sargassopsis decurrens* *Sargassum oligocystum* *Udotea orientalis*
TP6	Not surveyed	-	4.3±0.9	21	Not surveyed	-	127.0±19.0	9	Not surveyed	*Caulerpa lentillifera* *Dictyopteris* sp.

Site	Mean % Cover ± SE/m²				Mean Biomass (g) ± SE/m²				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
										Halimeda discoidea *Jania* sp. *Sargassum* sp. *Udotea argentea*
TP7	15.2±3.0	21	Not surveyed	-	700.0±216.8	6	Not surveyed	-	*Sargassopsis decurrens* *Sargassum sp.2* *Udotea argentea*	Not surveyed
LNGI1	26.1±5.2	21	23.2±4.8	21	504.0±109.8	5	482.5±130.7	8	*Halimeda* sp. *Hormophysa cuneiformis* *Sargassopsis decurrens* *Sargassum* sp.2	*Dictyopteris* sp. *Halimeda* sp. *Sargassopsis decurrens* *Sargassum* sp.2
LNGI2	Photographs could not be analysed by CPCe	-	Not surveyed	-	No samples in quadrats	-	Not surveyed	-	*Amphiroa fragilissima* Corallinaceae sp. *Dictyopteris* sp. *Dictyota* sp. *Galaxaura rugosa* *Laurencia* sp. Phaeophyceae sp.	Not surveyed
DS1	0.5±0.5	21	0.2±0.2	21	No samples in quadrats	-	No samples in quadrats	-	*Udotea* sp.	Phaeophyceae sp. *Udotea* sp.

8.4.6 Description of Macroalgal Assemblages at Representative Areas of the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

8.4.6.1 Sites in Representative Areas of the Zone of Influence on the Inshore Limestone Pavement

Mean macroalgal percentage cover at the two sites on the inshore limestone pavement south of Town Point (TP9, TP10) varied from ~8–12% in spring/summer (Table 8-4). At both sites, mean macroalgal biomass was >900 g wet weight/m^2. *Dictyopteris australis* was the most abundant species (diver visual estimate 15% cover) at TP9 and *Halimeda* cf. *cuneata* (diver visual estimate ~25% cover) at TP10 in spring/summer. *Halimeda* cf. *cuneata* also occurred at TP9 and *Udotea argentea* at TP10, but both were much sparser in cover (diver visual estimate 1% at each site). *Padina* sp. was also recorded at both sites (diver visual estimate ~1% cover at each site). Estimates of mean percentage cover, biomass and species diversity were markedly lower in winter at TP9.

At the site at Double Island (DI1), located on the inshore limestone pavement north of Town Point, macroalgal cover was sparse in winter (Table 8-4). Mean percentage cover and biomass were correspondingly low, but they were higher than at TP9. Four dominant species were recorded on the transects at this site in winter.

Sargassum spp., *Caulerpa* spp. and *Halimeda* spp. were recorded at TPC3, located south of Town Point on the slope between the limestone pavement and the deeper sand channel (Table 8-4). Quantitative estimates of macroalgal percentage cover and biomass in summer are not available for this site, but all 13 species recorded at this site were sparse in cover, with no species estimated as covering more than 1%.

8.4.6.2 Sites in Representative Areas of the Zone of Influence in the Sandy Channel East of the Inshore Limestone Pavement

Mean macroalgal percentage cover at LC1, located in the sandy channel east of the inshore limestone pavement, was 1.3% in spring/summer (Table 8-4). Eleven dominant macroalgae species were recorded at this site in spring/summer, and all species were sparse in terms of their cover (diver visual estimate of each site ≤1%). Sparse cover (diver visual estimate <1%) of fewer (one to three) macroalgae species was recorded on the transects at the two other sites in the sandy channel in spring/summer (LC4 and TPC1). No macroalgae were recorded in the biomass quadrats sampled at these sites.

8.4.6.3 Sites in Representative Areas of the Zone of Influence on the East Barrow Ridge

Mean macroalgal percentage cover at LNGR3, located on the southern end of the East Barrow Ridge was ~30–38% in both spring/summer and winter (Table 8-4). A winter biomass (1076 g wet weight/m^2) was recorded at this site. Of the 13 dominant species recorded at this site in spring/summer, two (*Sargassopsis. decurrens* and *Sargassum* sp.1) were the most abundant (diver visual estimate ~20% and ~5% cover respectively). In spring/summer, three species of *Sargassum* (*S. peronii*, *Sargassum* sp.1 and *Sargassum* sp.2) (diver visual estimate ~10%, ~1% and ~5% cover respectively) were recorded at LNGR2, located on the northern end of East Barrow Ridge. *Hormophysa cuneiformis* had the highest cover at this site (diver visual estimate ~15%).

8.4.6.4 Sites in Representative Areas of the Zone of Influence on the Lowendal Shelf

Mean macroalgal percentage cover at the site near the northern extent of the Zone of Influence near the Lowendal Islands (NEBWI1) was the highest recorded at any of the sites in spring/summer (55%) with a mean biomass of 1827 g wet weight/m^2 (Table 8-4). Fifteen dominant species were recorded on transects at this site in spring/summer. The most abundant species were *Sargassum* sp.1 and *Halimeda* cf. *discoidea* (diver visual estimate 45% and ~20% cover respectively).

8.4.6.5 Sites in Representative Areas of the Zone of Influence around the Dredge Spoil Disposal Ground

At DSS1, located south of the Dredge Spoil Disposal Ground, mean percentage macroalgal cover was either not recorded (spring/summer) or nil (0% in winter). No macroalgae were recorded in the biomass quadrats. The two dominant species observed on the transects at this site in spring/summer (*Halimeda macroloba* and *Udotea glaucescens*) had very sparse cover (diver visual estimate <1%) (Table 8-4).

Table 8-4 Macroalgal Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Sites in the Zones of Influence

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
TP9	11.6±2.4	20	0.6±0.6	20	1306.7±275.3	6	149.2±110.4	2	*Dictyopteris australis* *Halimeda* cf. *cuneata* *Padina* sp. *Sargassum* sp.	*Padina* sp. *Sargassum* sp.
TP10	7.9±1.0	21	Not surveyed	-	933.3±161.9	6	Not surveyed	-	*Caulerpa cupressoides* var. *mamillosa* *Halimeda* cf. *cuneata* *Padina* sp. *Spyridia filamentosa* *Udotea argentea*	Not surveyed
DI1	Not surveyed	-	2.9±1.0	21	Not surveyed	-	205.0±90.2	6	Not surveyed	*Caulerpa cactoides* *Dictyopteris woodwardii* *Dictyota* sp. *Padina* sp.
TPC3	Photographs could not be analysed by CPCe	-	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Avrainvillea obscura* *Bornetella oligospora / Codium dwarkense* *Caulerpa cupressoides* *Caulerpa lentillifera* *Codium dwarkense* *Galaxaura rugosa* *Halimeda discoidea* *Halimeda macroloba* *Penicillus nodulosus* Phaeophyceae sp.	Not surveyed

Site	Mean % Cover ± SE/m²				Mean Biomass (g) ± SE/m²				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
									Sargassum sp.3 *Udotea flabellum / U. orientalis*	
LC1	1.3±0.7	21	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Caulerpa brachypus* *Caulerpa cupressoides* *Halimeda discoidea* *Halimeda lacunalis* *Halimeda macroloba* *Heterosiphonia crassipes* *Penicillus* sp. *Sargassum* sp.3 *Udotea flabellum* *Udotea glaucescens* *Udotea* sp.	Not surveyed
LC4	Photographs could not be analysed by CPCe	-	Photographs could not be analysed by CPCe	-	No samples in quadrats	-	No samples in quadrats	-	*Halimeda cuneata*	
TPC1	Photographs could not be analysed by CPCe	-	Not surveyed	-	No samples in quadrats	-	Not surveyed	-	*Halimeda macroloba* *Penicillus* sp. *Udotea* sp.	Not surveyed
LNGR2	Photographs could not be analysed by CPCe	-	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Hormophysa cuneiformis* *Sargassum peronii* *Sargassum* sp.1 *Sargassum* sp.2	Not surveyed

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
LNGR3	31.0±4.6	22	38.0±3.4	21	No samples collected	-	1075.6±316.5	8	*Caulerpa corynephora* *Caulerpa lentillifera* *Caulerpa serrulata* *Cladophora catenata* *Codium dwarkense* *Sirophysalis trinodis* *Galaxaura rugosa* *Halimeda discoidea* *Lobophora variegata* *Padina boryana* *Sargassopsis decurrens* *Sargassum* sp.1 *Udotea orientalis*	*Caulerpa corynephora* *Caulerpa lentillifera* *Caulerpa serrulata* *Halimeda discoidea* *Sargassopsis decurrens* *Sargassum* sp.1
DSS1	Photographs could not be analysed by CPCe	-	0.0±0.0	19	No samples in quadrats	-	No samples in quadrats	-	*Halimeda macroloba* *Udotea glaucescens*	Phaeophyceae (turf)
NEBWI1	55.1±2.8	21	Not surveyed	-	1826.7±454.9	6	Not surveyed	-	*Asparagopsis taxiformis* *Caulerpa corynephora* *Caulerpa cupressoides* *Champia parvula* *Coelarthrum cliftoni* *Dictyopteris serrata* *Dictyopteris woodwardii* *Galaxaura rugosa* *Halimeda* cf. *discoidea* *Padina* sp. *Sargassopsis decurrens*	Not surveyed

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
									Sargassum oligocystum	
									Sargassum sp.1	
									Spatoglossum macrodontum	
									Sporochnus comosus	

8.4.7 Description of Macroalgal Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

8.4.7.1 Reference Site on the West Coast of Barrow Island

Mean macroalgal percentage cover at the Reference Site on the west coast of Barrow Island at Biggada Reef (BR) was the second highest recorded at any of the sites in spring/summer (42%) and winter (28%) (Table 8-5). A total of eleven dominant species were recorded at this site. The most abundant species in spring/summer were *Halimeda* cf. *cuneata* (diver visual estimate 20% cover) and *Sargassum* sp.1 (diver visual estimate ~10% cover); *Caulerpa cupressoides* and *Champia parvula* were also present, but in lower abundance (diver visual estimate ~10% cover each).

Table 8-5 Macroalgal Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Reference Sites not at Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
BR	41.7±4.2	21	27.6±2.8	21	No samples collected	-	565.9±107.1	12	*Caulerpa corynephora*	*Caulerpa corynephora*
									Caulerpa cupressoides	*Dictyopteris woodwardii*
									Champia parvula	*Champia parvula*
									Encyothalia cliftoni	*Encyothalia cliftoni*
									Halimeda cf. *cuneata*	*Halimeda* cf. *cuneata*
									Jania rosea	*Jania rosea*
									Padina sp.	*Padina* sp.
									Sargassopsis decurrens	Phaeophyceae sp.
									Sargassum sp.1	*Sargassopsis decurrens*

8.5 Discussion

Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed, shading by infrastructure, and physical removal of the substrate through dredging, or smothering and burial is predicted to affect macroalgae within the Marine Facilities Footprint, the Dredge Spoil Disposal Ground and in some areas of the Marine Disturbance Footprint within the Zones of High and Moderate Impact. The areas at risk of Material Environmental Harm, caused by elevated turbidity from the dredge plume and anchoring damage, include the Zones of Moderate Impact and those areas within the Zones of High Impact that are not within the Marine Facilities Footprint.

The Causeway footprint lies across the limestone pavement adjacent to Barrow Island; extending from the beach cliffs at Town Point, across the intertidal reef platform adjacent to the shore, out to approximately 7 m water depth at the Materials Offloading Facility (MOF) (Figure 2-1). The intertidal zone is approximately 200 m wide in this area and characterised by mixed turfing algae, with larger macroalgae and sparse seagrass in rock pools. The intertidal rock pools were dominated by mixed Phaeophyceae, in particular *Sargassaceae* spp. and *Sirophysalis trinodis.* The subtidal platform reef was covered in macroalgae with sparse sessile taxa. Macroalgal beds in the area of the Causeway footprint were dominated by several species, including *Sargassopsis decurrens*, *Sargassum* spp. (*S. oligocystum*, *Sargassum* sp.), *Padina* spp. (*P. australis*, *P. boryana*) and mixed Chlorophyta (particularly *Halimeda cuneata*). Less common macroalgae included *Udotea* spp. in sand patches and the turfing coralline alga *Galaxaura rugosa* on rock. Scattered bomboras (generally <2 m in diameter) were present amongst the macroalgal beds in shallow water (0-8 m). Bomboras in the nearshore areas of the platform were generally dominated by macroalgae and benthic macro-invertebrates, whereas bomboras on the offshore edge of the platform generally supported more live coral.

The MOF footprint lies on the deeper subtidal area of the platform adjacent to the east coast of Barrow Island. The dominant ecological element in the area was macroalgae, with subdominant levels of cover of other sparse sessile taxa. The macroalgal assemblage was dominated by mixed Phaeophyceae (including *Sargassopsis decurrens*, *Sargassum* spp. [*S. oligocystum*, and *Sargassum* sp.], *Dictyopteris* spp., *Padina* spp. [*P. australis* and *P. boryana*]) and mixed Chlorophyta (particularly, *Halimeda cuneata* and *Udotea* spp. (*Udotea* sp., *U. argentea*, *U. orientalis*).

The LNG Jetty footprint extends across the outer part of the limestone platform adjacent to Barrow Island for 500 m past the end of the MOF and then continues for a further 1200 m across the soft sediment assemblages in deeper water. The outer part of the reef platform within the LNG Jetty footprint was dominated by macroalgal assemblages with sparse sessile taxa, similar to those within the MOF footprint. Mixed Phaeophyceae was the dominant assemblage type in this area. The dominant macroalgal taxa were *Sargassum* and *Padina*.

The Turning Basin footprint lies in 8–11 m of water over limestone pavement with a sand veneer. The dominant benthic category comprised soft sediment (unvegetated sand) with sparse sessile taxa at subdominant levels of cover, including sparse cover of macroalgae. The LNG Jetty Access Channel footprint overlies a small section of the East Barrow Ridge (a raised limestone platform in approximately 7 m water depth) and the soft sediment habitats either side of the ridge. The area on the East Barrow Ridge within the LNG Jetty Access Channel footprint was characterised by areas mapped as 'Macroalgae with Sparse Sessile Taxa'. The dominant taxon within the macroalgal assemblages was *Sargassopsis decurrens* and *Sargassum* sp.; mixed Chlorophyta (mainly *Udotea* spp., *Halimeda* spp.) and mixed Rhodophyta (calcareous red algae) were also present.

There were no significant macroalgal assemblages observed within the Dredge Spoil Disposal Ground footprint.

The patchy distribution of macroalgae, as well as the spatial variability in percentage cover, makes it difficult to estimate the total area of macroalgae that will be impacted as a consequence of the construction of the Marine Facilities at Town Point. The construction of the Marine Facilities on the east coast of Barrow Island will result in the direct loss of approximately 35.5 ha (0.2%) within the Marine Facilities Footprint, of the total area of 'Macroalgae with Sparse Sessile Taxa' (~16 500 ha) in the Management Units on the east coast of Barrow Island.[4] The Marine Disturbance Footprint associated with the construction of the Marine Facilities will potentially impact up to approximately 285 ha (1.7%) of the area of 'Macroalgae with Sparse Sessile Taxa'.

[4] Fourteen Management Units were defined to assess impacts to benthic primary producer habitats associated with the Gorgon Gas Development, 11 on Barrow Island and three on the mainland (Section 11.4, Chevron Australia 2005; Section 8.8, Part C, Chevron Australia 2006).

8.6 Conclusions

Macroalgal assemblages represent the most extensive benthic habitat in the waters around Barrow Island (Figure 8-2). Percentage cover, biomass and species richness (excluding turfing and crustose coralline species) of the macroalgal assemblages were spatially variable, both between and within sites. The number of dominant species varied between one per site, up to a maximum of 15 species recorded in spring/summer at NEBWI1 located near the northern extent of the Zone of Influence near the Lowendal Islands (NEBWI1 recorded a total of 33 species; the highest of all sites) . At the majority of sites, macroalgae species were generally recorded as being sparse (diver visual estimate ≤25% cover) in spring/summer; only two species were recorded as having percentage covers ≥25%: *Halimeda* cf. *Cuneata* and *Sargassum* sp.1. The highest percentage cover recorded for any one species was 45% for *Sargassum* sp.1 at NEBWI1 in spring/summer. Percentage cover and biomass were generally highest on the areas of shallow limestone pavements and lowest on soft sediments. The highest estimates of percentage cover were recorded in spring/summer at the sites located near the Lowendal Islands (NEBWI1) and at Biggada Reef (BR) on the west coast, and the highest estimates of mean biomass were recorded in spring/summer at Biggada Reef (BR) and TP9.

Estimates of percentage cover, biomass and species richness were generally slightly lower at sites in the Zones of High Impact than at sites in the Zones of Influence. Many of the macroalgae species recorded at sites in the Zones of High and Moderate Impact were also recorded at sites within the Zones of Influence and at Reference Sites, including: the red macroalgae *Galaxaura rugosa*; the brown macroalgae *Dictyopteris australis*, *Hormophysa cuneiformis*, *Padina boryana*, Phaeophyceae sp., *Sargassopsis decurrens*, *Sargassum oligocystum*, *Sargassum* sp.2; and the green macroalgae *Udotea argentea*, *U. orientalis* and *Udotea* sp.. However, a number of taxa at sites within the Zones of High and Moderate Impact were not recorded at any other sites, e.g. *Amphiroa fragilissima* and *Laurencia sp*. (LNGI2 only) and *Hypnea pannosa* and *Coelathrix irregularis* (TP5 only).

9.0 Seagrass

9.1 Introduction

The diversity and distribution of seagrass species on the North West Shelf are not well documented. Huisman and Borowitzka (2003) identified nine species of seagrass in the Dampier Archipelago, from the families Hydrocharitaceae and Cymodoceaceae. Seagrass distribution in the waters surrounding Barrow Island is even less well-known. However, seagrass do not appear to form extensive beds in the area, but rather are sparsely interspersed between macroalgae, extending from the intertidal zone to approximately 15 m water depth (DEC 2007).

Seven species have been recorded to date from the Montebello/Barrow Islands region: *Cymodocea angustata*, *Halophila ovalis*, *H. spinulosa*, *Halodule uninervis*, *Thalassia hemprichii*, *Thalassodendron ciliatum* and *Syringodium isoetifolium* (DEC 2007). Of these, *Halophila* spp. are the most common on shallow soft substrates and sand veneers throughout the region (DEC 2007).

Ephemeral seagrass are widespread on the east coast of Barrow Island (Chevron Australia 2005). Seagrass, most often *Halophila* spp., are patchily distributed on sandy subtidal habitats, and areas of bare sand devoid of seagrass are also common along the east coast of Barrow Island (KJVG 2008). Rock pools in the area of the MOF and LNG Jetty support the growth of seagrass in varying densities ranging from occasional plants to small beds (Chevron Australia 2008). *Halophila ovalis* forms sparse beds in the deeper subtidal sand, while *Halophila* spp., *Halodule uninervis* and *Syringodium isoetifolium* are generally the most common species in rock pools (Chevron Australia 2005).

Seagrass beds in the Montebello/Barrow Islands region make an important contribution to the local productivity, as well as representing an important direct food source for some animals (e.g. Dugongs [*Dugong dugon*] and Green Turtles [*Chelonia mydas*]), and providing refuge for fish and invertebrates (Chevron Australia 2005; DEC 2007). Seagrass habitats in the Montebello/Barrow Islands region vary seasonally in response to water temperature, day length, reproductive cycles, physical disturbance and regrowth (DEC 2007).

9.2 Scope

This Section records the dominant species of seagrass (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the seagrass:

- within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

9.3 Methods

9.3.1 Site Locations

A total of 22 seagrass survey sites were selected within those areas where seagrass were identified as being present through broadscale benthic habitat mapping (Section 5.1). Four sites were located within the Zones of High Impact, two of which were located within the Zone of High Impact at the Dredge Spoil Disposal Ground (Table 9-1; Figure 9-1). Two sites were located in the Zone of Moderate Impact. Four sites (TP5, LNGI1, DS1 and DS2) were in the area at Risk of Serious Environmental Harm (Section 2.3.4) and two (TP2 and TP4) within the area at Risk of Material Environmental Harm (Figure 2-5), with all but three (TP2, DS1, DS2) of these sites within the Marine Disturbance Footprint (Figure 2-3).

Eleven sites were located within the Zones of Influence, including one adjacent to the Dredge Spoil Disposal Ground (Table 9-1; Figure 9-1). These sites are considered to be Reference Sites because, although located within the Zones of Influence, turbidity and sedimentation are not expected to impact on seagrass and no Material or Serious Environmental Harm is expected to affect these sites (see Section 2.3.4). These sites will only be used as Reference Sites in any future analyses if it is determined through the Dredging and Spoil Disposal Monitoring Program that they have not been impacted by dredging and spoil disposal activities. Five sites were located outside the Zones of Influence, four in the deeper soft sediments east of the East Barrow Ridge and one site at Biggada Reef on the west coast.

Please note that a total of 20 seagrass sites were initially selected to be surveyed during the spring/summer period of 2008/2009, and a subset of these (13) were resurveyed during winter. Two additional seagrass sites (DI1 and BR) were also sampled in winter (Table 9-1).

In addition, surveys were undertaken at the WAPET Landing (RPS Bowman Bishaw Gorham 2006; RPS 2009a).

Table 9-1 Seagrass Survey Sites and Dates

Location	Site Code	Easting	Northing	Latitude	Longitude	Survey Date		
		(GDA94, MGA Zone 50)		(GDA94)		Nov 2008	Jan 2009	Jul 2009
Zones of High Impact	TP5	342085	7699098	20° 48.079' S	115° 28.961' E	X		X
	LNGI1	344397	7696825	20° 49.323' S	115° 30.281' E		X	X
	DS1	348019	7691926	20° 51.996' S	115° 32.343' E		X	X
	DS2	347615	7689533	20° 53.291' S	115° 32.098' E		X	
Zones of Moderate Impact	TP2	342235	7700923	20° 47.091' S	115° 29.057' E	X		X
	TP4	342407	7698457	20° 48.428' S	115° 29.143' E	X		X
Zones of Influence	DI1	342869	7706775	20° 43.922' S	115° 29.454' E			X
	LC1	344931	7700025	20° 47.591' S	115° 30.606' E		X	X
	LC2	344619	7700316	20° 47.432' S	115° 30.428' E		X	X
	LNGR1	344321	7694295	20° 50.694' S	115° 30.224' E		X	X

Location	Site Code	Easting	Northing	Latitude	Longitude	Survey Date		
		(GDA94, MGA Zone 50)		(GDA94)		Nov 2008	Jan 2009	Jul 2009
	LNGR2	345444	7697787	20° 48.807' S	115° 30.890' E		X	
	TP9	341069	7695738	20° 49.895' S	115° 28.357' E	X		X
	TP10	337827	7694122	20° 50.754' S	115° 26.479' E	X		
	TPC1	342628	7694475	20° 50.587' S	115° 29.249' E		X	
	TPC2	342071	7694176	20° 50.747' S	115° 28.926' E		X	
	TPC3	342101	7694972	20° 50.315' S	115° 28.947' E		X	
	DSS1	347316	7687119	20° 54.598' S	115° 31.913' E		X	X
Reference Sites	DSR3	353494	7695109	20° 50.297' S	115° 35.516' E		X	
	DSR5	346075	7694125	20° 50.794' S	115° 31.234' E		X	X
	DGI0	342795	7690816	20° 52.571' S	115° 29.325' E		X	X
	DSR1	347711	7684857	20° 55.826' S	115° 32.129' E		X	X
	BR	329234	7705071	20° 44.774' S	115° 21.589' E			X

Note: The location of BR was adjusted between the November 2008 and July 2009 surveys because of issues associated with safe access to the site.

Note that some seagrass survey sites were also macroalgal and non-coral benthic macro-invertebrate survey sites where these ecological elements co-occurred in the same area.

9.3.2 Methods

At each site, three 30 m length transects were laid out from a central clump weight (RPS 2009). The first transect was orientated parallel to the anchor line and the two others at approximately 90° to the first. The co-ordinates of the start point of each transect was recorded using GPS.

Seven 1 m^2 photo-quadrats were positioned at 5 m intervals along the right side of each transect. In the July 2009 survey, each 1 m^2 photo-quadrat was comprised of four sub-quadrats of 0.25 m^2, which were individually photographed to improve image quality and thus increase the precision of percentage cover measurements. The seagrass present in the quadrat (or sub-quadrat) was recorded; the percentage cover estimated in situ by divers (November 2008 and January 2009 only), and the quadrat photographed. The seagrass species present in each quadrat (or sub-quadrat) were identified to the lowest reliable taxonomic level (to genus and species level where possible). Variability in species richness and percentage cover within and among transects was estimated based on the preliminary field data collected in November 2008, to confirm that the proposed sampling design would adequately account for natural variability at these spatial scales.

Voucher samples of those species that could not be reliably identified in the field were collected, preserved and catalogued for identification by Dr John Huisman (Murdoch University, Western Australia).

In the November 2008 and January 2009 surveys, the seagrass in two 0.25 m^2 quadrats along each transect were collected for total biomass measurement (i.e. a total of six samples per site). A quadrat was located at 10 m and 20 m intervals along the left side of each transect. In the July 2009 survey, the seagrass in two 0.25 m^2 quadrats were collected from each of the 10 m and 20 m intervals (i.e. a total of 12 samples per site). If the quadrat was on bare sand, no biomass sample was collected. Samples were blot-dried and total wet-weight recorded.

Qualitative surveys were undertaken at WAPET Landing to record the most common seagrass species, including photographing of 0.25 m^2 quadrats placed on the seabed. Note that the digital images were not suitable for CPCe analysis and measures of percentage cover were based on visual estimates.

9.3.3 Timing and Frequency of Sampling

Sampling was undertaken in late spring and summer (November 2008 and January 2009; Table 9-1) during the period of peak seagrass growth and biomass. Sampling at a subset of 13 sites surveyed in November 2008 and January 2009, as well as at two additional sites, was repeated in winter (July 2009). The sites sampled in July 2009 were selected based on their proximity to the proposed Marine Facilities and to include a number of sites in the different Dredge Management Areas.

Surveys at WAPET Landing were undertaken in July–August 2006 and June 2009 (Bowman Bishaw Gorham 2006; RPS 2009a).

9.3.4 Treatment of Survey Data

Digital images were analysed using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill 2006). Thirty random points were overlain over the image and each point visually classified by a trained scorer into a broad category of benthic cover (seagrass, macroalgae, coral, non-coral benthic macro-invertebrates, sand, pavement, rubble and unidentified). Estimates of the percentage cover of seagrass were then calculated.

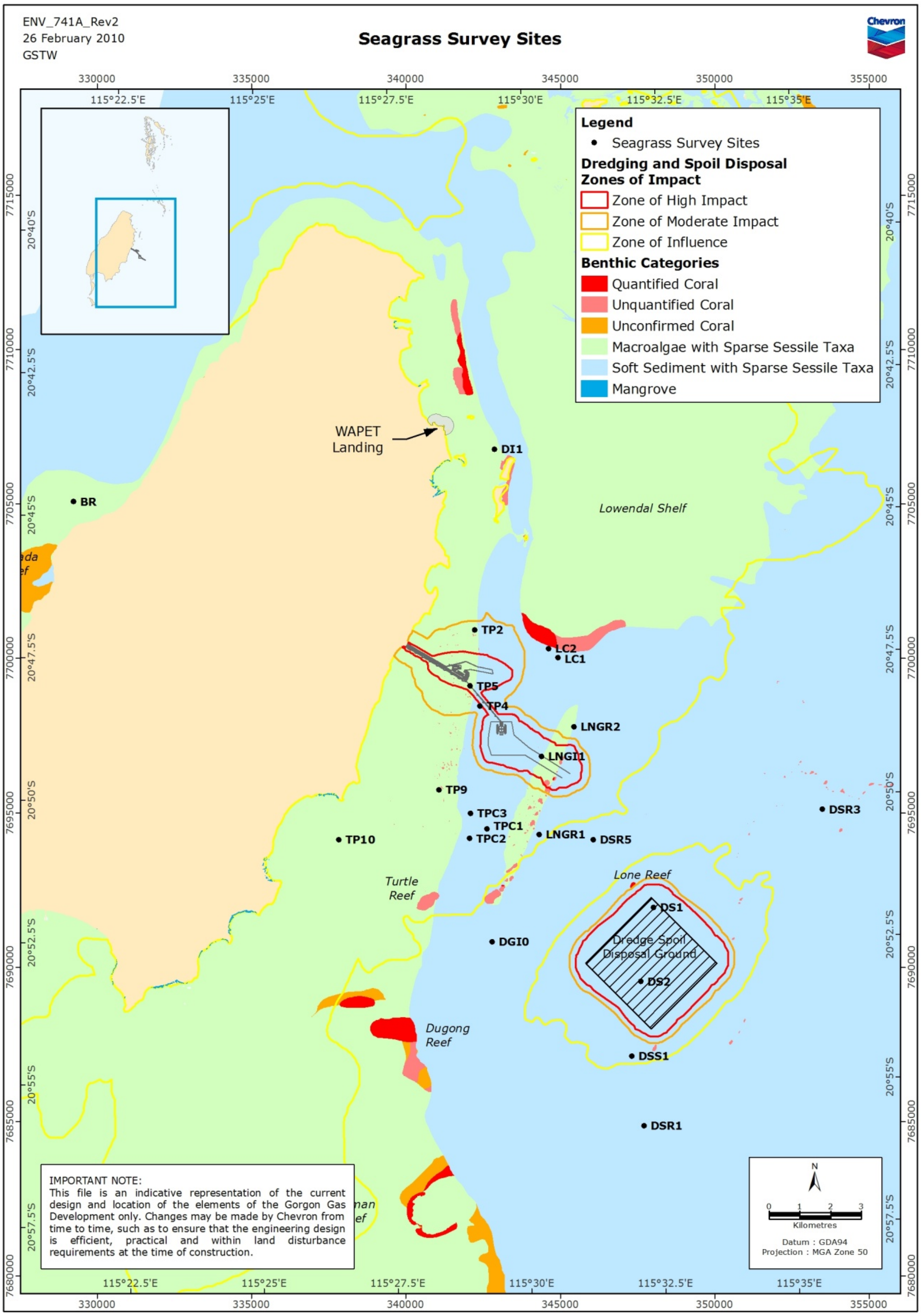


Figure 9-1 Seagrass Survey Sites

9.4 Results

9.4.1 Seagrass in Barrow Island Waters

Different techniques were used for the various components of the Marine Baseline Program, including broadscale mapping (Section 5.1) and small-scale quantitative sampling. These all contributed to the systematic collection of seagrass reported in Barrow Island waters. Six species of seagrass were identified during the Marine Baseline Program: *Cymodocea serrulata*, *Syringodium isoetifolium* and an unidentified species of *Halodule* (Family Cymodoceaceae) and *Halophila decipiens*, *H. ovalis* and *H. spinulosa* (Family Hydrocharitaceae). Refer to Appendix 5 for details of the seagrass species recorded at each site.

9.4.2 Dominant and Subdominant Seagrass

The dominant (or most common) seagrass in terms of percentage cover recorded in Barrow Island waters were *H. ovalis* and *H. spinulosa* (Plate 9-1). *Cymodocea serrulata*, *S. isoetifolium*, *Halodule* sp. and *H. decipiens* were less common.

Halophila ovalis

Halophila spinulosa

Plate 9-1 Seagrass Found in Waters Around Barrow Island

9.4.3 Distribution of Seagrass in Barrow Island Waters

Figure 9-2 shows the spatial distribution of seagrass in Barrow Island waters as point (presence/absence) observations derived from broadscale mapping and ground-truthing (towed video camera surveys, spot dives and transect surveys). 'Null observations' were recorded where seagrass were not observed during ground-truthing.

Seagrass were observed across a range of benthic substrates, including soft sediments at depths of 14–18 m, and on veneers of sand covering limestone pavement at depths of 5–10 m. Seagrass were observed as both mono-specific assemblages of *Halophila* spp. or, more rarely, mixed assemblages of *Halophila* spp. and *Syringodium* spp. Non-coral benthic macro-invertebrates and coral were occasionally recorded co-occurring with seagrass in the macroalgal-dominated assemblages. These mixed communities were most common along the shallow limestone pavement east of Barrow Island. Seagrass was also occasionally observed co-occurring with non-coral benthic macro-invertebrates in deeper soft sediment habitats.

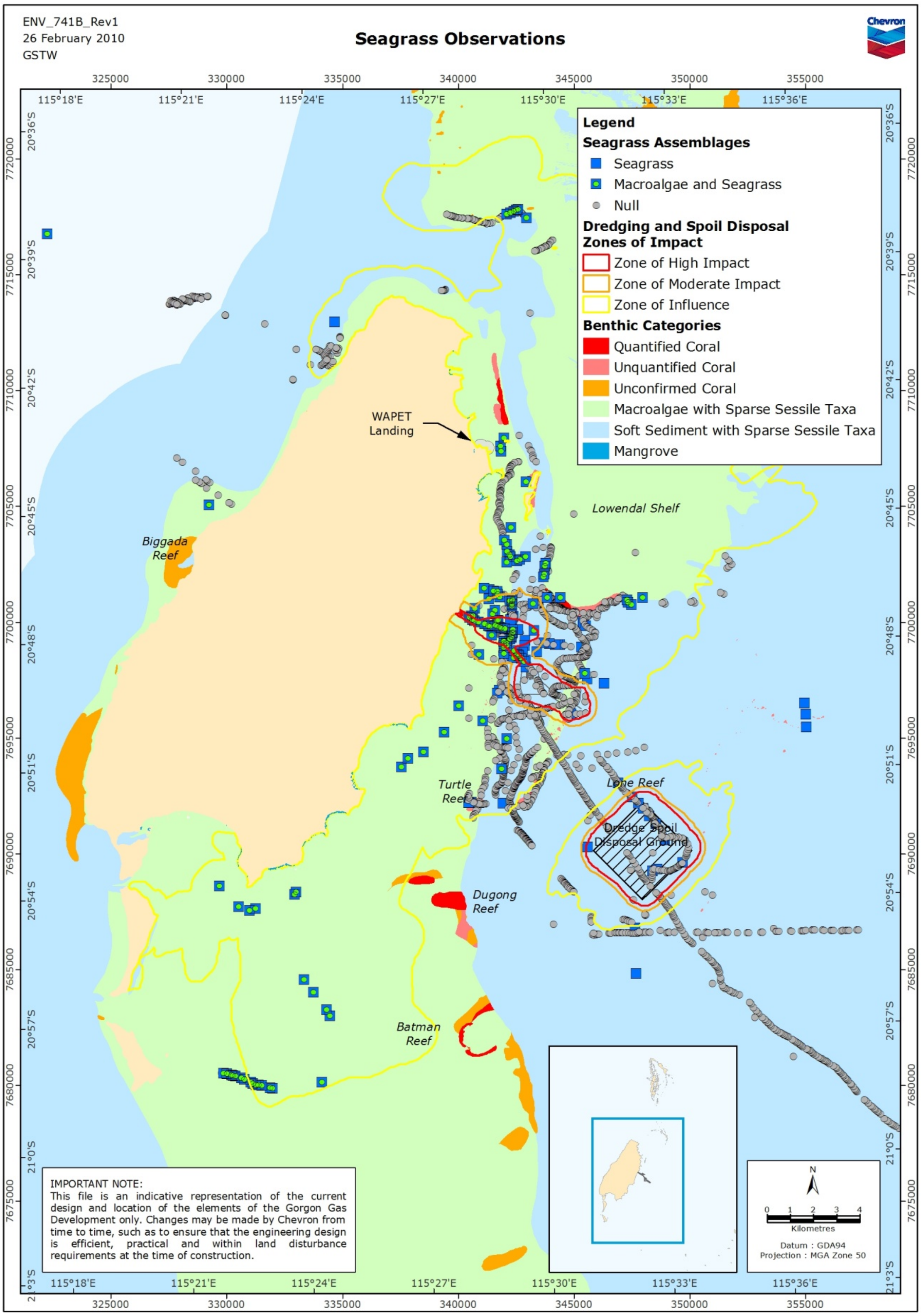


Figure 9-2 Observations of Seagrass in the Waters Around Barrow Island

9.4.4 Description of Seagrass Assemblages within the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

9.4.4.1 Seagrass Assemblages at Sites in the Vicinity of the MOF and Causeway and LNG Jetty Access Channel

Mean seagrass percentage cover at sites on the limestone pavement adjacent to Town Point (TP2, TP4, TP5): varied between <1-8% in spring/summer and <1–25% in winter (Table 9-2). Mean biomass was 60 g wet weight/m^2 in spring/summer at site TP4 (no samples were collected/insufficient data available in spring/summer to calculate biomass of TP2 and TP5 respectively), and varied between 27 and 128 g wet weight/m^2 in winter (TP4, TP2), with no seagrass recorded at TP5. Estimates of percentage cover and biomass were highest at TP4 in both spring/summer and winter; and *H. ovalis* and *H. spinulosa* were the most abundant species in spring/summer (diver visual estimate ~10% cover each). *Halophila ovalis* percentage coverage was very low (diver visual estimate <1%) at TP5 in spring/summer. The highest percentage cover (diver visual estimate ~40%) of *H. ovalis* in spring/summer was recorded at TP2, located north of Town Point.

Different species of seagrass (*H. decipiens*, *Syringodium isoetifolium*) were recorded on the transects at the site on the limestone pavement at East Barrow Ridge (LNGI1) (Table 9-2). Mean percentage cover of these species was low in winter (diver visual estimate <1% for each site), and zero in spring/summer.

9.4.4.2 Seagrass Assemblages at Sites in the Vicinity of the Dredge Spoil Disposal Ground

Mean seagrass percentage cover at DS1, located in the Dredge Spoil Disposal Ground, was low (3%), but with the highest mean biomass (178 g wet weight/m^2) recorded in the Zones of High and Moderate Impact in spring/summer (Table 9-2). *Halophila ovalis* was the most abundant seagrass in spring/summer (diver visual estimate ~5% cover), while percentage cover of *H. spinulosa* was very low (diver visual estimate <1%). *Halophila ovalis* was also observed at DS2 in spring/summer, (diver visual estimate 7% cover).

Table 9-2 Seagrass Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Sites in the Zones of High Impact and Zones of Moderate Impact

<table>
<tr><th rowspan="2">Site</th><th colspan="4">Mean % Cover ± SE/m²</th><th colspan="4">Mean Biomass (g) ± SE/m²</th><th colspan="2">Dominant Species</th></tr>
<tr><th>Spring/ Summer</th><th>n</th><th>Winter</th><th>n</th><th>Spring/ Summer</th><th>n</th><th>Winter</th><th>n</th><th>Spring/ Summer</th><th>Winter</th></tr>
<tr><td rowspan="2">TP2</td><td rowspan="2">7.3±1.3</td><td rowspan="2">21</td><td rowspan="2">12.0±2.2</td><td rowspan="2">21</td><td rowspan="2">No samples collected</td><td rowspan="2">-</td><td rowspan="2">27.1±7.9</td><td rowspan="2">12</td><td rowspan="2">Halophila ovalis</td><td>Halophila ovalis</td></tr>
<tr><td>Halophila decipiens</td></tr>
<tr><td rowspan="2">TP4</td><td rowspan="2">8.0±2.3</td><td rowspan="2">22</td><td rowspan="2">24.5±3.4</td><td rowspan="2">21</td><td rowspan="2">60.0±20.0</td><td rowspan="2">4</td><td rowspan="2">127.5±27.1</td><td rowspan="2">11</td><td>Halophila ovalis</td><td>Halophila ovalis</td></tr>
<tr><td>Halophila spinulosa</td><td>Halophila spinulosa</td></tr>
<tr><td>TP5</td><td>0.2±0.2</td><td>18</td><td>0.2±0.2</td><td>19</td><td>Insufficient data</td><td>-</td><td>No samples in quadrats</td><td>-</td><td>Halophila ovalis</td><td>Halophila ovalis</td></tr>
<tr><td rowspan="2">LNGI1</td><td rowspan="2">0±0</td><td rowspan="2">21</td><td rowspan="2">0.8±0.6</td><td rowspan="2">21</td><td rowspan="2">No samples in quadrats</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td>Halophila decipiens</td><td>Halophila decipiens</td></tr>
<tr><td>Syringodium isoetifolium</td><td>Syringodium isoetifolium</td></tr>
<tr><td rowspan="2">DS1</td><td rowspan="2">3.3±0.8</td><td rowspan="2">21</td><td rowspan="2">0.6±0.5</td><td rowspan="2">21</td><td rowspan="2">177.7±91.4</td><td rowspan="2">3</td><td rowspan="2">9.9±5.2</td><td rowspan="2">6</td><td>Halophila ovalis</td><td rowspan="2">Halophila ovalis</td></tr>
<tr><td>Halophila spinulosa</td></tr>
<tr><td>DS2</td><td>Photographs could not be analysed by CPCe</td><td>-</td><td>Not surveyed</td><td>-</td><td>Insufficient data</td><td>-</td><td>Not surveyed</td><td>-</td><td>Halophila ovalis</td><td>Not surveyed</td></tr>
</table>

9.4.5 Description of Seagrass Assemblages at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

The area of seabed at risk of Material and Serious Environmental Harm (Section 2.3.4), associated with the marine upgrade of the existing WAPET Landing, comprised limestone pavement with varying thicknesses of overlying sand veneer. Sparse patches of seagrass (e.g. *Halophila* and *Halodule* spp.) on sand were scattered through the dominant macroalgal assemblage (Figure 9-2) (RPS 2009a). The composition of the seagrass assemblage was similar to that in other parts of the shallow limestone pavement along the east coast of Barrow Island.

9.4.6 Description of Seagrass Assemblages at Representative Areas of the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

9.4.6.1 Sites in Representative Areas of the Zone of Influence on the Inshore Limestone Pavement

Estimates of mean seagrass percentage cover at the two sites on the inshore limestone pavement south of Town Point (TP9, TP10) varied from 2–4%– in spring/summer (Table 9-3). *Halophila ovalis* was the only species of seagrass recorded at these sites, occurring in sparse patches in spring/summer (diver visual estimates ~20% and 5% cover at TP9 and TP10 respectively). At the site at Double Island (DI1), located on the inshore limestone pavement north of Town Point, mean percentage cover was 1% and mean biomass 67 g/m^2 in winter. Two species of *Halophila* (*H. ovalis* and *H. spinulosa*) were recorded at this site.

9.4.6.2 Sites in Representative Areas of the Zone of Influence in the Sandy Channel East of the Inshore Limestone Pavement

Five sites (TPC1, TPC2, TPC3, LC1, LC2) were located in the sandy channel east of the inshore limestone pavement. In spring/summer, seagrass at sites LC1, LC2 and TPC3 co-occurred in small patches amongst macroalgae and non-coral benthic macro-invertebrates. No other benthic assemblages were recorded co-occurring with seagrass at TPC1 and TPC2. Mean seagrass percentage cover varied from 7–8% at LC1 and LC2 and mean biomass varied from 0–96 g wet weight/m^2 at TPC1, TPC2 and LC2 in spring/summer (Table 9-3). Estimates of mean percentage cover and biomass were lower at LC2 in winter compared to spring/summer, with *H. ovalis* and *H. spinulosa* recorded at both times.

Four species of seagrass were recorded in sparse abundance in spring/summer (diver visual estimate <1–5% cover) at LC1, the greatest number of dominant species at any site: *H. ovalis*, *H. spinulosa*, *H. decipiens* and *S. isoetifolium* (Table 9-3). There were three species of seagrass in sparse abundance in spring/summer (diver visual estimate <1–2% cover) at TPC3 (*H. decipiens*, *H. ovalis* and *H. spinulosa*). A sparse abundance of *H. ovalis* and *H. spinulosa* was recorded at LC2 in spring/summer (diver visual estimate 2% and ~5% cover respectively). *Halophila ovalis* was the only species recorded at TPC1 and TPC2 in spring/summer.

No seagrass was observed at two of the non-coral benthic macro-invertebrate sites located in the channel (TPCI1 and TPC12; see Figure 7-1). However, seagrass was observed in the vicinity of these sites in a previous survey undertaken in 2004, reflecting the temporal variability in the spatial distribution of seagrass in the waters around Barrow Island.

9.4.6.3 Sites in Representative Areas of the Zone of Influence on the East Barrow Ridge

Seagrass were recorded at two sites (LNGR1, LNGR2) on the East Barrow Ridge (Table 9-3). A sparse cover of *H. ovalis* was recorded in small patches at these sites in spring/summer (diver visual estimate <5% cover for each). *Halophila spinulosa* and *Syringodium isoetifolium* were also recorded at these sites in low abundance in spring/summer (diver visual estimate <1% cover).

9.4.6.4 Sites in Representative Areas of the Zone of Influence around the Dredge Spoil Disposal Ground

Mean seagrass biomass at DSS1, located in the Zone of Influence associated with the Dredge Spoil Disposal Ground, was 13 g wet weight/m^2 in spring/summer and 4 g wet weight/m^2 in winter (Table 9-3). Two *Halophila* species were recorded in sparse abundance (diver visual estimates <1–2%) at the site in spring/summer.

Table 9-3 Seagrass Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Sites in the Zones of Influence

Site	Mean % Cover ± SE/m²				Mean Biomass (g) ± SE/m²				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
TP9	4.0±1.5	20	0.0±0.0	20	No samples in quadrats	-	No samples in quadrats	-	*Halophila ovalis*	*Halophila ovalis*
TP10	2.0±1.0	21	Not surveyed	-	No samples in quadrats	-	Not surveyed	-	*Halophila ovalis*	Not surveyed
DI1	Not surveyed	-	1.4±0.8	21	Not surveyed	-	67.3±17.6	4	Not surveyed	*Halophila ovalis* *Halophila spinulosa* *Syringodium isoetifolium*
TPC1	Photographs could not be analysed by CPCe	-	Not surveyed	-	No samples in quadrats	-	Not surveyed	-	*Halophila ovalis*	Not surveyed
TPC2	Photographs could not be analysed by CPCe	-	Not surveyed	-	48.6±21.4	6	Not surveyed	-	*Halophila ovalis*	Not surveyed
TPC3	Photographs could not be analysed by CPCe	-	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Halophila ovalis* *Halophila spinulosa* *Halophila decipiens*	Not surveyed
LC1	7.7±1.7	21	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Halophila decipiens* *Halophila ovalis* *Halophila spinulosa* *Syringodium isoetifolium*	Not surveyed
LC2	7.2±2.6	17	1.7±0.9	21	96.1±42.5	3	41.6±13.2	2	*Halophila ovalis* *Halophila spinulosa*	*Halophila ovalis* *Halophila spinulosa*
LNGR1	Photographs could not be analysed by CPCe	-	0.0±0.0	20	No samples in quadrats	-	No samples in quadrats	-	*Halophila ovalis* *Halophila spinulosa*	*Halophila ovalis* *Halophila spinulosa*
LNGR2	Photographs could not be analysed by CPCe	-	Not surveyed	-	Macroalgae and Seagrass combined wet weight only	-	Not surveyed	-	*Syringodium isoetifolium* *Halophila ovalis*	Not surveyed

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
DSS1	Photographs could not be analysed by CPCe	-	0.0±0.0	19	13.2±4.0	2	4.0±0.8	2	*Halophila ovalis* *Halophila spinulosa*	*Halophila ovalis*

9.4.7 Description of Seagrass Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

9.4.7.1 Reference Sites in the Deep Soft Sediments east of the East Barrow Ridge

Four Reference Sites (DSR1, DSR3, DSR5 and DGI0) were located in the deeper (<18 m water depth) soft sediments east of the East Barrow Ridge. Mean seagrass biomass at DSR1, DSR3 and DGI0 was 0–90 g/m^2 in spring/summer (Table 9-4). Estimates of mean percentage cover (0–1%) and biomass (0–19 g/m^2) were lower in winter. *Halophila ovalis* was the most common seagrass recorded, occurring in sparse abundance at three of the sites in spring/summer (diver visual estimates <1–5%). *Halophila ovalis* was the only species observed at DSR5 and DGI0. *Halophila spinulosa* was the only species recorded at DSR1 with sparse cover in spring/summer (diver visual estimate <5%).

9.4.7.2 Reference Site on the West Coast of Barrow Island

Mean seagrass percentage cover (<1%) and mean biomass (9 g/m^2) were low in winter at the Reference Site on the west coast of Barrow Island at Biggada Reef (BR) (Table 9-4). *Syringodium isoetifolium* was the only species recorded on the transects at this site. No seagrass were recorded at this site in spring/summer.

Table 9-4 Seagrass Mean Percentage Cover ± SE, Mean Total Biomass ± SE and Dominant Species at Reference Sites not at Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m^2				Mean Biomass (g) ± SE/m^2				Dominant Species	
	Spring/ Summer	n	Winter	n	Spring/ Summer	n	Winter	n	Spring/ Summer	Winter
DSR1	Photographs could not be analysed by CPCe	-	1.0±0.5	21	89.7±23.1	4	18.8±2.7	4	*Halophila spinulosa*	*Halophila spinulosa*
DSR3	Photographs could not be analysed by CPCe	-	Not surveyed	-	26.4±22.8	2	Not surveyed	-	*Halophila decipiens* *Halophila ovalis*	Not surveyed
DSR5	Photographs could not be analysed by CPCe	-	0.0±0.0	21	No samples in quadrats	-	No samples in quadrats	-	*Halophila ovalis*	*Halophila ovalis*
DGIO	Photographs could not be analysed by CPCe	-	0.0±0.0	21	No samples in quadrats	-	No samples in quadrats	-	*Halophila ovalis*	*Halophila ovalis*
BR	0.0±0.0	21	0.5±0.3	21	No samples collected	-	9.0±3.8	4	No seagrass	*Syringodium isoetifolium*

9.5 Discussion

Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed, shading by infrastructure, physical removal of substrate through dredging, or smothering and burial in the Dredge Spoil Disposal Ground, is predicted to affect seagrass within the Marine

Facilities Footprint, the Dredge Spoil Disposal Ground and in some areas of the Marine Disturbance Footprint within the Zones of High and Moderate Impact. The areas at risk of Material Environmental Harm, caused by elevated turbidity from the dredge plume and by anchoring damage, include the Zones of Moderate Impact and those areas within Zones of High Impact that are not within the Marine Facilities Footprint or the Dredge Spoil Disposal Ground.

The Causeway footprint lies across the limestone pavement adjacent to Barrow Island; extending from the beach cliffs at Town Point, across the intertidal reef platform adjacent to the shore, out to approximately 7 m water depth at the Materials Offloading Facility (MOF) (Figure 2-1). The intertidal zone is approximately 200 m wide in this area and characterised by mixed turfing algae, with larger macroalgae and sparse seagrass in rock pools. Sparse assemblages of seagrass (*Halophila ovalis*, *H. spinulosa*, *Halodule* sp.) of varying cover were present on small sand patches scattered across the macroalgal-dominated subtidal platform reef.

The MOF footprint lies on the deeper subtidal area of the platform adjacent to the east coast of Barrow Island. There were sparse assemblages of seagrass (*H. ovalis*, *H. spinulosa*, *Halodule* sp.) on shallow patches of sand on the limestone pavement. The LNG Jetty footprint extends across the outer part of the limestone platform adjacent to Barrow Island for 500 m past the end of the MOF and then continues for a further 1200 m across the soft sediment assemblages in deeper water. The majority of the LNG Jetty footprint overlies habitat categorised as 'Soft Sediments with Sparse Sessile Taxa', including seagrass (e.g. *H. spinulosa*).

The Turning Basin footprint lies in 8–11 m of water over limestone pavement with a sand veneer. The dominant benthic category comprised soft sediment (unvegetated sand) with sparse sessile taxa at subdominant levels of cover, including sparse cover of seagrass. The LNG Jetty Access Channel footprint overlies a small section of the East Barrow Ridge (a raised limestone platform in approximately 7 m water depth) and the soft sediment habitats either side of the ridge. The area on East Barrow Ridge within the LNG Jetty Access Channel footprint was characterised by areas mapped as 'Macroalgae with Sparse Sessile Taxa', including patches of sediment (largely unvegetated bare sand) with subdominant levels of cover of seagrass.

The Dredge Spoil Disposal Ground footprint lies within an area mapped as 'Soft Sediments with Sparse Sessile Taxa'. These soft sediments supported scattered meadows of sparse seagrass (e.g. *H. spinulosa*).

The patchy distribution of seagrass, as well as the spatial variability in percentage cover, makes it difficult to estimate the total area of seagrass that will be impacted as a consequence of the construction of the Marine Facilities at Town Point. The construction of the Marine Facilities on the east coast of Barrow Island will result in the loss of approximately 35.5 ha (0.2%) within the Marine Facilities Footprint, of the total area of 'Macroalgae with Sparse Sessile Taxa' (~16 500 ha) in the Management Units on the east coast of Barrow Island.[5] The Marine Disturbance Footprint associated with the construction of the Marine Facilities will potentially impact on up to approximately 285 ha (1.7%) of the area of 'Macroalgae with Sparse Sessile Taxa'. The Marine Facilities Footprint will result in the loss of approximately 4.6 ha (0.02%) and the Marine Disturbance Footprint will potentially impact on up to approximately 441 ha (2%) of the total area of 'Soft Sediments with Sparse Sessile Taxa' (~22 400 ha).

9.6 Conclusions

Seagrass assemblages were reported in soft sediment habitats and on veneers of sand overlying limestone pavement, generally as small sparse patches rather than distinct beds. *Halophila spinulosa* was the most common species recorded in soft sediments, although abundance was

[5] Fourteen Management Units were defined to assess impacts to benthic primary producer habitats associated with the Gorgon Gas Development, 11 on Barrow Island and three on the mainland (Section 11.4, Chevron Australia 2005; Section 8.8, Part C, Chevron Australia 2006).

generally low with the seagrass occurring in small (<5 m^2) patches. The seagrass on the limestone pavement with sand veneers on the east coast of Barrow Island was most commonly small patches of *Halophila ovalis*, mixed with macroalgae and benthic macro-invertebrates. As reported for the macroalgal assemblages, seagrass assemblages were spatially variable in terms of their percentage cover, biomass and species richness.

The greatest species richness was recorded at DI1, located on the inshore limestone pavement north of Town Point. At the majority of sites, all seagrass species were generally recorded as being sparse (diver visual estimate <25% cover); with the exception of *H. ovalis* at TP2, located in the sandy channel east of the inshore limestone pavement. *Halophila ovalis* was the only species recorded as having >25% cover at any site in spring/summer. The highest percentage cover recorded for any one species was 40% for *H. ovalis* in spring/summer at TP2, located in the sandy channel east of the inshore limestone pavement. The highest mean biomass in spring/summer (89 g/m^2) was recorded at the Dredge Spoil Disposal Ground site DS1 and in winter (117 g/m^2) at TP4. The highest mean percentage cover (20%) was recorded at LC1 in spring/summer.

There were no clear patterns in percentage cover, biomass and species richness in relation to the location of sites in the Zones of High and Moderate Impact compared to sites in the Zones of Influence and Reference Sites outside the Zones of Influence. Nevertheless, all species recorded at sites in the Zones of High and Moderate Impact (*Halophila decipiens*, *H. ovalis*, *H. spinulosa* and *Syringodium isoetifolium*) were also recorded at sites within the Zones of Influence and at Reference Sites. All seagrass taxa at risk of Serious or Material Environmental Harm were also found outside these areas and were common within the local area and region.

10.0 Mangroves

10.1 Introduction

Mangroves along the northern coastline of Western Australia increase in species richness and diversity from the arid subtropics in the south with relatively small tides, to the tropical and humid Kimberley coast, which has a tidal range of >11 m (Alongi *et al.* 2005). The mangroves in the Pilbara region form relatively diverse fringing stands (Alongi *et al.* 2000), with trees often stunted but forming extensive forests (Duke 2006). The Grey Mangrove (*Avicennia marina*) and the Red Mangrove (*Rhizophora stylosa*) are the most commonly occurring species along the coastal plain, along with the Yellow-leaf Spurred Mangrove (*Ceriops tagal*) (Gordon *et al.* 1995; Alongi *et al.* 2000). Other species that occur in the region are the Club Mangrove (*Aegialitis annulata*), the River Mangrove (*Aegiceras corniculatum*) and the Ribbed-fruit Orange Mangrove (*Bruguiera exaristata*) (Chevron Australia 2005; DEC 2007).

Six species of mangrove are found in the Montebello/Barrow Islands region, including the Grey Mangrove, Ribbed-fruit Orange Mangrove, Yellow-leaf Spurred Mangrove, Red Mangrove, Club Mangrove and the River Mangrove (DEC 2007). The majority of mangrove forests in the area occur in the Montebello Islands (DEC 2007).

The Grey Mangrove (*Avicennia marina*) is the only species found around Barrow Island. This species is the most widespread mangrove species in Australia, found in coastal areas from Leschenault Estuary, Bunbury, Western Australia (33° 16' S; 115° 42' E), throughout northern Australia, to Corner Inlet, Victoria (38° 45' S; 146° 29' E) (Duke 2006). *Avicennia marina* is a tree or shrub that can grow to 10 m high and is categorised by its smooth bark that appears green when wet and chalky white when dry. The leaves are ovate-elliptical in shape and are 37–84 mm in length and 18–27 mm in width (Duke 2006). Flowering and maturation of *A. marina* propagules varies with latitude (Duke 2006). In the Barrow Island region, flowering often occurs between December and January while propagules mature mostly in March (Duke 2006). The pneumatophores of *A. marina* are often tall and slender and can reach heights of 30 cm. It grows in both soft sediments and on rock, as well as where sediment accumulates in the intertidal zone (KJVG 2008).

10.2 Scope

This Section records the dominant species of mangrove (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the mangroves:

- within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

10.3 Methods

10.3.1 Site Locations

Eight mangrove survey sites were selected in mangrove communities along the eastern and southern coasts of Barrow Island – at Square Bay, Mattress Bay, Perentie II Bay, Stokes Bay, Bandicoot Bay and Pelican Island (Table 10-1; Figure 10-1 and Figure 10-2). Six of these sites were located within the Zone of Influence and two Reference Sites (Bandicoot Bay and Pelican Island) were located outside the Zone of Influence. Aspect was considered in the selection of the survey sites as this is an important factor in relation to mangrove health, influencing the severity of impact from cyclone and storm events (Astron Environmental Services 2010).

Table 10-1 Mangrove Survey Sites

Location	Site Name (Code)	Easting	Northing	Latitude	Longitude
		(GDA94, MGA Zone 50)		(GDA94)	
Zone of Influence	Square Bay (BWISQ)	339638	7710880	20° 41.681' S	115° 27.615' E
	Mattress Bay North (BWIMTN)	340986	7706145	20° 44.254' S	115° 28.366' E
	Mattress Bay South (BWIMTS)	341167	7705389	20° 44.665' S	115° 28.466' E
	Perentie II Bay North (BWIP2N)	335121	7691780	20° 52.009' S	115° 24.906' E
	Perentie II Bay South (BWIP2S)	334290	7691118	20° 52.363' S	115° 24.423' E
	Stokes Bay (BWIST)	332713	7689488	20° 53.238' S	115° 23.504' E
Reference Sites	Bandicoot Bay (BWIBB)	326314	7691064	20° 52.348' S	115° 19.823' E
	Pelican Island (BWIPI)	326624	7691053	20° 52.356' S	115° 20.002' E

10.3.2 Methods

10.3.2.1 Mapping

High resolution aerial images of Barrow Island were analysed to map the distribution of mangroves in the area: a Barrow Island and Montebello Island aerial mosaic, as well as a more recent aerial photograph from 2005 (RPS 2009).

Aerial images were analysed using a Geographic Information System (GIS). The distribution of mangroves on Barrow Island along the intertidal shoreline was identified and the areas occupied by mangroves were delineated as polygons. The distribution of mangroves was then presented as polygons on scaled maps.

10.3.2.2 Vegetation Surveys

At each site, three permanent 1 m wide belt transects were installed perpendicular to the shoreline and intersecting the mangrove community (Astron Environmental Services 2010). Transect locations were selected to be representative of the general mangrove community (e.g. in terms of appearance and density) at each site. Each transect extended from the primary dune on the shoreward side of the mangroves to open water. The length and orientation of each transect thus varied depending on the size and extent of the mangrove community at each site. Transect lengths varied between 18 and 28 m at Square Bay and between 35 and 95 m at Stokes Bay. Species composition, estimated total canopy cover (m^2), the presence of mangrove seedlings and the total number of mangrove trees were recorded along each transect.

Five mangrove trees were randomly selected at each site and a digital light illuminance meter (Yokogawa 510-01 LUX Meter), which measures light at a single point through a translucent silicon dome of approximately 25 mm, was used to record incident light measurements from 40 randomly selected points beneath the canopy of each tree (i.e. a total of 200 under-canopy measurements per site) (Astron Environmental Services 2010). All light measurements were recorded at a fixed distance of 30 cm above the sediment surface. The mean canopy density for each tree was calculated as the inverse proportion of direct sunlight penetrating through the canopy. Ten additional light measurements were taken in direct unobstructed sunlight; five before and five after the measurements were recorded under each tree (i.e. a total of 50 unobstructed sunlight sample points per site). Light readings were taken between 10 am and 2 pm, during clear sky conditions.

Pneumatophore density was recorded at five randomly selected sample points along each transect (Astron Environmental Services 2010). At each point a 1 m^2 quadrat was positioned centred on the transect and the total number of exposed pneumatophores was recorded. Where numbers were too high to accurately count in the field, a digital photograph was taken and the total number of exposed pneumatophores counted.

Leaf pathology was assessed for five randomly selected trees within each site (Astron Environmental Services 2010). Six leaf pathogen indicators were assessed on each tree: leaf yellowing/discolouration, sooty mould, leaf galls, scaling, spotting and Nil Leaf Pathology (i.e. no indicators present). A count of all leaves with the six pathology indicators was taken from within a sub-sample of 100 randomly selected leaves. The sub-sample of leaves was spread throughout a four-sectioned stratified canopy on each sample tree, which included: coast-facing upper half, coast-facing lower half, dune-facing upper half and dune-facing lower half.

At each site, qualitative visual health assessments were recorded for ten mature/adult mangrove trees (i.e. trees with an established canopy, fully expanded foliage and good root distribution) (Astron Environmental Services 2010). Five of the trees corresponded with those selected for the leaf pathology assessment and five additional trees were randomly selected. Each tree was visually assessed and allocated a health score on six individual parameters based on the modified health score system developed by Eldridge *et al.* (1993) and Astron Environmental Services (2008) (Table 10-2). Based on the individual parameter scores, a total health score was derived to provide an overall estimate of mangrove health. The intent of the qualitative assessment was to complement and assist with the interpretation of the quantitative assessment.

Table 10-2 Qualitative Mangrove Health Scoring System

Damaged Leaves	
Total % Cover of Damaged Leaves	**Health Score**
100 – 90%	0
90 – 70%	1
70 – 50%	2
50 – 30%	3
30 – 10%	4
10 – 1%	5
<1%	6
Defoliated Branches	
Total % Cover of Completely Defoliated Branches	**Health Score**
100 – 90%	0
90 – 70%	1
70 – 50%	2
50 – 30%	3
30 – 10%	4
10 – 1%	5
<1%	6

New Foliage	
Total % Cover of New Leaves	**Health Score**
100 – 90%	6
90 – 70%	5
70 – 50%	4
50 – 30%	3
30 – 10%	2
10 – 1%	1
<1%	0
Canopy Cover/Density	
Total % Canopy Cover	**Health Score**
100 – 90%	6
90 – 70%	5
70 – 50%	4
50 – 30%	3
30 – 10%	2
10 – 1%	1
<1%	0
Reproductive Parts (flowers/fruits)	
Crypto-viviparous fruit (rounded)/flowers	**Health Score**
Absent	0
Present	1
Lateral Roots	
Exposed lateral roots from tree base	**Health Score**
Absent (Covered)	1
Present (Exposed)	0
TOTAL HEALTH SCORE (Totalled from scores above)	
Qualitative Description	**Health Score**
Heavily Defoliated/Dead	≤6
Degraded	7–10
Poor	11–14
Moderate	15–18
Good	19–22
Excellent	23–26

10.3.3 Timing and Frequency of Sampling

Sampling was undertaken in November 2009. This time of year is considered optimal for undertaking foliar and canopy-focused mangrove condition surveys as it is immediately prior to the commencement of flowering.[6]

10.3.4 Treatment of Survey Data

The quantitative canopy density and pneumatophore density data were analysed to determine if the data were normally distributed (Shapiro-Wilk test) (Astron Environmental Services 2010). Where the data were normally distributed, Analysis of Variance (ANOVA) using a multiple Tukey Honestly Significant Difference comparison test and a Dunnett's two-tailed test were used to analyse the population variance and significant differences between the site variables. Where the data were not normally distributed, Kruskal-Wallis (ANOVA equivalent) tests and a two-tailed Mann-Whitney U test (*t*-test equivalent) were used. All tests were conducted within a 95% Confidence Interval using XLSTAT (version 2008.3.02).

10.4 Results

10.4.1 Distribution of Mangroves around Barrow Island

Avicennia marina grows in sparse stands only on the east coast of Barrow Island (Figure 10-1 and Figure 10-2). It was distributed in a narrow band along soft sediment and rock substrates in the upper-littoral and supra-littoral zones of the intertidal area. Mangroves were recorded at Little Bandicoot Bay and Pelican Island, as well as further east at Bandicoot Bay, where a small number of trees extended further down the intertidal zone to the mid-littoral zone. Sparse stands of trees were recorded on the rocky intertidal shoreline from Stokes Point along the coast up to Shark Point. Stands of mangroves was also recorded further north at Mattress Bay, Ant Point and Square Bay. No mangrove stands were recorded on the west coast of Barrow Island.

[6] One tree on Pelican Island was observed flowering during the field program in November 2009 (Astron Environmental Services, pers. comm. November 2009).

Figure 10-1 Distribution of *Avicennia marina* along the North-east Coast of Barrow Island

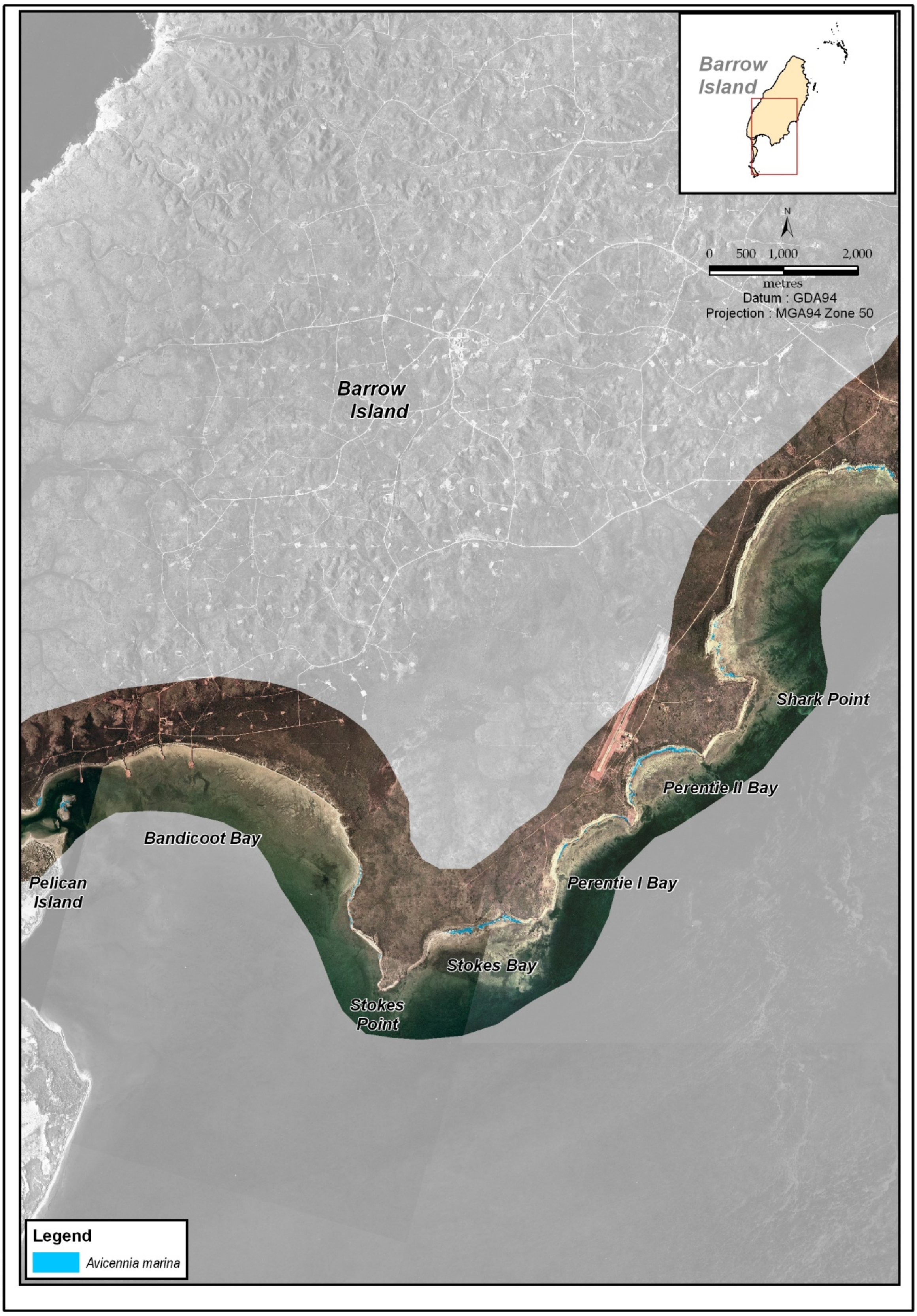


Figure 10-2 Distribution of *Avicennia marina* along the South Coast of Barrow Island

10.4.2 Description of Mangrove Communities at Representative Areas of the Zone of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal and at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

General descriptions of the mangrove survey sites are provided in Table 10-3.

Large variations in the quantitative light infiltration measurements were recorded between individual trees at each site. The highest mean canopy density, with mean canopy density calculated as the inverse proportion of direct sunlight penetrating the tree canopy, was recorded at Square Bay (82.9%) and the lowest at Perentie II Bay South (72.7%). However, there were no significant differences in mean canopy densities between the eight sites ($p < 0.302$).

There was considerable variability in pneumatophore densities between sites and between transects at the same site (Figure 10-3). Mean pneumatophore density was slightly lower at Zone of Influence sites (103 pneumatophores/m^2) compared to Reference Sites (122/m^2). The highest pneumatophore transect densities were recorded at Pelican Island, with a mean of 307 pneumatophores/m^2 recorded on Transect 2; the second highest density was recorded on Transect 1 at Square Bay (mean 242/m^2). The lowest density of pneumatophores (0/m^2) was also recorded on Transect 2 at Square Bay. There was also variability between quadrats and sampling position along the open beach. Densities of pneumatophores in quadrats varied between 0 pneumatophores/m^2 and 652/m^2 at Stokes Bay, however there were no significant differences in pneumatophore densities recorded in the quadrats at different sites ($p > 0.346$).

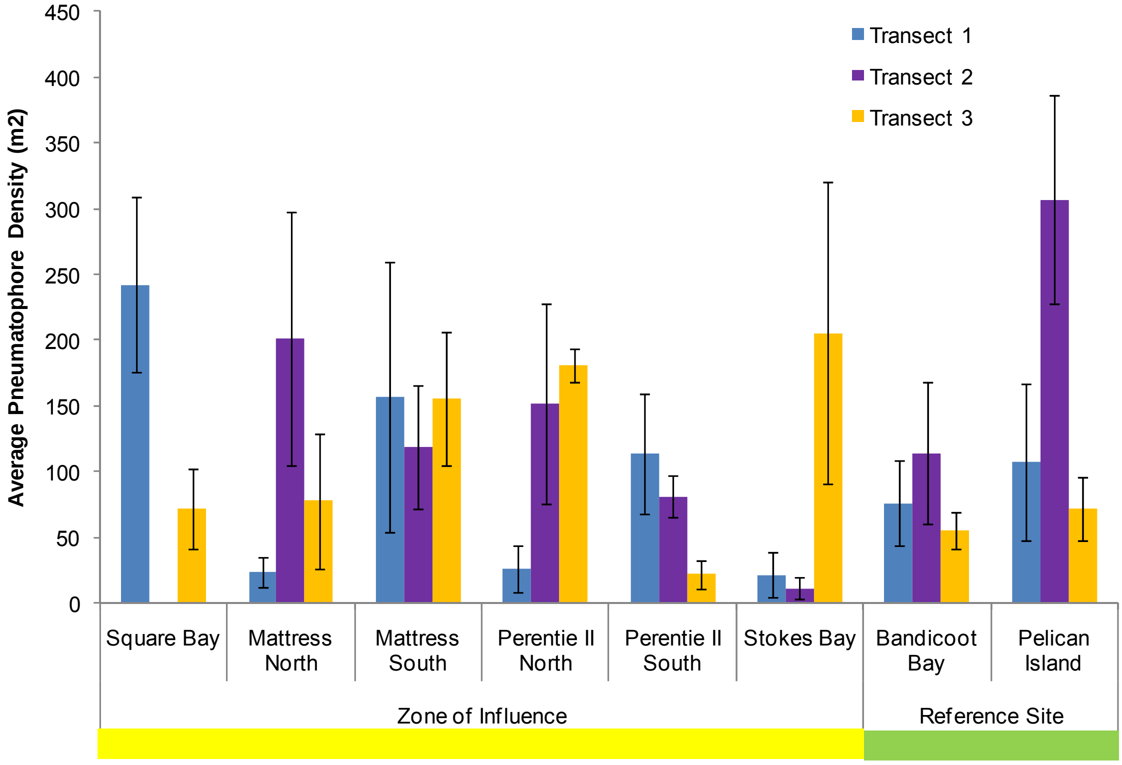


Figure 10-3 Mean (± SE) Pneumatophore Density Recorded on each Transect at each Site

Table 10-3 General Site Descriptions for each Mangrove Survey Site

Site	Mangrove Community Description	Orientation	Dominant Understorey Species
Square Bay	The mangroves at this site were located on a beach/dune system where the general appearance was very healthy with dense communities. Eighteen adult *A. marina* intersected the three transects although the overall size was small in comparison to the local Barrow Island mangrove community. The pneumatophore densities varied considerably at each of the three transects between ~1200 pneumatophores/m^2 at Transect 1, ~350 pneumatophores/m^2 at Transect 3 and 0 pneumatophores/m^2 at Transect 2. The pneumatophores at Transect 2 were completely covered from the beach/dune system. There were small numbers of seedling recruits.	Transect 1 faces south-east, Transect 2 faces east and Transect 3 faces north-north-east.	*Spinifex longifolius* (Beach Spinifex) on the primary dune.
Mattress Bay North	A wide open bay with expansive rocky tidal flats and a small dune system located behind the mangrove community. The mangrove community was medium sized and density in relation to the local Barrow Island mangrove community. Eleven adult *A. marina* trees intersected the three transects. The general condition of the mangrove community appeared healthy with minimal defoliation. There was no evidence of seedling recruitment. Pneumatophores at this site were all exposed.	South-east	*Spinifex longifolius* on the primary dune.
Mattress Bay South	Located on a small tidal inlet with a sediment foreshore. The mangrove community was medium to small in size and density in comparison to the local Barrow Island mangrove community. Thirteen adult *A. marina* intersected the three transects. The mangrove community appeared generally healthy with minimal leaf pathogens and defoliated branches. There was evidence of isolated seedling recruitment and a considerable number of pneumatophores were exposed.	North-north-east	A halophytic complex dominated by *Tecticornia halocnemoides* (Shrubby Samphire or Grey Glasswort) and *T. indica* on tidal flats. There was also a small primary dune system behind the mangroves dominated by *Triodia* spp. (Spinifex).
Perentie II Bay North	Located on expansive rocky tidal flats. The general size and density of the mangrove community was moderate in comparison to the local Barrow Island mangrove community. Total of 19 adult *A. marina* trees at this site; 11 on Transect 3. The general appearance of *A. marina* indicated that the trees were in healthy condition. There were also a considerable number of exposed pneumatophores and there was evidence of seedling recruitment along Transect 2.	South	A mixed halophytic complex of *Tecticornia* sp. with *Spinifex longifolius* occurring on the primary dune system.
Perentie II Bay South	The tidal flats were predominantly a rocky outcrop with scattered oyster beds. The mangrove community was medium to small in size and relatively dense in comparison to the local Barrow Island mangrove community. Seventeen adult *A. marina* trees intersected the three transects. The majority of the pneumatophores were covered by the rocky substrate and a thin layer of sediment. The general appearance of the mangrove community indicated that it was in good condition. There was no evidence of seedling recruitment.	East/north-east	A mixed halophytic complex and *Spinifex longifolius* in the primary dune.

Site	Mangrove Community Description	Orientation	Dominant Understorey Species
Stokes Bay	The tidal flats were predominantly a rocky outcrop that included a small narrow strip of mangrove community adjacent to the primary dune system. The overall size and density of the mangrove community at this site was moderate in comparison to the Barrow Island local mangrove community. Twenty-six *A. marina* trees intersected the three transects. There were some noticeable deaths of large adult trees on Transects 2 and 3, although the majority of the community appeared to be in good condition. There was no evidence of seedling recruitment and the majority of the pneumatophores were exposed with some limitations from the rocky substrate.	South	Predominantly a halophytic complex dominated by *Tecticornia halocnemoides* and *T. indica* on tidal flats with *Spinifex longifolius* occurring on the primary dune system.
Bandicoot Bay	Located on a beach/dune system. The overall size of the mangrove community was relatively small and the density was poor in comparison to the Barrow Island local mangrove community. Twenty adult *A. marina* located within the tidal zone and adjacent to the primary dune system. The mangroves located within the tidal zone appeared to be in better condition than the mangroves located near the primary dune. There appeared to be a higher percentage of branch defoliation and poor leaf condition on the mangroves near the primary dune. There were small numbers of seedling recruitment. The pneumatophores were covered near the coast side and became exposed closer to the primary dune.	East/east-south-east	A halophytic complex dominated by *Tecticornia halocnemoides* and *T. indica* on tidal flats and *Spinifex longifolius* on the primary dune system.
Pelican Island	Located on a small island. The size of the mangrove community was small and relatively dense in comparison to the Barrow Island local mangrove community. Transect 1 commenced on the oyster bed rocks and extended into the middle of the island, while Transects 2 and 3 were located on a small tidal inlet that provided the tidal zone for the mangrove community. Nineteen adult *A. marina* intersected the three transects. There was an abundance of pneumatophores and also a considerable number of seedling recruits.	Transect 1 faces west and Transects 2 and 3 face east.	A halophytic complex dominated by *Tecticornia halocnemoides* and *T. indica* on the tidal flats and the rocky outcrops.

Source: Astron Environmental Services 2010.

The site-averaged counts for each of the six leaf pathology indicators are presented in Figure 10-4. Leaf spotting was the most prevalent leaf pathology indicator at all the sites, with the highest incidence recorded at Perentie II Bay North (mean of 53.4 affected leaves per 100 leaf sample) and the lowest at Pelican Island (28.8/100 leaf sample). The mean number of yellowing leaves was highest at Mattress Bay South (16.8/100 leaf sample) and lowest at Square Bay (7.6/100 leaf sample). Mean leaf gall numbers were highest at Square Bay (22.6/100 leaf sample), Bandicoot Bay (20.8/100 leaf sample) and Mattress Bay South (20.0/100 leaf sample). They were lowest at Perentie II Bay South (10.4/100 leaf sample) and Mattress Bay North (10.6/100 leaf sample). The mean count of sooty mould affected leaves was generally similar across all the sites (13.2–24.6/100 leaf sample), with the exception of Square Bay where lower counts were recorded (3/100 leaf sample). Scaling was recorded at only two sites, Mattress Bay South (2.8/100 leaf sample) and Pelican Island (0.6/100 leaf sample).

All the leaves within each 100 leaf sample that did not contain any leaf pathology indicators were also recorded. The highest mean number of leaves per 100 leaf sample with 'nil' records of leaf pathogens were reported at Pelican Island (44.8/100 leaf sample), Square Bay (42.2/100 leaf sample) and Mattress Bay North (41.0/100 leaf sample). The lowest mean number of leaves per 100 leaf sample with 'nil' leaf pathogens were recorded at Perentie II Bay North (23.8/100 leaf sample), Bandicoot Bay (24.0/100 leaf sample) and Mattress Bay South (24.2/100 leaf sample).

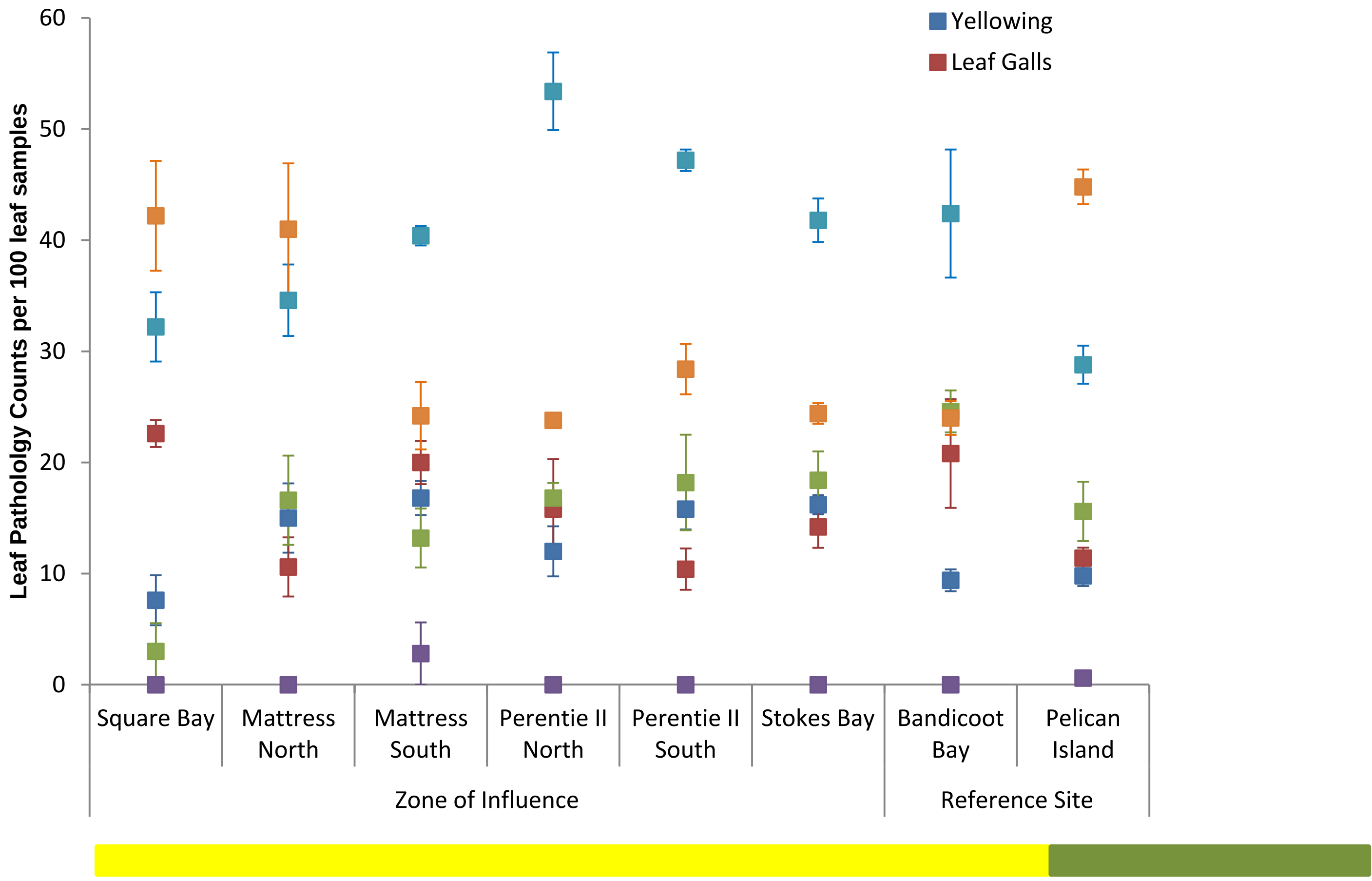


Figure 10-4 Mean (± SE) Leaf Pathology Counts per 100 Leaf Sample for each Site

Note: Leaves that did not contain any leaf pathology indicators were counted and recorded as 'nil'.

The mean qualitative visual health assessment scores for each site are presented in Figure 10-5. One site out of the eight surveyed, Square Bay, recorded a 'good' mean health score; six of the sites recorded a 'moderate' mean health score; while the Reference Site at Bandicoot Bay, recorded a 'poor' mean health score.

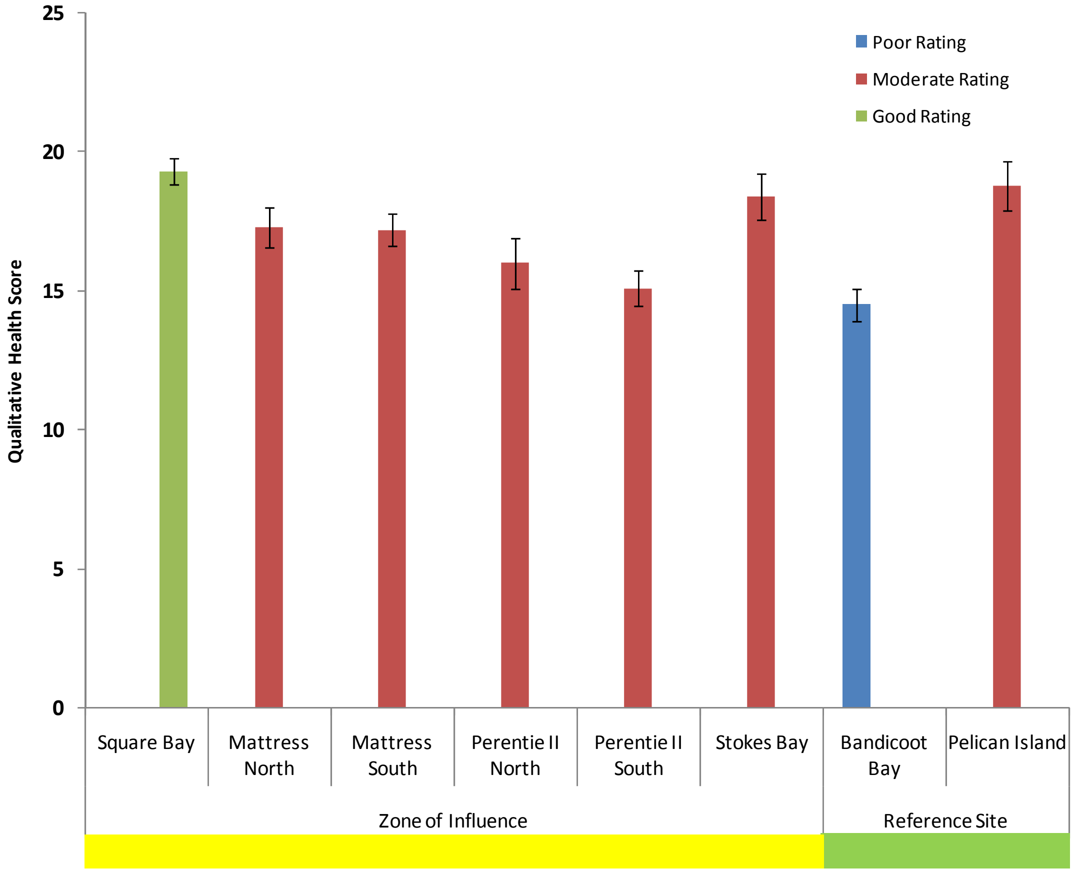


Figure 10-5 Mean (± SE) Qualitative Visual Health Assessment for Each Site

10.5 Conclusions

On Barrow Island, A*vicennia marina* grows as a narrow fringe in the sheltered embayments on the southern and eastern coasts from Bandicoot Bay to Shark Point, with small communities further north at Mattress Point, Ant Point and Square Bay. There are no stands of *A. marina* in the immediate vicinity of the Gorgon Gas Development facilities; the closest stands are located at the Donald River mouth, approximately 5 km north of Town Point (Chevron Australia 2005, 2008). There are no mangroves within the Zones of High and Moderate Impact on the east coast of Barrow Island, i.e. there is no mangrove cover relevant to the construction of the Materials Offloading Facility, LNG Jetty, Dredge Spoil Disposal Ground, or marine upgrade of the existing WAPET Landing. Similarly, there are no mangroves within the area at risk of Material or Serious Environmental Harm due to the construction or operation of the Materials Offloading Facility, LNG Jetty, Dredge Spoil Disposal Ground, or marine upgrade of the existing WAPET Landing.

There was natural spatial variability in both quantitative (light infiltration, pneumatophore density, leaf pathology) and qualitative (visual health score) assessments of mangrove communities on the east coast of Barrow Island, with variability generally observed at the quadrat, tree, transect and site scales. This indicates that there is a naturally high spatial variability in mangrove condition on Barrow Island. This variability was observed across sites in the Zone of Influence and at Reference Sites.

11.0 Demersal Fish

11.1 Introduction

There have been few ecological studies conducted on the fish species of north-western Australia, but the survey work to date has revealed a species-rich assemblage (Allen 1996; Hutchins 1999, 2001, 2003, 2004; Travers *et al.* 2006), with the North West Shelf in particular being considered a hotspot in terms of species richness (Fox and Beckley 2005). This reflects the strong biogeographic links with Indonesia and the west Pacific, facilitated by the Indonesian Throughflow and the diversity of available habitats in these waters (DEWHA 2008). However, the degree of endemism in the fish fauna of the North West Shelf is low when compared to the temperate waters of southern Western Australia (Fox and Beckley 2005).

Sampling conducted in tropical north-western Australia (in the Kimberley, Canning and Pilbara bioregions) between 2000 and 2002, yielded 23 377 fishes representing 32 families, 58 genera and 119 species (Travers *et al.* 2006). Of these, the most abundant species were *Lethrinus* sp. 3, Stripey Snapper *(Lutjanus carponotatus)* and Grass Emperor *(Lethrinus laticaudis)* (Travers *et al.* 2006). In the Pilbara bioregion specifically, the species that were found to typify fish assemblages were *Lethrinus* sp. 3, Stripey Snapper, Grass Emperor and Starry Triggerfish *(Abalistes stellatus)* (at Cape Preston) and *Lethrinus* sp. 3, Stripey Snapper and Spangled Emperor *(Lethrinus nebulosus)* (at Locker Point) (Allen 1998; Travers *et al.* 2006).

The Montebello/Barrow Islands region supports a rich diversity of fish fauna with 456 species from 75 families recorded during a Western Australian Museum survey in 1993 (Allen 2000), the majority of which exhibit wide distributions throughout the Indo–West Pacific region (DEC 2007). Two pipefish species recorded during this survey (*Doryrhamphus multiannulatis* and *Phoxocampus belcheri*) represent new records for Australia (DEC 2007). The region's fish fauna is considered to be closely related to that of the Dampier Archipelago (Hutchins 2004), which, along with other outer reef systems upstream in the Leeuwin Current, is thought to act as a supplementary recruitment source for the Montebello/Barrow Islands region (DEC 2007). Similarly, the Montebello/Barrow Islands region may act as a source of recruits for locations further south (DEC 2007).

A number of species occurring in the area are protected under Western Australian and Commonwealth legislation. These include, but are not limited to, the Potato Cod *(Epinephelus tukula)*, the Double-headed Maori Wrasse *(Cheilinus undulatus)* and species of syngnathids *(Hippocampus hystrix* and *Phoxocampus belcheri)*. Most of these species are regionally widespread (DEC 2007). In addition, numerous commercial and recreationally important fish species such as Spangled Emperor (*Lethrinus nebulosus*) and Bar-cheeked Coral Trout (*Plectropomus maculatus*) occur around Barrow Island (Chevron Australia 2005).

11.2 Scope

This Section records and describes the demersal fish assemblages characteristic of hard and soft coral, macroalgal, non-coral benthic macro-invertebrate, seagrass and mangrove communities (Condition 14.8.iii, Statement No. 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178):

- within the Zones of High Impact and the Zones of Moderate Impact and representative areas in the Zones of Influence, associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.v, Statement No. 800 and Condition 11.6.V, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the existing WAPET Landing (Condition 14.6.vi, Statement No. 800 and Condition 11.6.VI, EPBC Reference: 2003/1294 and 2008/4178)

- at Reference Sites not at risk of Material or Serious Environmental Harm due to construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.vii, Statement No. 800 and Condition 11.6.VII, EPBC Reference: 2003/1294 and 2008/4178).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

11.3 Methods

11.3.1 Site Locations

Surveys of the demersal fish assemblages that characterised hard and soft coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and bare sand communities were undertaken at 44 sites in the waters surrounding Barrow Island (Table 11-1). Note that seagrass (*Halophila* spp.) was present at three of the sessile benthic macro-invertebrates sites (DSI1, DSI2 and DSFR4-DGNR4/SIN7). The majority of sites surveyed in October 2008 were resurveyed in March 2009; additional sites were also surveyed in March to increase the statistical power of the sampling design. For further information, refer to the report Barrow Island Baseline Fish Survey Stereo BRUV: Fish Assemblages Associated with the Materials Offloading Facility, LNG Jetty and Dredge Spoil Disposal Ground (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix 6).

Table 11-1 Number of Demersal Fish Assemblage Survey Sites, Community-types and Dates

Survey Date	Location	Community-type			
		Coral	Macroalgae	Sessile Benthic Macro-invertebrates	Sand
October 2008	Zones of High Impact	1	-	2	-
	Zones of Moderate Impact	2	2	1	-
	Zones of Influence	5	4	4	1
	Reference	4	2	4	4
March 2009	Zones of High Impact	1	-	2	1
	Zones of Moderate Impact	2	2	-	1*
	Zones of Influence	4	5	2	3*
	Reference	3	3	2	8*

*Note: * Indicates a change in the observed habitat between the two baseline survey dates. One site from each of the following zones; ZoMI, ZoI and Ref (site SI1, SIN1 and SIFR3 respectively) were originally observed to be predominantly sessile invertebrates in 2008, but were observed to be predominantly sand in March 2009.*

Surveys of the demersal fish assemblages that characterise mangrove communities on the east coast of Barrow Island were undertaken in a relatively dense stand of mangroves at the southern end of Mattress Bay, located on the north-eastern coast of Barrow Island (Figure 11-1); in a relatively dense stand of mangroves at the eastern end of Stokes Bay located on the south-eastern coast of Barrow Island (Figure 11-2); and in Bandicoot Bay located on the southern coast of Barrow Island (Figure 11-3). The area of mangroves in Bandicoot Bay was small compared to those in Mattress Bay and Stokes Bay, and sampling was thus undertaken across the whole area of the sand flat. The substrate in the survey area at Mattress Bay was a mix of rock and sand, while at Stokes Bay the substrate was predominantly rock with large intertidal pools in the sand. There are no mangroves within the Zones of High and Moderate Impact on the east coast of Barrow Island. The mangrove stands at Mattress Point and Stokes Bay were within the Zone of Influence. The mangrove stands at Bandicoot Bay were located outside the Zone of Influence and thus represent a Reference Site.

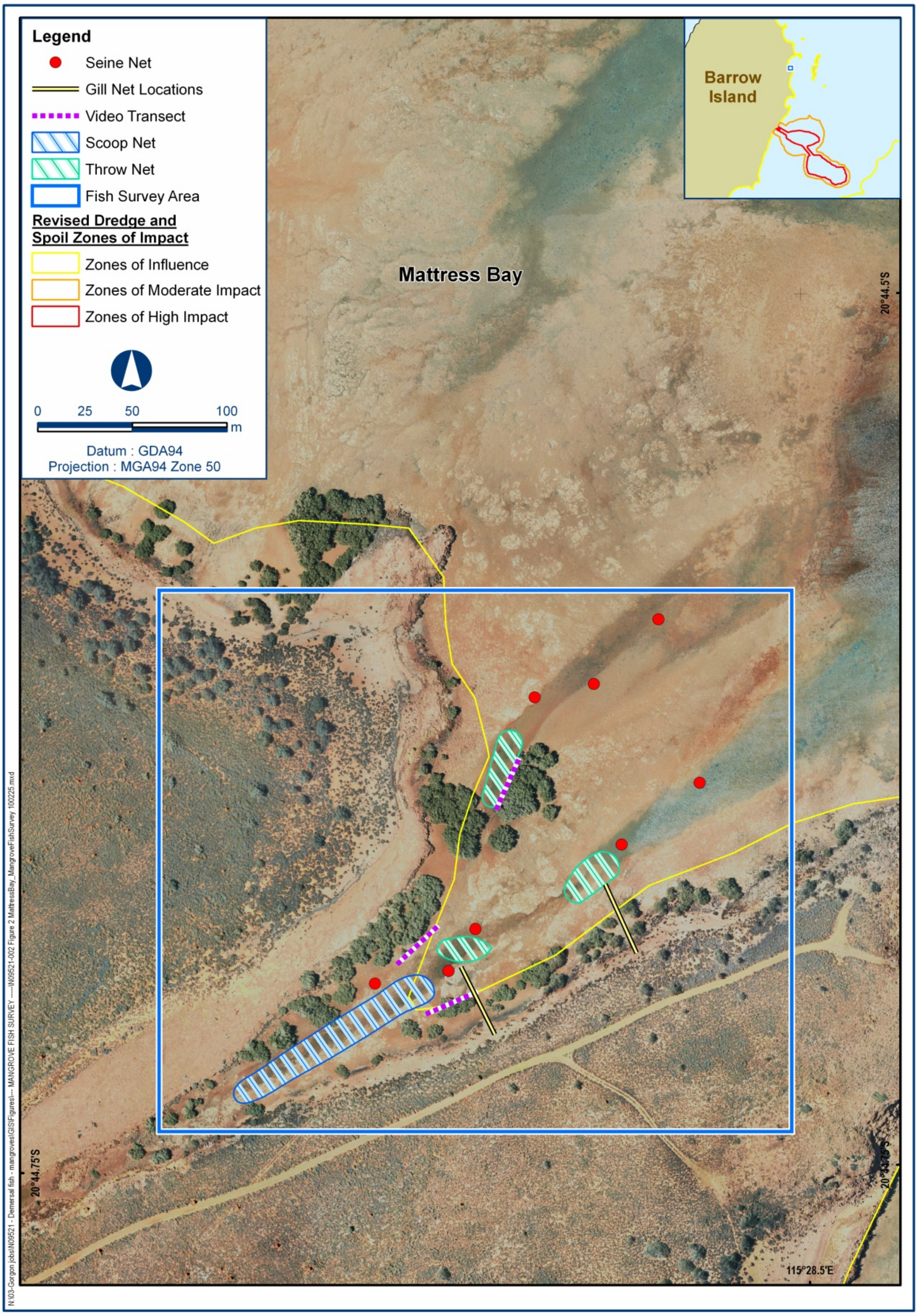


Figure 11-1 Fish Survey Areas in Mattress Bay

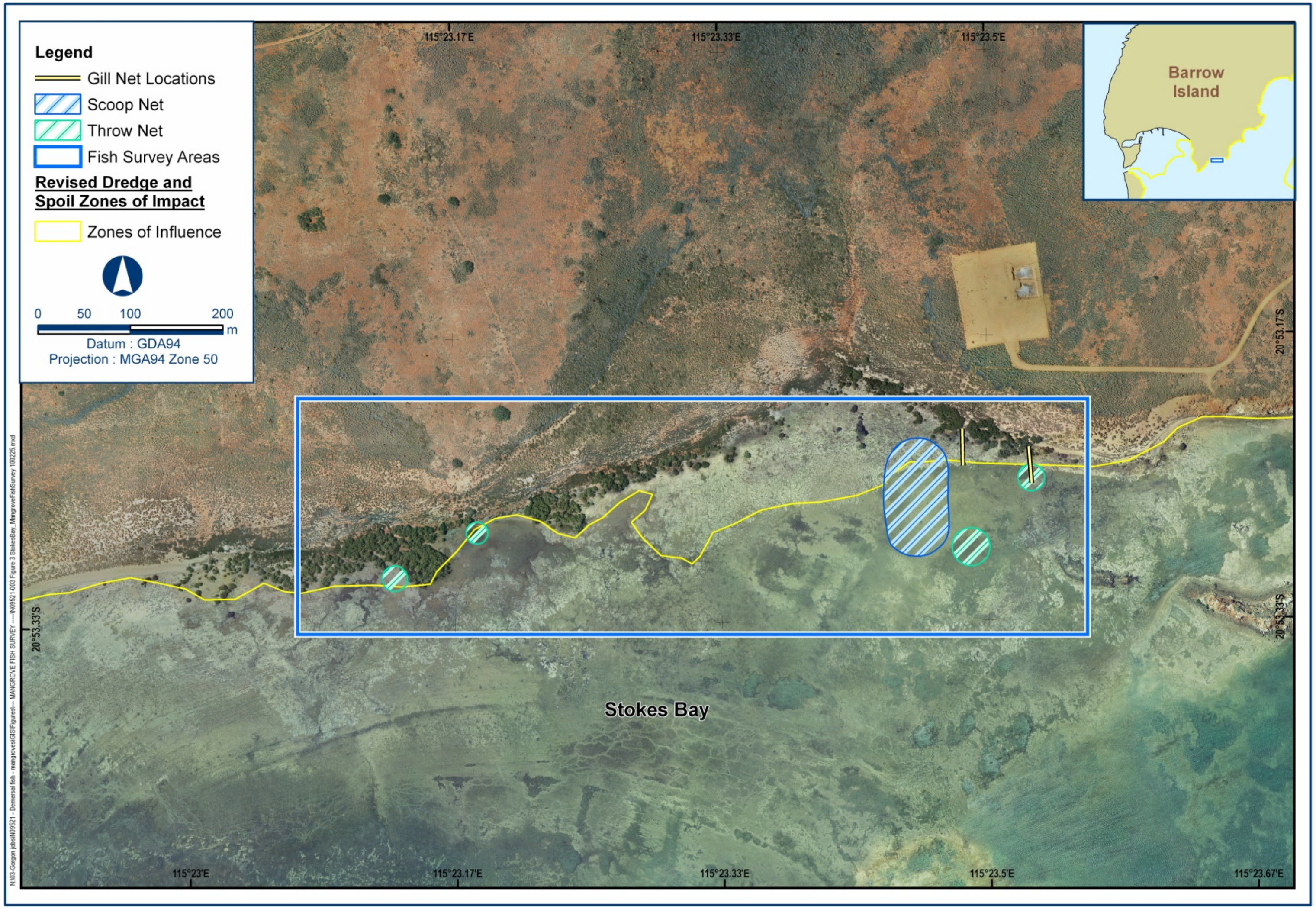


Figure 11-2 Fish Survey Areas in Stokes Bay

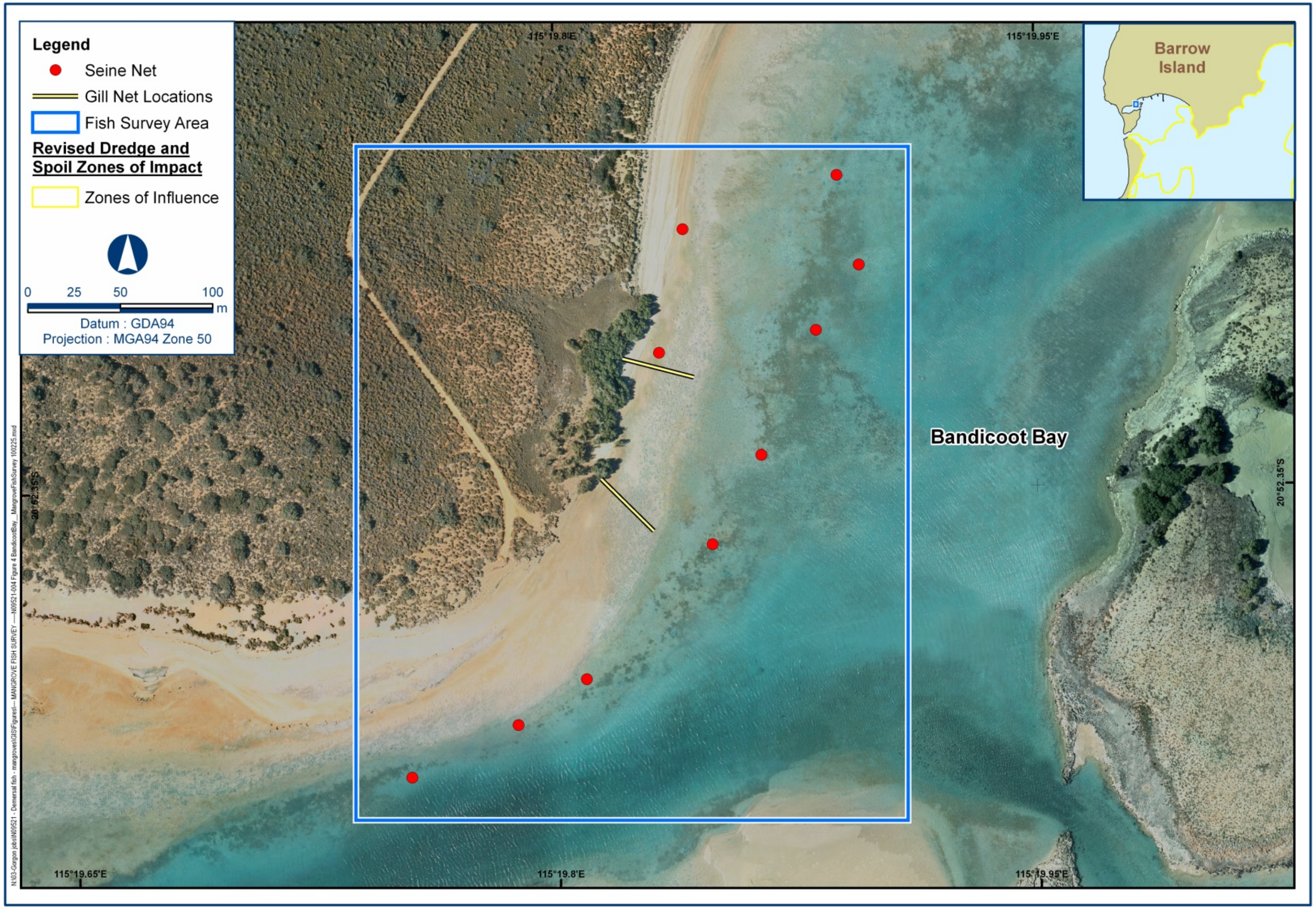


Figure 11-3 Fish Survey Areas in Bandicoot Bay

11.3.2 Methods

The demersal fish assemblages that characterised hard and soft coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and bare sand communities were surveyed using baited remote underwater stereo-video systems (stereo BRUVs). Five stereo BRUVs were deployed synchronously at each site for at least one hour, with at least 250 m between each deployment. Note that on some occasions, the stereo BRUVs landed with the camera facing upwards and this footage was not analysed. If either camera was obscured or out of focus, fish fork lengths were not able to be measured as both cameras are required for length measurements. Information on the design, measurement and calibration procedures are presented in the report Barrow Island Baseline Fish Survey Stereo BRUV: Fish Assemblages Associated with the Materials Offloading Facility, LNG Jetty and Dredge Spoil Disposal Ground (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix 6) and references therein.

The demersal fish assemblages that characterised mangrove communities were surveyed using a combination of gill, seine, throw and scoop nets with varying mesh sizes. The combination of sampling methods used at each survey site was determined by factors such as substrate type and water depth, with not all sampling methods suitable at each site. The mesh sizes (where applicable), area or length of net, duration of deployment (where applicable) and number of replicates are presented in Table 11-2 for each site and sampling method. Stereo BRUVs were not considered suitable for deployment in mangrove communities because of the shallow water, high turbidity and difficulties accessing the sites using a vessel.

Table 11-2 Dimensions and Number of Replicates for each Sampling Method at each Mangrove Survey Location

Survey Method	Mesh Size and Effort (area or time)			Replicates		
	Stretched Mesh Size	Area or length	Time	Mattress Bay	Stokes Bay	Bandicoot Bay
10 m Seine Net	4 mm	10 m	-	5	0	5
25 m Seine Net	6 mm	25 m	-	3	0	5
Gill Net	~10 cm and ~15 cm	40 m with 2.5 m drop	2 hours	2	2	2
Throw Net	10 mm	5 m^2	-	14	7	0
Video Transects	-	30 m	-	3	0	0

At each site, two gill nets were set perpendicular to the shoreline in a maximum water depth of approximately 1.5 m, approximately 150 m apart, to sample larger fish species, rays and sharks. The nets were set on a low tide and remained in place for a period of approximately two hours over the rising tide. The gill nets were monitored at all times in order to reduce fish mortality.

Seine nets have a much smaller mesh size than gill nets and sample smaller fish. Two seine nets were used, one 10 m in length with a 4 mm mesh and the other 25 m in length with a 6 mm mesh. A combination of 10 m and 25 m seine net collections were undertaken at each site where practicable. The seine nets were deployed either side of the high tide (incoming and outgoing) outside the period of inundation of the gill nets. Nets were walked out from the beach, stretching the net out parallel to the shoreline, and then rapidly dragging the net towards the shore. The number of replicate seine net drags at each site was determined by the area of sandy substrate available. Because of the risk of entanglement in rock/reef areas, seine netting was only effective over relatively flat, sandy substrates. At Bandicoot Bay there was an expansive area of sandy substrate and equal numbers of replicate 25 m and 10 m seine drags were undertaken. At Mattress Bay the number of replicate drags of the 25 m seine net was limited by the size of the areas of sandy substrate. Seine netting was not undertaken at Stokes Bay where the intertidal area was a coarse rock platform.

The throw net and scoop nets were used to target intertidal pools and also had a small mesh size capable of sampling small fish. Scoop nets were used to sample fish in small, shallow pools, whereas throw nets were used to target fish in pools greater than approximately 2 m in diameter. Throw and scoop nets were used either side of the high tide (incoming and outgoing) outside the period of inundation of the gill nets and when there was no water flowing into or out of the pools. The number of throw net collections was determined by the number of intertidal pools at each site, and multiple throw net collections were undertaken in larger pools.

Video footage was used to identify cryptic species that sheltered among the mangrove trees and were less likely to be sampled using nets. Video transect surveys were only possible at the Mattress Bay site due to sufficient water inundating the mangroves (less than ~10 cm of water reached the mangroves in Stokes Bay and Bandicoot Bay). Video transects were swum in straight lines along the base of the mangrove trees for a distance of approximately 30 m. The transect covered a survey width of approximately 2 m and the video camera was focussed on fish observed within this area for species identifications and counts. Filming was undertaken using a Sony DCR-HC52 with a x0.7 wide end conversion lens in a Top Dawg waterproof housing. A total of three video transects were completed at the Mattress Bay site in a water depth of approximately 0.5 m.

All fish sampled were identified to species level in the field where practicable; where this was not possible a sub-sample was preserved for subsequent identification based on an analysis of fin rays, scale and other distinguishing features. Fork lengths of the seven to ten most abundant species were recorded to the nearest millimetre, using a steel ruler or measuring tape. Note that a large number of the species caught were represented by a few individuals. Where large numbers of fish were collected, a sub-sample of approximately 100 individuals of each species was measured for fork length. Once at least 100 fish were measured, the remaining individuals of that species were counted and released. Generally, fish from the families Atherinidae and Gobiidae could not be reliably identified to species level in the field due to their small size and numerous similarities of sympatric members. Subsequent identification of a sub-sample of fish from these families indicated that samples contained two species from the Atherinidae family (Hardyheads) and three species from the Gobiidae family. The different species from each family were pooled for data analysis.

11.3.3 Timing and Frequency of Sampling

Surveys of the demersal fish assemblages that characterised hard and soft coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and bare sand communities were undertaken in October 2008 and March 2009. Surveys were undertaken in different seasons to provide additional statistical power to detect potential impacts and to ensure comprehensive coverage of community-types within each of the dredge management areas. Demersal fish assemblages were surveyed during daylight hours and therefore descriptions of species composition and abundance only reflect daylight hours. Additional species may be recorded and abundance-dominance patterns may be altered through inclusion of crepuscular and night-time sampling of fish assemblages.

Surveys of the demersal fish assemblages that characterised mangrove communities were undertaken in December 2009 during daylight hours over a spring tide period. One day was spent sampling at each site.

11.3.4 Treatment of Survey Data

11.3.4.1 Stereo BRUVs

Demersal fish assemblages that characterised hard and soft coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and bare sand communities were described in terms of the number of species, abundance of species, their commonality (number of sites) and size structure. A two-factor multivariate analysis was conducted to assess overall community-type effects on the fish assemblages, and a three-factor multivariate analysis was conducted to assess whether there were differences in the fish assemblages across the different dredge management areas and across community-types. Fish assemblages at sites within the Zones of Influence were also compared to those at Reference Sites. Patterns in the size structure of the fish assemblages were compared using length–frequency histograms and tested using a Kolmogorov–Smirnov distribution test. Further information on the statistical analyses undertaken is presented in the report Barrow Island Baseline Fish Survey Stereo BRUV: Fish Assemblages Associated with the Materials Offloading Facility, LNG Jetty and Dredge Spoil Disposal Ground (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix 6).

11.3.4.2 Seine and Throw Nets

Relative abundance data are presented for all fish species captured by the seine and/or throw nets, and length data are presented for the seven most abundant species. The areas surveyed by the seine and throw nets were quantified and the data from these two survey methods were pooled to determine the estimates of relative abundance of each species. Relative abundance data were standardised between methods and different seine net sizes by converting fish numbers to fish per m^2. Each drag of the seine net was counted as a replicate and the area for each drag was estimated based on the width at the mouth of the net and distance dragged. Each deployment (throw) of the throw net was similarly treated as a replicate and area was based on the area of the net when extended (5 m^2). The length data were also derived from a combination of seine and/or throw net collections.

11.3.4.3 Gill Nets

Relative abundance data for each fish species sampled by the gill nets was determined based on the total number of fish captured for each species divided by the total length of net deployed (80 m) and duration of deployment (two hours). The relative abundance of fish species captured in the gill nets is presented as fish per hour per metre of net.

11.3.4.4 Scoop Nets

Scoop netting is a method of targeted sampling requiring fish to be visible within a pool and directly selected with the net. It is therefore not possible to estimate relative abundance or density and these data were only used for species presence/absence.

11.3.4.5 Video Transects

Relative abundance was calculated on a fish per metre basis. Each transect was approximately 30 m long and the total abundance of fish observed was divided by 30 for each transect. The mean relative abundance was calculated from the three replicate transects.

The demersal fish assemblages characteristic of the mangrove communities at each site were described in terms of the number of species, relative abundance of each species and the size-structure of the most abundant species. Descriptive statistics (e.g. mean and standard errors) for the replicate samples were used to summarise the relative abundance and length data.

11.4 Results

11.4.1 Description of Demersal Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities in Barrow Island Waters

The results are presented in full in the report Barrow Island Baseline Fish Survey Stereo BRUV: Fish Assemblages Associated with the Materials Offloading Facility, LNG Jetty and Dredge Spoil Disposal Ground (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix 6 and Appendix 7). Note that while the focus of the surveys was on describing the demersal fish assemblages that characterised hard and soft coral, macroalgae, soft sediments with sessile benthic macro-invertebrates and bare sand communities, transient species (e.g. mackerel species [scombrids], trevally species [*Carangoides* spp.]) were also recorded and included in the analyses as a number of these species were consistently common and abundant during both survey periods and they exhibited strong links to particular community-types.

During the first survey in October 2008, a total of 11 393 individuals from 248 species and 52 families were recorded from 150 stereo BRUV deployments. On average 17.5 ± 0.8 species were observed during each stereo BRUV deployment. The highest species richness recorded for a single deployment was 49 species at a coral site within the Dredge Spoil Ground Zone of Influence. Numbers recorded in the second survey in March 2009 were similar with a total of 13 440 individuals from 247 species and 54 families recorded from 183 stereo BRUV deployments. On average 17.0 ± 0.8 species were observed during each stereo BRUV deployment. The highest species richness recorded for a single deployment was 50 species at a coral Reference Site located in the Montebello Islands.

The most diverse family recorded at Barrow Island was the labrids, with 31 species recorded in 2008 and 29 species in 2009, followed by pomacentrids (25 and 26 species respectively), serranids (14 and 16 species respectively), carangids (13 and 15 species respectively) and chaetodontids (13 and 15 species respectively). During 2008, the five most common demersal fish species were the Blue Tuskfish (*Choerodon cyanodus*), Blackspot Tuskfish (*Choerodon schoenleinii*), Northwest Threadfin Bream (*Pentapodus porosus*), Purple Threadfin Bream (*Pentapodus emeryii*) and the Bluespotted Tuskfish (*Choerodon cauteroma*). In 2009, the five most common demersal species were Northwest Threadfin Bream, Blue Tuskfish, Blackspot Tuskfish, Bar-cheeked Coral Trout (*Plectropomus maculates*) and the Bluespotted Tuskfish.

There were significant among-community-type differences in fish assemblages in terms of species richness, relative abundance, and composition and size structure on both survey occasions. Fish assemblages characteristic of coral communities were the most species rich, characterised by the high abundance of many small-bodied pomacentrids and the common occurrence of larger serranids, labrids, lutjanids and lethrinids. In contrast, fish assemblages characteristic of macroalgae communities were characterised by high abundances of lethrinids, nemipterids and labrids, as well as the presence of juveniles of many different species (lethrinids, siganids and labrids) indicating that macroalgal habitats act as important nursery grounds for numerous fish species, including those where the adults were observed in different community-types. Stereo BRUVs deployed in areas of sand were often visited by transient predators, including carangids and scombrids. Also high in abundance in these areas were monacanthids, nemipterids and tetraodontids. The fish assemblages characteristic of areas of soft sediments with sessile benthic macro-invertebrates had high abundances of lethrinids, nemipterids and carangids. In general, the fish assemblages characteristic of sand and soft sediments with sessile benthic macro-invertebrate communities were less species rich than those in coral or macroalgae communities during daylight over the survey periods and with the gear employed. Fish assemblage structure in soft sediments with sessile benthic macro-invertebrate communities tended to not be as uniform as those in bare sand.

The size structure of the fish assemblages varied across the four community-types. Fish assemblages characteristic of coral communities comprised a greater proportion of larger-bodied individuals (>240 mm fork length) than the other community-types, reflecting a higher abundance and commonality of many lethrinids, lutjanids and serranids. The size structure of the fish assemblages characteristic of macroalgae communities were significantly different to the other community-types, with the exception of those characteristic of soft sediments with sessile benthic macro-invertebrates, despite comprising different species. These assemblages were characterised by a high proportion of individuals in the 80–200 mm fork length range, reflecting the higher abundance of nemipterids and juvenile *Lethrinus* (Emperor) and *Choerodon* (Tuskfish) species. Fish assemblages characteristic of soft sediments with sessile benthic macro-invertebrates comprised a large proportion of individuals in the 120–240 mm fork length size range.

There were some differences in the fish assemblages between the two surveys. These differences reflected the presence/absence of schooling species, the varying community-type locations of schooling species, and the varying presence of juveniles.

11.4.2 Description of Demersal Fish Assemblages Characteristic of Mangrove Communities in Barrow Island Waters

A total of 4645 fish, representing 42 species and 25 families, were collected using seine, gill, scoop and throw nets in mangrove communities at Mattress Bay, Stokes Bay and Bandicoot Bay (Table 11-3). The greatest number of fish were sampled at Bandicoot Bay (3520 individuals), with lower numbers at Mattress Bay (1000 individuals) and Stokes Bay (125 individuals). Seventeen species were also recorded in the video transects at Mattress Bay; two of these species (Blackspot Tuskfish [*Choerodon schoenleinii*] and Mangrove Whipray [*Himantura granulata*]) were not otherwise recorded in the seine, gill, or throw nets. In addition a number of fish species were recorded from visual sightings in shallow water at each of the survey sites.

Table 11-3 Total Number of Fish Species Recorded at each Survey Location Sampled using Different Methods

Sampling Location	Seine Nets	Gill Nets	Throw Net	TOTAL
Mattress Bay	16	1	12	23
Stokes Bay	-	6	10	16
Bandicoot Bay	18	4	-	22
TOTAL	**25**	**7**	**16**	**39**

The full list of recorded species (47 species), sampling method and their occurrence at the three sites surveyed is presented in Table 11-4. Six of the species were recorded at all three sites and 17 at two of the sites. Larger fish, rays and sharks were observed using the mangrove habitat and adjacent intertidal flats as feeding areas during periods of inundation at high tide.

Table 11-4 Demersal Fish Species Recorded and the Sampling Method in the Mangrove Communities at each Survey Location

Family	Genus species	Common Name	Survey Location		
			Mattress Bay	Stokes Bay	Bandicoot Bay
Atherinidae	*Atherinomorus endrachtensis*	Endracht Hardyhead	S, T, VT	T	S
	Craterocephalus capreoli	Rendahls Hardyhead			
Blenniidae	*Salarius fasciatus*	Banded Blenny	-	-	S
Bothidae	*Pseudorhombus elevatus*	Deep-bodied Flounder	S, T	-	S
Carangidae	*Caranx ignobilis*	Giant Trevally	-	G	-
	Gnathanodon speciosus	Golden Trevally	VT	-	S
	Scomberoides commersonnianus	Giant Queenfish	-	G	-
	Trachinotus blochii	Snub-nosed Dart	-	-	S
Carcharhinidae	*Carcharhinus cautus*	Nervous Shark	G	G	G
	Carcharhinus melanopterus	Blacktip Reef Shark	-	G	G
	Negaprion acutidens	Lemon Shark	-	G	G
Chanidae	*Chanos chanos*	Milkfish	-	G	-
Dasyatidae	*Himantura granulata*	Mangrove Whipray	VT, V	V	V
	Pastinachus sephen	Cowtail Stingray	-	V	-
	Taeniura lymma	Bluespotted Fantail Stingray	V	V	-
	Taeniura meyeni	Blotched Fantail Ray	-	-	V

Family	Genus species	Common Name	Survey Location		
			Mattress Bay	Stokes Bay	Bandicoot Bay
	Urogymnus asperrimus	Porcupine Ray	-	-	S
Gerreidae	*Gerres oyena*	Common Silver Biddy	S, T, VT	T	S
Gobiidae	*Acentrogobius caninus*	Tropical Sand Goby	S	-	S
	Acentrogobius janthinopterus	Robust Mangrove Goby			
	Amoya gracilis	Mangrove Goby			
	Amblygobius sp.	Goby	-	T	-
	Amblygobius phalaena	Banded Goby	S, VT	-	S
Harpodontidae	*Saurida gracilis*	Slender Grinner	-	-	S
Hemiramphidae	*Arrhamphus sclerolepis*	Snub-nosed Garfish	-	-	S
Labridae	*Choerodon cyanodus*	Blue Tuskfish	T, VT	-	-
	Choerodon schoenleinii	Blackspot Tuskfish	VT	-	-
Lutjanidae	*Lutjanus argentimaculatus*	Mangrove Jack	T	-	-
	Lutjanus fulviflamma	Blackspot Snapper	S, T, VT	T	-
	Lutjanus russellii	Moses' Snapper	T	T	-
Mugilidae	*Liza argentea*	Flat-tail Mullet	S, T	T, V	S
	Liza vaigiensis	Diamond-scale Mullet	T, VT	V	-
Nemipteridae	*Scaevius milii*	Coral Monocle Bream	S, VT	T	S
Platycephalidae	*Platycephalus endrachtensis*	Bar-tailed Flathead	T	-	S
Pomacentridae	*Abudefduf septemfasciatus*	Banded Sergeant	S, VT	T	-
Rhinobatidae	*Rhinobatos typus*	Giant Shovelnose Ray	VT, V	-	G
Scatophagidae	*Selenotoca multifasciatus*	Striped Butterfish	S, VT	-	-
Serranidae	*Epinephelus coioides*	Goldspotted Rockcod	-	T	-
	Epinephelus malabaricus	Blackspotted Rockcod	S, VT	V	-
Sillaginidae	*Sillago burrus*	Trumpeter Whiting	S	-	S
Sparidae	*Acanthopagrus latus*	Western Yellowfin Bream	T, VT	-	-
Sphyraenidae	*Sphyraena barracuda*	Great Barracuda	S	-	-
	Sphyraena jello	Pickhandle Barracuda	-	-	S
	Sphyraena putnamiae	Saw-tooth Barracuda	S, VT	-	S
Terapontidae	*Amniataba caudovittata*	Yellowtail Trumpeter	S, T, VT	T	-
Tetraodontidae	*Arothron manillensis*	Narrow-Lined Toadfish	-	-	S
	Torquigener hicksi	Hick's Toadfish	S	-	-

Note: S = seine net; G = gill net; T = throw net; VT = video transect; V = visual observation

11.4.3 Description of Demersal Fish Assemblages within the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

11.4.3.1 Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities at Sites in the Vicinity of the MOF and Causeway and LNG Jetty Access Channel

There were no differences in the species richness, relative abundance and composition of fish assemblages between the Zone of High Impact, Zone of Moderate Impact and the Zone of Influence for both sampling occasions.

There were some minor differences in the size structure of fish assemblages between the different zones, reflecting high abundances of particular species at certain sites. For example, the coral site surveyed in the Zone of High Impact recorded a different fish assemblage size structure to coral sites in the Zone of Moderate Impact and the Zone of Influence due to the presence of schooling Neon Fusilier (*Pterocaesio tile*) in 2008 and schooling Threadfin Pearl Perch (*Glaucosoma magnificum*) in 2009. For macroalgae communities, the size structure of fish assemblages differed between all of the zones on each sampling occasion. For example in 2008, sites within the Zone of Moderate Impact had a higher proportion of individuals in the 160–200 mm fork length range than sites in the other zones because of high numbers of small Emperor (*Lethrinus* sp.). In contrast, there was no difference in the size structure of fish assemblages in soft sediments with sessile benthic macro-invertebrate sites across the zones in 2008, while a sand site in the Zone of High Impact sampled in 2009 had a similar size structure to the sand site within the Zone of Influence, but both had different size structures to the site within the Zone of Moderate Impact.

11.4.3.2 Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities at Sites in the Vicinity of the Dredge Spoil Disposal Ground

The most common and abundant fish species observed at the sites within the Zone of High Impact at the Dredge Spoil Disposal Ground were Northwest Threadfin Bream (*Pentapodus porosus*) and Gold-spotted Trevally (*Carangoides fulvoguttatus*). In general, the majority of species recorded at the Dredge Spoil Disposal Ground sites were typical of soft sediments with sessile benthic macro-invertebrate communities.

There were some differences in the size structure of fish assemblages between the different zones. In 2008, the site within the Zone of Influence had a different size structure of fish assemblages to the sites in the Zone of High Impact, reflecting the higher abundances of Northwest Threadfin Bream (*P. porosus*) at this site. There were no differences in size structure of fish assemblages in 2009.

11.4.4 Description of Demersal Fish Assemblages at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

The WAPET Landing area has been classified as a macroalgal fish habitat. Given the high level of association between habitat and fish assemblages demonstrated within the survey report, the fish assemblage at risk of Material or Serious Environmental Harm (Section 2.3.4) due to the marine upgrade of the existing WAPET Landing is expected to be similar to that recorded at the macroalgal sites to the south. The fish assemblage at this location is therefore likely to be similar to that characteristic of macroalgal habitats elsewhere around Barrow Island and include fish from the families Labridae, Lethrinidae, and Nemipteridae, with species from the genus *Choerodon* and *Pentapodus* most common.

11.4.5 Description of Demersal Fish Assemblages at Representative Areas of the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

11.4.5.1 Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities at Sites in Representative Areas of the Zones of Influence in the Vicinity of the MOF and Causeway and LNG Jetty Access Channel

Representative areas in the Zone of Influence in the vicinity of the MOF, Causeway and LNG Jetty Access Channel included four coral sites, four macroalgal sites and four soft sediments with sessile benthic macro-invertebrate sites in 2008. The same number of sites was sampled in 2009, with some variation in community-types. The fish assemblages characteristic of the coral communities in the Zone of Influence were not significantly different to those surveyed in coral communities within the Zones of High and Moderate Impact. Large serranids and lethrinids and small pomacentrids were common.

Macroalgal communities were characterised by high abundance of lethrinids, labrids, siganids and nemipterids. Tuskfish species (*Choerodon* spp.) were common with many juveniles observed (*C. cauteroma, C. cyanodus, C. schoenleinii* at >70% of drops). Families characteristic of soft sediments with sessile benthic macro-invertebrates communities within the Zone of Influence were the nemipterids, scombrids, mulled and labrids.

11.4.5.2 Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities at Sites in Representative Areas of the Zones of Influence in the Vicinity of the Dredge Spoil Disposal Ground

Two community-types were surveyed in the vicinity of the Dredge Spoil Disposal Ground in the Zone of Influence – coral and sand. The coral site surveyed within the Zone of Influence was very small in area and comprised a coral bombora. Nevertheless the fish assemblage was characteristic of coral reefs with high diversity and the occurrence of serranids, lutjanids, pomacentrids, labrids, chaetodontids and scarids. This was the only site where manta rays (*Manta birostris*) were recorded.

The fish assemblages in the Dredge Spoil Disposal Ground Zone of Influence sand communities were generally characteristic of sand communities in Barrow Island waters (Section 11.4.1). Common species included Gold-spotted Trevally (*Carangoides fulvoguttatus*), scombrids, Bream (*Nemipterus* spp.), Giant Queenfish (*Scomberoides commersonnianus*) and Western Butterfish (*Pentapodus vitta*).

11.4.5.3 Fish Assemblages Characteristic Mangrove Communities at Sites in Mattress Bay and Stokes Bay

Twenty-two fish species were recorded from seine and throw net surveys at Mattress Bay (Table 11-5). The most abundant species recorded was the Common Silver Biddy (*Gerres oyena*) with a mean relative abundance of 0.6 ± 0.16 fish/m^2. Other abundant species included Flat-tail Mullet (*Liza argentea*) (0.3 ± 0.14 fish/m^2), Yellowtail Trumpeter (*Amniataba caudovittata*) (0.1 ± 0.05 fish/m^2) and Hardyheads (*Atherinomorus*/*Craterocephalus* spp.) (0.1 ± 0.05 fish/m^2). The three most abundant species recorded in the video transects were Yellowtail Trumpeter, Hardyheads and Common Silver Biddy; the first two were recorded at higher relative abundances in the video transects than in the seine and throw nets (Table 11-6). The only species recorded from the gill net surveys was the Nervous Shark (*Carcharhinus cautus*) (0.03 fish/hour/m of net) (Table 11-7).

The size structure of the most abundant species recorded at Mattress Bay indicates that the mangrove communities at this site provide habitat for juveniles and adults of small fish species such as the Common Silver Biddy (*G. oyena*) and Gobies (*Acentrogobius*/*Amoya* spp.), as well as juveniles of larger species (e.g. Blackspot Snapper [*Lutjanus fulviflamma*] and Trumpeter Whiting [*Sillago burrus*]) (Table 11-5). The maximum fork lengths recorded for Blackspot Snapper and Trumpeter Whiting were approximately half that of their maximum recorded length (Allen 2004).

Table 11-5 Mean Relative Abundance ± SE of Fish, and Mean ± SE and Range of Fork Lengths for the Most Abundant Fish Species Captured in Seine and Throw Nets at Mattress Bay, Stokes Bay and Bandicoot Bay

Common Name	Zone of Influence								Reference			
	Mattress Bay				Stokes Bay				Bandicoot Bay			
	Mean Relative Abundance ± SE (n=22)	Fork Length			Mean Relative Abundance ± SE (n=7)	Fork Length			Mean Relative Abundance ± SE (n=10)	Fork Length		
		Mean ± SE (mm)	Range (mm)	n		Mean ± SE (mm)	Range (mm)	n		Mean ± SE (mm)	Range (mm)	n
Common Silver Biddy	0.591 ± 0.166	60.1 ± 2.39	9–140	339	0.229 ± 0.081	79.5 ± 2.16	70–87	8	0.624 ± 0.180	26.2 ± 0.34	14–41	161
Flat-tail Mullet	0.288 ± 0.138	213.5 ± 8.78	47–280	40	0.057 ± 0.057	86.5± 1.5	85–88	2	0.002 ± 0.002	-	-	-
Yellowtail Trumpeter	0.077 ± 0.052	96.4 ± 15.81	17–225	16	2.286 ± 1.218	103.8 ± 1.67	69–142	80	-	-	-	-
Hardyhead*	0.076 ± 0.054	29.4 ± 0.96	15–65	144	0.057 ± 0.057	25.5± 0.5	25–26	2	2.031 ± 0.514	27.8 ± 0.74	15–58	124
Blackspot Snapper	0.055 ± 0.030	131.6 ± 3.16	60–185	52	0.029 ± 0.029	-	110	1	-	-	-	-
Goby**	0.052 ± 0.030	23.8 ± 0.43	12–34	101					0.011 ± 0.006	30.3 ± 1.09	24–35	9
Trumpeter Whiting	0.020 ± 0.011	60.8 ± 5.37	26–118	29	-	-	-	-	0.060 ± 0.017	64.7 ± 1.50	25–97	99
Western Yellowfin Bream	0.018 ± 0.018	-	-	-	-	-	-	-	-	-	-	-
Deep-bodied Flounder	0.0010 ± 0.006	-	-	-	-	-	-	-	0.0003 ± 0.000	-	-	-
Banded Goby***	0.009 ± 0.006	-	-	-	0.029 ± 0.029	-	-	-	0.002 ± 0.002	-	-	-
Blue Tuskfish	0.009 ± 0.009	-	-	-	-	-	-	-	-	-	-	-
Diamond-scale Mullet	0.009 ± 0.009	-	-	-	-	-	-	-	-	-	-	-
Mangrove Jack	0.009 ± 0.009	-	-	-	-	-	-	-	-	-	-	-
Moses' Snapper	0.009 ± 0.009	-	-	-	0.029 ± 0.029	-	100	1	-	-	-	-
Bar-tailed Flathead	0.009 ± 0.009	-	-	-	-	-	-	-	0.001 ± 0.001	-	-	-
Saw-tooth Barracuda	0.002 ± 0.001	-	-	-	-	-	-	-	0.006 ± 0.004	50.3 ± 10.05	30–78	4

Common Name	Zone of Influence								Reference			
	Mattress Bay				Stokes Bay				Bandicoot Bay			
	Mean Relative Abundance ± SE (n=22)	Fork Length			Mean Relative Abundance ± SE (n=7)	Fork Length			Mean Relative Abundance ± SE (n=10)	Fork Length		
		Mean ± SE (mm)	Range (mm)	n		Mean ± SE (mm)	Range (mm)	n		Mean ± SE (mm)	Range (mm)	n
Banded Sergeant	0.002 ± 0.002	-	-	-	0.029 ± 0.029	-	80	1	-	-	-	-
Coral Monocle Bream	0.002 ± 0.001	-	-	-	0.086 ± 0.059	114.7±20.6	87 – 155	3	0.006 ± 0.005	33.8 ± 1.24	30–37	5
Striped Butterfish	0.002 ± 0.002	-	-	-	-	-	-	-	-	-	-	-
Hick's Toadfish	0.001 ± 0.001	-	-	-	-	-	-	-	-	-	-	-
Blackspotted Rockcod	0.001 ± 0.001	-	-	-	-	-	-	-	-	-	-	-
Great Barracuda	0.001 ± 0.001	-	-	-	-	-	-	-	-	-	-	-
Goldspotted Rockcod	-	-	-	-	0.029 ± 0.029	-	300	1	-	-	-	-
Snub-nosed Garfish	-	-	-	-	-	-	-	-	0.011 ± 0.007	245.8 ± 8.70	158–350	28
Slender Grinner	-	-	-	-	-	-	-	-	0.003 ± 0.002	-	-	-
Narrow-lined Toadfish	-	-	-	-	-	-	-	-	0.001 ± 0.001	-	-	-
Golden Trevally	-	-	-	-	-	-	-	-	0.001 ± 0.001	-	-	-
Pickhandle Barracuda	-	-	-	-	-	-	-	-	0.001 ± 0.001	-	-	-
Banded Blenny	-	-	-	-	-	-	-	-	0.0004 ± 0.000	-	-	-
Snub-nosed Dart	-	-	-	-	-	-	-	-	0.0003 ± 0.000	-	-	-
Porcupine Ray	-	-	-	-	-	-	-	-	0.0003 ± 0.000	-	-	-

Note: Mean Fork Length and Range of Fork Length are reported for the seven most abundant species at Mattress Bay and Bandicoot Bay, and the ten most abundant species at Stokes Bay where there were five species of equal abundance. The 'n' values presented for mean abundance are calculated on the number of sites within each location.

** 'Hardyhead' is comprised of two species:* Atherinomorus endrachtensis *(Endrachts hardyhead) and* Craterocephalus capreoli *(Rendahls hardyhead). ** 'Goby' refers to three species of Gobiidae that were identified from retained samples;* Acentrogobius caninus *(Tropical sand goby),* Acentrogobius janthinopterus *(Robust mangrove gob), and* Amoya gracilis *(Mangrove goby).*

**** "Banded Goby' refers to two species of Amblygobius: the Banded Goby (*Ambyglobius phalaena*) and Ambyglobius sp.*

Table 11-6 Mean Relative Abundance of Fish Species Recorded in 30 m Video Transects at Mattress Bay

Common Name	Mean Relative Abundance ± SE
Yellowtail Trumpeter	2.367 ± 2.150
Hardyhead*	1.111 ± 1.111
Common Silver Biddy	0.289 ± 0.198
Western Yellowfin Bream	0.222 ± 0.078
Blackspot Snapper	0.189 ± 0.095
Diamond-scale Mullet	0.133 ± 0.117
Striped Butterfish	0.056 ± 0.056
Golden Trevally	0.044 ± 0.029
Mangrove Whipray	0.044 ± 0.011
Banded Sergeant	0.033 ± 0.019
Banded Goby**	0.033 ± 0.033
Saw-tooth Barracuda	0.022 ± 0.011
Blue Tuskfish	0.011 ± 0.011
Blackspot Tuskfish	0.011 ± 0.011
Blackspotted Rockcod	0.011 ± 0.011
Coral Monocle Bream	0.011 ± 0.011
Giant Shovelnose Ray	0.011 ± 0.011

*Note: * 'Hardyhead' is comprised of two species:* Atherinomorus endrachtensis *(Endrachts hardyhead) and* Craterocephalus capreoli *(Rendahls hardyhead).*

*** 'Banded Goby' refers only to* Amblygobius phalaena*.*

Table 11-7 Total Abundance (Fish/Hour/Metre of Net) and Length Range (mm Fork Length) of Fish Recorded in Gill Nets in Mattress Bay, Stokes Bay and Bandicoot Bay

Common Name	Zone of Influence				Reference	
	Mattress Bay		Stokes Bay		Bandicoot Bay	
	Total Abundance (n)	Range of Fork Length (mm) (n)	Total Abundance (n)	Range of Fork Length (mm) (n)	Total Abundance (n)	Range of Fork Length (mm) (n)
Nervous Shark	0.031 (5)	600 – 720 (5)	0.019 (3)	600–670 (2)	0.106 (17)	410–910 (17)
Lemon Shark	-	-	0.100 (16)	460–1300 (17)	0.063 (10)	600–1500 (10)
Giant Trevally	-	-	0.019 (3)	300–350 (3)	-	-
Blacktip Reef Shark	-	-	0.006 (1)	620 (1)	0.006 (1)	610 (1)
Milkfish	-	-	0.006 (1)	510 (1)	-	-
Giant Queenfish	-	-	0.006 (1)	420 (1)	-	-
Giant Shovelnose Ray	-	-	-	-	0.056 (9)	400–1200 (9)

Note: Values in parentheses within each cell represent the count (n) of fish used to calculate either the total abundance or the range of fork length.

Ten fish species were recorded from throw net surveys at Stokes Bay (Table 11-5). The three most abundant species recorded were Yellowtail Trumpeter (*A. caudovittata*), Common Silver Biddy (*G. oyena*) and Coral Monocle Bream (*Scaevius milii*), with mean relative abundances of 2.3 ± 1.22 fish/m^2, 0.2 ± 0.08 fish/m^2 and 0.1 ± 0.06 fish/m^2, respectively. The number of species collected from throw net surveys at Stokes Bay was lower than collected from seine and throw net surveys at Mattress Bay. This is likely to reflect the difficulty in sampling fish over rocky substrates with nets and also due to the lack of sandy substrate at the Stokes Bay site. Similar to Mattress Bay, the most abundant fish collected in Stokes Bay were generally small, and included juveniles and adults of small fish species as well as juveniles of larger species, e.g. Moses' Snapper (*Lutjanus russellii*) (Table 11-5).

Six species of fish, including three shark species, were recorded from gill net surveys in Stokes Bay: Giant Trevally (*Caranx ignobilis*), Giant Queenfish (*Scomberoides commersonnianus*), Nervous Shark (*C. cautus*), Blacktip Reef Shark (*Carcharhinus melanopterus*), Lemon Shark (*Negaprion acutidens*) and Milkfish (*Chanos chanos*) (Table 11-7). Lemon Shark was the most abundant of these, with 16 individuals captured and a total abundance of 0.1 fish/hour/m of net.

11.4.6 Description of Demersal Fish Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the MOF, LNG Jetty or Dredge Spoil Disposal Ground

11.4.6.1 Fish Assemblages Characteristic of Hard and Soft Coral, Macroalgae, Soft Sediments with Sessile Benthic Macro-invertebrates and Bare Sand Communities at Reference Sites

Data from the 2008 and 2009 surveys suggest that fish assemblages at Reference Sites around Barrow Island do not differ from fish assemblages in Zones of High Impact, Zones of Moderate Impact or Zones of Influence (refer to Section 11.4.3 and Section 11.4.5). Reference Sites for all community-types were sampled in 2008 and 2009, with each community-type characterised by distinct fish assemblages (Section 11.4.1). The only community-types with similar fish assemblages were at reference sand and soft sediments with sessile benthic macro-invertebrate sites in March 2009. The size structure of fish assemblages differed across most of the community-types, particularly in 2008 when each of the community-types had a unique size structure.

11.4.6.2 Fish Assemblages Characteristic Mangrove Communities at Bandicoot Bay

Eighteen fish species were recorded from seine net surveys at Bandicoot Bay (Table 11-5). The three most abundant species recorded from seine net surveys in Bandicoot Bay were Hardyheads (*Atherinomorus*/*Craterocephalus* spp.), Common Silver Biddy (*Gerres oyena*) and Trumpeter Whiting (*Sillago burrus*) with mean relative abundances of 2.0 ± 0.51 fish/m^2, 0.6 ± 0.18 fish/m^2 and 0.1 ± 0.02 fish/m^2, respectively. Common Silver Biddy and Hardyheads were also recorded at Mattress Bay and Stokes Bay although in lower abundances, whereas Trumpeter Whiting was not recorded at Stokes Bay and was less abundant at Mattress Bay. Trumpeter Whiting has a preference for sandy substrates (Allen 2004) and the higher abundance of this species at Bandicoot Bay is likely to be a reflection of the expansive area of sandy substrate at this site.

The largest of the abundant fish species recorded at Bandicoot Bay was Snub-nosed Garfish (*Arrhamphus sclerolepis)*, with a maximum fork length of 350 mm (Table 11-5). The maximum fork length recorded for the remainder of these abundant fish was <100 mm. This includes juveniles of larger fish species (e.g. Saw-tooth Barracuda [*Sphyraena putnamiae*]), as well as fish species that only reach a maximum size of approximately 100 mm, such as Hardyheads (*Atherinomorus/Craterocephalus* spp.) and Gobies (*Acentrogobius/Amoya* spp.).

Three species of shark, Nervous Shark (*Carcharhinus cautus*), Blacktip Reef Shark (*Carcharhinus melanopterus*) and Lemon Shark (*Negaprion acutidens*), and one species of ray, Giant Shovelnose Ray (*Rhinobatos typus*), were recorded from gill net surveys in Bandicoot Bay (Table 11-7). The most abundant of these was Nervous Shark (*C. cautus*) (0.1 fish/hour/m of net).

11.5 Conclusions

During daylight periods over the different surveys and with the gear employed to sample the demersal fish assemblages, there were no differences in the composition of fish assemblages characteristic of hard and soft coral, macroalgae, soft sediments and sessile benthic macro-invertebrates and bare sand communities and the relative abundances of fish species at sites in the Zones of High Impact, Zones of Moderate Impact, representative areas in the Zones of Influence and Reference Sites. The fish assemblages characteristic of mangrove communities in representative areas in the Zone of Influence and Reference Sites were generally similar, with differences reflecting the different substrate types (e.g. rocky substrate, sandy substrate), as well as the sampling methodologies. The fish assemblages characteristic of hard and soft coral, macroalgae, soft sediments and sessile benthic macro-invertebrates and bare sand communities within the Zones of High and Moderate Impact were well represented in those community-types within the Zones of Influence and Reference Sites, as well as elsewhere within Barrow Island waters. There were minor differences in the size structure of these fish assemblages across the different Zones and Reference Sites, reflecting high abundances of particular species at certain sites.

12.0 Surficial Sediments

12.1 Introduction

Barrow Island lies on the shallow (generally <5 m depth) limestone shelf that underlies the Montebello/Barrow Islands group. There is a broad intertidal platform adjacent to the Island that grades to the subtidal limestone shelf. On the east coast of Barrow Island, the intertidal limestone reef flats and shallow pavement reef are overlain by sands and gravels, with more rubble in areas where the water currents are stronger. The unconsolidated sediments overlying the limestone pavement range in thickness between 0.5 m (in the area of the MOF) and 3 m, with the thicker sediment layers being in the deeper water offshore the nearshore platform (Chevron Australia 2006). The surficial sediments of the Montebello/Barrow Islands region are generally in an undisturbed condition, apart from localised areas affected by drilling and aquaculture (DEC 2007).

12.2 Scope

This Section reports on the characteristics of surficial sediments where dredging and dredge spoil disposal may affect the environment and at Reference Sites where the environment will not be affected (Condition 14.8.vii, Statement No. 800; Condition 11.8.VII, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the surficial sediment characteristics:

- within the Zones of High Impact, the Zones of Moderate Impact, and representative areas in the Zones of Influence associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.i, Statement No. 800; Condition 11.6.I, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the WAPET Landing (Condition 14.6.iii, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.iv, Statement No. 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

12.3 Methods

12.3.1 Site Locations

Surficial sediment samples were collected from 185 sites in the waters around Barrow Island, including water quality and coral monitoring sites, sites within the Zones of High and Moderate Impact, the Zones of Influence, and Reference Sites outside the Zones of Influence near Barrow Island (Table 12-1; Figure 12-2). The sites included 36 locations sampled as part of the Sea Dumping Permit required under the *Environment Protection (Sea Dumping) Act 1981* (Cth) (URS 2006) and 10 locations sampled during previous baseline surveys for the Gorgon Gas Development (RPS Bowman Bishaw Gorham 2007). In addition, surveys were undertaken in the areas surrounding the existing WAPET Landing (RPS Bowman Bishaw Gorham 2006).

Priority areas for sampling were those in proximity to construction, dredging and spoil disposal activities, specifically the Dredge Spoil Disposal Ground, the MOF, LNG Jetty, the LNG Jetty Access Channel, Turning Basin and areas where modelling predicted that sediment from the dredge plume was likely to accumulate once dredging is completed (GEMS 2008).

Sites were also located:

- where soft sediments are known or were predicted to occur, based on interpretation of remotely sourced data and ground-truthing
- along the likely route of the dredge during transit to the Dredge Spoil Disposal Ground
- along transects running between the Dredge Spoil Disposal Ground and nearby sensitive assemblages (coral reefs)
- at macroalgal, seagrass and non-coral benthic macro-invertebrate survey sites.

Table 12-1 Number of Surficial Sediment Samples Collected in the Zones of High and Moderate Impact, Zones of Influence, and at Reference Sites

Location	Number of Samples
Zones of High and Moderate Impact	47
Zones of Influence	77
Reference Sites	61
TOTAL	**185**

12.3.2 Methods

At each site sampled in the Marine Baseline Program, sediment samples were collected using grabs or cores, or multiple scrapes of the surficial sediments (<5 cm) within a 4 m^2 area were collected directly into 250 mL sample containers to form two composite samples. Only the surficial sediments (top 2 cm) were sampled as this is considered to be the sedimentologically most recent and active layer, representing an important part of the sediment profile in terms of biological effects (benthic habitat, sediment feeding, water/sediment interactions) and the most likely to influence the distribution and abundance of benthic macrofauna.

Where visibility permitted, photographs were taken of the seabed at each site for visual documentation of the sediments. A description of the dominant physical characteristics of the sediment samples was recorded on proforma log sheets, as were the site coordinates and the date and time of sampling.

Standard laboratory analytical procedures were employed and laboratories with National Association of Testing Authorities (NATA)-accredited methods (or laboratories with demonstrated Quality Assurance/Quality Control [QA/QC] procedures in place) undertook the analyses (RPS 2009). The sediment samples were analysed for:

- Particle-size Distribution (PSD) – laser diffraction and wet sieving
- Total Organic Carbon (TOC) (organically bound carbon) – furnace combustion
- Total Inorganic Carbon (TIC) – furnace combustion.

Analysis of sediment organic and inorganic carbon content was undertaken by the Chemistry Centre of Western Australia. Samples were analysed for total carbon by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved carbon (as CO_2) measured by infra-red detection. Samples were analysed for total organic carbon (TOC) by acidification to remove inorganic carbonates, followed by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved organic carbon (as CO_2) measured by infra-red detection. Total inorganic carbon (TIC) was determined as the difference between total carbon and total organic carbon. Total organic carbon and total inorganic carbon content were reported as a percentage of total dry weight.

Particle-size analysis was undertaken by the CSIRO Division of Minerals. The results are expressed as a cumulative percentage volume of particles that occupy six different size ranges. Laboratory results and sediment classifications are presented in Appendix 8.

12.3.3 Timing and Frequency of Sampling

Samples taken during the Marine Baseline Program were collected from September 2008 to April 2009, in conjunction with surveys for the other ecological elements. Sampling was also undertaken in May–June 2004 (URS 2006) and July–August 2006 (RPS Bowman Bishaw Gorham 2007).

12.3.4 Data Analysis

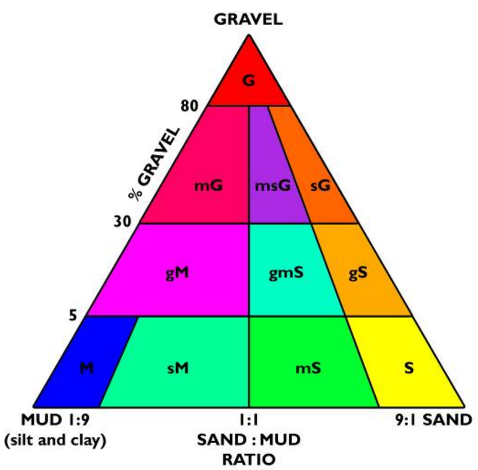
Based on the results of particle-size analysis, each sediment sample was classified into a sediment type according to a simplified version of the scheme proposed by Folk (1954). This scheme was also used for the National Marine Sediments Database and Seafloor Characteristics Project (Passlow *et al.* 2005). The simplified version has four fewer categories than the full version as it amalgamates some categories that contain less than 5% gravel content. Most of the sediments around Barrow Island were expected to contain relatively large gravel fractions and so the extra differentiation offered by the full scheme at the lower end of the gravel content scale was not considered necessary.

The sediment classification scheme is based on a triangular diagram divided into sediment textural groups, according to measured percentages of gravel, sand and mud constituents (Figure 12-1). The method provides an approach to describing the sediments with a complete range of mixtures of the three components, producing a single description and classification value (Passlow *et al.* 2005).

According to the classification scheme, sediment grains were first categorised into three size-classes based on their diameter:

- mud <0.063 mm
- sand 0.063–2 mm
- gravel >2 mm.

The percentage composition of each of the grain-size classes and the ratios between them were then used to classify the sediment into 11 discrete sediment types (Figure 12-1).



Abbreviation	Description
G	Gravel
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
gM	gravelly Mud
gmS	gravelly muddy Sand
gS	gravelly Sand
M	Mud
sM	sandy Mud
mS	muddy Sand
S	Sand

Figure 12-1 Simplified Folk Triangle Sediment Classification Scheme

Note: This diagram is not to scale – it is a representation of the classification subdivisions.

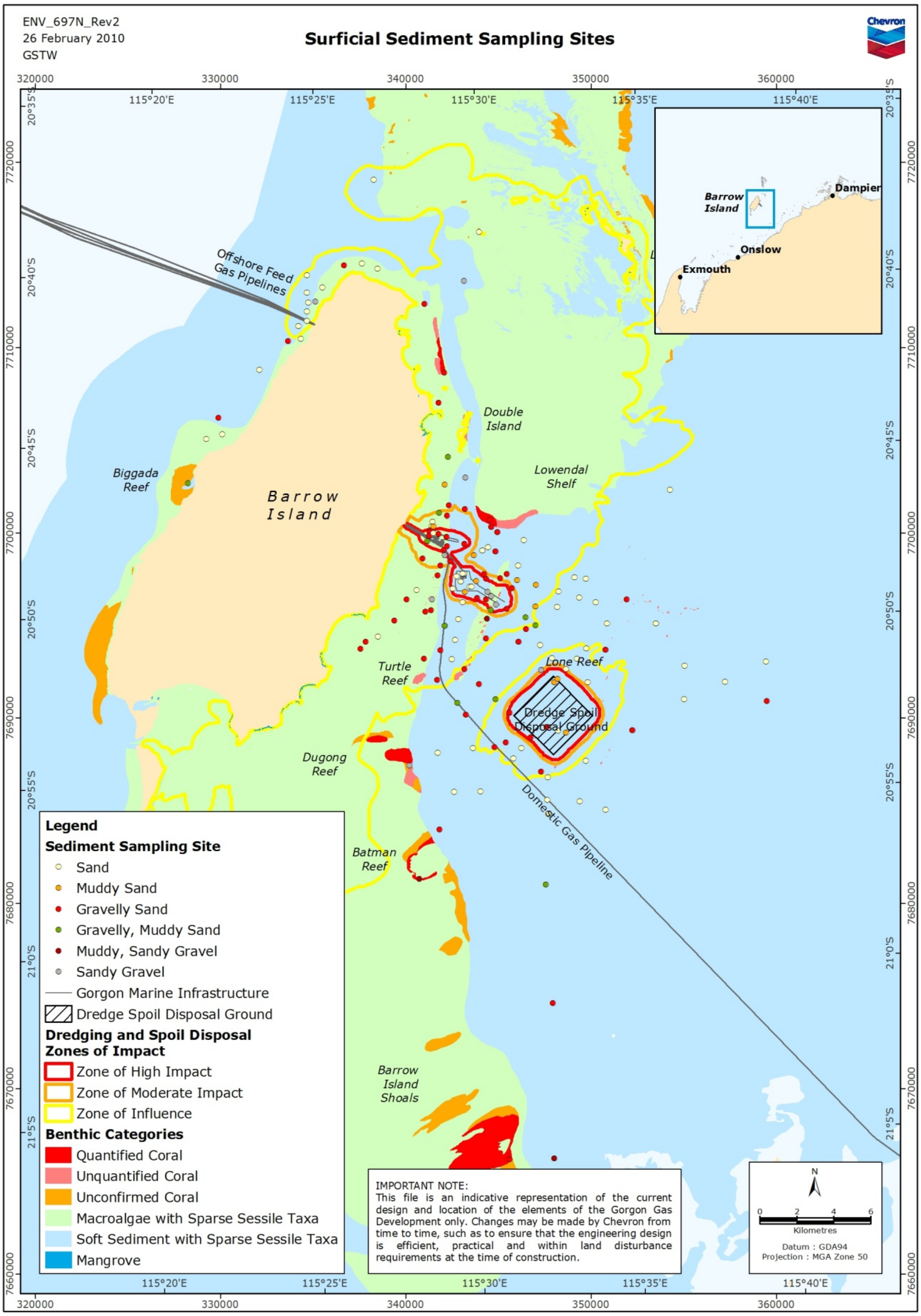


Figure 12-2 Surficial Sediment Sampling Sites

12.4 Results and Conclusions

The spatial distribution of sediment types within the waters around Barrow Island is presented as spatially rectified point observations (Figure 12-2) and interpreted within the context of the area's biotic habitats and hydrodynamic characteristics.

The sediments in the waters surrounding Barrow Island were characterised by six sediment types (Sand, gravelly Sand, sandy Gravel, muddy Sand, gravelly muddy Sand, muddy sandy Gravel). TOC varied between <0.05% and 0.8% and TIC between 5.4% and 11.4%. Sediments on the east coast of Barrow Island were generally more variable than on the west coast, including higher proportions of mud and gravel.

12.4.1 Surficial Sediment Characteristics within the Zones of High Impact and Zones of Moderate **Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal**

12.4.1.1 Surficial Sediment Characteristics at Sites in the Vicinity of the MOF and Causeway and the LNG Jetty Access Channel

Sediments in the shallow inshore area on the east coast predominantly comprised of a thin veneer of gravelly Sand overlying a solid limestone pavement (Figure 12-2; Plate 12-1). Surficial sediments at the majority (approximately 85%) of sites within the vicinity of the MOF and LNG Jetty had >70% sand and <10% and <20% mud and gravel respectively.

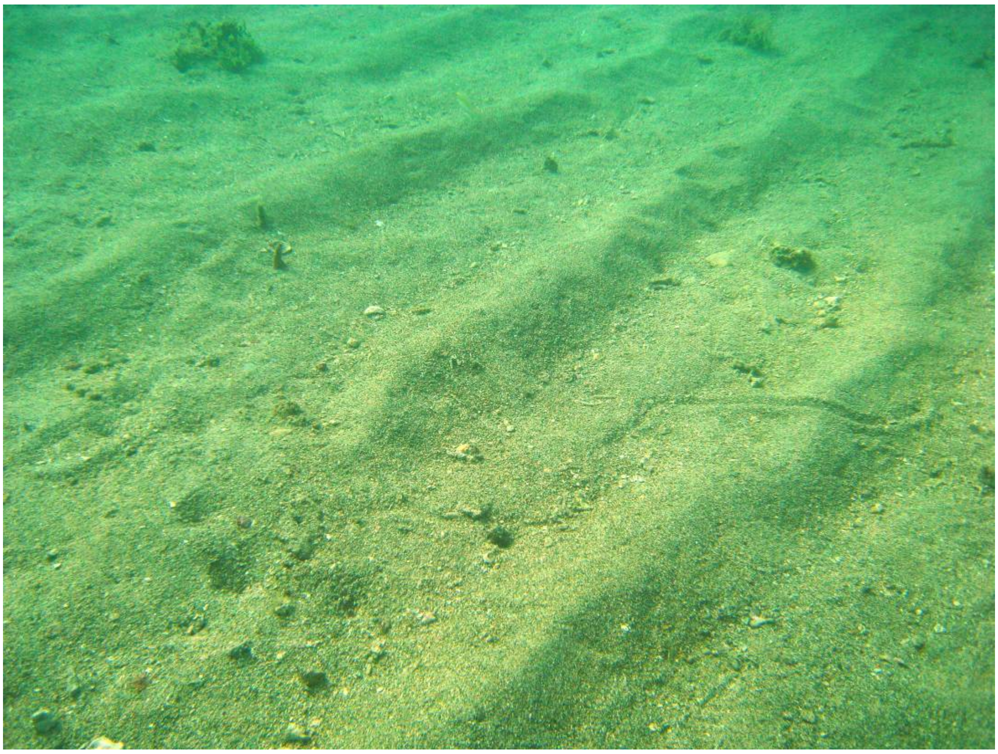


Plate 12-1 Seabed in the Shallow Inshore Area near the MOF Showing Unvegetated Fine-to-Coarse Grained Sands with Gravel

Sediments collected in the vicinity of the MOF were dominated by gravelly Sand, with Sand, gravelly muddy Sand, muddy Sand, and sandy Gravel also occurring at four sites. Sediments collected near the LNG Jetty were characterised by Sand and gravelly Sand, with approximately 30% of samples a variety of sandy Gravel, muddy Sand, and gravelly muddy Sand.

The sediments within the channel were varied, although fine-to-coarse grained sand fractions were most common, with <10% of particles classified as mud or gravel at the majority (approximately 85%) of sites (Figure 12-2; Plate 12-2). Sediments within the ZoHI and ZoMI on the East Barrow

Ridge (Figure 12-2) mainly comprised sand (66-81%) and gravel (14-32%%) fractions of varying depths overlying the limestone pavement ridge. The high gravel content was likely due to the presence of shell grit and coral rubble generated by the bombora fields and scattered coral colonies that occur along the ridge.

The total organic carbon in the sediment varied across the MOF and LNG Jetty area, with no clear trends in the distribution of organic carbon content.

Plate 12-2 Seabed in the Centre of the Channel between East Barrow Ridge and the Shallow Inshore Pavement

*Note: Heart urchins (*Echinocardium cordatum*) can be seen on the sediment surface.*

12.4.1.2 Surficial Sediment Characteristics at Sites in the Vicinity of the Dredge Spoil Disposal Ground

Four sediment types occurred within the Dredge Spoil Disposal Ground: Sand, gravelly Sand, muddy Sand and sandy Gravel. Fine-to-coarse grained sand fractions characterised these sediment types with the majority (approximately 90%) of samples comprising>75% sand (Figure 12-2; Plate 12-3), while the mud and gravel fractions were more variable among sites. The variation observed in sediment characteristics across the Dredge Spoil Disposal Ground indicates that localised hydrodynamic effects may lead to deposition of finer sediments in some areas. The level of organic carbon in the sediments also varied across the Dredge Spoil Disposal Ground.

Plate 12-3 Sandy Sediments within the Dredge Spoil Disposal Ground

12.4.2 Surficial Sediment Characteristics at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

South of the WAPET Landing, the sediment was made up of fine sands overlain with coarser material made up of shells, shell grit and scattered rubble (RPS Bowman Bishaw Gorham 2006). Within the vicinity of WAPET Landing, sediments were classified as gravelly Sand and contained more than 80% sand (the majority medium to coarse), 7–16% gravel, and only traces of mud (<2%).

12.4.3 Surficial Sediment Characteristics at Representative Areas of the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal, at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground and in Regionally Significant Areas

12.4.3.1 Coral Monitoring Sites

Five sediment types characterised the sediments at the coral monitoring sites: Sand, gravelly Sand, sandy Gravel, gravelly muddy Sand, muddy sandy Gravel (Figure 12-2). The sediments at Ant Point Reef, Southern Lowendal Shelf, Ah Chong, Biggada Reef, Dugong Reef, Batman Reef, LNG3, and Southern Barrow Shoals were typically characterised by high proportions of coarse sand (32–72%) and gravel (5–53%) fractions, reflecting the coral rubble and shell grit generated from the reef areas. The sediments at Dugong Reef had the highest percentage by volume of gravel and the lowest gravel content was recorded at Ah Chong. Sediments at Batman Reef and Biggada Reef had the highest content of silts (10% and 13% respectively) and along with LNG3, fine sands (14%, 12%, and 13% respectively). Higher proportions of finer particles in the sediments at these sites may be a reflection of the reef structure causing localised hydrodynamic conditions favourable to deposition. The total organic carbon content varied between 0.25% and 0.36% among the sites.

12.4.3.2 Other Sites

The sediments in the deeper water areas to the south-east of the East Barrow Ridge were mostly sands of varying thickness (approximately 90% of samples were >70% sand). The sediments generally comprised fine-to-coarse grained sand fractions, with <10% of particles classified as mud (approximately 90% of samples) and <20% as gravel (approximately 85% of samples).Further inshore along the east coast shelf at sites with a shallow underlying limestone pavement, higher gravel fractions were present. Mud deposits were also recorded at some shallow inshore sites between Double Island and the MOF and at the southern end of the channel adjacent to the East Barrow Ridge. The total organic carbon content varied among the sites.

13.0 Water Quality (Turbidity and Light)

13.1 Introduction

The prevailing oceanographic processes and water circulation in the region (Section 3.4) influence the transport, dispersal and mixing of sediments, biota and pollutants and, consequently, the quality of the waters of the Montebello/Barrow Islands region (DEC 2007). Nearshore water movement and mixing patterns in the region are primarily driven by strong currents, moderate tidal ranges and winds, with wave action, seabed topography and the effect of islands and reefs in the area also playing an important role (DEC 2007).

The water quality of the Montebello/Barrow Islands region is generally considered pristine, apart from some areas of localised disturbance (DEC 2007). Sources of localised disturbance include sewage outfalls from the accommodation facilities on Barrow Island and Varanus Island, and discharges from the pearling industry, recreational and commercial fishing vessels. Water clarity in the region varies according to water movement and sediment type, but is generally clearer on the western side of Barrow Island. Water turbidity generally increases towards the south-eastern side of Barrow Island, mainly due to the influence of coastal water discharges that have a high load of fine sediments (DEC 2007).

13.2 Scope

This Section reports on the background water quality (including measures of turbidity and light attenuation) and the natural rates and spatial patterns of sediment deposition (Condition 14.8.vii, Statement No. 800; Condition 11.8.VII, EPBC Reference: 2003/1294 and 2008/4178) and describes the water quality, including turbidity and light attenuation:

- within the Zones of High Impact, the Zones of Moderate Impact, and representative areas in the Zones of Influence associated with the generation of turbidity and sediment deposition from dredging and dredge spoil disposal required for the MOF, LNG Jetty and Dredge Spoil Disposal Ground (Condition 14.6.v, Statement No. 800; Condition 11.6.V, EPBC Reference: 2003/1294 and 2008/4178)
- in areas at risk of Material or Serious Environmental Harm due to the marine upgrade of the WAPET Landing (Condition 14.6.vi, Statement No. 800)
- at Reference Sites not at risk of Material or Serious Environmental Harm due to the construction or operation of the MOF, LNG Jetty, Dredge Spoil Disposal Ground and the marine upgrade of the existing WAPET Landing (Condition 14.6.vi, Statement No. 800; Condition 11.6.VI, EPBC Reference: 2003/1294 and 2008/4178).
- water quality data and data on natural rates and spatial patterns of sediment deposition will be collected for at least one full annual cycle prior to the construction of the MOF, LNG Jetty and Dredge Spoil Disposal Ground, as required by Condition 14.9, Statement No. 800 and Condition 11.9, EPBC Reference: 2003/1294 and 2008/4178 (Table 13-3).

Note that turbidity (measured as Nephelometric Turbidity Units [NTU]) was used in the Marine Baseline Program as a surrogate for concentrations of Total Suspended Solids (TSS). While TSS is of more relevance to coral health and survival, it is not practicable to measure TSS continuously in situ. There is, however, no universal relationship between turbidity and suspended solids, as TSS depends on the total weight of particles in suspension and is a direct function of the number, sizes and specific gravities of the particles; while turbidity is a direct function of the number, surface areas and refractive indices of the particles, but is an inverse function of their size (Thackston and Palermo 2000). Turbidity can be only used to estimate suspended solids concentrations if site-specific algorithms are developed based on field data. Site-specific correlation curves between TSS and turbidity have been derived for each site through laboratory measurements of the instrument response to water containing known (measured) concentrations of sediment collected from each site (Section 13.3.4.3).

The Marine Baseline Report for the marine upgrade of the existing WAPET Landing (Condition 14.3.vi, Statement No. 800) was initially approved on 3 November 2009 by the former DEC (under delegation from the Minister), and no further approval is sought in relation to this Marine Facility; therefore material in this Report is provided for information only.

13.3 Methods

13.3.1 Site Locations

13.3.1.1 LTD Loggers

Light-Turbidity-Deposition (LTD) loggers were deployed at 16 sites in the waters surrounding Barrow Island to provide a semi-continuous record of temporal changes in water quality and light climate at the seabed (Table 13-1; Figure 13-1). Twelve LTD loggers were deployed at the coral monitoring sites (see Section 6.3.1) to measure ambient light, turbidity and sediment deposition, with the intent to establish links between water quality and coral health (as required under Condition 20.4.iii.e and Condition 21.1 of Statement No. 800). One LTD logger was deployed within the MOF and LNG Jetty Zone of High Impact; two LTD loggers were deployed within the MOF and LNG Jetty Zone of Moderate Impact and one within the Zone of Moderate Impact associated with the Dredge Spoil Disposal Ground; and six LTD loggers were deployed within the MOF and LNG Jetty Zone of Influence.

In addition, three LTD loggers were deployed at sites in coral reef habitats located between coral monitoring sites, to provide greater spatial coverage of the baseline data and increased spatial resolution for detecting changes to light, turbidity and sediment deposition during dredging and spoil disposal activities.

One LTD logger was deployed at the HDD site on the west coast of Barrow Island in May 2009. The water quality results for this site are reported in the Marine Baseline Report for the Offshore Feed Gas Pipeline System and marine component of the shore crossing (Chevron Australia 2010a).

Table 13-1 LTD Logger Sites

Location	Site Name (Code)	Easting	Northing	Latitude	Longitude	Depth (m)
		(GDA94, MGA Zone 50)		(GDA94)		
Zone of High Impact	LNG0 (LNG0)	344796	7696102	20° 49.716' S	115° 30.507' E	9.0
Zones of Moderate Impact	MOF1 (MOF1)	342089	7698785	20° 48.249' S	115° 28.961' E	6.0
	LNG1 (LNG1)	344584	7695833	20° 49.861' S	115° 30.384' E	8.8
	Lone Reef (LONE)	347316	7692607	20° 51.623' S	115° 31.942' E	9.3
Zone of Influence	Ant Point Reef (ANT)	342065	7708657	20° 42.898' S	115° 29.001' E	4.0
	Southern Lowendal Shelf (LOW)	344504	7700689	20° 47.229' S	115° 30.363' E	3.0
	MOF2 (MOF2)	341709	7697690	20° 48.840' S	115° 28.736' E	5.8
	MOF3 (MOF3)	341412	7696411	20° 49.532' S	115° 28.558' E	5.5
	LNG2 (LNG2)	344396	7695372	20° 50.110' S	115° 30.273' E	6.0
	HDD (HDD)	334648	7711741	20° 41.188' S	115° 24.746' E	15.0
Reference Sites	Ah Chong Reef (AHC)	350243	7731659	20° 30.472' S	115° 33.829' E	6.5
	LNG3 (LNG3)	343157	7692657	20° 51.575' S	115° 29.544' E	6.5
	Dugong Reef (DUG)	340102	7687962	20° 54.104' S	115° 27.757' E	6.3

Location	Site Name (Code)	Easting	Northing	Latitude	Longitude	Depth (m)
		(GDA94, MGA Zone 50)		(GDA94)		
	Batman Reef (BAT)	340703	7681301	20° 57.717' S	115° 28.066' E	3.5
	Southern Barrow Shoals (SBS)	345599	7666195	21° 5.929' S	115° 30.810' E	4.8
	Biggada Reef (BIG)	328237	7702674	20° 46.068' S	115° 21.001' E	1.5

13.3.1.2 Terrestrial Light Logger

To measure the irradiance incident at the sea surface, a Licor LI-192 2π light sensor attached to a Licor LI-1400 data logger (the ‘terrestrial light logger’) (Plate 13-1) was installed on the east coast of Barrow Island adjacent to the camp facilities (338251E, 7696175N), remote from any source of non-atmospheric shading. The sensor was subsequently relocated to the Terminal Tanks Facility near Town Point (339974E, 7701581N) (Figure 13-1). The 2π sensor only records downward irradiance and therefore avoids any potential errors as a result of light being reflected upwards from surfaces below the sensor (e.g. the ground). The sensor provided a measure of the incident Photosynthetically Active Radiation (PAR) reaching the sea surface and enabled the calculation of Light Attenuation Coefficients (LAC) at each site using the terrestrial light sensor and the sub-surface LTD loggers.

Appendix 9 sets out the details of a Pilot Study undertaken to assess the validity of this approach to the measurement of light attenuation in the waters around Barrow Island compared to the measurement of light attenuation using two in-water sensors (e.g. EPA 2005). This study demonstrated a significant, strong positive correlation between the results obtained from both methods, indicating that the variation in light attenuation is adequately captured by the above-water to in-water method and that the results are comparable to the measurement of light attenuation using two in-water sensors.

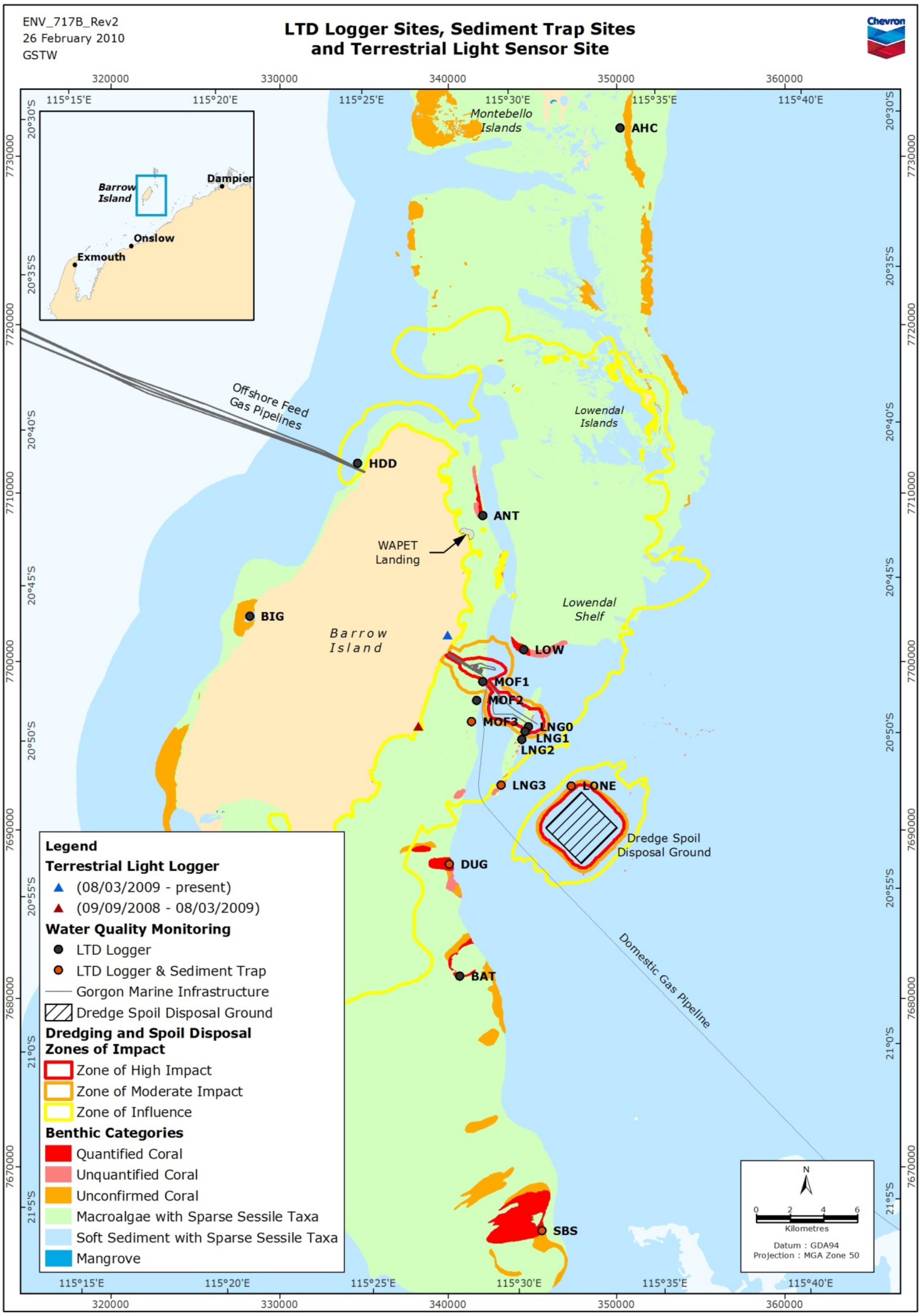


Figure 13-1 LTD Logger Sites, Sediment Trap Sites and Terrestrial Light Sensor Site

13.3.1.3 Sediment Traps

Sediment trap arrays were deployed at five sites (Table 13-2; Figure 13-1). These sites were selected to provide a broad spatial coverage and encompass the expected natural range of particle flux at the coral monitoring sites. Site selection was based on a review of the turbidity data recorded by the 12 LTD loggers deployed over the December 2007–March 2008 period (Figure 13-2).

Table 13-2 Sediment Trap Array Sites

Location	Site Name (Code)	Easting	Northing	Latitude	Longitude
		(GDA94, MGA Zone 50)		(GDA94)	
Zone of Moderate Impact	Lone Reef (LONE)	347316	7692607	20° 51.623' S	115° 31.942' E
Zone of Influence	MOF3 (MOF3)	341412	7696411	20° 49.532' S	115° 28.558' E
Reference Sites	LNG3 (LNG3)	343157	7692657	20° 51.575' S	115° 29.544' E
	Dugong Reef (DUG)	340102	7687962	20° 54.104' S	115° 27.757' E
	Southern Barrow Shoals (SBS)	345599	7666195	21° 5.929' S	115° 30.810' E

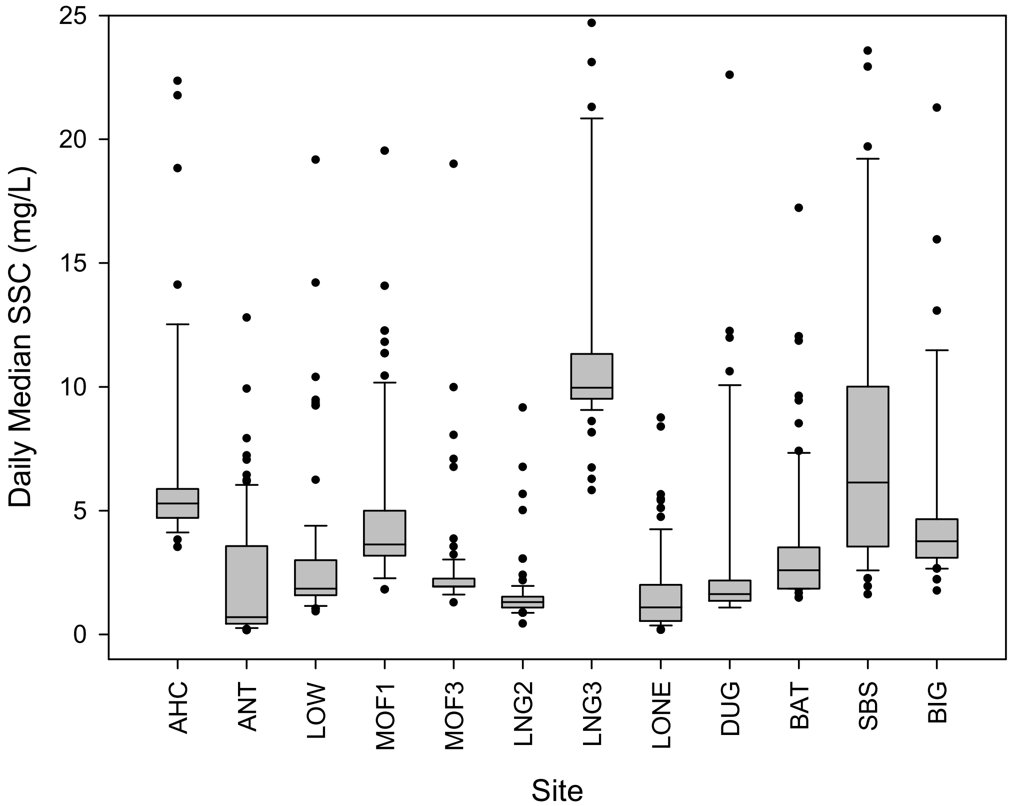


Figure 13-2 Box Plots of Daily Median Suspended Sediment Concentration (SSC) Estimated from Turbidity Data Recorded by LTD Loggers at the Water Quality Monitoring Sites, 2 December 2007–5 March 2008

Note: Boxes = range of lower and upper quartiles; solid horizontal line within the box = median SSC; whiskers = 10th and 90th percentiles; circles = outliers (outliers >25 mg/L are not shown).

13.3.2 Methods

13.3.2.1 Meteorological Data

Meteorological data recorded at the weather station on Barrow Island (Station ID 005094) were obtained from the Bureau of Meteorology (BOM). The weather station is situated at the Barrow Island airport (334210E, 7691864N), located approximately 1 km from the east coast. Meteorological data recorded for the period November 2007 to October 2009 included:

- wind speed
- wind direction
- maximum wind gusts
- air temperature
- rainfall.

13.3.2.2 Physical–Chemical Parameters

13.3.2.2.1 LTD Loggers

Simultaneous measurements of sediment deposition, turbidity and light (Photosynthetically Active Radiation [PAR]) at the seabed, as well as pressure, were recorded semi-continuously by the LTD loggers deployed at each site.[7] Light was recorded through an upwards-oriented, 2π quantum sensor (Section 13.3.2.5.1). Turbidity was recorded using a sideways-oriented Optical Backscatter Sensor (OBS, also known as a nephelometer) and the data were converted to measurements of Suspended Sediment Concentrations (SSC) using site-specific algorithms (Appendix 10). Sediment deposition was measured using an upward-oriented OBS (Section 13.3.2.5.1). Pressure was measured using an absolute pressure sensor, which is calibrated to give depth in meters. Ten readings are taken sequentially and used to calculate Root Mean Square Water Depth which gives an indication of wave height.

Each sensor was mounted in a common housing and the entire unit attached to a steel frame during deployment, such that the sensors were positioned approximately 40 cm from the seabed (Plate 13-1). The external surface of each sensor was automatically wiped clean every two hours by an automated wiper assembly to allow longer deployment periods where biofouling would affect the readings. The data were logged to an internal hard drive and downloaded during routine maintenance visits.

13.3.2.2.2 Water Column Profiles

A Seabird Electronics SBE19 SEACAT Profiler was deployed to provide in situ information on the physical-chemical characteristics of the water column at each water quality monitoring site. The SEACAT Profiler, a high-precision Conductivity-Temperature-Depth (CTD) meter with auxiliary sensors, measured conductivity, temperature, depth, dissolved oxygen (DO), pH, turbidity and Photosynthetically Active Radiation (PAR) at 0.5 second intervals. This information supplemented the semi-continuous measures at the seabed provided by the LTD loggers. Note that the SEACAT Profiler uses a different turbidity sensor to that used by the LTD loggers, thus the turbidity data from the SEACAT Profiler are not comparable with the LTD logger data.

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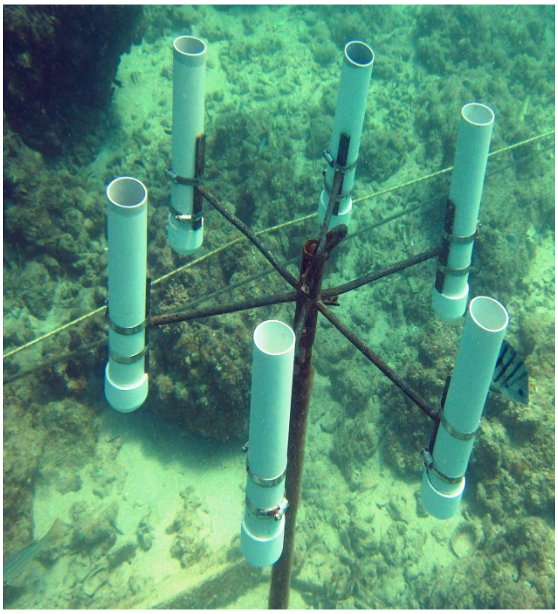
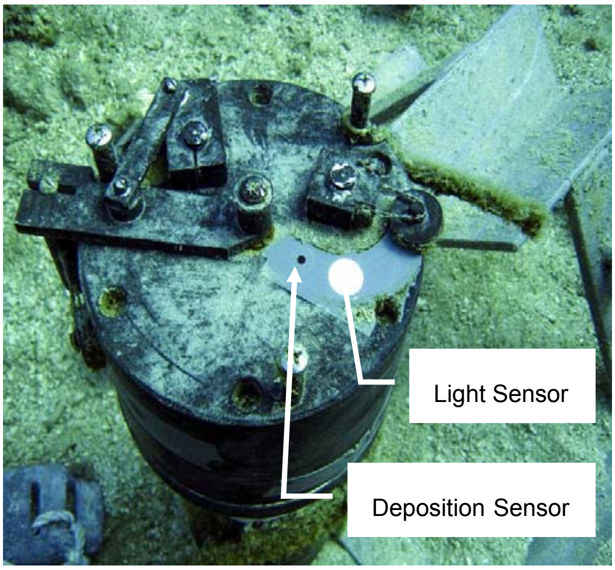
[7] The LTD loggers were developed by Professor Peter Ridd and colleagues at James Cook University, Queensland. Similar loggers have been used in other dredging programs in Western Australia (Pluto LNG, Woodside; Cape Lambert 85 MTPA Port Upgrade, Pilbara Iron).

LTD Logger



Sediment Trap Array



LTD Logger Showing Cleaned Light and Deposition Sensors

Terrestrial Light Sensor and Data Logger

Plate 13-1 Data Loggers and Sediment Traps Deployed During the Marine Baseline Program

13.3.2.3 Total Suspended Solids

Water samples for the analysis of Total Suspended Solids (TSS) were collected from 12 of the monitoring sites on two occasions over the duration of the Marine Baseline Program for comparison with the LTD logger data. TSS is a measure of the dry weight of suspended solids and includes both inorganic solids (e.g. clay, silt and sand) and organic solids (e.g. plankton and biological detritus) suspended in the water column.

Three replicate 3 L water samples were collected from approximately 0.5 m above the seabed adjacent to the LTD logger using a Niskin bottle. Each sample was filtered through a pre-dried and weighed 0.8–1.2 µm filter paper, rinsed with deionised water, folded and wrapped in a dry filter paper, placed inside a pre-labelled envelope and frozen. Samples were dried to remove all the water and re-weighed, with the difference between the two weights the particulate material present in the water, typically expressed as mg/L.

13.3.2.4 Light Attenuation

A daily Light Attenuation Coefficient (LAC) was calculated for each site using data from the terrestrial light logger on Barrow Island (Section 13.3.1.2) and the underwater light sensors (LTD loggers) deployed on the seabed at each site (Section 13.3.1.1). The data from the terrestrial light logger were used to represent the average incident light falling on the sea surface at each site for each time period. An approximate measure of the amount of light penetrating the sea surface at each site was derived by applying a correction factor of 0.96 to account for the reflection of light at the air–water interface (Kirk 1994; Cooper *et al.* 2008). The LTD loggers also recorded water depth each time a light measurement was made. The light attenuation path (i.e. the distance that a beam of light travels from the air–water interface to the seabed sensor) is a function of the water depth and the angle of incidence of the incoming light due to the solar zenith angle.[8] To enable comparison of the LAC values throughout the year, the LAC values were normalised to account for the solar zenith angle (Section 13.3.4.2).

13.3.2.5 Sediment Deposition and Vertical Particle Flux

13.3.2.5.1 LTD Loggers

The spatial and temporal patterns of natural sediment deposition and vertical particle flux were measured using a combination of semi-continuous and discontinuous methods. Sediment deposition was measured semi-continuously using an upward-oriented Optical Backscatter Sensor (OBS) incorporated into the LTD logger. The OBS response increases as particles accumulate on the sensor and the output is related to the amount of accumulated sediment. The difference in reading before and after a wiping gives a measure of the mass of sediment deposited per unit area. The sediments that deposit on the sensor are subject to resuspension by hydrodynamic forces and the accumulation of sediments is not considered to be significantly biased by the design of the sensor and housing. In the event that there is no deposition, the upward-oriented sensor records a value similar to the sideways-oriented turbidity sensor, as it is effectively the same sensor. The difference between the two sensors thus gives an indication of the quantity of material that has accumulated on the deposition sensor (Thomas and Ridd 2004, 2005).

13.3.2.5.2 Sediment Traps

Measurements of semi-continuous sediment accumulation were supplemented by the deployment of sediment traps to provide an estimate of the vertical particle flux of suspended materials at the sites. While attempts have been made to define the 'ideal sediment trap' (Thomas and Ridd 2004), trap designs are not standardised. As sediment trap studies have previously been undertaken in the region (Forde 1985), the design of the sediment trap arrays for the Marine Baseline Program were consistent with those studies to facilitate comparisons between datasets. Each sediment trap was a 320 mm long, 55 mm diameter, vertically-oriented, open-topped PVC cylinder, with an aspect ratio of 5.82. Each array was made up of six sediment traps, positioned approximately 1.5 m above the seabed with a separation distance of at least 310 mm between each trap (Plate 13-1). Six traps were deployed at each site to account for inter-trap variability and to provide for contingency in the event that animals (e.g. fish) occupied the traps.

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[8] The midday solar zenith angle changes incrementally each day, following a cyclical (annual) pattern due to the tilt of the earth's rotational axis with respect to its orbital plane. This cyclical change in zenith angle results in a longer light attenuation path for a given water depth when the sun is lower in the sky (e.g. during winter), than when the sun is higher in the sky.

At the end of the sampling period, cylinders were inspected for occupants, capped and brought to the surface, where the contents were decanted into a sterile vessel and chilled until analysis. Samples were discarded where fish occupation was evident.

The samples were analysed for:

- total dry weight
- total organic carbon (TOC)
- total inorganic carbon (TIC).

These parameters were consistent with those measured for surficial sediment samples (Section 12.3.2).

Standard laboratory analytical procedures were employed throughout and laboratories with NATA-accredited methods undertook the analyses. The sample was filtered through a pre-dried and weighed 1.2 µm filter paper, which was then dried and re-weighed to provide a measure of total dry weight. Samples were analysed for total carbon by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved carbon (as CO_2) measured by infra-red detection. Samples were analysed for total organic carbon by acidification to remove inorganic carbonates, followed by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved organic carbon (as CO_2) measured by infra-red detection. Total inorganic carbon was determined as the difference between total carbon and total organic carbon. Total organic carbon and total inorganic carbon content were reported as a percentage of total dry weight and averaged across the six replicates. A random subset of samples was also analysed for particle-size distribution by laser diffraction and wet sieving to determine the physical size characteristics of the trapped sediments.

13.3.3 Timing and Frequency of Sampling

Details of the sampling periods for the LTD loggers, the terrestrial light logger, water column profiles and sediment trap arrays are provided in Appendix 11.

13.3.3.1 LTD Loggers

Twelve LTD loggers were deployed in December 2007 (Table 13-3). The LTD logger at MOF2 was deployed in April 2008, the logger at LNG1 in July 2008, and the logger at LNG0 in January 2009. The logger at the HDD site was deployed in May 2009. The loggers at the Biggada Reef and MOF2 sites were removed in mid-October 2009. With the exception of the HDD site, more than one complete annual cycle of water quality data has been collected at each of the monitoring sites. The water quality data for HDD are reported in the Marine Baseline Report for the Offshore Feed Gas Pipeline System and marine component of the shore crossing (Chevron Australia 2010a).

Table 13-3 Deployment Dates of LTD Loggers and Number of Days of Data Collection

Zone	Site Name (Code)	Deployment Date	No. of Data Days*[9]
Zone of High Impact	LNG0 (LNG0)	19/01/2009	430
Zone of Moderate Impact	MOF1 (MOF1)	6/12/2007	612

[9] A ‘data day’ is considered to be any day where data were collected from at least one of the four sensors on the LTD logger. The number of data days reported was the maximum number of days of data recorded by any one of the individual sensors at a site. This underestimates the total number of data days as it is likely that data would have been recorded by other sensors on at least some of the days. The ‘>’ indicates that the total number of days exceeds the listed value.

Zone	Site Name (Code)	Deployment Date	No. of Data Days*[9]
	LNG1 (LNG1)	15/07/2008	426
	Lone Reef (LONE)	10/12/2007	636
Zone of Influence	Ant Point Reef (ANT)	3/12/2007	705
	Southern Lowendal Shelf (LOW)	3/12/2007	661
	MOF2 (MOF2)	2/04/2008	456
	MOF3 (MOF3)	6/12/2007	694
	LNG2 (LNG2)	6/12/2007	646
	HDD (HDD)	18/05/2009	233
Reference Sites	Ah Chong (AHC)	9/12/2007	682
	Biggada Reef (BIG)	8/12/2007	655
	LNG3 (LNG3)	5/12/2007	628
	Dugong Reef (DUG)	4/12/2007	681
	Batman Reef (BAT)	4/12/2007	673
	Southern Barrow Shoals (SBS)	7/12/2007	659

*Note: *From deployment to mid-January/mid-March 2010.*

The LTD loggers measure light, turbidity and deposition in a burst of samples over a 1 s period, with depth measurements taken over a period of 10 s (10 bursts of samples). The average of each burst was logged to the internal memory as a single data point (see Thomas and Ridd 2005). The sampling interval was initially programmed to 20 minutes over the first deployment period (December 2007–mid-January 2008); and was subsequently decreased to 10-minute sampling intervals. Note that the logger at the HDD site was programmed for a 30-minute sampling interval to extend the battery life.

Due to rapid biofouling, all subsurface equipment was serviced at a maximum interval of eight weeks. During these times, the LTD loggers were removed from the seabed, the data downloaded, checked and visually verified, batteries replaced as required and the sensors cleaned and anti-fouled as necessary. The wiper arm design was modified early in the Marine Baseline Program following damage to the wiper assemblies from fish interference and the consequent deterioration of data recovery and data quality. However, ongoing fish interference resulted in deterioration of data recovery throughout the Marine Baseline Program, including periods of complete data loss. LTD logger malfunction were less common, but on occasion resulted in periods of data loss. Overall, data recovery rates from the LTD loggers were ~80% across all sites and parameters measured.

13.3.3.2 Terrestrial Light Logger

The terrestrial light logger was installed on 9 September 2008 and relocated on 8 March 2009.[10] The sensor measures the incident irradiance in a burst of samples taken once every minute and averages the readings over 15-minute logging intervals. For the purposes of the Marine Baseline Program, only the data recorded during the midday period were used to calculate the LACs (see Section 13.3.4.2).

[10] The terrestrial light logger was relocated in March 2009 because the original location was cleared for construction activities.

13.3.3.3 Water Column Profiles

Between five and 12 profile measurements were obtained at approximately monthly intervals at each water quality monitoring site using a SEACAT Profiler. Note that as the field surveys were scheduled around neap tides, the profiles are mostly representative of the water column during periods of lower tidal flow and may not therefore be representative of conditions during periods of greater tidal flow. In addition, profiles were only undertaken during periods when wind speeds were <15 knots and thus do not represent the conditions that may occur during periods of rough weather.

13.3.3.4 Total Suspended Solids

Water samples for the analysis of TSS were collected over the periods 9–28 September 2008 and 18–24 February 2009 for comparison against the data collected by the LTD loggers.

13.3.3.5 Sediment Traps

The sediment trap arrays were progressively installed between June and October 2008 and were sampled and redeployed approximately monthly to capture temporal variation in the sedimentation regime. On some occasions, due to logistical constraints, sediment traps were deployed for up to three months, resulting in a loss of temporal resolution. Sediment traps remain in situ for ongoing data collection and additional baseline results have been presented in subsequent revisions of the Marine Baseline Report.

13.3.4 Data Processing and Analyses

13.3.4.1 Processing of Raw Data

13.3.4.1.1 Meteorological Data

The meteorological data were visually checked for consistency and any incomplete or erroneous data records removed.

13.3.4.1.2 LTD Loggers

On completion of each LTD logger field maintenance visit, the raw data downloaded from the LTD loggers were sent to James Cook University for conversion, analysis and preliminary interpretation. The instrument output readings were visually checked for accuracy and erroneous data (including those associated with periods of instrument malfunction that required recalibration and those suspected to be influenced by fouling of the sensors whilst in service) were removed. Note the LTD loggers were rotated through the monitoring sites such that any variability (and thus bias) was distributed amongst the sites. The data were converted and calibrated to units of measurement using site-specific algorithms to provide values of Suspended Sediment Concentrations (SSC) in mg/L, Accumulated Sediment Surface Density (ASSD) in mg/cm^2 and light ($\mu E/m^2/s$). Refer to Appendix 10 for more detailed information.

Note that the data presented in the Marine Baseline Report are subject to Quality Assurance and Quality Control (QA/QC) procedures that periodically involve some post-recovery amendments to data. These corrections are applied to the data when there is an indication that a calibration error has occurred; however, the correction often cannot be applied until there is sufficient contextual information to identify those data that require correction. Similarly, for data that require a correction through application of more recent calibration equations, the correction cannot be implemented until the LTD logger is recalibrated. Some (corrected) data may therefore not be issued until some months after the initial reporting. Thus, data presented in this revision of the Marine Baseline Report represent the most reliable data from the information available at the time of analysis.

13.3.4.1.3 Terrestrial Light Logger

The terrestrial light logger was regularly downloaded using instrument-specific software which output the data as units of measurement ($\mu E/m^2/s$). The sensor-specific calibration coefficient was input into the data logger, thus no calibration or conversion of raw data was required.

13.3.4.1.4 Water Column Profiles

Water column profile data collected using the SEACAT Profiler were downloaded and converted into units of measurement using instrument-specific software (SEASOFT-WIN32). The raw data were imported into Microsoft Excel and visually checked to ensure all sensors had operated correctly during each profile.

Erroneous data associated with equilibration periods and any data that showed interference when the instrument was at shallow depths (e.g. depths <60 cm) were removed. Adjustments to pH data were applied as necessary, based on calibrations performed at the conclusion of each field program.

13.3.4.1.5 Sediment Traps

The contents of each sediment trap were analysed to determine the total weight of sediment. This was converted to a daily rate of deposition ($g/m^2/d$) using the trap surface area and the deployment period. No correction was made for dissolution or degradation of organic sediment components contained within the traps that may have occurred during the deployment period.

13.3.4.2 Calculation of Light Attenuation Coefficients

The daily Light Attenuation Coefficient (LAC) was calculated for each site using data from the terrestrial light logger on Barrow Island (Section 13.3.1.2) and the underwater light sensors (LTD loggers) deployed on the seabed at each site (Section 13.3.1.1). The daily mean surface irradiance value was derived by averaging all measurements from the terrestrial light logger for the midday period (10:00–14:00 Australian Western Standard Time [WST]). Values outside this period may be subject to a continuum of variation associated with the angle of incidence of the sun, which changes incrementally (cyclically) due to the earth's orbit. The daily mean was multiplied by a factor of 0.96 to estimate the irradiance immediately below the air–water interface (surface) at each site. Similarly, the daily mean irradiance at the seabed at each site was calculated by averaging all measurements recorded by the LTD loggers for the midday period.

To account for fluctuating water height and effective vertical separation distance between the two observation points, an average depth for the midday period was calculated from the pressure data recorded by each individual LTD logger.

The daily LAC for each site was calculated according to the following equation:

$$LAC = [(\text{Log}_e \text{ average light at seabed} - \text{Log}_e \text{ average light at surface}) \div \text{average water depth}].$$

This daily value was then normalised to account for changes in solar zenith angle (Mobley 1994). The following equation was used to calculate the underwater solar zenith angle:

$$S_{ZAUW} = \arcsin(\sin S_{ZA}/1.34)$$

where S_{ZA} is the above-water solar zenith angle; 1.34 is the refractive index of water; and S_{ZAUW} is the underwater solar zenith angle. The above-water solar zenith angle for Barrow Island was sourced from a solar elevation calculator (Geoscience Australia 2009).

The LAC was then normalised by applying the following equation:

$$LAC_n = LAC_m.\cos(S_{ZAUW})$$

where LAC_n is the normalised LAC; LAC_m is the measured LAC; and S_{ZAUW} is the underwater solar zenith angle.

13.3.4.3 Comparison of Total Suspended Solids and Suspended Sediment Concentrations

The measurements of turbidity recorded by the LTD loggers were converted to an estimate of SSC according to a linear regression derived from calibration experiments (Appendix 10). A NTU/SSC calibration profile was derived for each site, using sediments sampled from adjacent to the LTD logger. Note that the primary error associated with the calibration is that the grain-size distribution of sediments taken from adjacent to the LTD logger may not be representative of the grain-size distribution of the sediments suspended in the water column. This could result in up to a factor of two error between the actual (samples collected and TSS weighed) and estimated concentration (measured NTU × conversion factor).

Under calm wave and, to a lesser extent, tide conditions, the composition of the sediments adjacent to the LTD loggers is unlikely to be representative of the particles in suspension flowing past the LTD loggers, as the hydrodynamic conditions are not conducive to mass resuspension of sediments. However, under rough weather conditions, the composition of the suspension is more likely to be influenced by the resuspension of mobile fractions of sediments in close proximity to the LTD loggers. The estimates of SSC produced from the LTD turbidity data are therefore likely to be more accurate under marginal weather conditions than under calm weather conditions.

To compare actual TSS concentrations and corresponding SSC estimates from the LTD loggers, water samples were collected at 12 monitoring sites on two occasions for the measurement of actual TSS concentrations. The measurements of TSS and the corresponding (daily median) estimated SSC values from the LTD loggers are presented in Table 13-4. Both sampling events were undertaken during calm weather conditions, thus the results represent a small range of the TSS concentrations that are likely to occur under different weather conditions.

Table 13-4 Measured TSS Concentrations and Corresponding SSC Estimates, 9–28 September 2008 and 18–24 February 2009

Site Code	September 2008		February 2009	
	Measured TSS (mg/L)	Estimated SSC – Daily Median (mg/L)	Measured TSS (mg/L)	Estimated SSC – Daily Median (mg/L)
MOF1	6.10	1.00	3.43	2.37
LNG1	5.73	3.38	4.03	5.43
Ant Point Reef	4.63	1.50	3.23	1.38
Southern Lowendal Shelf	4.87	3.53	5.43	2.52
MOF2	6.23	0.81	4.37	0.98
MOF3	4.57	0.50	5.50	4.54
LNG2	4.73	2.56	3.03	1.69
Ah Chong	4.27	4.00	3.20	12.92
LNG3	4.53	2.28	6.20	2.93
Dugong Reef	4.73	1.62	6.17	4.23
Batman Reef	4.37	2.66	5.07	2.47
Southern Barrow Shoals	3.87	4.21	4.80	2.88

The data demonstrate that, under calm weather conditions, the SSC estimates from the LTD loggers were generally below the measured TSS. It might be expected that, because of the way the data were converted, the accuracy of the SSC estimates would be greater during rough weather conditions, when localised resuspension of sediments occurs.

13.3.4.4 Comparison of Sediment Deposition and Vertical Particle Flux

The LTD loggers measure sediment deposition on a short time scale, in the order of minutes to hours. The sediments that deposit on the sensor are subject to resuspension by hydrodynamic forces and the accumulation of sediments is not considered to be significantly biased by the design of the sensor and housing. In contrast, sediment traps are deployed over longer time periods (weeks to months) and are designed to capture particles in the water column, therefore largely removing the processes that occur at the water–sediment interface such as saltation and resuspension of sediments by hydrodynamic forces. Trends in the data from the LTD loggers or the sediment traps may not therefore be reflected in the other, as the factors and processes that influence the measurements are different. For example, higher average vertical particle flux rates experienced during turbid conditions will not necessarily be reflected in ASSD measurements, as the hydrodynamic forces may still be sufficient to remove the increased volume of settling particles from the deposition sensor surface within a short timeframe. However, similarities in trends between turbidity and vertical particle flux are likely, as both are different forms of measuring particles suspended in the water column.

Examination of the raw ASSD data at all sites indicated that the amount of deposition on the ASSD sensor was generally considered below the detection limit because of the removal of deposited sediments by hydrodynamic forces prior to accumulation. It can therefore be inferred that the particles captured within the sediment traps, which represent particles settling through the water column over a broad range of conditions, do not generally accumulate on the deposition sensor.

The contents of two sediment traps from each of two sites (MOF3 and LNG3) over one sampling period were analysed for particle-size distributions. The volume weighted mean particle-size of the trap contents was between 128–144 µm (Table 13-5). During dredging and spoil disposal activities, particles in this size range are at the upper size limit of particles that are expected to form the plume generated by the dredging. Given that under baseline conditions, particles in this size range do not normally accumulate on the deposition sensor, deposition may only be recorded during dredging and spoil disposal activities by LTD loggers located in close proximity to the dredge (e.g. within the Zones of High and Moderate Impact).

Table 13-5 Volume Weighted Mean Particle-sizes of Sediments Captured in Sediment Traps at LNG3 and MOF3, September–December 2008

Sample	Volume weighted mean particle-size (µm)
LNG3-1	134.5
LNG3-2	144.2
MOF3-1	130.6
MOF3-2	127.6

Note that while the ASSD data has been presented in the earlier revisions of the Marine Baseline Report for information purposes, sediment accumulation was not recorded and the data were considered to be below the limits of accurate quantification[11], and therefore not suitable for deriving trigger levels for monitoring of impacts during dredging and spoil disposal activities. ASSD data are thus not presented in this revision of the Marine Baseline Report.

13.3.4.5 Analysis of LTD Logger Data

A subset of the converted LTD logger data were analysed using Microsoft Access, Microsoft Excel and SYSTAT v12 (Cranes Software International Pty. Ltd.) to determine a suitable temporal

[11] Generally the full range at low range, which is normally used in these types of environments, is around 0–100 NTU. The raw data has a 12-bit resolution which can give 0.1 NTU resolution between consecutive readings in a time-series. The resolution of differences over longer time periods, or between sites, is more problematic as it is dependent on longer term drifts in the instrument (which is common for all instruments) and is especially problematic at very low turbidity levels (around 1 NTU). It is thus not usually possible to resolve differences of <1 NTU between sites or over long time periods. The accuracy of the reading is considered at best 1 NTU at low values and worse at higher values (1% of 100 NTU) (Prof. Ridd, May 2009).

resolution for analysis of the entire dataset and the presentation of the data. A range of sites were analysed with consistent results; however, only the analysis of the data from Ant Point Reef (ANT) is presented here for illustrative purposes. This site was selected as it has strong tidal currents compared to the other sites and was thus more likely to display tidal influences on water quality parameters if these occurred. Time-series plots of SSC, turbidity (nephelometric turbidity units [NTU]), ASSD, light and Wave Height Index were produced. Comparisons of time-series data for SSC and Wave Height Index for both 10-minute intervals and daily medians from Ant Point Reef are presented in Figure 13-3. On the basis of the consistency of the trends in 10-minute interval measurements and daily median values, daily measures were used in subsequent analyses.

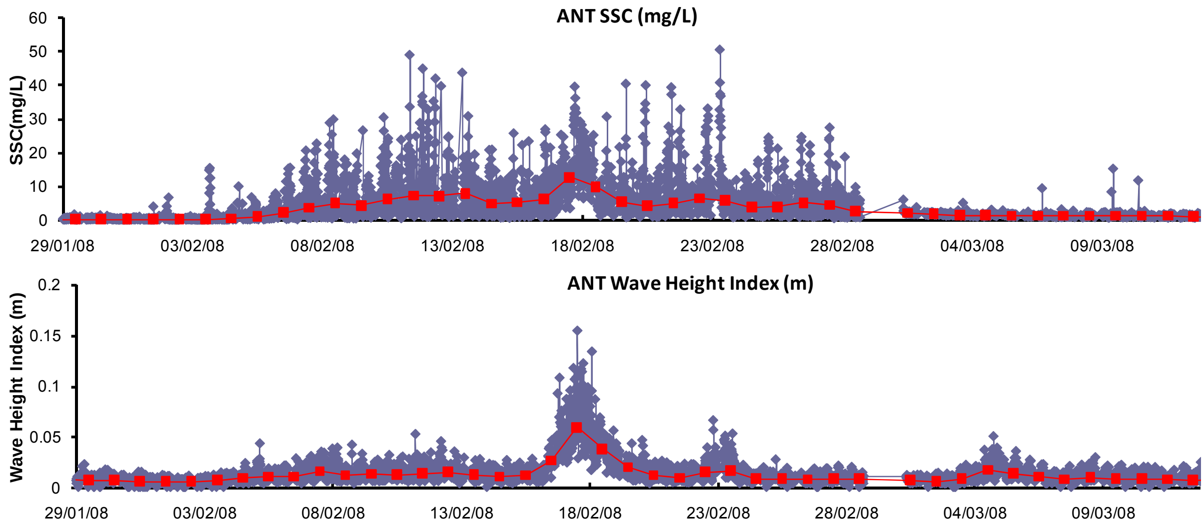

Figure 13-3 Time-series Plots of 10-Minute Interval and Daily Median SSC and Wave Height Index at Ant Point Reef

To test if there were well-defined patterns underlying the data within 24-hour periods, the SYSTAT v12 autocorrelation function was applied to the 10-minute frequency SSC, ASSD, light, Water Height and Wave Height Index data. Examination of the autocorrelation results for SSC, ASSD and Wave Height Index indicated a strong correlation of measurements over short time periods (lag) with the relationship dissipating with time (Figure 13-4; Figure 13-5; Figure 13-6). The results are shown for one site, Ant Point Reef, but similar patterns were found at all sites.

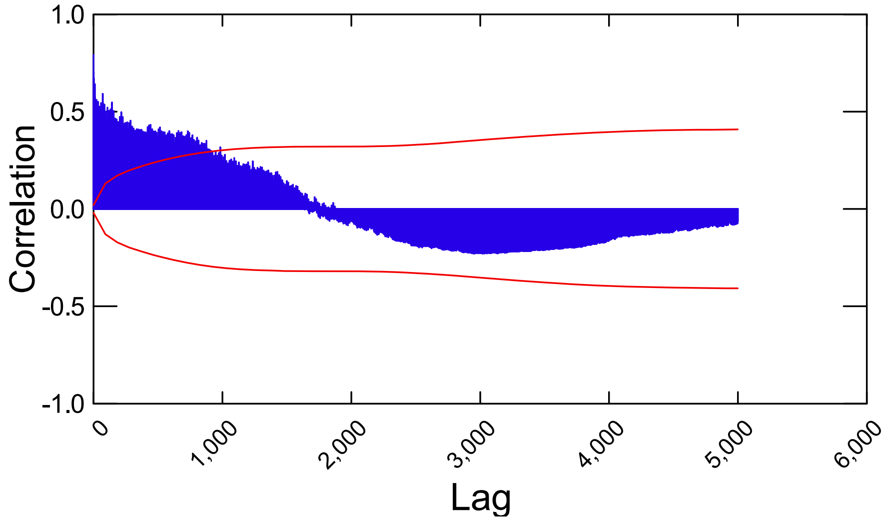

Figure 13-4 Autocorrelation with a 5000 Data Point Lag (34.7 days) and 95% Confidence Interval Line, for Ant Point Reef 10-Minute Interval SSC Data (21 January 2008–24 February 2008)

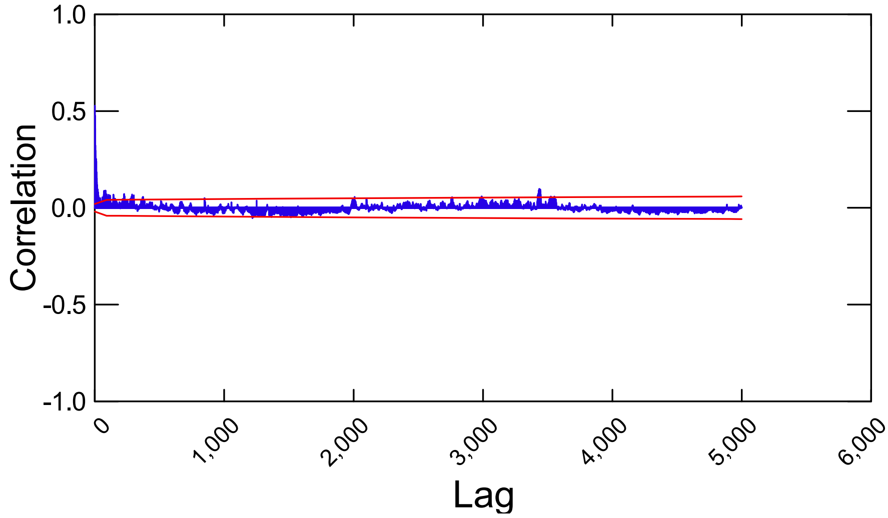

Figure 13-5 Autocorrelation with a 5000 Data Point Lag (34.7 days) and 95% Confidence Interval Line, for Ant Point Reef 10-Minute Interval ASSD Data (21 January 2008–24 February 2008)

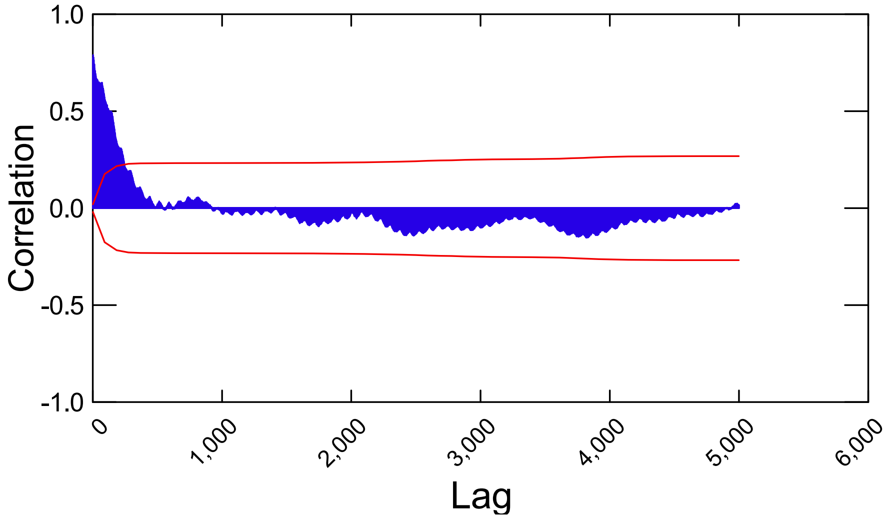

Figure 13-6 Autocorrelation with a 5000 Data Point Lag (34.7 days) and 95% Confidence Interval Line, for Ant Point Reef 10-Minute Interval Wave Height Index Data (21 January 2008–24 February 2008)

The results from the autocorrelation analysis did not indicate that there were cyclical patterns (e.g. 6 or 12 hours) over 24-hour periods (144 lag) evident in SSC, ASSD or Wave Height Index, suggesting limited relationships between these variables and daily patterns of tide or light. If a relationship to tide or light was evident, the results would be similar to Figure 13-7 and Figure 13-8, which represent the autocorrelation results for light and Water Height (tide) and that are tidal dependent. It is important to note that these results do not infer that tide has no influence on SSC, only that during the baseline conditions there was no detectable influence of tidal range on SSC given other forces that appear to be driving most of the variation in water quality (e.g. fluctuations in water height from swell and wind-generated seas). This may change during dredging and spoil disposal activities. Similarly, there was a lack of correlation between daily tidal range and daily median SSC during baseline conditions (Appendix 12). If there was a strong tidal influence, it might be expected that on days with greater tidal ranges there would have been greater turbidity or sedimentation (i.e. a positive correlation).

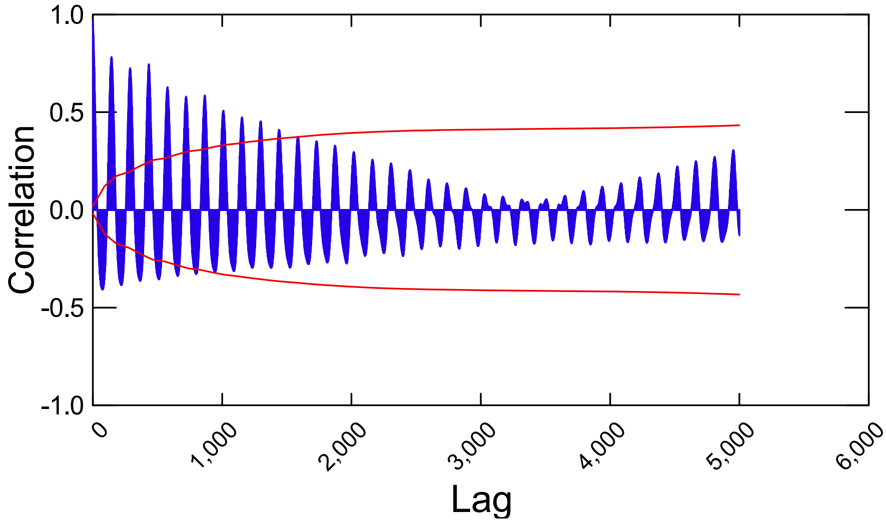

Figure 13-7 Autocorrelation with a 5000 Data Point Lag (34.7 days) and 95% Confidence Interval Line, for Ant Point Reef 10-Minute Interval Light Data (21 January 2008–24 February 2008)

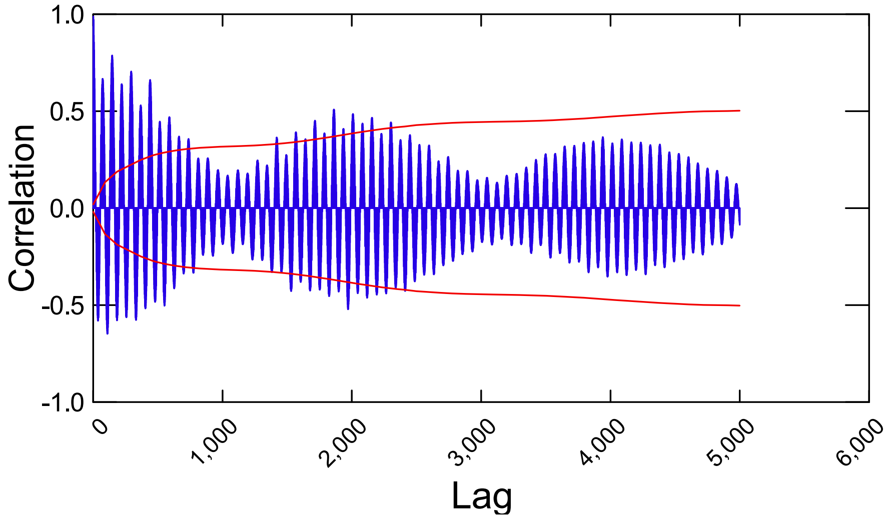

Figure 13-8 Autocorrelation with a 5000 Data Point Lag (34.7 days) and 95% Confidence Interval Line, for Ant Point Reef 10-Minute Interval Water Height Data (21 January 2008–24 February 2008)

The consistent autocorrelation trend over a 24-hour period (lag of 144), including consistent statistical significance of correlations, support the use of daily measures of SSC and Wave Height. Daily median values also reduced the impact of outliers on the daily measures of SSC and Wave Height Index.

Following the initial data analysis, analyses were then undertaken for the complete LTD logger dataset collected from each site. All light measurements were coded according to whether the measurement fell within the midday period (Section 13.3.4.2). The use of midday period light was also supported by statistically significant autocorrelation results that showed a consistent cyclical pattern of light during midday periods (Figure 13-7). Absent and zero values were excluded from the dataset on the basis that zero light during the day was extremely unlikely at the depths of the loggers (<10 m) and instead reflected missed data recordings by the logger. The daily median light values for the midday period were calculated using SYSTAT v12 and a time-series plot and summary statistics generated for each season.

Using similar techniques, distributions of daily median turbidity and SSC values were calculated for each season. In contrast to the light values, measurements were not excluded based on the time of day. Null and zero turbidity and SSC values were considered erroneous and excluded from the analysis as it was unlikely that the waters surrounding Barrow Island would ever be as clear as pure seawater (the zero reading).

Patterns of increasing ASSD readings before clearing, generally observed with cumulative deposition and subsequent removal by the wiper mechanism (see Ridd *et al.* 2001), were not evident at any site. Where deposition was detected, the readings were generally short-term (< two hours). The lack of accumulation and periodic removal by the wiper was also evident in the autocorrelation analysis (Figure 13-5). This suggests that the natural hydrodynamic regime of the area was sufficient to remove whatever sediment had deposited on the sensor prior to a wiping event. Because of the difficulty of establishing when a wiping event had occurred and when deposition was removed naturally, the 95th percentile of the calculated hourly deposition rates that occurred each day was selected as an indicative measurement of the maximum potential deposition rate. The 95th percentile was selected rather than the maximum, to remove erroneous data from the calculations that may have been caused by transitory fauna interfering with the sensor. The ASSD values were first divided by two to give an hourly deposition rate (as the measurement period is two hours), then the 95th percentile of the deposition rates was calculated for each day using SYSTAT v12. Time-series plots and summary statistics of the daily values were generated, however given that the data were considered to be below the limits of accurate quantification, the ASSD data are not presented in the Marine Baseline Report.

13.3.4.6 Correlating LTD Logger Parameters with Meteorological and Oceanographic Variables

Daily measures of the LTD logger parameters (daily median SSC, daily median NTU, daily median Wave Height Index, LAC and median midday light) were collated. Each data point was classified into two broad periods, 'summer' and 'winter', based on preliminary analysis of data trends, which suggested that turbidity was largely influenced by season and therefore stratification of the data into seasons would produce clearer relationships. The seasonal periods were chosen to align with those used for modelling the extent of sediment plumes generated by the dredging and spoil disposal activities (GEMS 2008), which identified two major wind patterns that occur in the Barrow Island region. The 'winter period' was defined as May to October and the 'summer period' as November to April (Section 3.3).

A measure of daily tidal water movement was calculated from Bureau of Meteorology tide prediction data by subtracting the lowest daily water height measurement from the highest measurement. Daily measures of average air temperature, rainfall to 09:00 WST and five measures of wind speed were calculated from the meteorological data. These daily wind measurements were:

- Average of the 30-minute average: In each half-hour sampling interval, the average wind speed for the last 10 minutes of that period is recorded by the Barrow Island weather station. The 'average of the 30-minute average' is the average of all half-hourly average wind speeds.
- Maximum of the 30-minute average: The maximum of the half-hourly average wind speeds.
- Average of the 30-minute maximum: In each half-hour sampling interval, the maximum wind speed (sustained gust) measured in that period is recorded by the Barrow Island weather station. The 'average of the 30-minute maximum' is the average of the half-hourly maximum wind speeds.
- Median of 30-minute maximum: The daily median of the half-hourly maximum wind speeds.
- Maximum of the 30-minute maximum: The maximum of the half-hourly maximum wind speeds.

To reduce the number of variables of interest, the relationships between all LTD logger parameters and meteorological measurements were first investigated in detail at two sites using the program R (Ihaka and Gentleman 1996). The Ant Point Reef (ANT) and Ah Chong (AHC) sites were selected because of their relatively long time-series of LTD logger data, as well as their varied habitat types and hydrodynamic characteristics.

Scatter plots with trend lines, Pearson's R-squared values and levels of significance (*p*-values) were created for all pair-wise combinations of variables at these two sites. Visual inspection of the scatter plots and correlations allowed the identification of those relationships of most interest. Variables were eliminated if clear relationships were not evident (e.g. rainfall and SSC) or if more suitable measures of a variable were available (e.g. the daily median of 30-minute maximum wind reading was used instead of the other wind measurements as it had a strong relationship with SSC and reduced the impact of outlier measures).

The refined set of variables of interest was:

- Daily median of daily 30-minute maximum wind: The median of the half-hourly maximum wind speeds recorded on that day.
- Daily maximum tidal movement: The difference in water height between the predicted lowest low tide and the highest high tide on that day.
- Daily median SSC: The median of the 10-minute SSC measurements recorded on that day.
- Daily median NTU: The median of the 10-minute NTU measurements recorded on that day.

- LAC.
- Daily median of midday light: The median of 10-minute light measurements recorded between the hours of 10:00 and 14:00 WST.
- Daily median Wave Height Index: The median of the Wave Height Index (Root Mean Square water depth) measurements recorded for that day.

A matrix of scatter plots with trend lines, Pearson's R-squared values and levels of significance were produced for the refined set of variables of interest across all sample sites (Appendix 12). This matrix was used to assess the type, strength and ubiquity of relationships between variables across sites.

13.4 Results

13.4.1 Meteorological Data

Box plots of the daily average air temperature data recorded from November 2007 to February 2010 at the Barrow Island weather station are presented in Figure 13-9. There was a marked decrease in the average air temperature between April and June, indicating the transition between summer and winter. The average air temperature was consistent between June and September before rising to approximately 25 °C in October. The average air temperature was similar over the October to December period, prior to another increase to almost 30 °C during the period January to March.

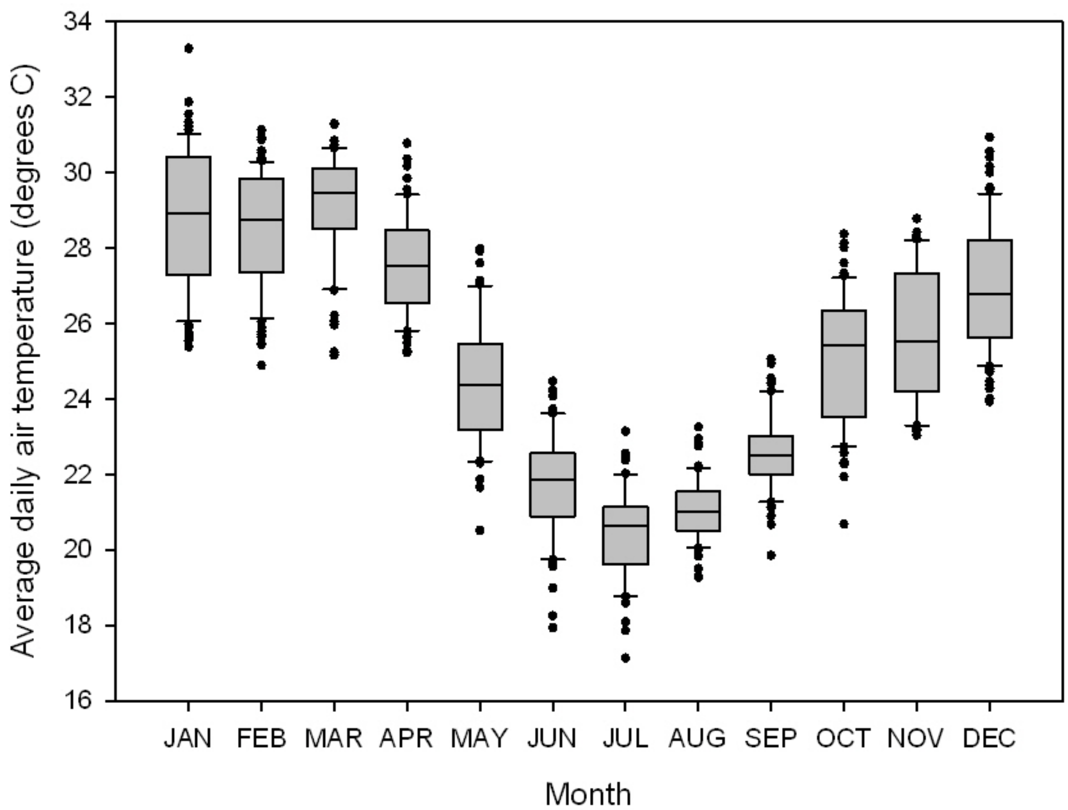

Figure 13-9 Monthly Box Plots of the Daily Average Air Temperature Recorded at the BOM Weather Station on Barrow Island, November 2007–February 2010

Note: boxes = range of lower and upper quartiles; solid horizontal line within the box = median; whiskers = 10th and 90th percentiles; circles = outliers.

Ten tropical cyclones were recorded off the Western Australian coastline near Barrow Island during the 2007/2008, 2008/2009 and 2009/2010 cyclone seasons (Figure 13-10 shows the travel paths for the 2007/2008 and 2008/2009 seasons). Some of these cyclones had a measurable influence on the water quality at sites, predominantly through the generation of waves. The effects are noticeable in the time-series graphs produced for each site (Section 13.4.2).

A brief summary of the cyclones is presented below:

- Cyclone Melanie (Tropical Cyclone [TC] 1): Reached cyclone intensity on 28 December 2007 and passed approximately 350 km to the west of Barrow Island between 30–31 December 2008 as a Category 2 cyclone. No rainfall associated with Tropical Cyclone Melanie was recorded on Barrow Island.
- Cyclone Nicholas (TC 2): Formed in the offshore Kimberley region and tracked parallel to the coast until it passed approximately 150 km west of Barrow Island on 18 February 2008 as a Category 3 cyclone before crossing the coast south of Coral Bay on 20 February 2008. A total 83 mm of rainfall was recorded on Barrow Island from 11–24 February 2008 associated with the cyclone, including falls of 30.6 mm and 19.8 mm on 18 and 19 February 2008, respectively. Wind speeds of over 80 km/h were recorded on the island.
- Cyclone Ophelia (TC 3): Also formed in the Kimberley region and passed within 400 km to the north and west of Barrow Island as a Category 2 cyclone between 4 and 6 March 2008. No rainfall was recorded on Barrow Island during this period.
- Cyclone Pancho (TC 4): Formed in the Indian Ocean on 24 March 2008 and passed >900 km west of Barrow Island on 27 March 2008 as a Category 4 cyclone. Tropical Cyclone Pancho produced heavy rainfall in the Pilbara and Gascoyne regions, with Barrow Island receiving more than 180 mm of rain in a 24-hour period.
- Cyclone Anika (TC 5): Formed on 19 November 2008 and reached Category 2 intensity by 20 November 2008. Tropical Cyclone Anika was downgraded to a tropical low on 21 November 2008. The cyclone was too far west for strong winds to be experienced at Barrow Island.
- Cyclone Billy (TC 6): Formed in the Kimberley region near Broome and tracked west out to sea. The cyclone reached Category 4 intensity on 24 December 2008 and travelled within approximately 350 km of Barrow Island at its closest point. No rainfall was recorded on Barrow Island as a result of the cyclone.
- Cyclone Dominic (TC 7): Formed within 150 km of Barrow Island from a tropical low that originated in the Kimberley region. Once formed, the cyclone moved south and the eye of the cyclone passed within 10 km of the west coast of Barrow Island on 26 January 2009. A maximum sustained wind gust of 102 km/h was recorded on Barrow Island and approximately 90 mm of rainfall was recorded within a 24-hour period.
- Cyclone Freddy (TC 8): Formed as a cyclone on 7 February 2009 well off the Western Australian coastline and tracked west before weakening to a tropical low on 9 February 2009.
- Cyclone Laurence: Formed as a cyclone west of Darwin on 13 December 2009. The cyclone reached Category 5 intensity on 16 December 2009 before crossing the Kimberley coast and reverting to a tropical low. On 19 December, the low redeveloped into a tropical cyclone near Broome. Cyclone Laurence crossed the Pilbara coast near Wallal, 230 km east of Port Hedland as a Category 5 cyclone on 21 December 2009. No rainfall or unusually strong winds were recorded on Barrow Island during this time (BOM 2010).
- Cyclone Magda: Formed in the Timor Sea on 20 January 2010. Tracking roughly south, Cyclone Magda varied in intensity before crossing the Kimberly coast on 22 January 2010. No unusual affects were recorded by the Barrow Island weather station (BOM 2010).

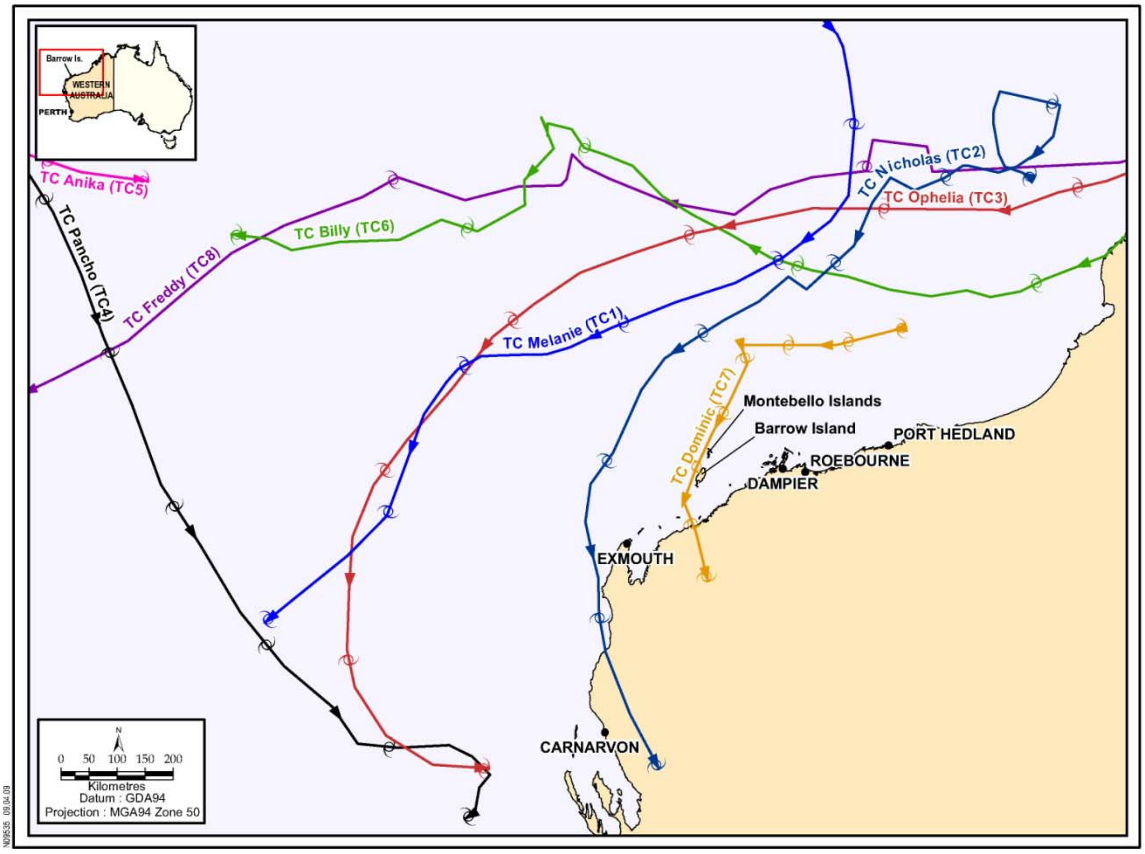

Figure 13-10 Tracks of Tropical Cyclones that Passed near Barrow Island During the 2007/2008 and 2008/2009 Cyclone Seasons

A time-series graph of the daily maximum sustained wind gust recorded at the Barrow Island weather station is provided in Figure 13-11. The figure shows that, in general, winds during the summer period are more consistent but punctuated by strong wind conditions recorded during the passage of tropical cyclones, depending on the distance of the cyclone from Barrow Island. Winds during the summer period are generally from the south-west and west, shifting towards the south during March (Asia-Pacific Applied Science Associates [APASA] 2005), hence the majority of the sites are somewhat protected by the Island from the prevailing winds and seas/swell during this period.

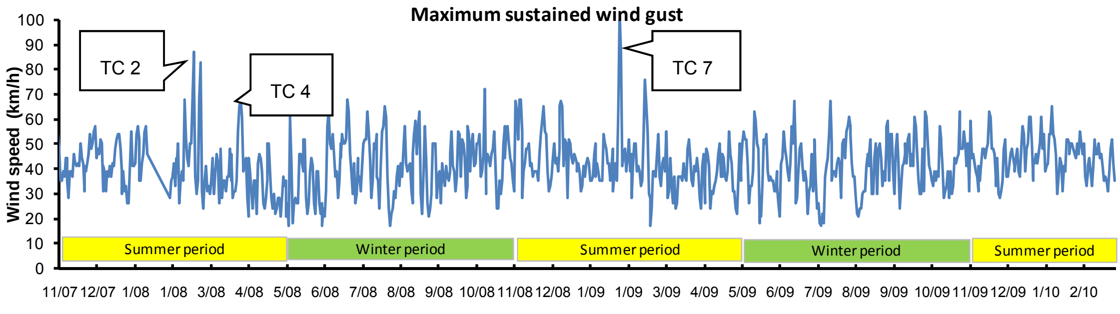

Figure 13-11 Time-Series Graph of the Daily Maximum Sustained Wind Speed Recorded at the Barrow Island Weather Station, 1 November 2007 to 28 February 2010

The maximum sustained wind in the winter period shows many peaks associated with the strong easterly winds that prevail during the winter months (APASA 2005). These winds often remain consistently strong for extended periods (up to 5–6 days) during certain weather patterns, generating wind seas that propagate into the east coast of Barrow Island. Thus at the majority of the sites there was a measurable effect on water quality, with suspended sediment concentrations generally higher during winter when easterly winds are more common. The west coast of Barrow Island is exposed to the open ocean and a relatively vigorous wave climate, bringing long period Southern Ocean swells and shorter-period local wind waves, particularly during the summer months, when winds prevail from the south-west.

13.4.2 LTD Logger and Sediment Trap Results

13.4.2.1 Water Quality (including Measures of Turbidity and Light Attenuation) at Sites in the Zones of High Impact and Zones of Moderate Impact Associated with the Generation of Turbidity and Sediment Deposition from Dredging and Dredge Spoil Disposal

13.4.2.1.1 LNG0

Daily median light levels recorded at the seabed at LNG0 were higher in summer (151.1 $\mu E/m^2/s$) than in winter (135.2 $\mu E/m^2/s$) and the seasonal trend in daily median light levels at the seabed corresponded with the trend evident in the terrestrial light data (Figure 13-12). Short periods of reduced light at the seabed were evident throughout the monitoring period and were often coincident with short-term increases in light attenuation.

The median Wave Height Index was variable over the first seven months of the monitoring period due to the influence of tropical cyclones in the 2008/2009 summer period and strong easterly breezes in winter 2009 (Figure 13-12). From September 2009 onwards, the median Wave Height Index was comparatively stable, due primarily to the reduced influence of tropical cyclones on the weather in the Barrow Island area. The median Wave Height Index was higher in winter (0.014 m) than summer (0.009 m).

The median SSC at LNG0 was consistent in summer (0.8 mg/L) and winter (0.8 mg/L) (Figure 13-12). Short-term fluctuations in SSC were often coincident with elevations in wave height. Reduced light levels at the seabed and increases in LAC were also recorded during these periods, due to increased turbidity in the water column during these conditions.

The level of significance and relatively high Pearson's R-squared values indicate that, in winter, Wave Height Index was correlated with SSC/NTU and LAC; and SSC/NTU with LAC and light (Appendix 12). In summer, Wave Height Index was correlated with LAC, and SSC/NTU with light.

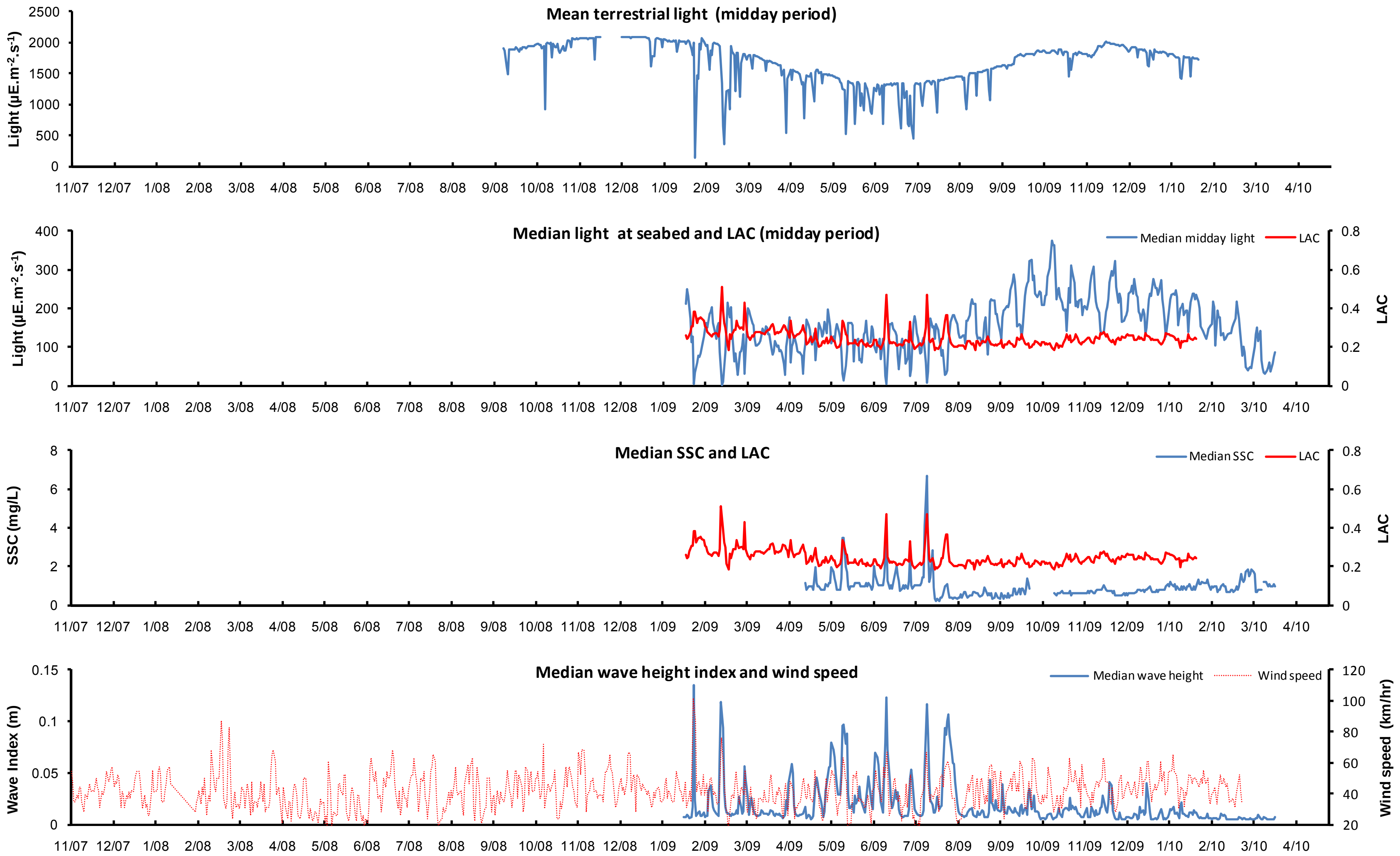

Figure 13-12 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at LNG0 and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.1.2 MOF1

A seasonal pattern of greater daily median light levels in summer (191.4 $\mu E/m^2/s$) and lower levels in winter (167.7 $\mu E/m^2/s$) was recorded at MOF1, associated with the higher incident light levels that occurred in summer (Figure 13-13). Significant reductions in light levels were recorded throughout the monitoring period.

Significant wave events at MOF1 were more frequent in winter and the winter median Wave Height Index (0.012 m) was higher than during summer (0.008 m) (Figure 13-13). The Wave Height Index exhibited trends similar to other sites, with more frequent peaks during winter and large peaks associated with Tropical Cyclones Nicholas, Ophelia and Pancho in summer.

Despite the higher median Wave Height Index in winter, the median SSC at MOF1 was greater in summer (2.4 mg/L) than winter (1.1 mg/L), due to what appeared to be a higher baseline level or lower limit of concentrations (Figure 13-13).

The level of significance and relatively high Pearson's R-squared values indicate that, in winter, Wave Height Index was correlated with SSC/NTU (Appendix 12). With the exception of wind and Wave Height Index, there were no strong relationships between the measured environmental variables and the analysed water quality variables during summer.

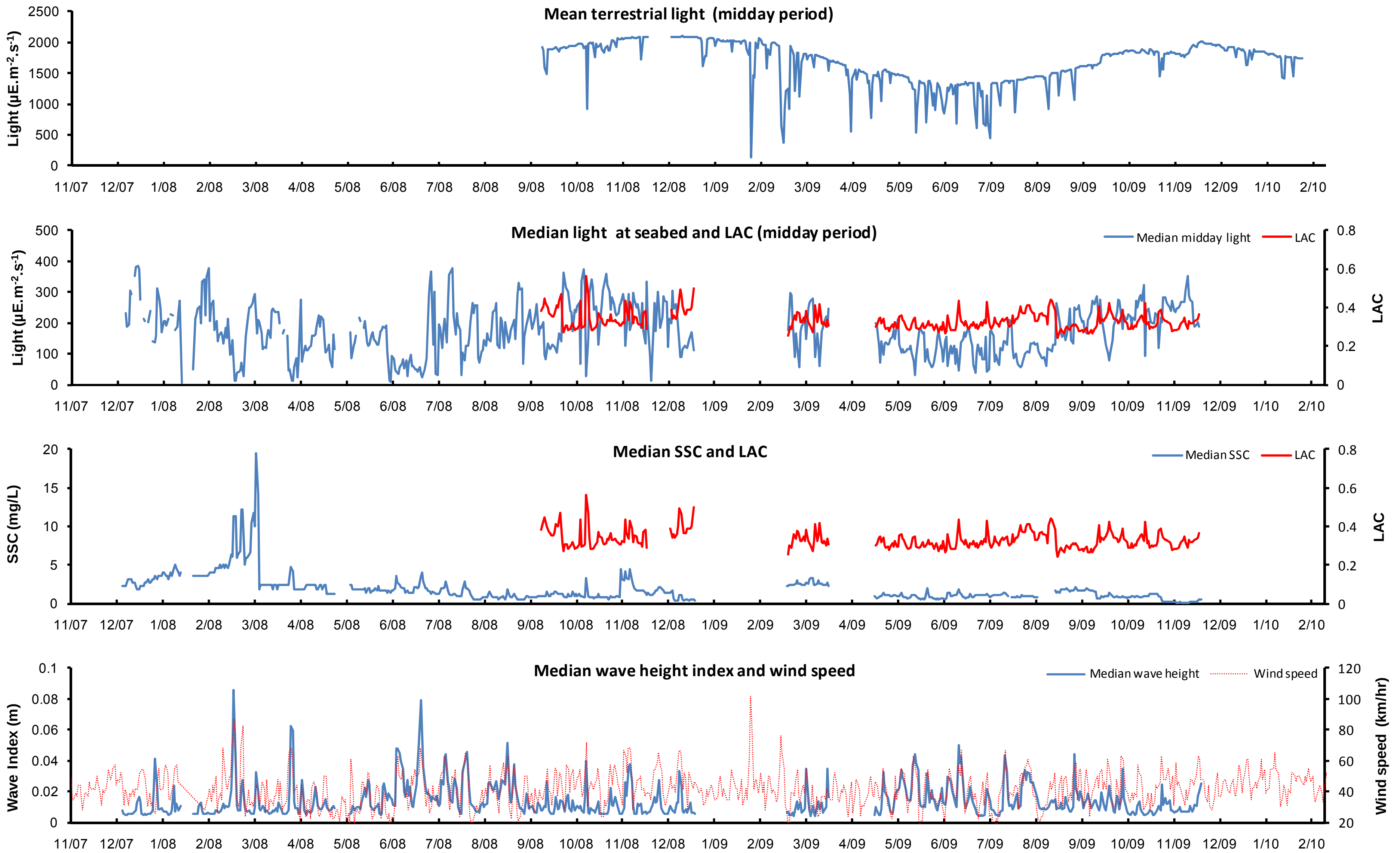

Figure 13-13 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at MOF1 and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.1.3 Lone Reef (LONE)

Lone Reef, located adjacent to the Dredge Spoil Disposal Ground, is the deepest site (average depth approximately 9.5 m) and the light levels at the seabed reflect the deeper water relative to the other monitoring sites. The daily median light levels recorded in summer at Lone Reef were greater (139.8 µE/m^2/s) than those recorded during winter (127.6 µE/m^2/s) (Figure 13-14). Severe light reduction events occurred throughout the sampling period, although these were more prevalent during winter. Reduced light levels consistently coincided with elevated wave and SSC levels throughout the sampling period.

Similar to the other sites, the median Wave Height Index at Lone Reef was higher in winter (0.018 m) than in summer (0.013 m), with more frequent peaks indicating significant wave events (Figure 13-14). Peaks in wave height during summer were recorded during the passage of the four tropical cyclones that affected conditions near Barrow Island in the 2007/2008 cyclone season and Tropical Cyclones Billy and Dominic in the 2008/2009 season.

The median SSC at Lone Reef was generally similar in both summer (1.6 mg/L) and winter (1.7 mg/L) (Figure 13-14). Elevations in SSC tended to coincide with peaks in wave height; in summer this was demonstrated during the passage of tropical cyclones.

The lowest average vertical particle fluxes were recorded over the October–December 2008 and September 2009–February 2010 deployment periods (26.4 ± 0.4 g.m^{-2}.d^{-1} and 13.2 ± 2.3 g.m^{-2}.d^{-1}) and coincided with relatively low measures of wave height and SSC (Figure 13-15). Mean TOC was 1.42 ± 0.04% and mean TIC 7.40 ± 0.13% over the October–December 2008 period and 1.99 ± 0.12% and 8.47 ± 0.20%, respectively, over the September 2009–February 2010 period. Similar to other sites, the average flux recorded during the December 2008–February 2009 and April–June 2009 deployments were greater than during the previous deployment periods (237.7 ± 5.4 g.m^{-2}.d^{-1} and 238.3 ± 5.1 g.m^{-2}.d^{-1}) and reflected the peaks in wave height and SSC that coincided with the passage of Tropical Cyclone Dominic on 26–27 January 2009. Mean TOC was 0.68 ± 0.02% and mean TIC 8.86 ± 0.11% over the December 2008–February 2009 period; and mean TOC was 0.72 ± 0.01% and mean TIC 9.03 ± 0.08% over the April–June 2009 period.

In summer, the levels of significance and relatively high Pearson's R-squared values indicate that Wave Height Index was correlated with SSC/NTU; and SSC/NTU with LAC (Appendix 12). In winter, Wave Height Index was correlated with SSC/NTU, LAC and light; and SSC was correlated with LAC.

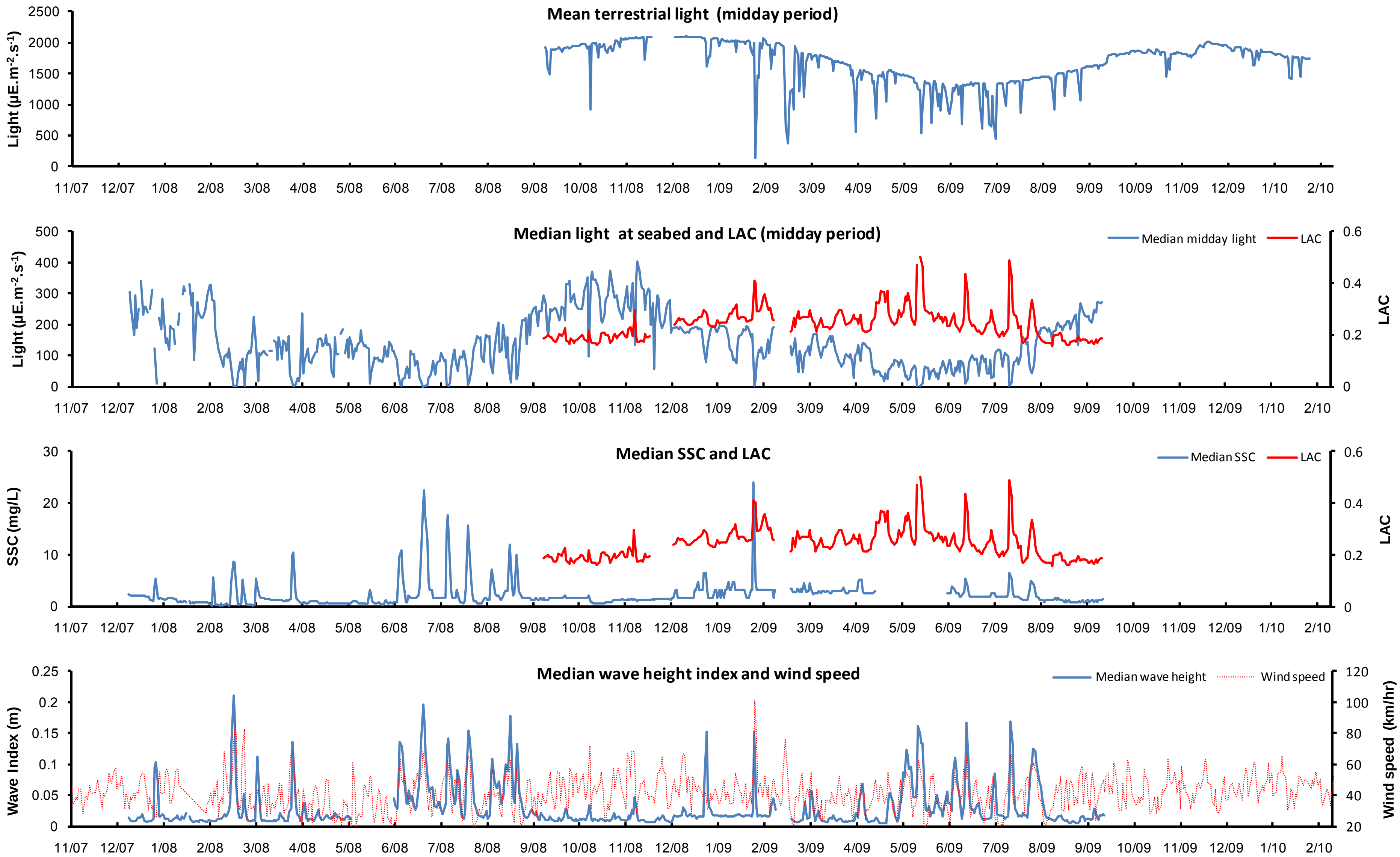

Figure 13-14 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Lone Reef and Daily Maximum Sustained Wind Speed at Barrow Island

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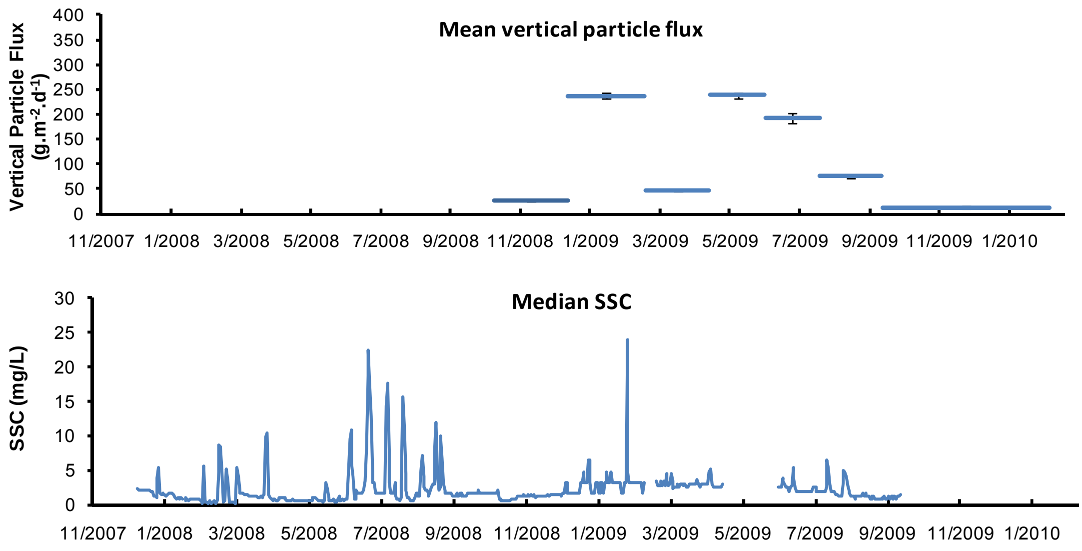

Figure 13-15 Plots of Daily Mean (± SE) Vertical Particle Flux into Sediment Traps over Seven Separate Deployments and Daily Median SSC at Lone Reef

13.4.2.1.4 LNG1

The daily median light levels recorded in summer at LNG1 were greater (213.3 µE/m^2/s) than those recorded during winter (163.8 µE/m^2/s) (Figure 13-16).

Wave events at LNG1 were generally less frequent in summer (median Wave Height Index 0.010 m), although the passage of tropical cyclones was evident through the generation of larger waves (increased Wave Height Index) (Figure 13-16). Periods of elevated wave height during winter (median 0.013 m) were most likely associated with the prevailing easterly breezes that dominate the weather pattern in the Pilbara area during winter.

The median SSC at LNG1 was higher in winter (3.1 mg/L) than in summer (2.7 mg/L). Large elevations in SCC coincided with peaks in wave height during the sampling period and reduced light levels also coincided with these events, presumably as a consequence of increased turbidity in the water column (Figure 13-16).

The level of significance and relatively high Pearson's R-squared values suggest that Wave Height Index was correlated with SSC/NTU and LAC in winter; and SSC/NTU with LAC and light Appendix 12). In summer, Wave Height Index was correlated with SSC/NTU and SSC/NTU with LAC.

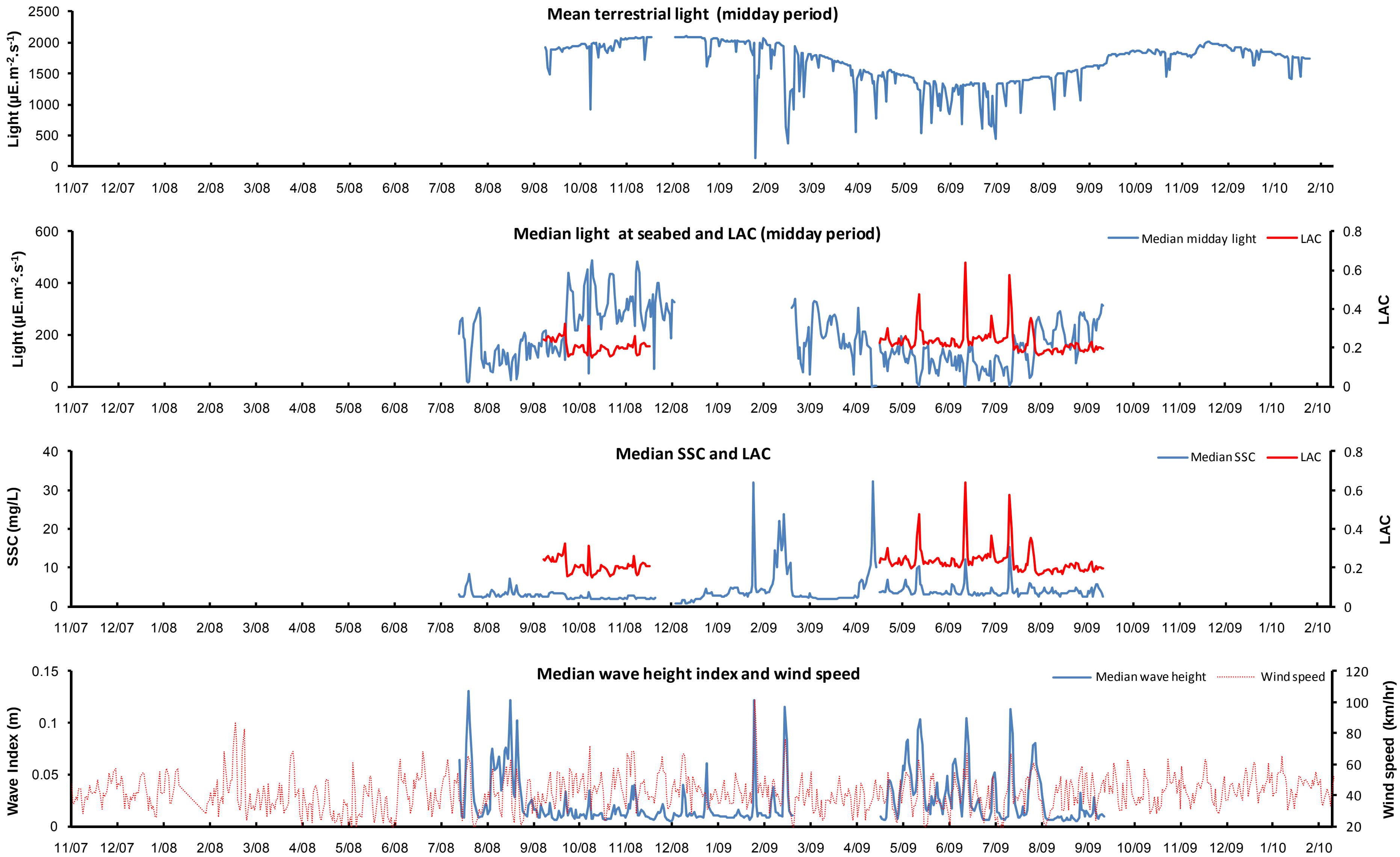

Figure 13-16 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at LNG1 and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.2 Water Quality (including Measures of Turbidity and Light Attenuation) at Risk of Material or Serious Environmental Harm due to the Marine Upgrade of the Existing WAPET Landing

Water quality at the WAPET Landing within the Marine Disturbance Footprint is at risk of Material or Serious Environmental Harm (Section 2.3.4). Water quality in the adjacent area is likely to display similar traits and patterns to those observed at Ant Point Reef (see Section 13.4.2.3.1), located approximately 1.5 km to the north-east. Both locations are sheltered from south-westerly winds, which are common during summer, and exposed to the strong easterly breezes that dominate the weather pattern during winter months. Based on the patterns in water quality that characterise the Ant Point Reef site, the average turbidity is likely to be slightly higher and light intensity at the seabed slightly lower at the WAPET Landing during winter. Due to its sheltered location, conditions during summer are expected to produce relatively consistent turbidity and light penetration, although severe weather conditions such as cyclones would likely influence the turbidity levels in the water column. Water temperatures may be slightly higher at the WAPET Landing than at Ant Point Reef due to the lower exchange of solar heated waters of the inshore Landing area with cooler offshore waters.

13.4.2.3 Water Quality (including Measures of Turbidity and Light Attenuation) at Sites in the Zones of Influence Associated with the Generation of Turbidity and Sediment Deposition from Dredging

13.4.2.3.1 Ant Point Reef (ANT)

Daily median light levels recorded at the seabed at Ant Point Reef were generally greater during summer (332.5 $\mu E/m^2/s$) than in winter (270.6 $\mu E/m^2/s$) (Figure 13-17). The overall higher light levels, compared to other deeper sites such as Lone Reef, reflected the shallow depth of the site (average depth approximately 4.0 m). Periods of severe light reduction were recorded throughout the sampling period, though light reduction events were generally less intense during winter. Many of these reductions in light were coincident with increases in light attenuation.

The median Wave Height Index at Ant Point Reef was higher in winter (0.012 m) than in summer (0.008 m) (Figure 13-17). Wave events, indicated by peaks in the Wave Height Index, were more frequent in winter than in summer and coincided with the strong easterly breezes that dominate the weather patterns in the Pilbara area at this time of year. Ant Point Reef is close to the north-east coast of Barrow Island and is sheltered from waves driven by south-westerly winds in the summer months. Wind-generated wave events from this direction were less frequent and less intense than experienced at other sites, but still punctuated by elevated periods associated with cyclonic activity, such as those recorded during the passage of Tropical Cyclones Nicholas, Pancho and Dominic.

The median SCC at Ant Point Reef was similar in winter (1.5 mg/L) and summer (1.1 mg/L) (Figure 13-17). The largest increase in SSC was recorded during the passage of Tropical Cyclone Nicholas, when the median SSC on 17 February 2008 was 12 mg/L, or approximately an order of magnitude greater than the summer median. Similarly, the median Wave Height Index was at its highest during this period. Elevations in SSC and reduced light levels were consistently recorded during periods of elevated wave height throughout the sampling period.

During summer there were significant correlations and relatively high Pearson's R-squared values, between Wave Height Index and SSC/NTU (Appendix 12). There were no strong relationships between the measured environmental variables and the analysed water quality variables during winter.

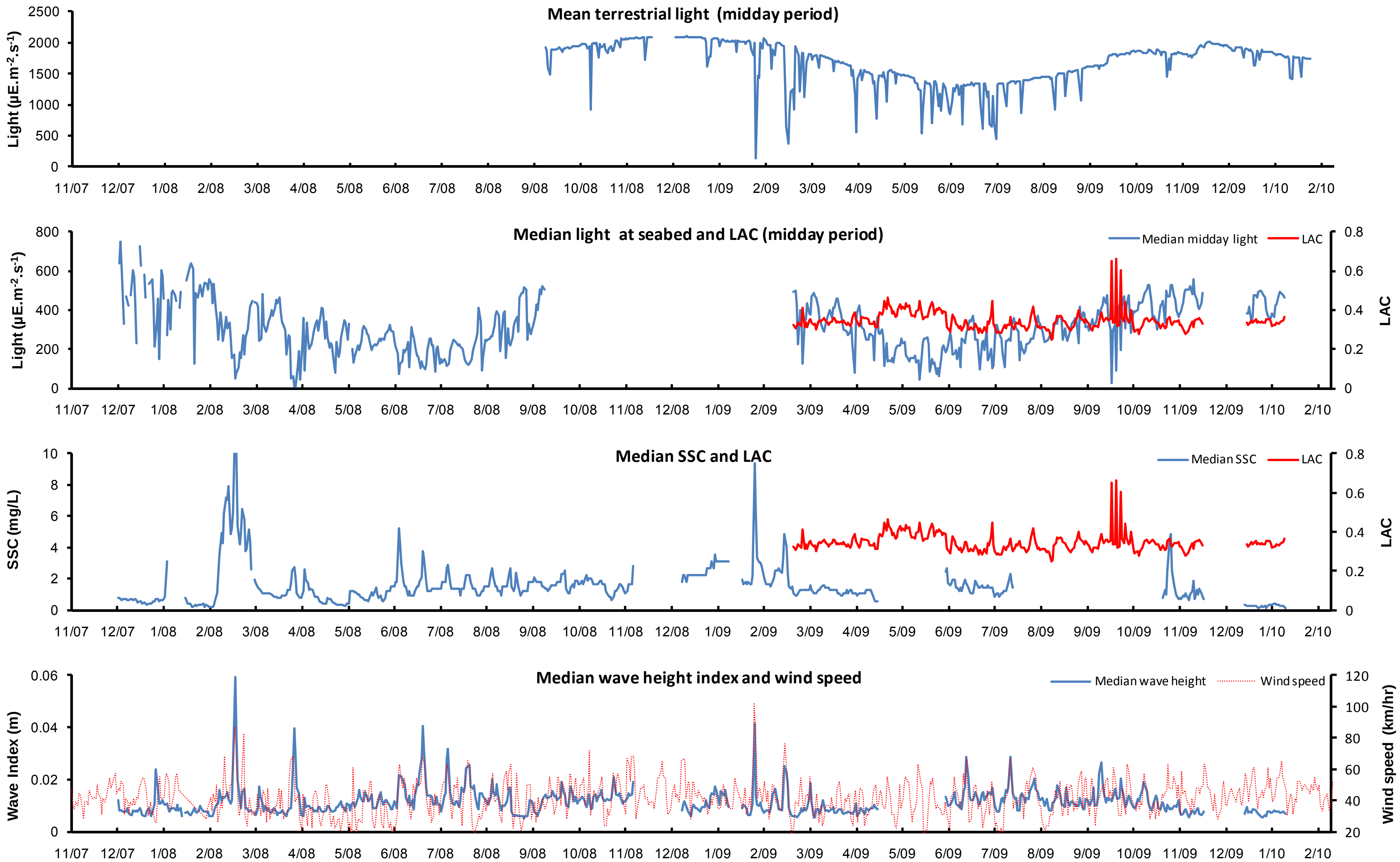

Figure 13-17 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Ant Point Reef and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.3.2 Southern Lowendal Shelf (LOW)

Southern Lowendal Shelf is a shallow site compared to other sites, with an average water depth of approximately 3.0 m. The shallow nature of this site was reflected in the greater light readings compared to those of other monitoring sites. A seasonal pattern of higher daily median light levels in summer was evident, with the summer median (483.3 $\mu E/m^2/s$) approximately 45% higher than the winter median (334.3 $\mu E/m^2/s$) (Figure 13-18).

Peaks in the median Wave Height Index at Southern Lowendal Shelf were frequent throughout summer (0.015 m) and winter (0.018 m), although they were generally more intense during summer, associated with the passage of tropical cyclones (Figure 13-18). Significant wave events in summer included those associated with Tropical Cyclones Nicholas and Pancho, where the Wave Height Index was considerably higher than the summer median. Peaks in wave height during winter were likely to be associated with the prevailing easterly winds, to which the Southern Lowendal Shelf is exposed.

Peaks in SSC often coincided with elevated levels of Wave Height Index at Southern Lowendal Shelf; this was particularly evident during the passage of Tropical Cyclones Nicholas and Pancho, where the median daily SSC was more than a factor of ten higher than the summer median of 1.6 mg/L (Figure 13-18).

The levels of significance and relatively high Pearson's R-squared values suggest wind was correlated with Wave Height Index, and Wave Height Index with SSC/NTU, in winter (Appendix 12). With the exception of wind and Wave Height Index, there were no strong relationships between the measured environmental variables and the analysed water quality variables during summer.

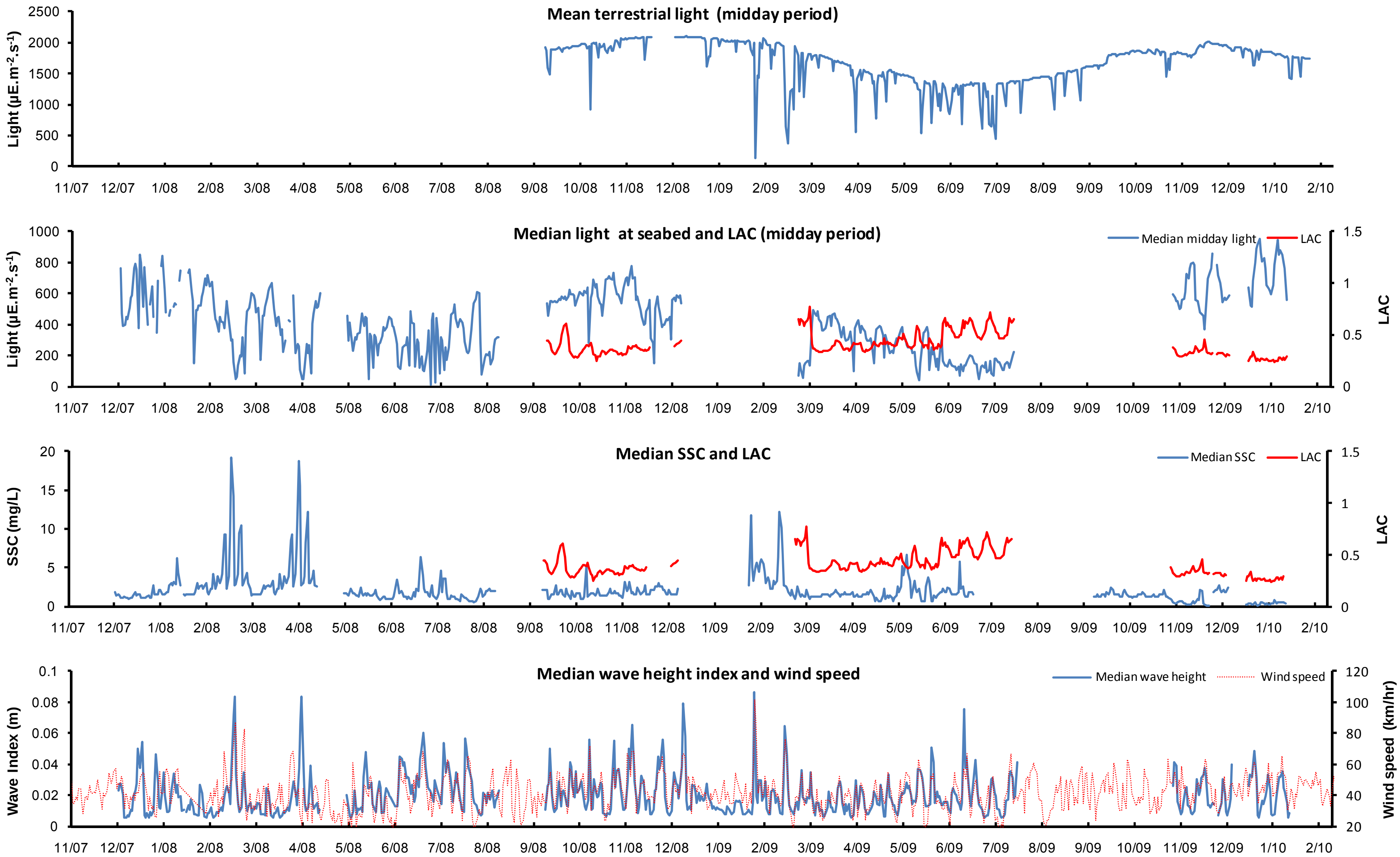

Figure 13-18 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Southern Lowendal Shelf and Daily Maximum Sustained Wind Speed at Barrow Island

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13.4.2.3.3 MOF2

Collection of light, SSC and ASSD data at MOF2 was hindered by instrument malfunctions that occurred from late April to mid-July 2008. The median light levels recorded at MOF2 were greater in summer (231.5 $\mu E/m^2/s$) than winter (190.5 $\mu E/m^2/s$) and periods of greatly reduced light were recorded throughout the monitoring period (Figure 13-19).

Overall, the median Wave Height Index at MOF2 was consistent throughout the sampling period, though the wave events in winter were more frequent and intense, indicated by the higher 90^{th} percentile in winter (0.035 m) compared with summer (0.024 m) (Figure 13-19).

The median SSC at MOF2 was 0.8 mg/L during summer and winter (Figure 13-19). There were significant elevations in SSC above the median levels recorded during periods of elevated wave height, such as those that occurred during the passage of Tropical Cyclone Dominic. Reduced light levels and increased light attenuation also coincided with these events, due to the increased turbidity in the water column.

During summer, the high levels of significance and relatively high Pearson's R-squared values indicate there were correlations between Wave Height Index with SSC/NTU and LAC; and between SSC/NTU and LAC (Appendix 12). There were no strong relationships between the measured environmental variables and the analysed water quality variables during winter.

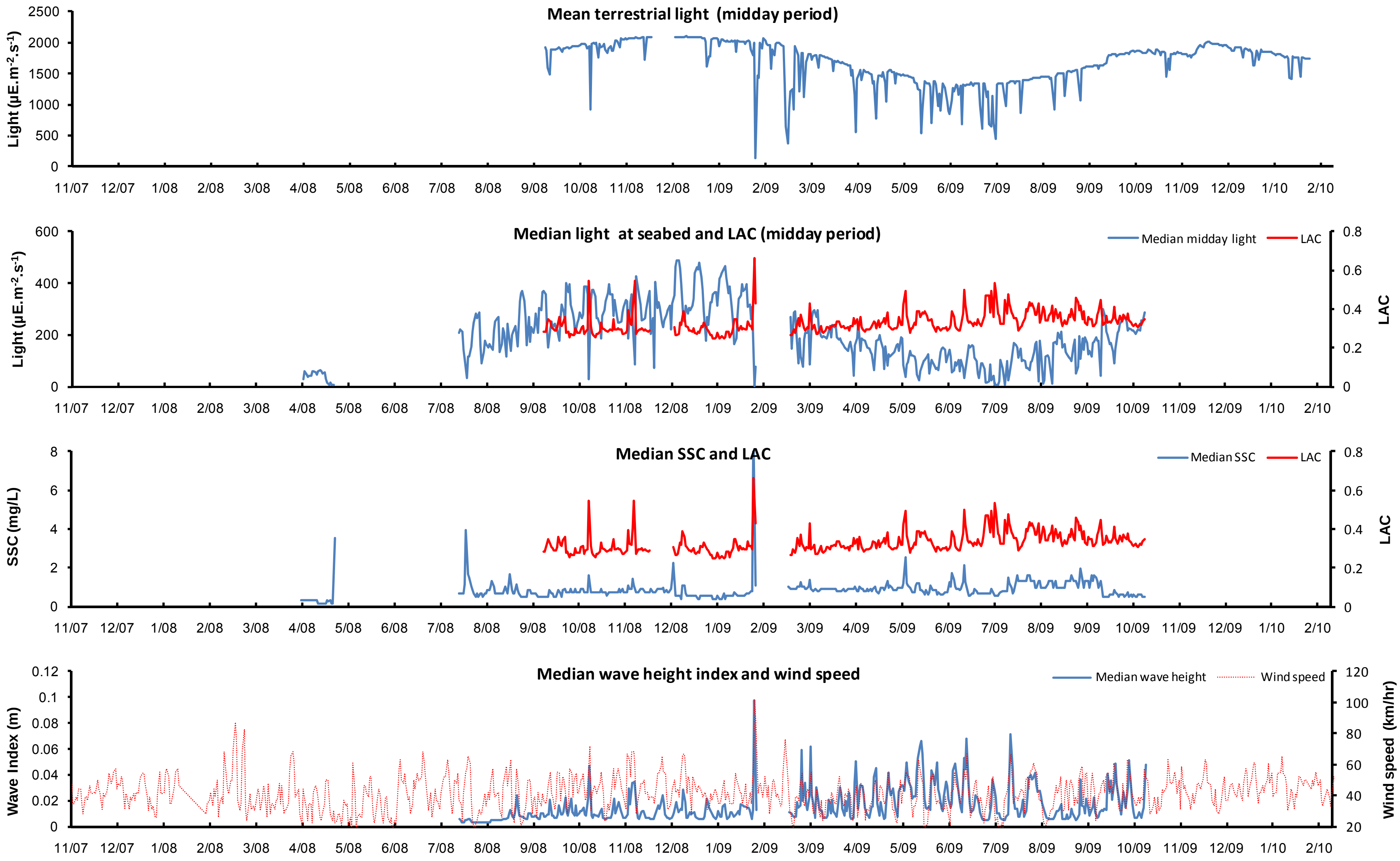


Figure 13-19 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at MOF2 and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.3.4 MOF3

Daily median light levels at MOF3 were higher during summer (273.6 μE/m^2/s) than winter (258.0 μE/m^2/s), displaying the seasonal pattern evident at most of the monitoring sites (Figure 13-20). Periods of greatly reduced light levels were recorded throughout the monitoring period.

Wave events at MOF3 were more frequent in winter; this was reflected in the winter median Wave Height Index (0.013 m), which was approximately 50% higher than the summer median Wave Height Index (0.009 m) (Figure 13-20). While the median Wave Height at MOF3 was much lower in summer, significant wave events were recorded during the passage of the four tropical cyclones that passed close to Barrow Island during the 2007/2008 cyclone season and during Tropical Cyclone Dominic in January 2009.

The median SSC at MOF3 was generally similar throughout the sampling period (summer 2.1 mg/L; winter 2.4 mg/L) (Figure 13-20). Peaks in SSC often coincided with elevations in Wave Height Index, as recorded during Tropical Cyclones Nicholas, Pancho and Dominic.

Mean vertical particle flux was greatest during the July 2008 (162.3 ± 0.9 g.m^{-2}.d^{-1}) and December 2008–February 2009 (161.5 ± 6.2 g.m^{-2}.d^{-1}) sediment trap deployment periods (Figure 13-21). Mean TOC was 0.98 ± 0.03% and 1.06 ± 0.09% respectively, and mean TIC 9.38 ± 0.03% and 10.00 ± 0.16% respectively. Periods of elevated Wave Height Index and SSC were experienced during the July–August deployment, and the December–February deployment coincided with the passage of Tropical Cyclone Dominic. In contrast, the flux during the September–November 2009 deployment period was much lower (18.1 ± 0.8 g.m^{-2}.d^{-1}) and occurred during periods of relatively low Wave Height Index and SSC compared to other deployment periods. Mean TOC was 2.04 ± 0.06% and mean TIC 7.92 ± 0.15%.

In summer, the levels of significance and the relatively high Pearson's R-squared values indicate there were significant correlations between Wave Height Index and LAC (Appendix 12). There were no strong relationships between the measured environmental variables and the analysed water quality variables during winter.

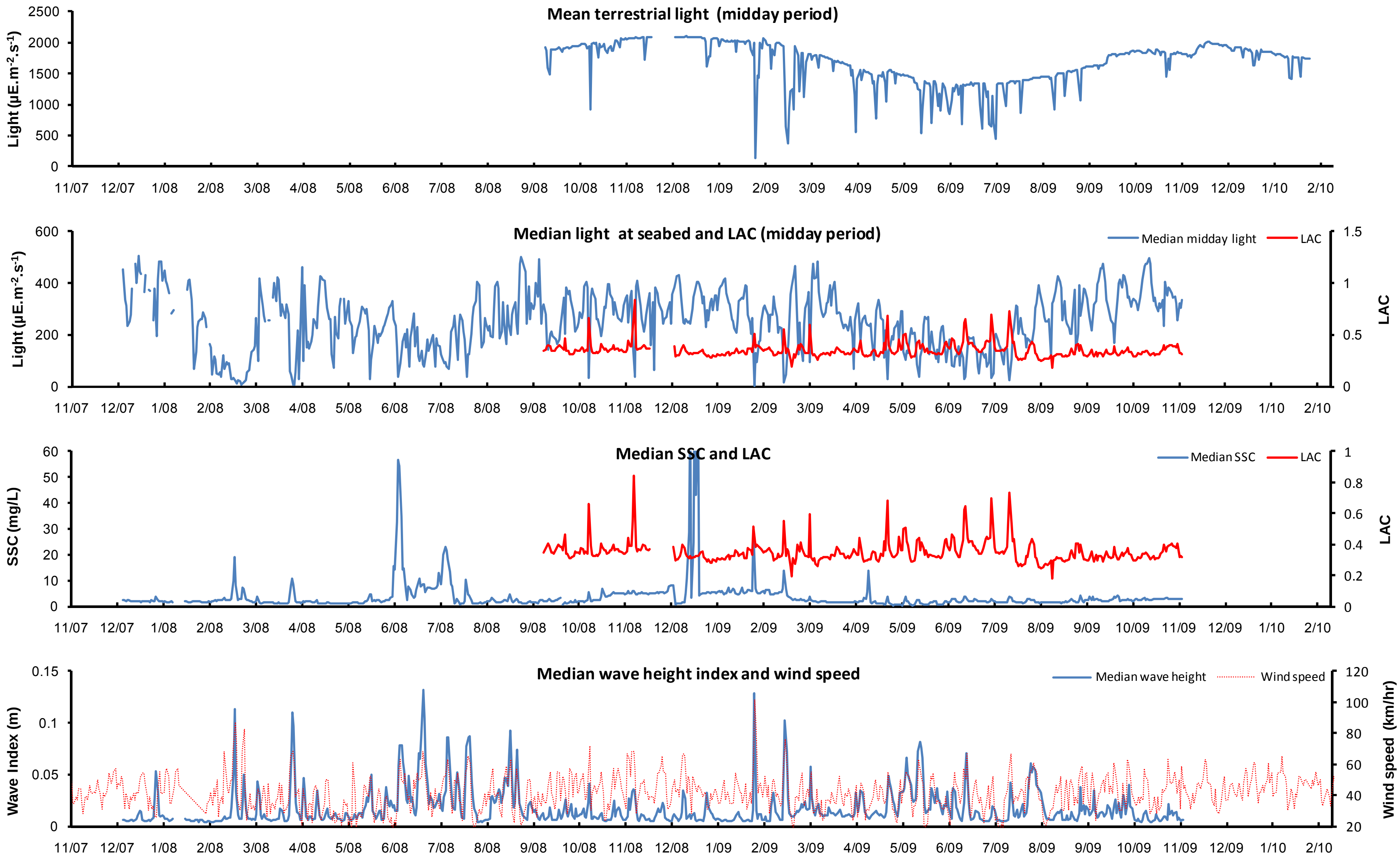


Figure 13-20 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at MOF3 and Daily Maximum Sustained Wind Speed at Barrow Island

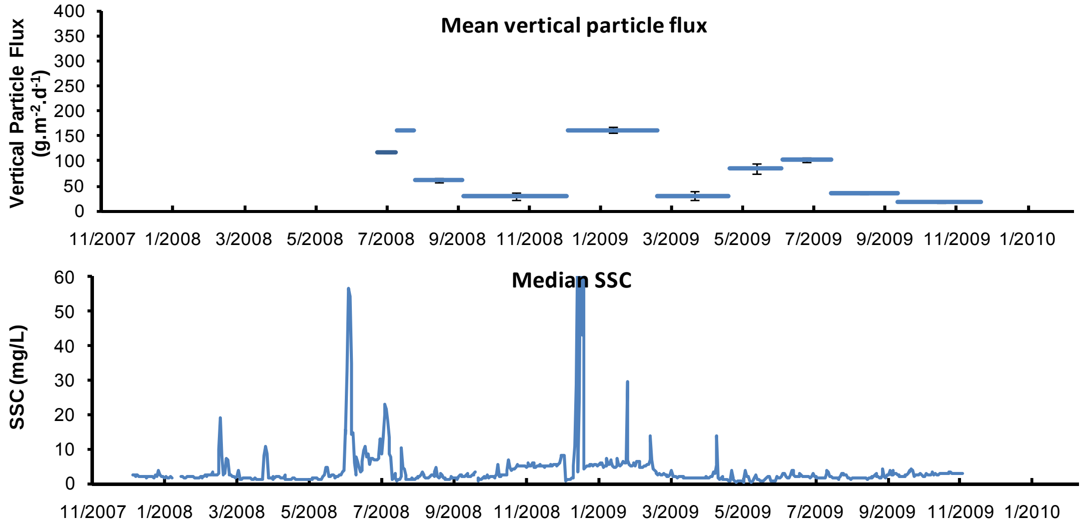


Figure 13-21 Plots of Daily Mean (± SE) Vertical Particle Flux into Sediment Traps over Ten Separate Deployments and Daily Median SSC at MOF3

13.4.2.3.5 LNG2

Light recorded at the seabed at LNG2 showed a distinct seasonal pattern, with a trend of decreasing daily median light levels from summer to winter (228.1 μE/m^2/s and 157.3 μE/m^2/s, respectively) (Figure 13-22). Periods of greatly reduced light were recorded throughout the monitoring period, although the events were more frequent in winter.

The median Wave Height Index was higher in winter (0.013 m) than summer (0.010 m) and significant wave events were more frequent in winter (Figure 13-22). Large peaks in wave height during summer were recorded during the passage of tropical cyclones, where the Wave Height Index measurements were more than a factor of ten greater than the median.

The median SSC at LNG2 was higher in winter (1.7 mg/L) than in summer (1.5 mg/L) (Figure 13-22). Throughout the sampling period, large elevations in SSC were mostly coincident with peaks in wave height, as evident during Tropical Cyclones Nicholas and Pancho. Reduced light levels and elevated light attenuation were also recorded during these periods, due to the increased turbidity in the water column.

During summer, the levels of significance and relatively high Pearson's R-squared values suggest Wave Height Index was correlated with SSC/NTU (Appendix 12). Wave Height Index was correlated with LAC and light in winter; and SSC with LAC.

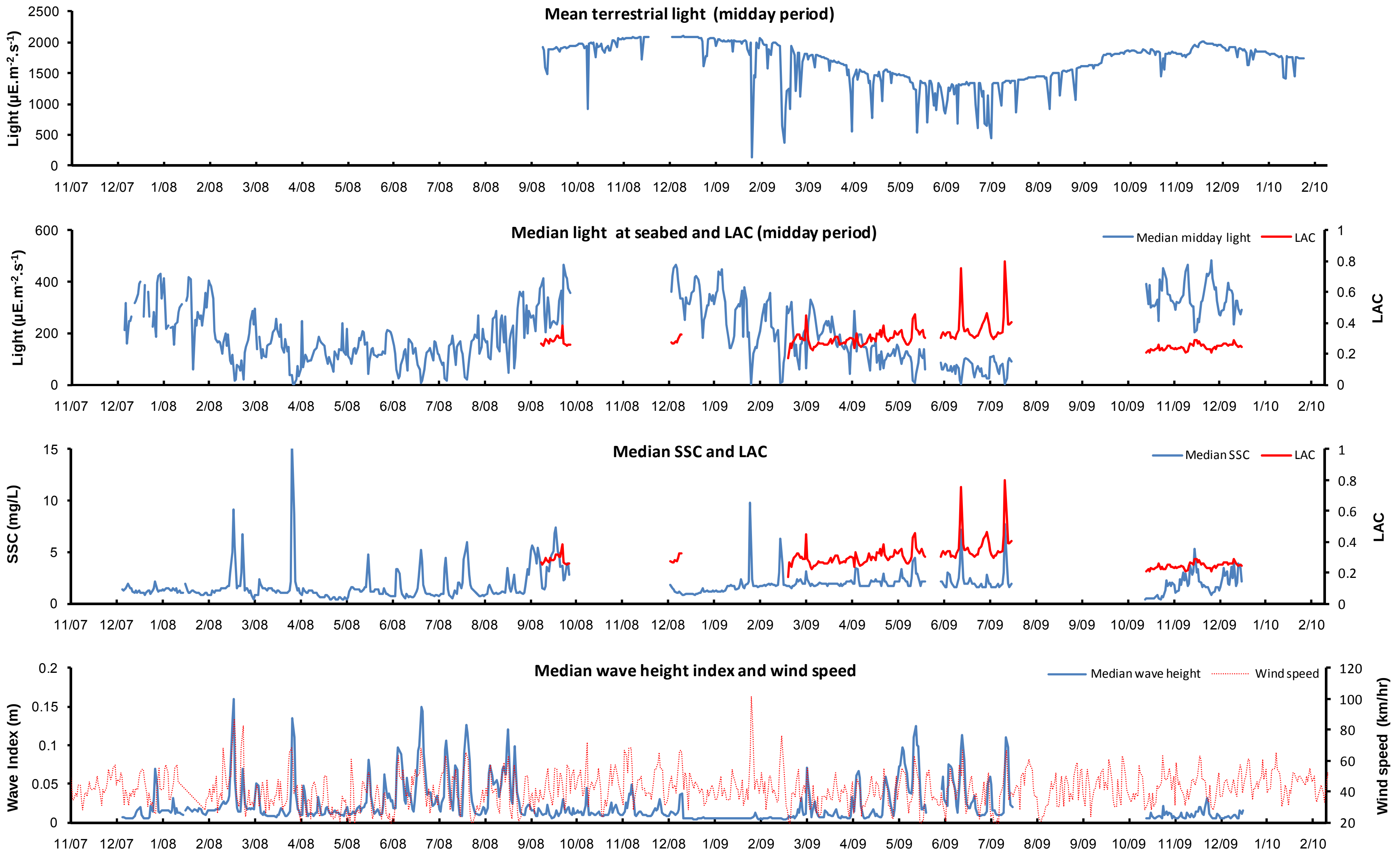


Figure 13-22 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at LNG2 and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.4 Water Quality (including Measures of Turbidity and Light Attenuation) at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Upgrade of the Existing WAPET Landing, MOF, LNG Jetty or Dredge Spoil Disposal Ground

13.4.2.4.1 Ah Chong (AHC)

Daily median light levels recorded at the seabed at Ah Chong showed a seasonal pattern, with higher median daily light levels in summer (207.6 μE/m^2/s) compared to winter (186.9 μE/m^2/s) (Figure 13-23). The seasonal pattern reflected the higher levels of incident radiation evident in summer, associated with solar elevation. Periods of greatly reduced light were recorded throughout the sampling period, although these events were more frequent in winter. These events were often coincident with increases in the LAC.

The median Wave Height Index at Ah Chong was greater in winter (0.020 m) than in summer (0.014 m) due to a greater frequency of significant wave events, indicated by peaks in the Wave Height Index (Figure 13-23). Ah Chong is relatively sheltered from the prevailing westerly swell and the south-westerly winds common in summer, though peaks in wave height during summer were recorded during the passage of many of the tropical cyclones in the 2007/2008 and 2008/2009 seasons.

The median SSC at Ah Chong was lower in winter (2.7 mg/L) than in summer (3.0 mg/L) (Figure 13-23). Large elevations in SSC coincided with peaks in wave height throughout the sampling period, reduced light levels at the seabed and increased light attenuation, reflecting a reduction in light penetration due to wave-driven turbidity.

In summer and winter, there were significant correlations and relatively high Pearson's R-squared values between Wave Height Index and SSC/NTU, LAC and light; and SSC/NTU were correlated with LAC (Appendix 12).

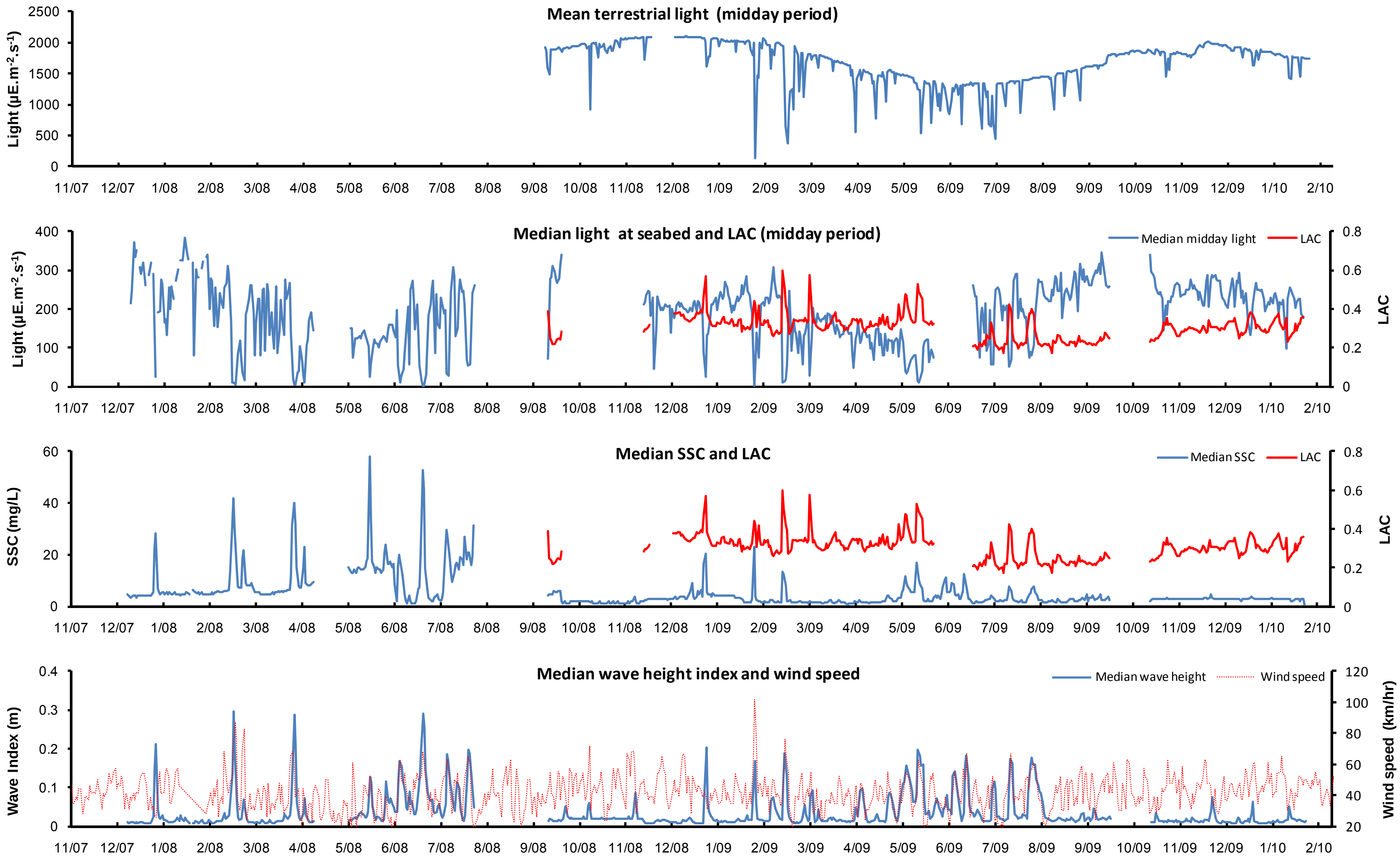


Figure 13-23 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Ah Chong and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.4.2 Biggada Reef (BIG)

The Biggada Reef site is in the shallowest location with an average depth of 1.5 m, and the LTD logger may have been temporarily exposed above the water surface during the lowest spring low tides. During the first deployment period (7 December 2007–14 January 2008), the sensitivity of the light meter resulted in 'off-scale' measurements of light due to the shallow nature of the site (Figure 13-24). The sensitivity of the meter was adjusted for future deployments and daily variations in light measurements were more accurately recorded from 14 January 2008 onwards. However, the same effect occurred between 12 October and 16 November 2008, where light measurements were off-scale. These light measurements were removed from the dataset. Due to the shallow nature of this site and the inconsistent light measurements, the light data are provided for information only.

Wave events at Biggada Reef were more frequent in summer than winter, with obvious peaks coinciding with Tropical Cyclones Melanie, Nicholas and Pancho (Figure 13-24). Biggada Reef is exposed to the prevailing westerly swell and is in a shallow location on the leeward/landward side of a fringing coral reef. Unlike sites on the east coast, wave conditions at Biggada Reef are predominantly influenced by a combination of swell and tidal stage (height and flow rate), rather than localised wind-generated waves that are common on the east coast.

Median SSC at Biggada Reef was generally lower in winter (2.6 mg/L) than in summer (3.0 mg/L) (Figure 13-24). Peaks in SSC during summer coincided with the passage of tropical cyclones, where SSC were elevated by more than a factor of ten times greater than summer median levels.

The measured environmental variables were not correlated to any of the analysed water quality variables in summer or winter (Appendix 12).

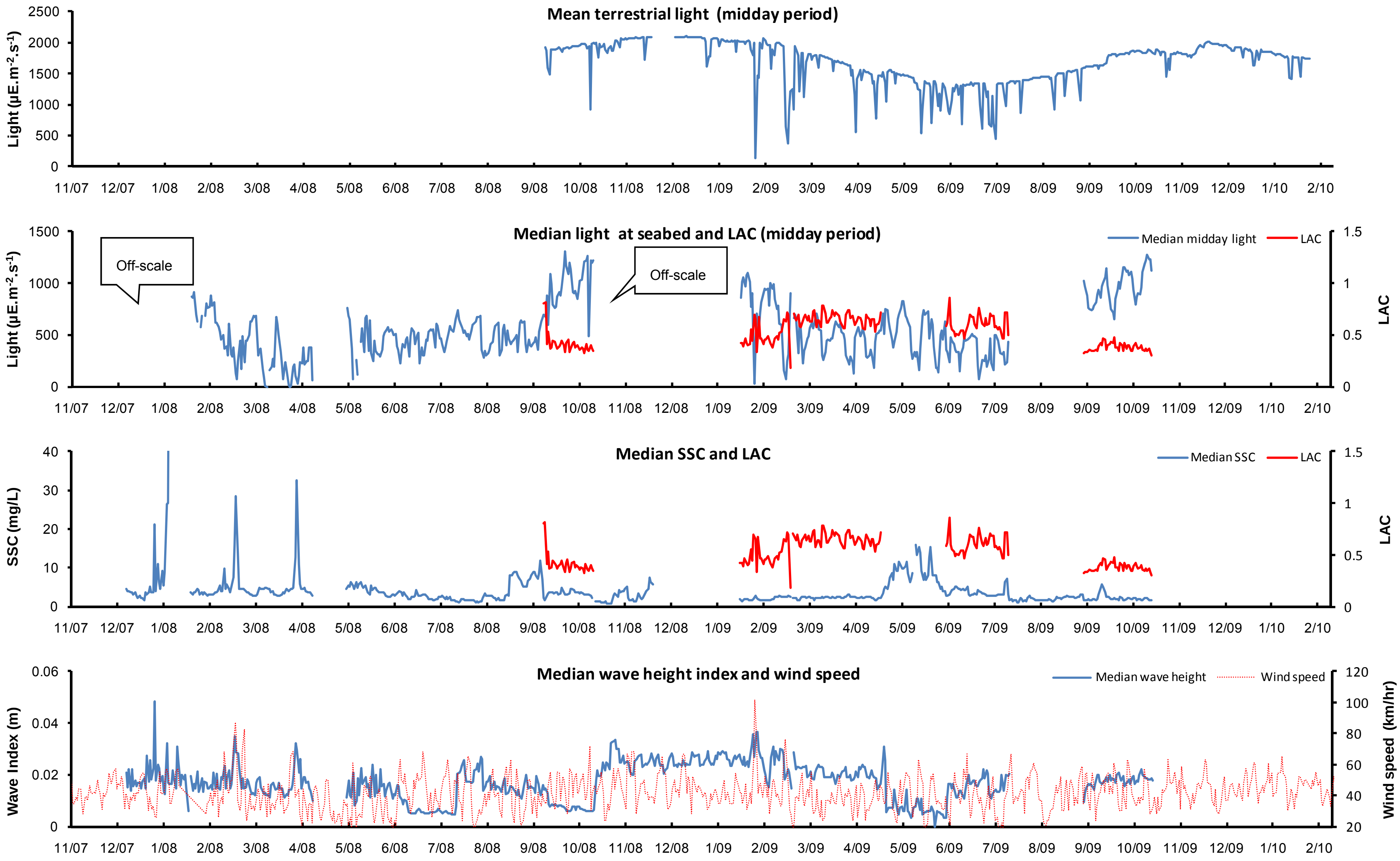


Figure 13-24 Time Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Biggada Reef and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.4.3 LNG3

A seasonal pattern in light levels was not particularly evident at LNG3 (Figure 13-25). The median light level in winter (191.6 µE/m^2/s) was higher than in summer (164.1 µE/m^2/s).

The median Wave Height Index at LNG3 was higher in winter (0.014 m) than summer (0.012 m) (Figure 13-25). Distinct peaks in wave height during summer occurred during the passage of the four tropical cyclones in the 2007/2008 season.

The median SSC at LNG3 in summer (2.7 mg/L) was slightly lower than in winter (2.8 mg/L) (Figure 13-25). Peaks in SSC were often associated with peaks in Wave Height Index, as evident during the tropical cyclones.

Vertical particle flux varied between the ten deployment periods (Figure 13-26). The highest mean rates occurred during the July 2008 and the December 2008–February 2009 deployment periods (310.6 ± 4.1 g.m^{-2}.d^{-1} and 245.9 ± 8.6 g.m^{-2}.d^{-1}, respectively) when sustained peaks in Wave Height Index and SSC were experienced. The December 2008–February 2009 deployment coincided with peaks in SSC and wave height during the passage of Tropical Cyclone Dominic. Mean TOC was 0.84 ± 0.04% and mean TIC 9.04 ± 0.09% over the July 2008 period; and mean TOC was 0.53 ± 0.04% and mean TIC 9.64 ± 0.10% over the December 2008–February 2009 period. The lowest mean rates (23.8 ± 1.4 g.m^{-2}.d^{-1} and 21.4 ± 1.4 g.m^{-2}.d^{-1}) were recorded over the September–December 2008 and September 2009–February 2010 deployment periods. Mean TOC was 1.10 ± 0.26% and mean TIC 7.12 ± 0.43% over the September–December 2008 period and 2.01 ± 0.06% and 8.14 ± 0.07%, respectively, over the September 2009–February 2010 period. These coincided with an extended period of relatively low Wave Height Index and SSC compared to the other deployment periods. However, the September–December 2008 deployment period was punctuated with one occurrence of elevated SSC levels in early November 2008.

In winter, there were significant correlations and relatively high Pearson's R-squared values between Wave Height Index and SSC/NTU, LAC and light (Appendix 12). There were no correlations evident between the measured environmental variables and the analysed water quality variables in summer.

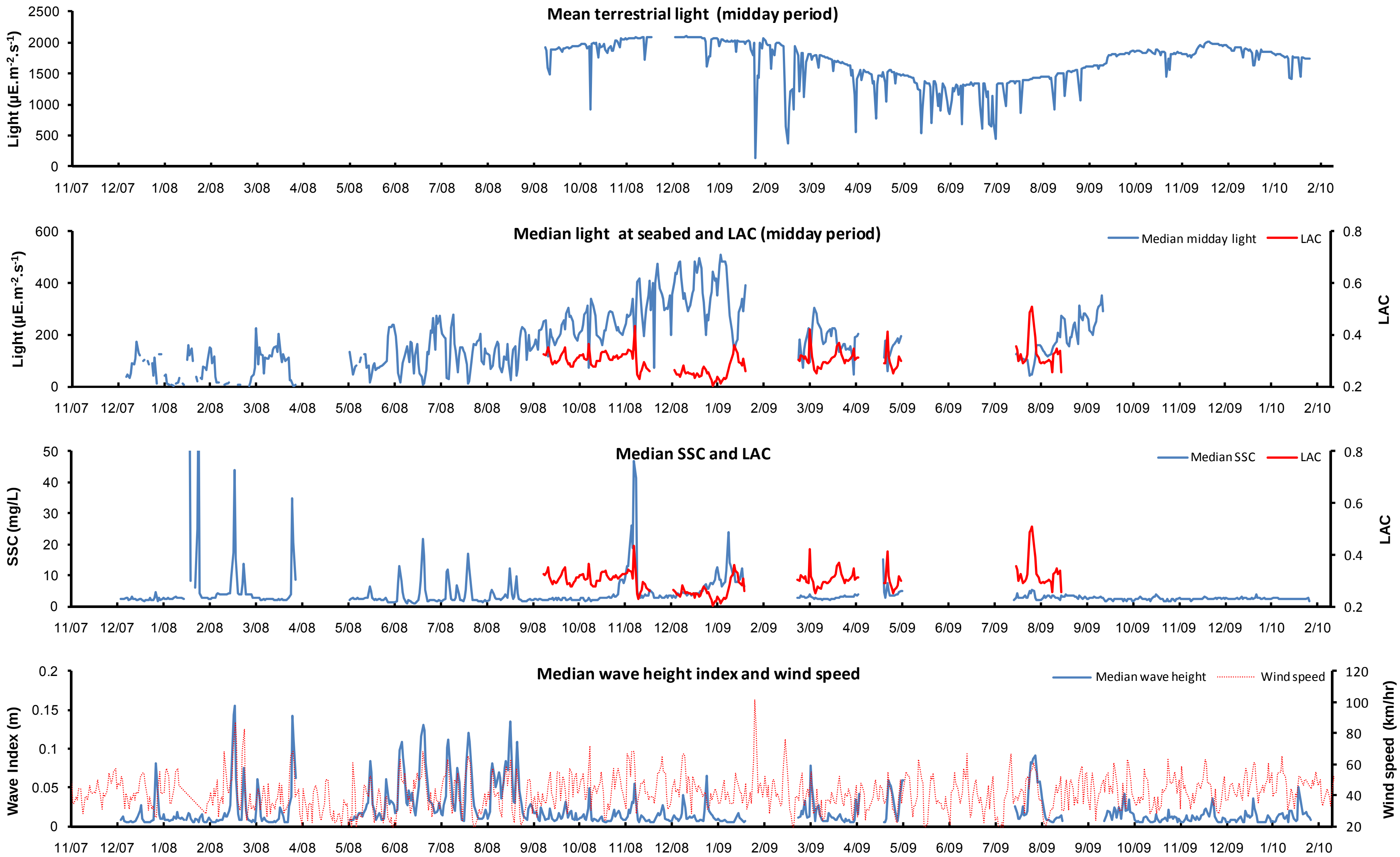


Figure 13-25 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at LNG3 and Daily Maximum Sustained Wind Speed at Barrow Island

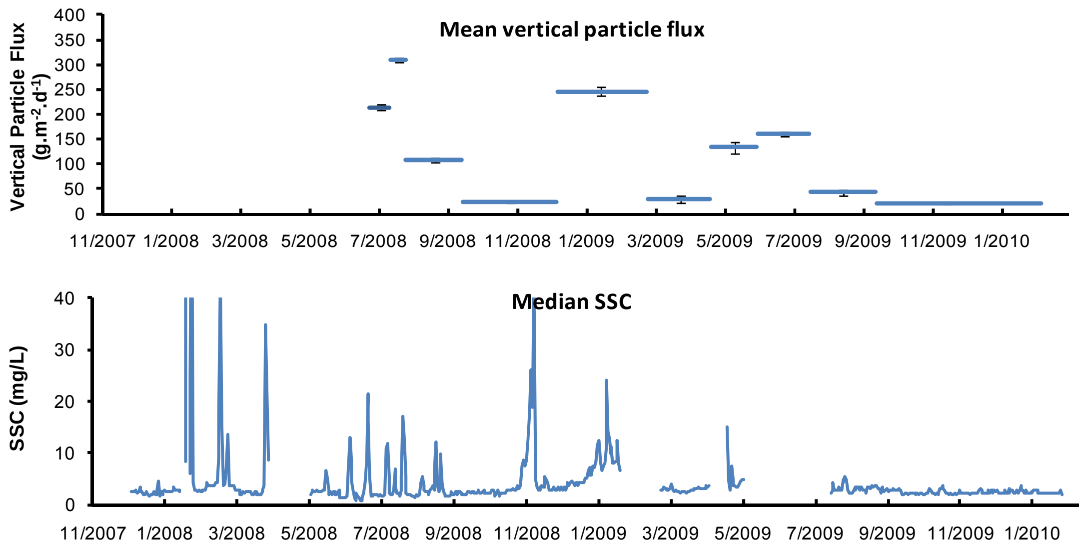


Figure 13-26 Plots of Daily Mean (± SE) Vertical Particle Flux into Sediment Traps over Ten Separate Deployments and Daily Median SSC at LNG3

13.4.2.4.4 Dugong Reef (DUG)

A seasonal pattern of greater daily median light levels in summer (285.2 µE/m^2/s) than in winter (230.9 µE/m^2/s) was evident at Dugong Reef (Figure 13-27). Periods of low light were recorded throughout the sampling period, although they were more frequent in winter.

The median Wave Height Index at Dugong Reef was higher in winter (0.013 m) than in summer (0.008 m), and significant wave events were also more frequent in winter (Figure 13-27). Large peaks in wave height during summer were recorded during the passage of tropical cyclones, and were associated with strong easterly breezes during winter.

The median SSC at Dugong Reef was 1.7 mg/L in both summer and winter, with elevations in SSC regularly coinciding with peaks in wave height during the passage of tropical cyclones and periods of strong easterly winds (Figure 13-27). Reduced light levels were recorded during peaks in SSC, presumably as a result of increased turbidity in the water column; LAC also increased during these periods.

Vertical particle flux calculated from the sediment trap results varied between the seven sediment trap deployment periods at Dugong Reef (Figure 13-28). The average particle flux was much lower (24.8 ± 0.8 g.m^{-2}.d^{-1}) in the first deployment period (September–December 2008) and the final deployment period (9.0 ± 1.0 g.m^{-2}.d^{-1}; September–November 2009), during which Wave Height Index and SSC were relatively low. Mean TOC was 1.53 ± 0.05% and mean TIC 8.13 ± 0.08% over the first period and 1.88 ± 0.09% and 7.93 ± 0.13%, respectively, over the final period. Tropical Cyclone Dominic affected weather conditions during the second deployment period December 2008–February 2009), and the relatively large average particle flux (143.0 ± 2.2 g.m^{-2}.d^{-1}) during this period was a reflection of the high levels of SSC and turbidity experienced during the tropical cyclone. Mean TOC was 0.66 ± 0.03% and mean TIC 9.28 ± 0.06%.

During winter, the level of significance and relatively high Pearson's R-squared values suggest Wave Height Index was correlated with SSC/NTU, LAC and light; and SSC/NTU were correlated with LAC and light (Appendix 12). During summer, there was a correlation between Wave Height Index and LAC.

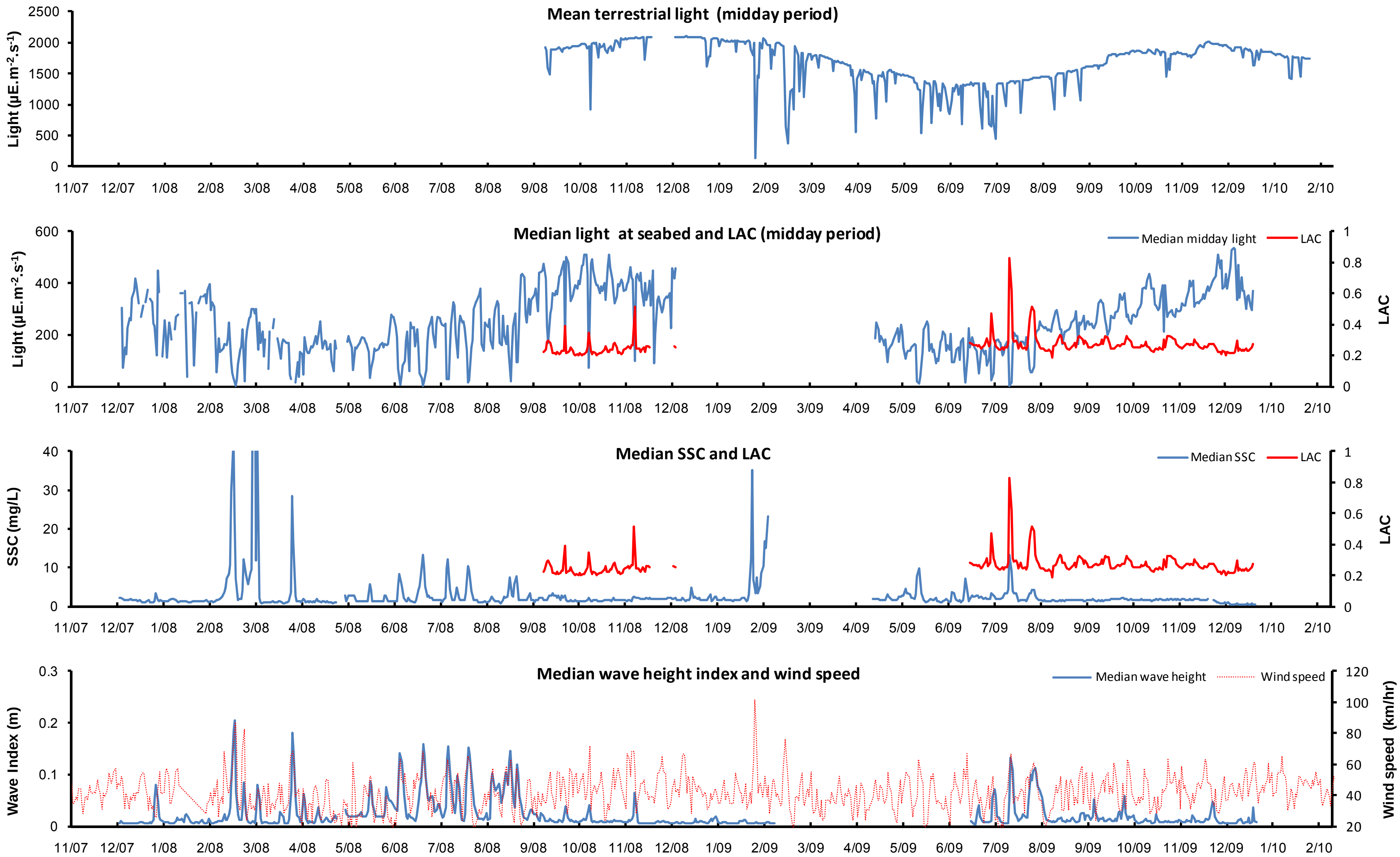


Figure 13-27 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Dugong Reef and Daily Maximum Sustained Wind Speed at Barrow Island

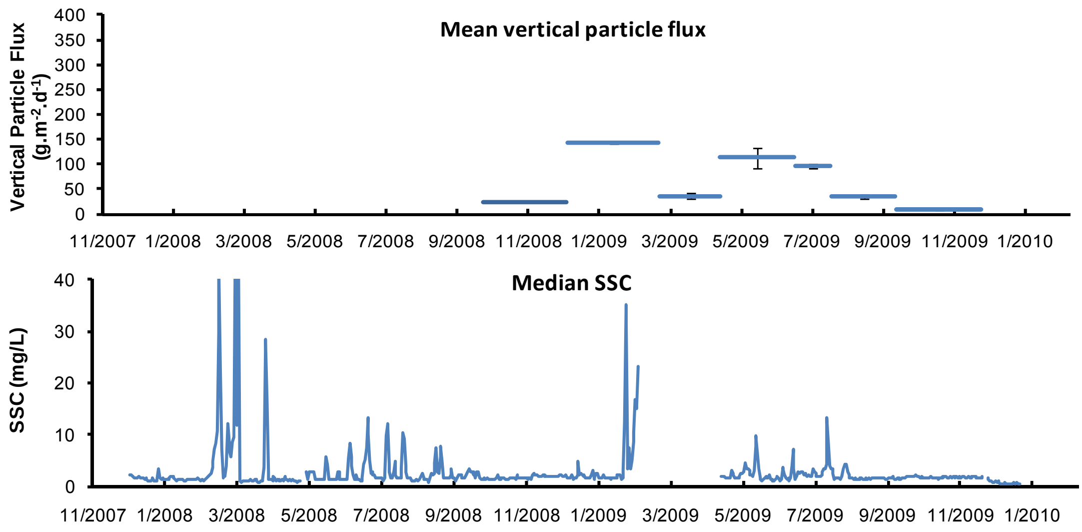


Figure 13-28 Plots of Daily Mean (± SE) Vertical Particle Flux into Sediment Traps over Seven Separate Deployments and Daily Median SSC at Dugong Reef

13.4.2.4.5 Batman Reef (BAT)

The Batman Reef site is located in a relatively shallow location and the light levels recorded at the seabed reflect the water depth. A seasonal pattern of greater midday median light intensity during summer (363.5 µE/m^2/s) compared to winter (317.3 µE/m^2/s) was evident (Figure 13-29). Periods of reduced light occurred throughout the sampling period, although these appeared to be more frequent during winter.

Wave events at Batman Reef were generally less frequent in summer (median Wave Height Index 0.007 m), although the passage of tropical cyclones were evident through the generation of larger waves (higher Wave Height Index) (Figure 13-29). Periods of elevated wave height during winter (0.008 m) were associated with the prevailing easterly breezes.

The median SSC at Batman Reef was higher in winter (2.0 mg/L) than in summer (1.9 mg/L) and the daily medians were >10 mg/L on more than 25 occasions (Figure 13-29). Large elevations in SSC coincided with peaks in wave height throughout the sampling period and this was particularly evident during the passage of tropical cyclones. Reduced light levels also coincided with these events, presumably as a result of increased turbidity in the water column.

The levels of significance and relatively high Pearson's R-squared values during winter suggested a correlation between Wave Height Index and SSC/NTU; and between SSC/NTU and light (Appendix 12). During summer there was a correlation between wind and Wave Height Index, as well as SSC/NTU with LAC.

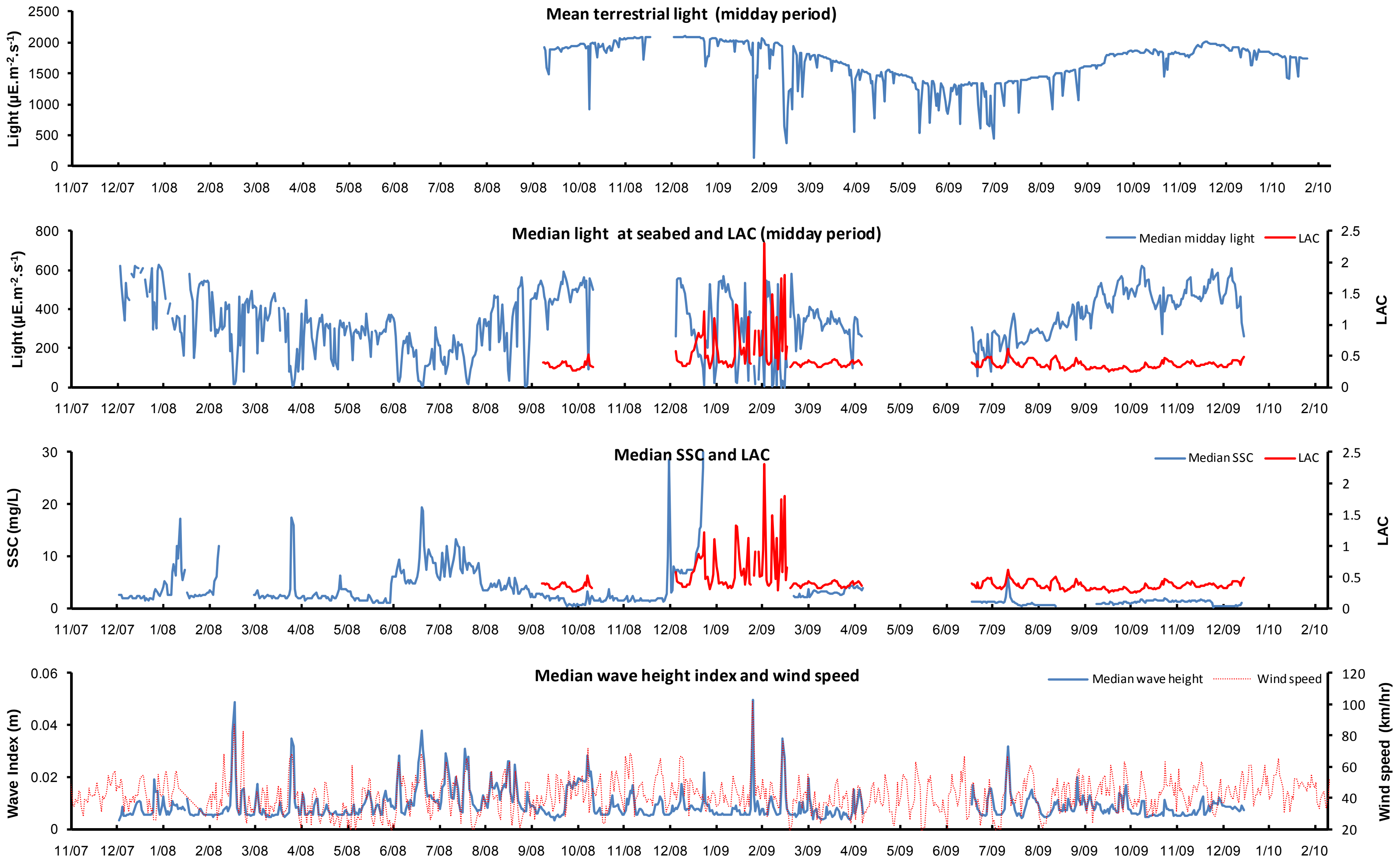


Figure 13-29 Time-Series Plots of Daily Light, LAC, Median SSC and Median Wave Height Index at Batman Reef and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.2.4.6 Southern Barrow Shoals (SBS)

The daily median light level recorded at the seabed at the Southern Barrow Shoals site was approximately 19% greater in summer (368.9 μE/m^2/s) than in winter (309.8 μE/m^2/s) (Figure 13-30). Periods of low light were more common throughout winter, and coincided with the passage of Tropical Cyclones Melanie, Nicholas and Ophelia in summer.

The median Wave Height Index was higher in winter (0.014 m) than in summer (0.011 m) and significant wave events were also more common over this period (Figure 13-30). Wave events generally coincided with peaks in SSC, as indicated by the elevated levels recorded during the passage of Tropical Cyclones Melanie, Nicholas and Pancho and during the periods of strong easterly winds recorded from June–August 2008.

The median SSC at Southern Barrow Shoals was greater in summer (3.6 mg/L) than in winter (2.7 mg/L), although the results were influenced by data gaps in winter caused by instrument malfunction (Figure 13-30). Throughout the sampling period, large elevations in SSC were mostly coincident with peaks in wave height. Reduced light levels and elevated light attenuation were also recorded during these periods as a result of increased turbidity in the water column.

Vertical particle flux, as measured by the sediment traps, varied between the seven deployment periods (Figure 13-31). The lowest mean flux (16.7 ± 2.0 $g.m^{-2}.d^{-1}$) was recorded over the October–November 2009 deployment period, which coincided with an extended period of relatively low median Wave Height Index and SSC. Mean TOC was 2.16 ± 0.03% and mean TIC 7.02 ± 0.05%. The elevated mean flux (244.2 ± 8.5 $g.m^{-2}.d^{-1}$) observed in the December 2008–February 2009 period coincided with peaks in wave height resulting from the passage of Tropical Cyclone Dominic in late January 2009. Mean TOC was 0.73 ± 0.02% and mean TIC was 8.66 ± 0.04%.

During summer, the levels of significance and the relatively high Pearson's R-squared values indicated correlations between Wave Height Index and SSC/NTU; between Wave Height Index and LAC; as well as between SSC/NTU with LAC (Appendix 12). In winter, there were significant correlations between Wave Height Index with SSC/NTU and LAC, as well as between SSC/NTU and LAC.

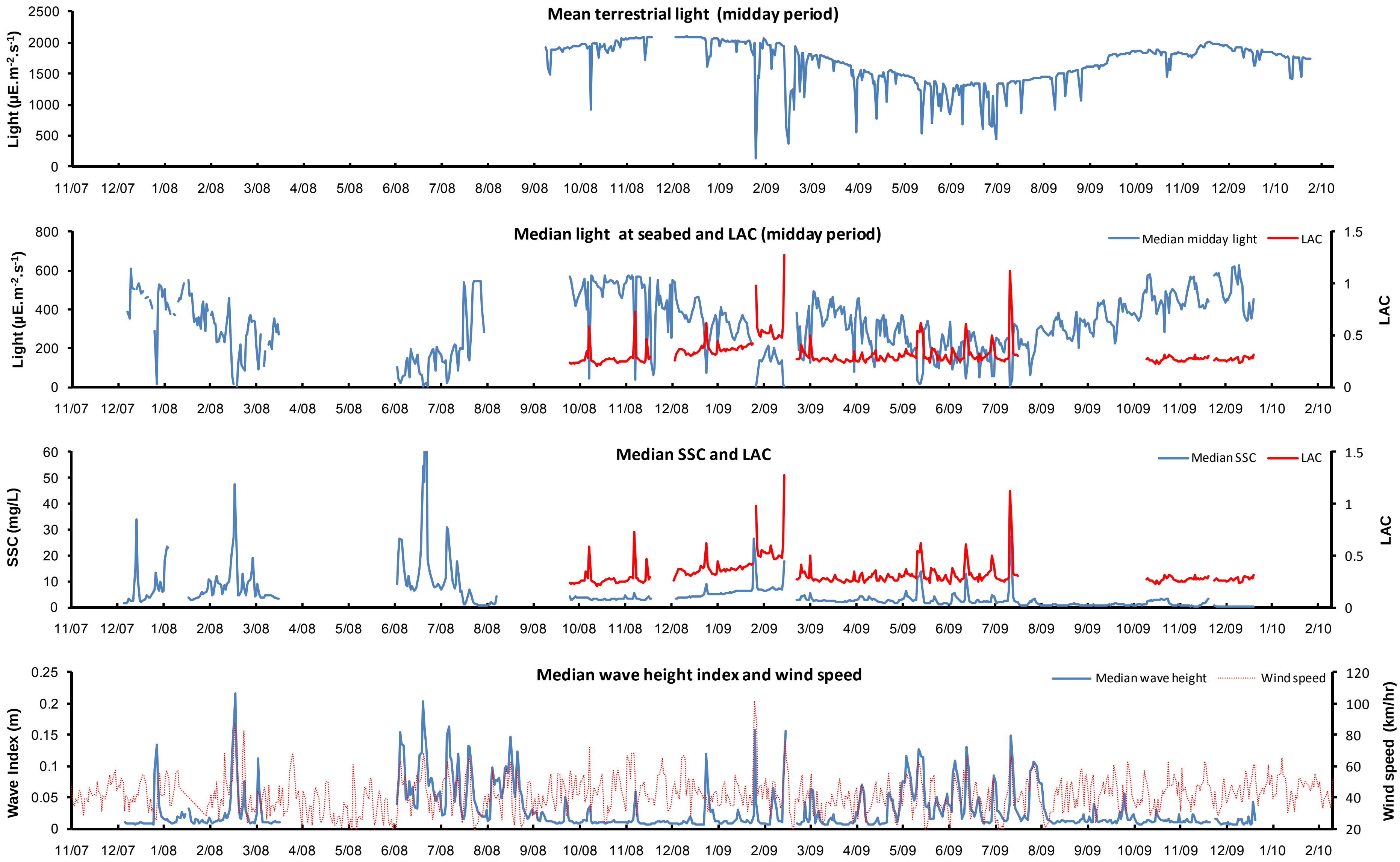


Figure 13-30 Time-Series Plots of Daily Light, LAC, Median SSC and Wave Height Index at Southern Barrow Shoals and Daily Maximum Sustained Wind Speed at Barrow Island

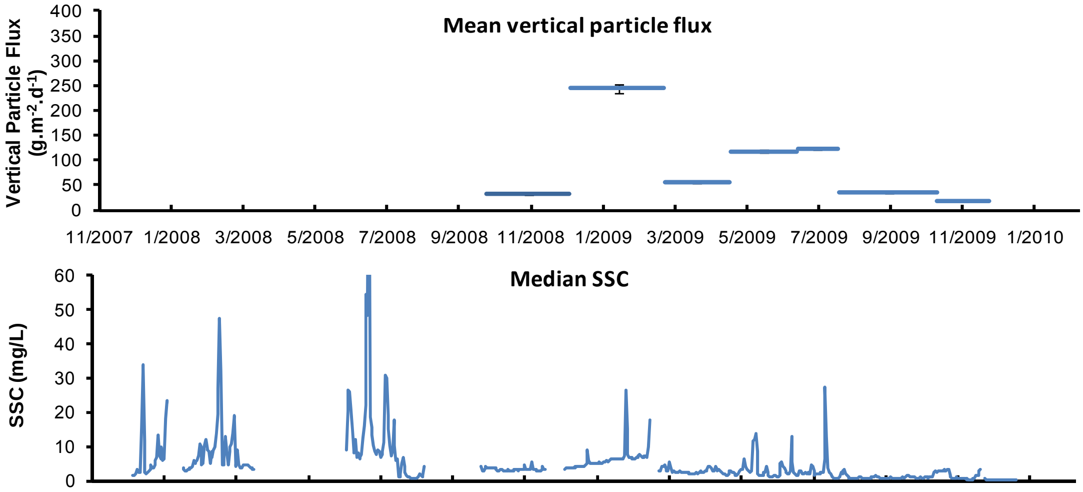


Figure 13-31 Plots of Daily Mean (± SE) Vertical Particle Flux into Sediment Traps over Seven Separate Deployments and Daily Median SSC at Southern Barrow Shoals

13.4.2.5 LTD Logger Data: Comparisons Between Sites

Summaries of the data collected to date are presented below in a series of 'box and whisker plots'. The data are presented in Appendix 13.

Median daily light was highest at Biggada Reef over both summer (495.4 μE/m^2/s; Figure 13-32) and winter (543.3 μE/m^2/s; Figure 13-33). During summer, median daily light was higher at Southern Lowendal Shelf (483.3 μE/m^2/s), Southern Barrow Shoals (368.9 μE/m^2/s), Batman Reef (363.5 μE/m^2/s) and Ant Point Reef (332.5 μE/m^2/s), and lowest at Lone Reef (139.8 μE/m^2/s) and LNG0 (151.1 μE/m^2/s). Median daily light was generally lower at all sites over winter, with the lowest values recorded at Lone Reef (127.6 μE/m^2/s) and LNG0 (135.2 μE/m^2/s).

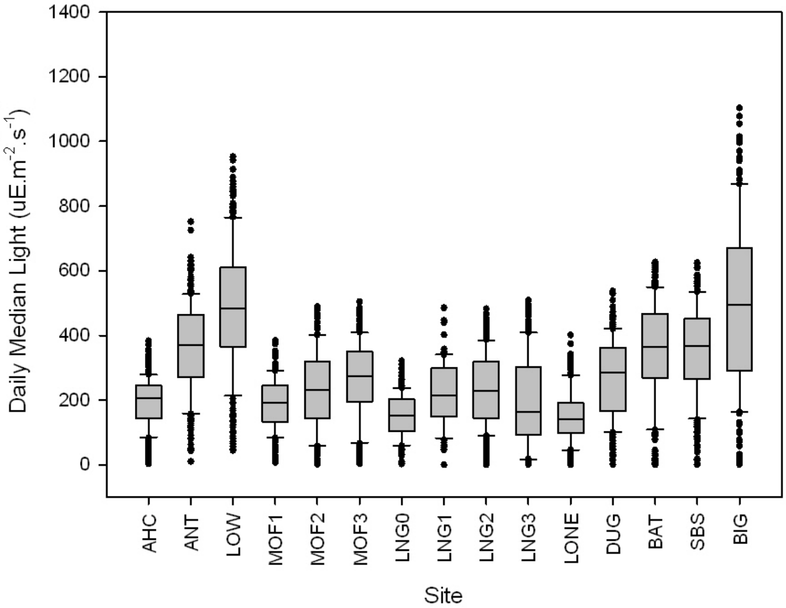


Figure 13-32 Box Plots of the Daily Median Light Levels During Summer

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers (outliers above 1400 μE/m^2/s are not shown).

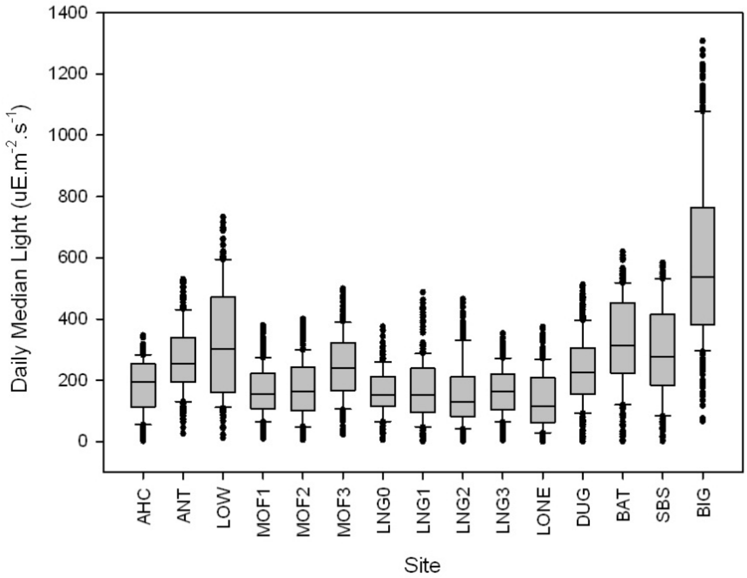


Figure 13-33 Box Plots of the Daily Median Light Levels During Winter

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10^{th} and 90^{th} percentiles; circles = outliers (outliers above 1400 µE/m^2/s are not shown).

Daily median LAC were highest at Biggada Reef (0.63 m^{-1}), Batman Reef (0.37 m^{-1}), Southern Lowendal Shelf (0.35 m^{-1}) and Ant Point Reef (0.34 m^{-1}), and were lowest at LNG1 (0.22 m^{-1}), Dugong Reef (0.25 m^{-1}), LNG0 (0.26 m^{-1}) and Lone Reef (0.26 m^{-1}) over summer (Figure 13-34). Daily median LAC were highest at Biggada Reef (0.52 m^{-1}), Southern Lowendal Shelf (0.40 m^{-1}) and Batman Reef (0.37 m^{-1}), and were lowest at LNG1 (0.21 m^{-1}), LNG0 (0.23 m^{-1}) and Lone Reef (0.24 m^{-1}) over winter (Figure 13-35).

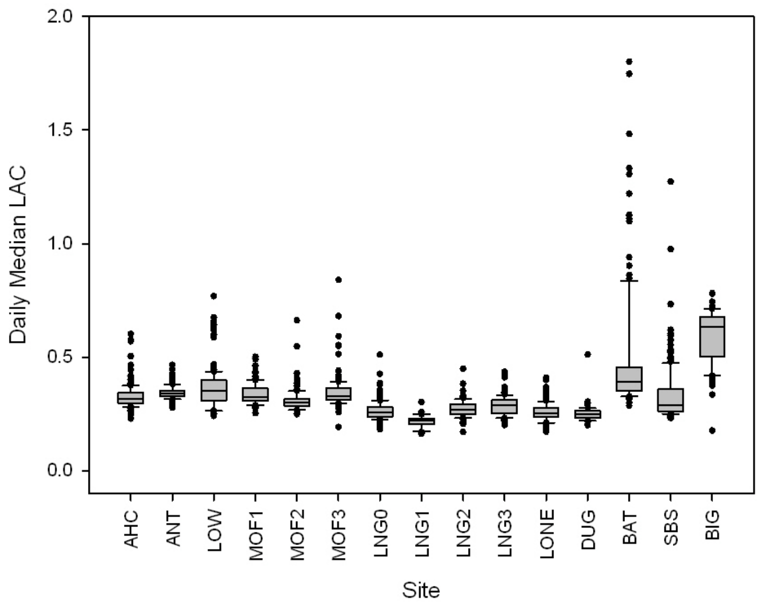


Figure 13-34 Box Plots of the Daily Median LAC During Summer

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10^{th} and 90^{th} percentiles; circles = outliers.

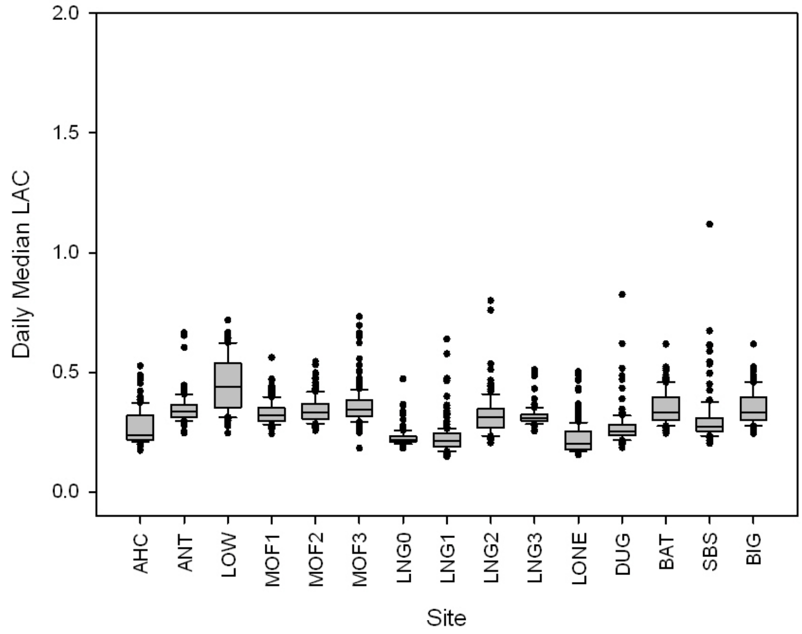


Figure 13-35 Box Plots of the Daily Median LAC During Winter

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers.

Median daily turbidity was highest at Southern Barrow Shoals (2.2 NTU), MOF1 (1.8 NTU) and Biggada Reef (1.6 NTU), and lowest at Lone Reef (0.7 NTU) and Ant Point Reef (0.7 NTU) over summer (Figure 13-36). Over winter, median daily turbidity was highest at Southern Barrow Shoals (1.7 NTU) and lowest at Lone Reef (0.7 NTU) (Figure 13-37). The data indicate that sites relatively close to each other may have different water quality characteristics in terms of turbidity.

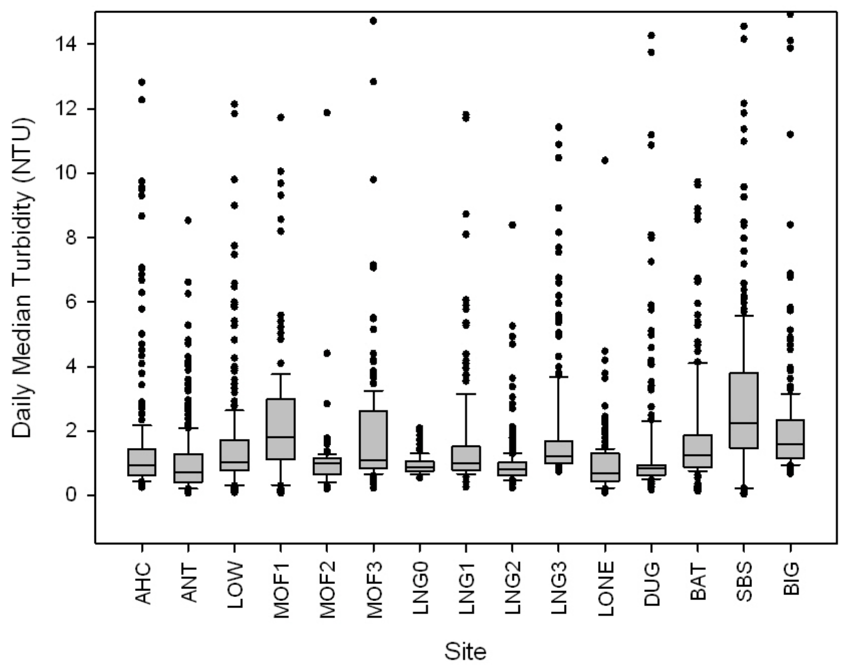


Figure 13-36 Box Plots of the Daily Median Turbidity During Summer

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers (outliers above 15 NTU are not shown).

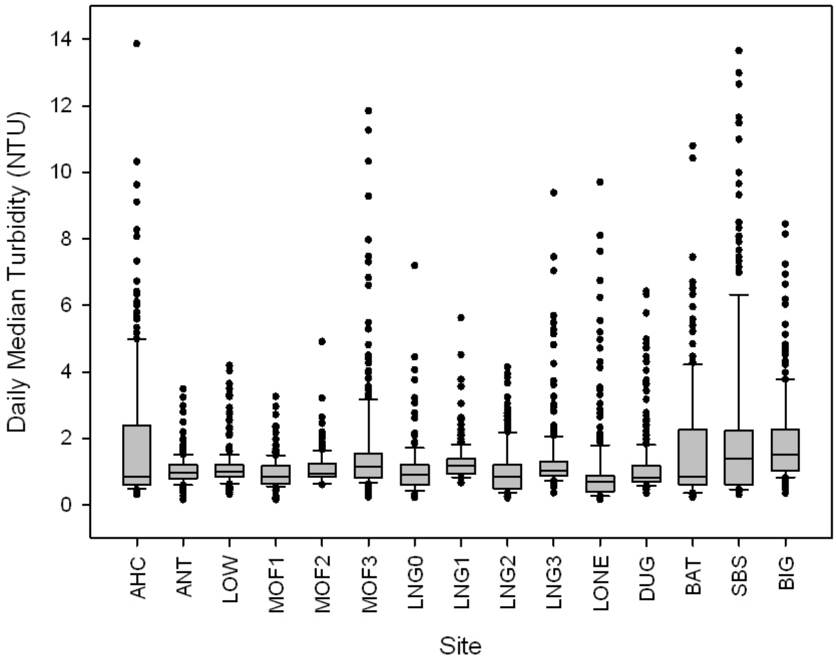


Figure 13-37 Box Plots of the Daily Median Turbidity During Winter

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10^{th} and 90^{th} percentiles; circles = outliers (outliers above 15 NTU are not shown).

Median daily estimated SSC were highest at Southern Barrow Shoals (3.6 mg/L), Ah Chong (3.0 mg/L) and Biggada Reef (3.0 mg/L), and lowest at LNG0 (0.8 mg/L) and MOF2 (0.8 mg/L) over summer (Figure 13-38). The highest median daily estimated SSC over winter was at LNG1 (3.1 mg/L), LNG3 (2.8 mg/L), Southern Barrow Shoals (2.7 mg/L) and Ah Chong (2.7 mg/L), and the lowest at LNG0 (0.8 mg/L) and MOF2 (0.8 mg/L) (Figure 13-39).

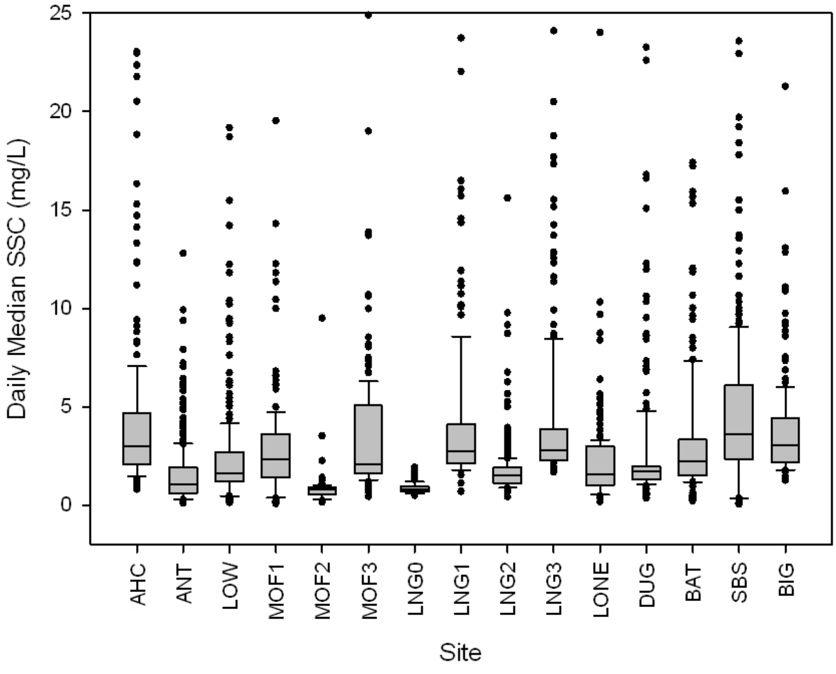


Figure 13-38 Box Plots of the Daily Median (estimated) SSC During Summer

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10^{th} and 90^{th} percentiles; circles = outliers (outliers above 25 $mg.L^{-1}$ are not shown).

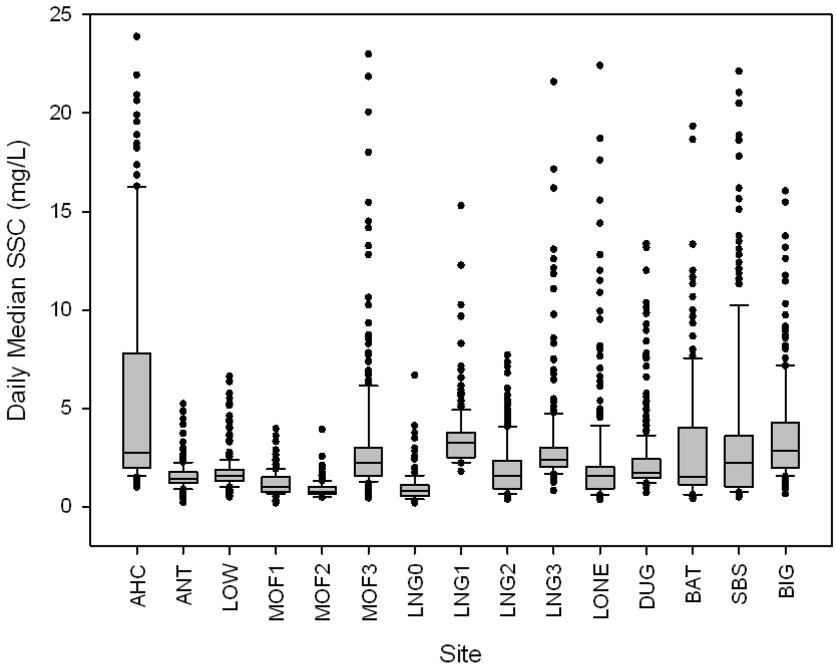


Figure 13-39 Box Plots of the Daily Median (estimated) SSC During Winter

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers (outliers above 25 mg.L^{-1} are not shown).

The daily median (between 0.007 m and 0.015 m) and inter-quartile range of Wave Height Index was generally similar at all sites over summer, with the exception of Biggada Reef (0.021 m) (Figure 13-40). The daily median (between 0.008 and 0.020 m) and inter-quartile range of Wave Height Index were generally higher and exhibited greater variability at all water quality monitoring sites over winter (Figure 13-41).

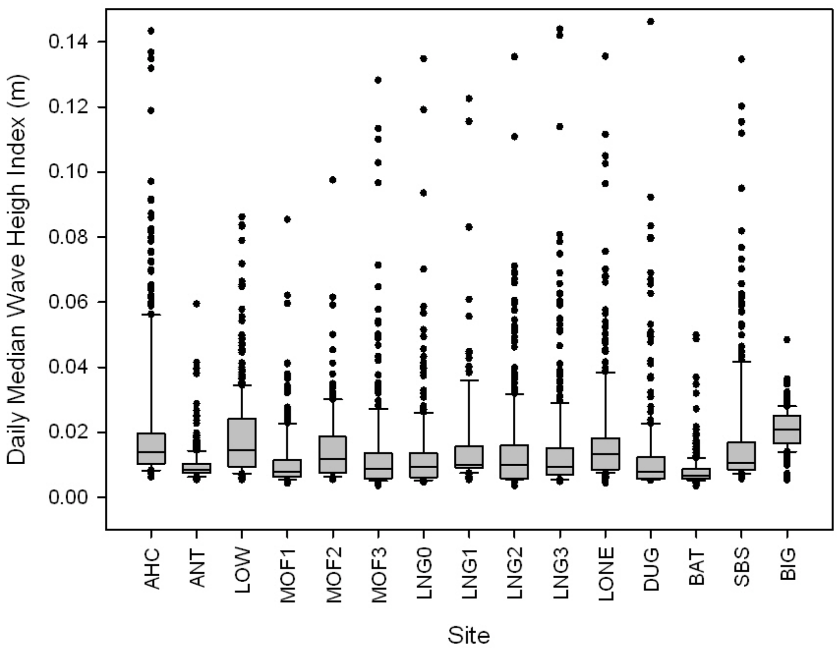


Figure 13-40 Box Plots of the Daily Median Wave Height Index During Summer

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers (outliers above 0.15 m are not shown).

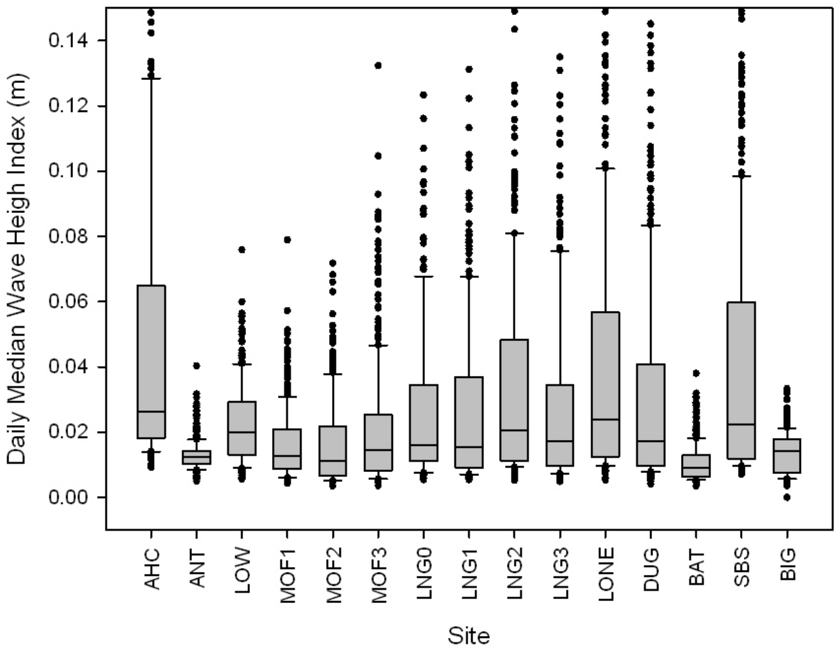


Figure 13-41 Box Plots of the Daily Median Wave Height Index During Winter

Note: Boxes = range of lower and upper quartiles; solid horizontal line = median; whiskers = 10th and 90th percentiles; circles = outliers (outliers above 0.15 m are not shown).

13.4.3 Water Column Profiles

In general, the water column profile data demonstrate a consistently well-mixed water column in the waters surrounding Barrow Island. The profiles were indicative of an offshore area with limited influence from surface water run-off and groundwater inflow, combined with good flushing and mixing by tidal and atmospheric forcing. The monthly near-surface (~1 m below the surface) and near-seabed (~0.5 m above the seabed) salinity, temperature and turbidity data for each site are presented in full in Appendix 14.

13.4.3.1 Sites in the Zones of High Impact and Zones of Moderate Impact

13.4.3.1.1 LNG0

Salinity ranged from 35.2 Practical Salinity Units (PSU), equivalent to parts per thousand (ppt), in surface waters in October 2009 and surface and bottom waters in December 2009 to 35.4 PSU in bottom waters in October 2009 and surface and bottom waters in September 2009. Temperature ranged from 21.6 °C in July in both surface and bottom waters, to 27.7 °C in surface waters and 27.0 °C in bottom waters in December 2009. Turbidity ranged between 9.3 NTU in surface waters in December 2009 and 12.2 NTU in bottom waters in November 2009.

13.4.3.1.2 MOF1

Salinity ranged between 35.2 and 35.6 PSU. The lowest salinity was recorded in surface waters in September 2008 and bottom waters in October 2009, whilst the highest salinity was recorded in both surface and bottom waters in January 2008 and November 2009. Temperatures ranged from 21.4–29.9 °C. The lowest temperature was recorded in July 2009 in surface and bottom waters, whilst the highest temperature was recorded in March 2008 in surface waters. The lowest turbidity (8.8 NTU) was recorded in July 2008 in surface and bottom waters. A maximum turbidity of 11.7 NTU was recorded in November 2009 in bottom waters.

13.4.3.1.3 Lone Reef (LONE)

A minimum salinity of 35 PSU was recorded in May 2008 in surface and bottom waters and in October 2008 in surface waters. The highest salinity of 35.5 PSU was recorded in July 2008 and June and August 2009 in surface and bottom waters. Temperatures varied from 21.6–30.1 °C. The lowest temperatures of 21.6 °C in bottom waters were recorded in July and August 2009, the lowest surface water temperature (21.7 °C) was also recorded in July 2009. Highest temperatures of 29.8 °C in bottom waters and 30.1 °C in surface waters were recorded in March 2008. Turbidity varied between 8.3 NTU in surface waters in July 2008 and 10.7 NTU recorded in surface and bottom waters in June 2009.

13.4.3.1.4 LNG1

Salinity varied between 35.1 PSU, which was recorded in both surface and bottom waters in September and October 2008, and 35.5 PSU, which was recorded in surface waters in July 2008. Temperatures ranged from a minimum of 21.9 °C in surface and bottom waters in July 2009, to a maximum of 24.4 °C in surface waters in September 2008. Turbidity was lowest in July 2008 in surface waters (8.8 NTU) and highest in October 2008 in surface waters (11.7 NTU). Turbidity in bottom waters ranged from 9.8 NTU in July 2008 to 10.3 NTU in September and October 2008 and July 2009.

13.4.3.2 Sites in the Zones of Influence

13.4.3.2.1 Ant Point Reef (ANT)

Salinity at Ant Point Reef varied from 35.8 PSU in November 2008 to 35.2 PSU in March and September 2008. On each sampling occasion, there were no differences in the salinity recorded in surface and bottom waters; similarly, temperature data at the surface and seabed were identical on each sampling occasion. Temperature varied from 23.1°C in November 2008, corresponding with the highest recorded salinity, to 30.1°C in March 2008. Turbidity ranged from 10.2 NTU in June 2009 in both surface and bottom waters to 12.7 NTU in surface waters in October 2009.

13.4.3.2.2 Southern Lowendal Shelf (LOW)

Salinity ranged from 35.1–35.6 PSU. The lowest salinity was recorded in surface and bottom waters in January 2008 and September 2008. The highest salinity was recorded in bottom waters in November 2008. A minimum temperature of 21.6 °C was recorded in July 2008 in surface and bottom waters. The highest surface and bottom waters temperatures were 28.2 °C and 28.1 °C, respectively; both were recorded in January 2008. The lowest turbidity recorded was 9.3 NTU, which was recorded in surface waters in January 2008 and bottom waters in July 2008, and in both surface and bottom waters in August 2009. The highest turbidity recorded was 13.2 NTU, which was recorded in November 2008 in surface waters; at the same time, 12.7 NTU was recorded in bottom waters.

13.4.3.2.3 MOF2

Salinity, temperature and turbidity measurements at MOF2 were available only for September 2008 and September 2009. The salinity was the same in surface and bottom waters on each sampling occasion (35.4 PSU). Turbidity was 10.3 NTU in September 2008 in surface and bottom waters, while in September 2009, 9.8 NTU and 9.3 NTU were recorded at surface and bottom waters respectively. Temperature varied from 22.3 °C in surface and bottom waters in September 2009 to 23.6 °C in surface waters in September 2008.

13.4.3.2.4 MOF3

Salinity varied slightly between 35.2 and 35.5 PSU. The lowest salinity was recorded in October 2008 in surface and bottom waters. The highest salinity was recorded in January 2008 and September 2009 in bottom waters and in June and November 2009 in both surface and bottom waters. Temperatures recorded in surface and bottom waters ranged from 21.4 °C in July 2009 to 29.8 °C in March 2008. A minimum turbidity of 9.3 NTU was recorded in surface waters September 2009. A maximum turbidity of 10.7 NTU was recorded in surface and bottom waters in October 2008, bottom waters in June 2009 and surface waters in November 2009.

13.4.3.2.5 LNG2

Salinity ranged from 35.1 to 35.5 PSU. The lowest salinity was recorded in May and September 2008, whilst the highest salinity was recorded in July 2008 and June 2009. A minimum temperature of 21.9 °C was recorded in bottom waters in July 2009. A maximum temperature of 29.5 °C was recorded in March 2008 in surface and bottom waters. Turbidity varied from 9.1–10.3 NTU. The lowest turbidity was recorded in surface waters in July 2008. The highest turbidity was recorded in bottom waters in May 2008 and June 2009; and surface and bottom waters in September 2008 and July 2009.

13.4.3.3 Reference Sites Outside the Zones of Influence and Not at Risk of Material or Serious Environmental Harm

13.4.3.3.1 Ah Chong (AHC)

Salinity varied from 35.0 PSU in May 2008 in surface waters to 35.3 NTU in June 2009 at both locations within the water column and March 2008 in bottom waters. Temperature ranged from 23.0 °C in June 2009 at surface waters to 29.9 °C in surface waters in March 2008. Turbidity was highest in November 2008 (11.7 NTU) in surface and bottom waters and lowest in both January 2008 and September 2008 when 9.3 NTU was recorded in surface waters.

13.4.3.3.2 Biggada Reef (BIG)

Salinity varied slightly from 34.9 to 35.1 PSU. The lowest salinity was recorded in June 2008 in surface and bottom waters. Highest salinity was recorded on all other occasions in surface and bottom waters, with the exception of January 2008, when 35 PSU was recorded in bottom waters. The lowest temperature recorded was 22.4 °C in August 2009 in surface waters. A maximum temperature of 29.8 °C was recorded in March 2008 in surface waters. The lowest turbidity recorded was 9.8 NTU in January 2008 in surface and bottom waters; and in June 2008 in bottom waters. The highest turbidity recording was 11.7 NTU in October 2008 in bottom waters.

13.4.3.3.3 LNG3

Salinity ranged from 35.1 to 35.6 PSU. The lowest salinity was recorded in surface waters in March and May 2008. The highest salinity was recorded in bottom waters in June and August 2009. A minimum temperature of 21.3 °C was recorded in August 2009 in bottom waters, and a maximum temperature of 30.3 °C was recorded in March 2008 in surface waters. The highest temperature in bottom waters was 29.9 °C, also recorded in March 2008. A minimum turbidity of 8.8 NTU was recorded in July 2008 in surface and bottom waters and August 2009 in surface waters. A maximum turbidity of 11.7 NTU was recorded in November 2008 in bottom waters.

13.4.3.3.4 Dugong Reef (DUG)

Salinity ranged from 35.2 to 35.6 PSU, with the lowest recorded in May 2008 in bottom waters and the highest recorded in November 2008 in surface and bottom waters. The lowest temperature was 21.9 °C, which was recorded in September 2009 in bottom waters. A maximum temperature of 30.7 °C was recorded in surface waters in January 2008. Turbidity ranged from 9.8–11.7 NTU, with the lowest recorded in January, May and September 2008 and September 2009 in bottom waters, and May 2008 and September 2009 in surface waters. The highest turbidity was recorded in November 2008 in surface and bottom waters.

13.4.3.3.5 Batman Reef (BAT)

The lowest salinity was 35.2 PSU, recorded in March, May and October 2008 in surface and bottom waters. The highest salinity was 35.7 PSU, which was recorded in surface and bottom waters in October 2009. Temperatures ranged from 21.5 to 30.6 °C in surface waters, with little variation on any sampling occasion with bottom waters. The lowest temperature was recorded in August 2009 and highest temperatures recorded in March 2008. A minimum turbidity of 9.3 NTU was recorded in surface waters in January 2008. The highest turbidity recorded was 11.7 NTU in bottom waters in November 2009.

13.4.3.3.6 Southern Barrow Shoals (SBS)

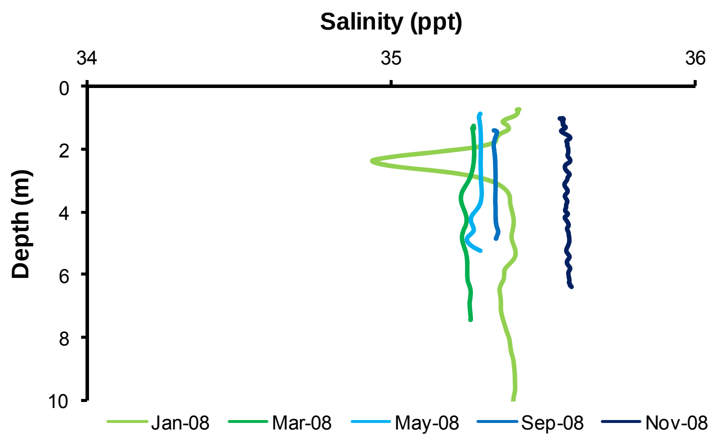
Salinity varied from 35.3 to 36.5 PSU, with the lowest recorded in March 2008 and the highest in October 2009. Measurements of salinity were consistent in surface and bottom waters on each sampling occasion. The lowest temperature was 21.1 °C, recorded in July 2009 in surface and bottom waters. A maximum temperature of 30.0 °C was recorded in March 2008 in surface waters. Turbidity ranged from 8.8 to 10.7 NTU. Lowest turbidity was recorded in July 2008 in bottom waters, whilst the maximum was recorded in January 2008 in surface waters and in September 2008 and June 2009 in surface and bottom waters.

13.4.3.4 Water Column Profiles: Summary

Salinity ranged from 34.9 to 36.5 PSU. The lowest surface and bottom waters salinity was recorded at Biggada Reef in June 2008, whilst the highest surface and bottom waters salinity was recorded at Southern Barrow Shoals in October 2009. Overall, there was little difference in salinity between the surface and bottom waters or over the year at any of the water quality monitoring sites. The salinity recorded at the anchor location adjacent to the Biggada Reef site on the west coast of Barrow Island was frequently slightly lower than the salinity recorded at the east coast monitoring sites. The salinity recorded at Southern Barrow Shoals was slightly higher than at other monitoring sites on the east coast.

Surface water temperatures varied between 21.1 °C and 30.7 °C; and bottom waters between 21.1 °C and 30.5 °C. The lowest temperature was recorded in surface and bottom waters at Southern Barrow Shoals in July 2009 and the highest surface water temperature (30.7 °C) at Dugong Reef in January 2008 and the highest bottom water temperature (30.5 °C) at Batman Reef in March 2008. Surface waters were generally slightly warmer by 0.1–0.4 °C and occasionally by more than 1 °C. There was a clear seasonal trend, with the warmest surface and bottom waters reported in later summer (27–30 °C) and the coolest waters in winter (21–24 °C).

Temperature stratification due to heating of surface waters (up to 5 m depth) occasionally occurred, particularly at the deeper sites, such as Ah Chong, Dugong Reef and LNG2. Stratification at sites on the east coast was observed to be greatest during periods of calm wind/wave conditions and neap tides, in particular during the summer months. The profile for the Dugong Reef site in January 2008 indicates a slight halocline and a thermocline, indicating the presence of a slightly cooler and fresher surface layer (Figure 13-42). The highest surface water temperature was also recorded at this site on this occasion.



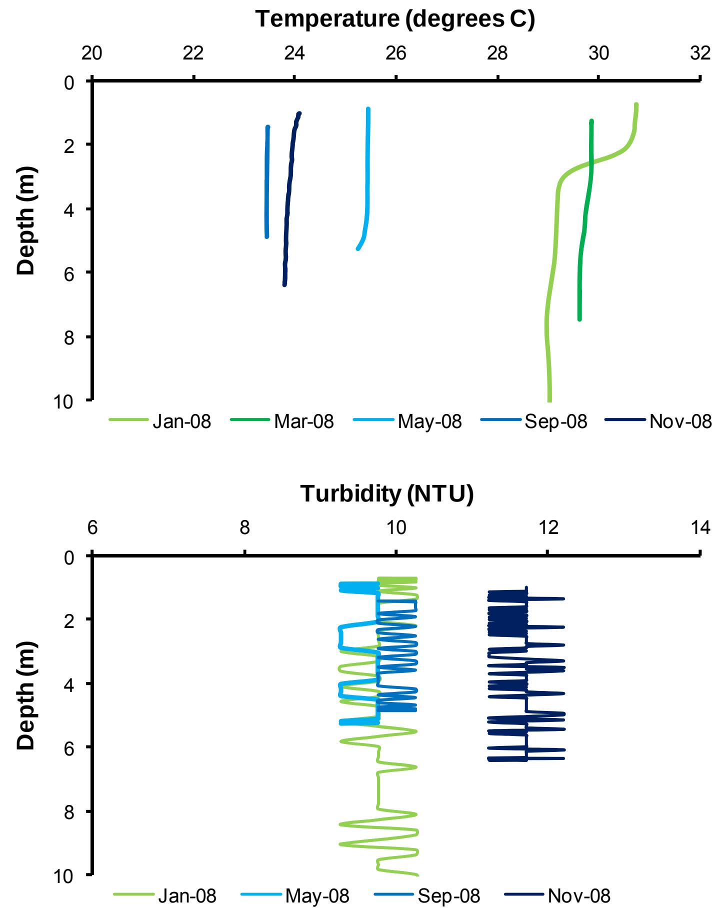


Figure 13-42 Salinity, Temperature and Turbidity Profiles at Dugong Reef on Five Occasions in 2008[12]

Turbidity varied between 8.3 and 13.2 NTU in surface waters and 8.8–12.7 NTU in bottom waters. The lowest surface water turbidity was recorded in July 2008 at Lone Reef, and the highest surface water turbidity was recorded in November 2008 at Southern Lowendal Shelf. The lowest turbidity recorded in bottom waters was 8.8 NTU in July 2008 at MOF1, LNG3 and Southern Barrow Shoals. The highest turbidity recorded in bottom waters was recorded in November 2008 at Southern Lowendal Shelf. Turbidity was generally higher in bottom waters than in surface waters and there was some indication of a seasonal trend with the highest turbidities recorded in spring/early summer (Figure 13-42).

13.5 Discussion

The results from the baseline water quality (light and turbidity) and sediment deposition monitoring program indicate that in the waters around Barrow Island, turbidity and concentrations of suspended sediments were generally low (<5 mg/L) and indicative of clear water environments. There were very low levels of sediment deposition over the duration of the baseline program

[12] The electronics of the nephelometer produce ‘step’ readings which correspond to increments of approximately 0.5 NTU when the millivolt readings are converted to NTU readings. The accuracy of the sensor is thus limited by these steps (as are all nephelometers) and the sensor oscillates in steps of 0.5 NTU around the correct reading. Note that the turbidity data have not been modified, smoothed or corrected as the data are primarily used in a relative context and to determine if turbidity is consistent throughout the profile.

(below the limits of instrument detection) and any deposition that did occur was temporary and rapidly resuspended by waves and tidal flow.

At most sites, wave activity was significant in contributing to local resuspension of sediments, resulting in elevated turbidity and suspended sediment concentrations. In winter, easterly winds can generate wind seas that propagate into the east coast of Barrow Island. Thus, at the majority of the sites, there was a measurable effect on water quality, with suspended sediment concentrations generally higher during winter when easterly winds are more common. The west coast of Barrow Island is exposed to the open ocean and a relatively vigorous wave climate, bringing long period Southern Ocean swells and shorter-period local wind waves, particularly during the summer months, when winds prevail from the south-west. Extreme weather events, such as tropical cyclones, also had a strong influence on water quality. Short periods of elevated suspended sediment concentrations, reduced light levels and elevated light attenuation as a consequence of increased turbidity in the water column, coincided with the passage of tropical cyclones. Higher average particle flux rates were also recorded during periods of increased wave activity and elevated suspended sediment concentrations, as well as following the passage of a tropical cyclone. Conversely, relatively low flux rates were observed during extended periods of calm conditions.

Water column profiles consistently demonstrate that the water column was well mixed with little evidence of stratification, indicative of an offshore environment with limited influence from surface water run-off and groundwater inflow, combined with good flushing and mixing by tidal and atmospheric forcing.

Seabed light levels were primarily influenced by depth and there were seasonal patterns in the daily average light levels at most sites, with summer values generally higher than winter.

The Marine Baseline Program indicates that there is considerable variability, with water quality and sediment deposition varying markedly between sites in close proximity to each other and sites responding dissimilarly to the same hydrodynamic conditions (e.g. waves). Seasonal patterns, such as higher light levels in summer than in winter, were also more evident at some sites than others. Similarly, the influence of environmental parameters on water quality also varied over relatively small spatial scales.

Sedimentation and turbidity are major influences on the health and survival of scleractinian corals and other benthic primary producers through alteration of both physical and biological processes. The extent and severity of impacts related to turbidity, light attenuation and sedimentation are highly variable and depend on a number of factors including the species and morphology of corals, sediment grain size, and water temperature (Rogers 1990). Additionally, the magnitude, duration and frequency of turbidity and sedimentation events, as well as the pre-event condition of the coral, also affect the extent and severity of impacts. Coral health data collected during the baseline program showed no discernible impacts on coral health associated with water quality (turbidity and light attenuation) or sediment deposition.

14.0 Auditing and Reporting

14.1 Auditing

14.1.1 Internal Auditing

Chevron Australia has prepared the internal ABU Compliance Assurance Process (Chevron Australia 2009) to manage compliance, and which it internally requires its employees, contractors, etc. to comply with. This Process will also be applied to assess compliance of the Gorgon Gas Development and Jansz Feed Gas Pipeline against the requirements of Statement No. 800, Statement No. 769, and EPBC Reference: 2003/1294 and 2008/4178 where this is appropriate and reasonably practicable.

An internal Audit Schedule has been developed and will be maintained for the Gorgon Gas Development and Jansz Feed Gas Pipeline (with input from the Engineering, Procurement and Construction Management [EPCM] Contractors) that includes audits of the Development's environmental performance and compliance with the Ministerial Conditions. A record of internal audits and the audit outcomes is maintained. Actions arising from internal audits are tracked until their close-out.

Under EPBC Reference: 2003/1294 and 2008/4178, Condition 24 also requires that the person taking the action must maintain accurate records of activities associated with or relevant to the conditions of approval and make them available on request by the Commnonwealth (DotE). Such documents may be subject to audit by DotE and used to verify compliance with the conditions of approval.

Any document that is required to be implemented under this Report will be made available to the relevant DPaW/DotE auditor.

14.1.2 External Auditing

Audits and/or inspections undertaken by external regulators will be facilitated via the Gorgon Gas Development and Jansz Feed Gas Pipeline's Regulatory Approvals and Compliance Team. The findings of external regulatory audits will be recorded and actions and/or recommendations will be addressed and tracked. Chevron Australia may also undertake independent external auditing during the Gorgon Gas Development and Jansz Feed Gas Pipeline.

Under EPBC Reference: 2003/1294 and 2008/4178, Condition 23 also requires that upon the direction of the Minister, the person taking the action must ensure that an independent audit of compliance with the Conditions of approval is conducted and a report submitted to the Minister. The independent auditor must be approved by the Minister prior to the commencement of the audit. Audit criteria must be agreed to by the Minister and the audit report must address the criteria to the satisfaction of the Minister.

14.2 Reporting

14.2.1 Compliance Reporting

Condition 4 of Statement No. 800 and Condition 2 of EPBC Reference: 2003/1294 and 2008/4178 requires Chevron Australia to submit a Compliance Assessment Report annually to address the previous 12-month period. Condition 4 of Statement No. 769 similarly requires that Chevron Australia submit an Audit Compliance Report on an annual basis, for the previous 12-month period.

For the purpose of this Report a compliance reporting table is provided in Appendix 15 to assist with auditing for compliance with Statement No. 800, EPBC Reference: 2003/1294 and 2008/4178, and Statement No.769. Note that all the commitments identified in Appendix 15 have now been met and further details are provided in Appendix 15.

14.2.2 Environmental Performance Reporting

Condition 5.1 of Statement No. 800, Statement No. 769, and Condition 4 of EPBC Reference: 2003/1294 and 2008/4178 require that Chevron Australia submits an Environmental Performance Report to the Western Australian Minister for Environment and to the Commonwealth Minister, respectively, on an annual basis, for the previous 12-month period.

In addition, under Condition 5.3 of Statement No. 800 and Statement No. 769, and Condition 4.2 for EPBC Reference: 2003/1294 and 2008/4178, every five years from the date of the first annual Report, Chevron Australia shall submit to the Western Australian Minister for Environment an Environmental Performance Report covering the previous five-year period.

Specific details on the content of the Environmental Performance Report are defined in Condition 5.2 and Schedule 3 of Statement No. 800, Condition 5.2 of Statement No. 769, and Schedule 3 of EPBC Reference: 2003/1294 and 2008/4178.

The information in the Environmental Performance Report will also partly meet the requirements of Condition 3.7 of EPBC Reference: 2003/1294 and 2008/4178.

14.2.3 Routine Internal Reporting

The Gorgon Gas Development and Jansz Feed Gas Pipeline will use a number of routine internal reporting formats to effectively implement the requirements of this Report. Routine reporting is likely to include daily, weekly and/or monthly HES reports for specific scopes of work on the Development. These reports include information on a number of relevant environmental aspects, such as details of environmental incidents (if any), environmental statistics and records, records of environmental audits and inspections undertaken, status of environmental monitoring programs, tracking of environmental performance against performance indicators, targets and criteria, etc.

14.2.4 Incident Response and Reporting

Chevron Australia has prepared the ABU Emergency Management Process (Chevron Australia 2010c) and Incident Investigation and Reporting Process (Chevron Australia 2010d), which it internally requires its employees, contractors, etc. to follow in the event of environmental incidents. These procedures will also be applied to environmental incidents identified in this Report, where this is appropriate and reasonably practicable.

The environmental incidents, reporting requirements and timing specific to this Report are provided in Table 14-1. Note that under Condition 3.2.7 of EPBC Reference: 2003/1294 and 2008/4178 Significant Impacts detected by the monitoring programs under this Report, will follow protocols for reporting to the Commonwealth (DotE), whether or not the impact is caused by the Gorgon Gas Development.

Table 14-1 Incident Reporting Requirements

Incident	Reporting to	Timing
Material or Serious Environmental Harm outside the Marine Disturbance Footprint (MDF)	DPaW/DotE	Within 48 hours of detection or as soon as reasonably practicable
Significant Impacts detected by the monitoring program for matters of National Environmental Significance	DotE	Within 48 hours of detection

14.2.5 Review of this Report

Chevron Australia is committed to conducting activities in an environmentally responsible manner and aims to implement best practice environmental management as part of a program of continuous improvement. This commitment to continuous improvement means Chevron Australia will review the Marine Baseline Report as required (e.g. in response to new information).

Reviews will address matters such as the overall design and effectiveness of the Report, progress in environmental performance, changes in environmental risks, changes in business conditions, and any relevant emerging environmental issues.

If the Report no longer meets the aims, objectives or requirements of the Report, if works are not appropriately covered by the Report, or measures are identified to improve the Report, Chevron Australia may submit an amendment or addendum to the Report to the Minister for approval under Condition 36 of Statement No. 800 and Condition 21 of Statement No. 769.

If Chevron Australia wishes to carry out an activity otherwise than in accordance with the Report, Chevron Australia will update the Report and submit it for approval by the Minister in accordance with Condition 25 of EPBC Reference: 2003/1294 and 2008/4178. The Commonwealth Minister may also direct Chevron Australia to revise the Report under Condition 26 of EPBC Reference: 2003/1294 and 2008/4178.

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