Determination of the baseline levels of key chemical parameters in a proposed aquaculture development zone

Nigel West

Project No. 2012/738

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This project was conducted by ChemCentre, PO Box 1250, Bentley Delivery Centre WA 6983, and

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Non-Technical Summary

PROJECT No. 2012/738 Determination of the baseline levels of key chemical parameters in a proposed aquaculture development zone

PRINCIPAL INVESTIGATOR: **Nigel West**

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The Department of Fisheries, Western Australia (Department), proposes to create an 'Aquaculture Development Zone' (Strategic proposal) within the State Waters, of the Abrolhos Islands approximately 75 kilometres west of Geraldton. The Mid-West Aquaculture Development Zone (MWADZ) has been selected to maximise suitability for marine finfish aquaculture, and minimise potential impacts on existing marine communities and human use. Under part IV of the *Environmental Protection Act 1986*, an environmental impact assessment (EIA) of proposed operations within the proposed MWADZ is required as part of a Public Environmental Review to determine whether the Strategic proposal is acceptable. The Minister for the Environment will not approve the MWADZ proposal until he is satisfied that derived proposals, associated with the Strategic proposal, can be managed to meet the Environmental Protection Authority's (EPA) environmental quality objectives.

Four sets of seawater samples (Autumn, Winter, Spring and Summer) and two sets of sediment samples (Winter and Summer) were collected by the Department, Marine Ecology and Monitoring Section (MEMS). The samples were analysed to provide data to support the Environmental Impact Assessment (EIA) that was to be developed by the Department. The EIA will be central in demonstrating to the EPA that the potential impact to the marine environment of this Mid-West location is acceptable, thereby justifying the approval. This EIA involves investigating the influence of various factors such as nutrient and contaminant input, establishment of infrastructure, management practices, and the hydrodynamics of the surrounding marine environment.

In addition to more routine analyses, ChemCentre needed to provide an ultra trace analytical capability for the analysis of polycyclic aromatic hydrocarbons (PAHs) from seawaters and sediments at a level more than 100 times lower than US EPA guidelines. PAHs are known carcinogens and are formed when there is a lack of available oxygen during a combustion process e.g. the burning of fossil fuels in engines. In this off-shore location PAHs are very likely to be derived solely from anthropogenic sources and as such can be used as a marker of contamination of local industries. ChemCentre also needed to ensure that other testing on the sediment and seawater samples was carried out at as low a detection limit as was practicable, to ensure that the EIA could be constructed in a defensible manner.

The ultra trace analysis of PAHs still has some reproducibility issues, as some replicate data was not within acceptable limits and one batch from the sixteen batches analysed, did not pass its quality control (QC) checks. This batch was most likely contaminated, after extraction but prior to analysis. Though the point of contamination has not been confirmed, we believe it occurred when oil stored in the same room as the sealed containers diffused into the extracts. The very low analytical levels reached have made previously routine laboratory practises now a potential source of contamination.

Even at the ultra trace levels, there were no significant levels of PAHs in either the sea water or sediment samples. Only naphthalene was routinely detected in either matrix and generally this was at levels very close to the practical quantitation limit of 0.001 µg/L (sea water) or 0.001 mg/kg (sediment). Though

these results may not be as beneficial for modelling as was originally anticipated, the baseline levels established for the PAHs should contribute to the adoption of trigger values for the management of industries operating within the proposed aquaculture zone.

Of the analytes determined by ChemCentre, Total Organic Carbon (TOC) was detected in approximately half of the seawater samples, whilst total nitrogen was routinely detected in each of these samples. In the sediment samples, several metals were routinely detected as were nitrogen, phosphorus, nitrogen as ammonium and TOC. The elements that were detected in both matrices were normalised against TOC. As a rule the abundance of the elements in the sediment was slightly higher in Winter than in summer (relative to TOC), with the exception of total nitrogen, which more closely aligns with the trend identified in the sea water samples, where the total nitrogen was higher in summer than Winter (relative to TOC). As for the PAHs, this data, which will be used as part of the EIA, should also contribute to the adoption of trigger values for the management of industries operating within the proposed aquaculture zone.

The data generated in this program will be used by the Department to complete an EIA as part of its proposal to be assessed by the EPA which will be requesting approval to create a zone for aquaculture of marine finfish at the Abrolhos Islands to the west of Geraldton.

Abstract

The Department of Fisheries (Department) carried out a sampling campaign in the Abrolhos Islands (West of Geraldton) from June 2014 to March 2015. Over four hundred seawater samples, four batches (Winter, Spring, Summer and Autumn) and over seventy sediment samples, two batches (Spring and Autumn) were received by ChemCentre from the Department. Each sample was analysed for a range of compounds. These compounds were chosen so as to provide baseline data for a planned Environmental Impact Assessment (EIA) that the Department would be forwarding to the Environmental Protection Authority (EPA). The ultimate planned benefit of this EIA is the establishment of an area in the Mid-West of Western Australian waters, suitable for large-scale commercial marine finfish aquaculture.

The current internationally accepted detection limits for the analysis of polycyclic aromatic hydrocarbons (PAHs) from water (1 µg/L) and sediment (1 mg/kg) samples, as described by the EPA in the Uniited States, were not sufficiently low and were unlikely to detect any of this group of compounds from this environment. Analytical methods for the ultra trace level determination of PAHs in seawater (0.001 µg/L) and sediment (0.001 mg/kg) were developed using a complex extraction protocol, followed by a large scale injection into a capillary gas chromatography–mass spectrometry (GC/MS) system. Naphthalene and to a lesser extent phenanthrene were the most frequently detected compounds at levels very close to the practical quantitation level in the samples collected from the proposed and reference sites. Though these results may not be as beneficial for modelling as was originally anticipated, the baseline levels established for the PAHs should contribute to the adoption of trigger values for the management of industries operating within the proposed aquaculture zone.

Of the other analytes determined by ChemCentre, Total Organic Carbon (TOC) was detected in approximately half of the seawater samples, whilst total nitrogen was routinely detected in each of the samples. In the sediment samples, several metals were routinely detected as were nitrogen, phosphorus, nitrogen as ammonium and TOC. To aid in the evaluation of the data, the elements that were detected in both matrices were normalised against TOC. As a rule the abundance of the elements in the sediment was slightly higher in Winter than in summer (relative to TOC), with the exception of total nitrogen, which more closely aligned with the trend identified in the sea water samples, where the total nitrogen was higher in summer than Winter (relative to TOC). As for the PAHs, this baseline data, will inform the EIA,

and in particular, is required for determining trigger values for the management of industries operating within the proposed aquaculture zone.

OUTCOMES ACHIEVED

By gathering baseline data it will now be possible for the Department to develop a comprehensive ecosystem model. The ultimate planned benefit of this model to the aquaculture industry is the establishment of an area in the Mid-West of Western Australian waters, selected according to its suitability for large-scale commercial marine finfish aquaculture; with consideration of its environmental, economic and social attributes; and established with an effective management framework, including an efficient approval process, for aquaculture operators within that area. The model will support an EIA which will be central in demonstrating to the EPA that the potential impacts of aquaculture on the marine environment at this Mid-West location can be managed within acceptable limits, thereby justifying approval of the Strategic proposal.

LIST OF OUTPUTS PRODUCED

New methods for the analysis of PAHs at 0.001 µg/L in sea water and 0.001 mg/kg in sediment were developed. These new levels are more than 100 times lower than detectable using previous methods. Data showed that of the PAHs monitored, only naphthalene and to a lesser extent phenanthrene were present in the samples at the lower detection limit. Aquaculture is not usually associated with elevated PAH concentrations; however, due to the aquaculture industry intended use of vessels in the marine water of the Mid-West of WA, it is conceivable that aquaculture could be a minor source of PAH, thereby contributing to contamination of waters and sediment. This data is required for determining trigger values for the management of industries operating within the proposed aquaculture zone.

ACKNOWLEDGEMENTS

John Eyres and David Abdo; Dept of Fisheries Western Australia.

Document Control

Version	File Name	Date	Description	Author
1	001292V02.nigel.west	03/02/2015	Draft adapted from Dept of Fisheries Sampling and Analysis Plan	NW / JE
2	001292V04.nigel.west	April 2014	Revised after input from Graham Mair (SEAFOOD CRC) and John Eyres (Department). Addition of coloured maps (Department)	NW

1. Introduction and Background

1.1. Need

The Department of Fisheries, Western Australia (Department), on behalf of the Minister for Fisheries proposes to create an 'Aquaculture Development Zone' to provide a management precinct for prospective aquaculture proposals within the State Waters, of the Houtman Abrolhos Islands (HAI) Fish Habitat Protection Area (FHPA), approximately 75 kilometres west of Geraldton. The Mid-West Aquaculture Development Zone (MWADZ) has been selected by the Department to maximise suitability for marine finfish aquaculture, and minimise potential impacts on existing marine communities and human use.

The MWADZ is proposed to encompass an area of 3000 hectares (ha) across two development locations. The study sites (Figure 1) encompass an area of 4740 hectares which includes the two locations of the MWADZ area:

- a 3000 ha area located in Zeewijk Channel, between the Pelsaert and Easter Groups; and
- a 1740 ha study area located immediately north of Murray Island in the Pelsaert Group

The Environmental Scoping Document (ESD) associated with the proposed MWADZ, requires the Department to undertake an environmental impact assessment (EIA) as part of a Public Environmental Review (PER) of the Strategic proposal, in accordance with the Western Australian *Environmental Protection Act 1986* (EP Act). The objectives of the strategic proposal are fourfold:

a) Identify all potential significant environmental impacts and develop management framework, prior to start-up operations;

b) provide for greater level of certainty to local communities and proponents in relation to future aquaculture developments;

c) improve capacity to manage potential cumulative effects of multiple aquaculture operations; and

d) provide flexible timeframes for consideration of potential environmental impacts.

To fulfil the requirements of the ESD and the preparation of the PER, the Department engaged an external consultant to undertake modelling and technical studies to inform the EIA associated with operations within the proposed MWADZ. This involves investigating the influence of various factors such as nutrient and contaminant input, establishment of infrastructure, industry practices, and the hydrodynamics of the surrounding marine environment. The Department collected baseline samples to support the EIA studies being undertaken and provided these samples to ChemCentre and other analytical facilities. This data will provide the information required for the modelling and technical studies.

Of particular interest to this study are the polycyclic aromatic hydrocarbons (PAHs), these can be derived from oil spills; they are also formed when there is a lack of available oxygen during a combustion process e.g. the burning of fossil fuels in engines. Some of these compounds are known carcinogens, they can have severe impacts on aquaculture and put pressure on marine habitats and will bio-accumulate in molluscs, mussels, fish and other mammals and thus can present a health hazard to human

consumers.[1],[2]. It is possible to use ratios to identify sources of PAHs (anthropogenic or biological) and as such PAHs can be used as a marker of to identify the source of any potential contamination. The analysis of these compounds at levels that they are likely to be present at in this environment is critical for accurate baseline description of this proposed aquaculture zone and for future environmental management.

1.2. Site selection

The study area comprises two areas

The Zone proposal envisages 3,000 hectares of WA waters within the Abrolhos Islands Fish Habitat Protection Area (Figure 1.) The Zone is divided into two separate areas of water within the HAI FHPA in the Mid-West region of Western Australia:

1. The Southern Site is an 800 hectare area to the north of Sandy Island in the Pelsaert Group. The Southern Site comprises an existing aquaculture licenced site and has an average depth of 35 metres.

2. The Northern Site is a 2,200 hectare site east of Wooded Island in the Easter Group and north of Gee Bank reef. The Northern Site is approximately three times larger than the Southern Site and has an average depth of 40 metres.

It should be noted that some of the Strategic proposal is located within grounds utilised by commercial fishing industries.

Figure 1: MWADZ Study Area, actual location is inside the Red Square.

[1] Bernem et. al., 2008.
[2] Retnama et. al. 2013.

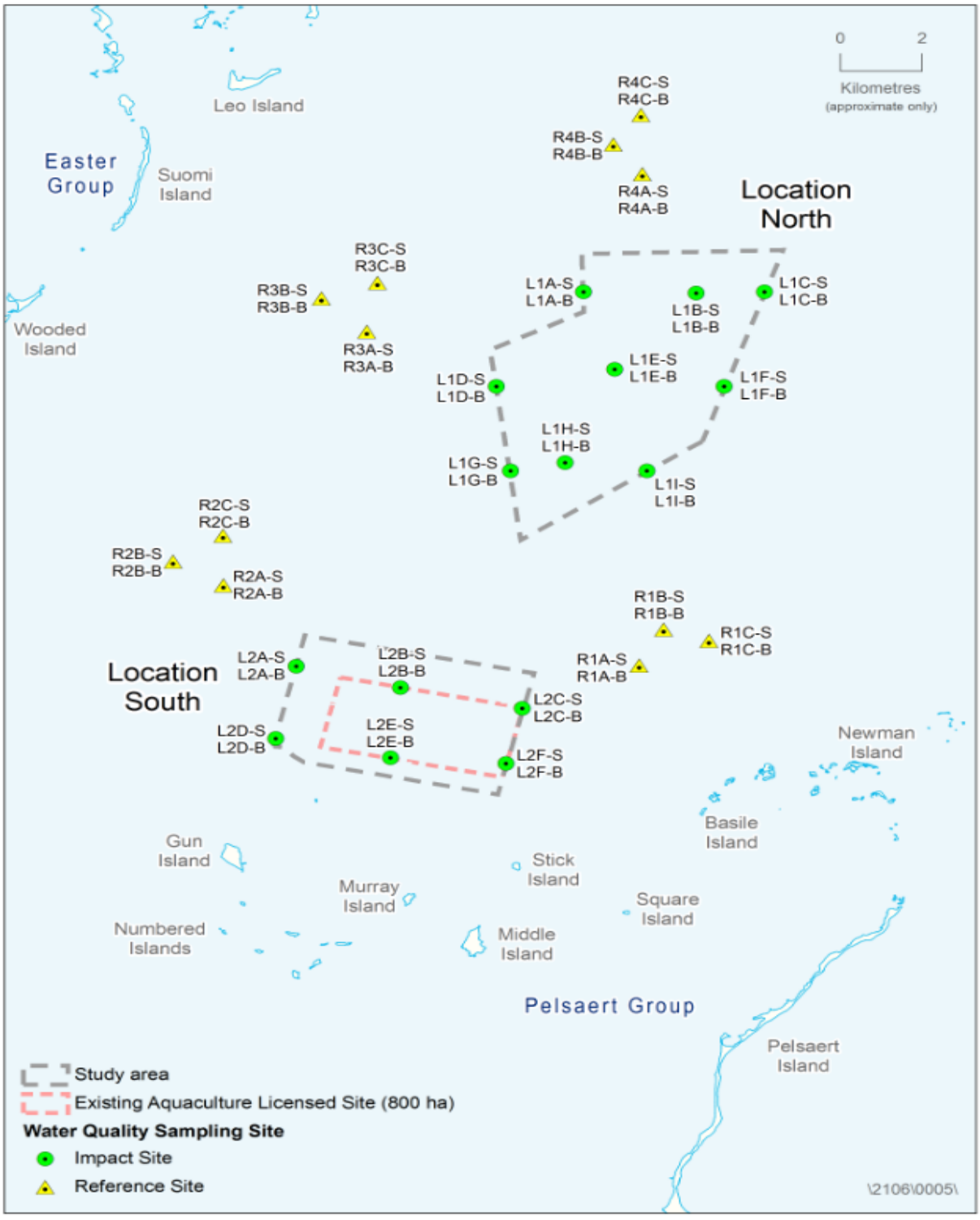


Figure 2: Sampling sites and identifiers for collection of sea water quality baseline data to support the MWADZ EIA.

Baseline sea water quality data were collected between May 2014 and March 2015 from a total of twenty seven (27) sites, comprising of nine (9) sites within the Northern Location and six (6) sites within the Southern Location. An additional twelve (12) reference sites, grouped in 4 areas of three sites, were also sampled, a more detailed view of the sampling sites is given in **Error! Reference source not found.**. All sites were located within a similar depth contour (approximately 30-40m).

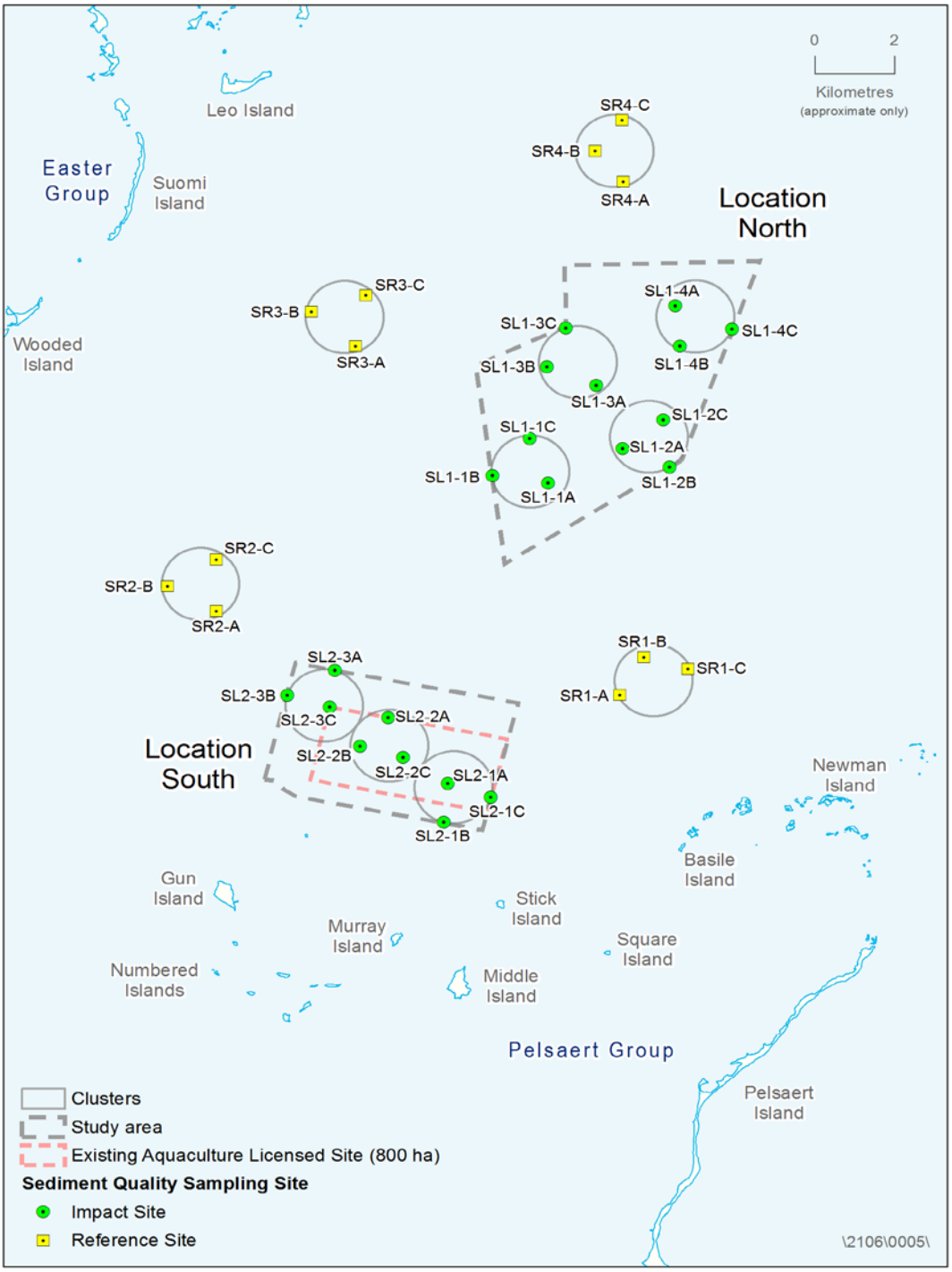
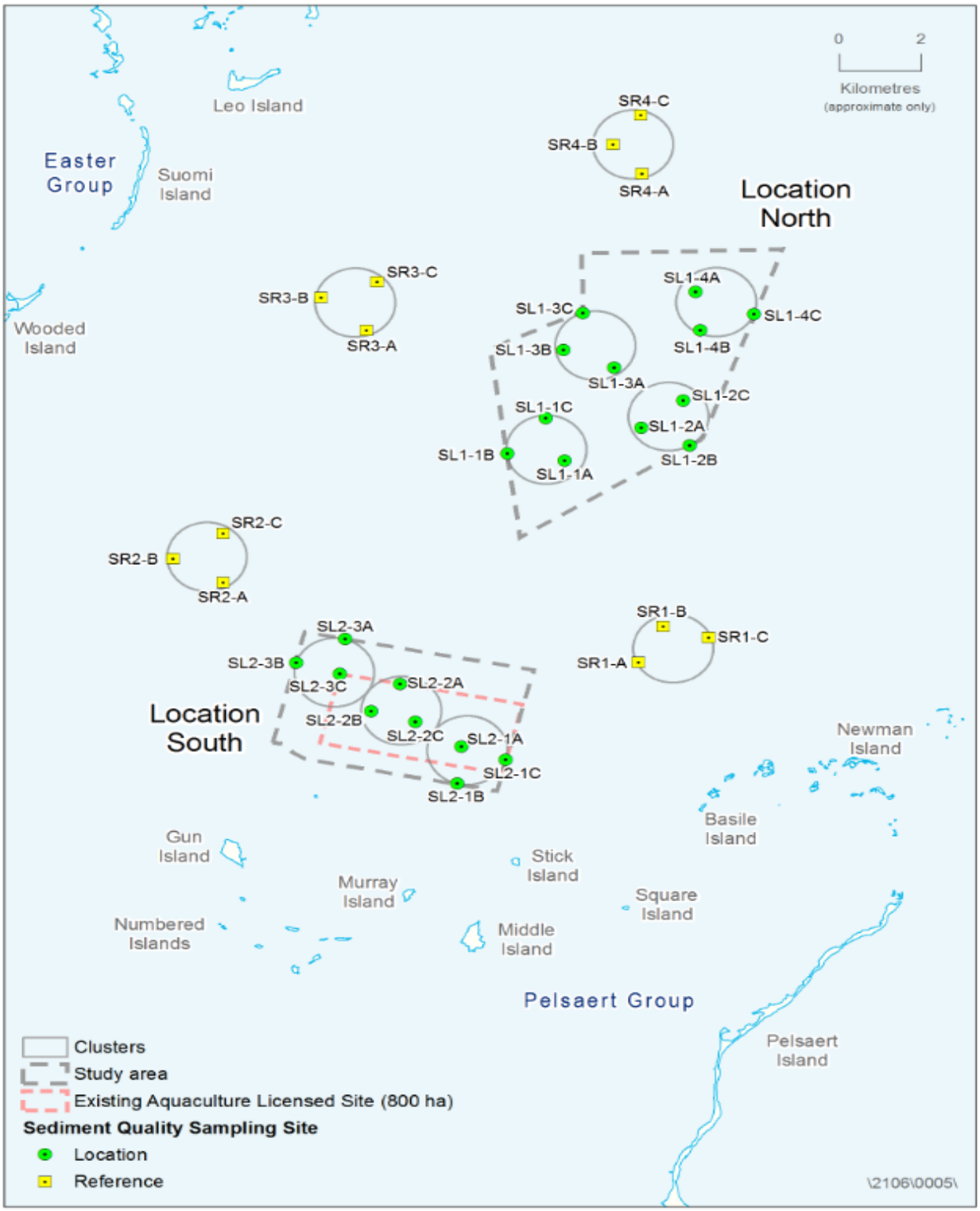


Figure 3: Sampling sites and identifiers for collection of Sediment quality baseline data to support the MWADZ EIA.

Sediment quality baseline data were collected in August 2014 and February 2015 from a total of thirty three (33) sites, twelve (12) in Location 1 and nine (9) in Location 2. Twelve (12) reference sites, grouped in four (4) areas of three (3) sites, (as with the water quality sampling) were also sampled for sediment quality. The location and site codes are shown in Figure 3.



1.3. Objectives

ChemCentre needed to improve the detection limits of the polycyclic aromatic hydrocarbon (PAH) component of the testing and ensure that other testing on the sediment and seawater samples was carried out to achieve as low a detection limit as was practicable. Four sets of seawater samples (nominally Autumn, Winter, Spring and Summer) and two sets of sediment samples (nominally Winter (August 2014) and Summer (February 2015)) were provided by the Department for a range of analyses. The EIA developed from the baseline data collected as part of this project will be central in demonstrating to the EPA that the risk of impact to the marine environment of this Mid-West location is acceptable, thereby accelerating the approvals process.

2. Methods

2.1. Water Quality

At each water quality monitoring site, water samples were collected and delivered to ChemCentre for the determination of:

- Total Suspend Solids (TSS), including Loss on Ignition[2]
- Total Phosphorus (TP) + Total Nitrogen (TN)[2]
- Total Organic Carbon (TOC) + Dissolved Organic Carbon (DOC)[1]
- Hydrogen Sulphide (H_2S)[2] – subset of sites and bottom sample only from summer and Winter only
- Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace Level)[2]
- Total Petroleum Hydrocarbons (TPH)[2]

In addition to these water quality monitoring site samples, other water samples were analysed at other facilities for the determination of:

- Ammonium (NH_4)[3]
- Orthophosphate (FRP)[2]
- Nitrate (NO_3) + Nitrite (NO_2), as NOx[1]
- Chlorophyll-a (Chla)[4]
- Phytoplankton community[5]

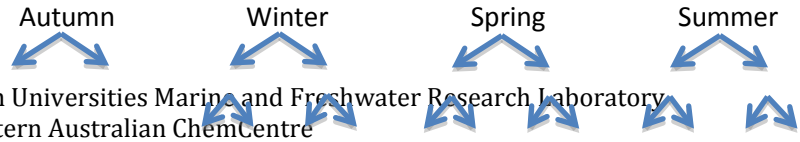
In situ simultaneous measurements water quality parameters were collected at each water quality monitoring site. The parameters monitored were:

- Temperature (°C)
- pH/ORP (pH units, mV)
- Conductivity/Salinity (mS/cm, ppt)
- Dissolved Oxygen (DO) (mg/L) – measured with Luminescent DO sensor
- Turbidity (NTU)
- Depth (m)
- Photosynthetically Active Radiation (PAR) – measured with dual PAR sensor

Water samples were collected using a 4.2L Van Dorn sampler deployed at each of the 27 water quality sampling sites (**Error! Reference source not found.**), at two time points within each season. Water samples were collected from the surface (0-1m) and bottom (approx. 1m from seafloor) of the water column using Department procedure MEMS WQ SOP.

Once retrieved, the water samples were divided into the various aliquots required for each water quality analysis (see **Error! Reference source not found.**). Once each required sub-sample was obtained, the respective sample bottle was placed into an esky with ice or ice bricks. At the HAI Department research station, samples were appropriately stored or post-processed as outlined in **Error! Reference source not found.**, to await transportation to the appropriate laboratory for analysis with its associated Chain of Custody form (CC).

Table 1 MWADZ temporal sampling design. Note S= Surface, and B = Bottom of the water column.



[3] Analysis to be performed by Murdoch Universities Marine and Freshwater Research Laboratory
[4] Analysis to be performed by the Western Australian ChemCentre
[5] Analysis to be performed by Sydney Water

	May		Jun		Aug		Sep		Nov		Dec		Feb		Mar	
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
In situ PAR dataloggers		In		Out		In		Out		In		Out		In		Out
Water quality sampling																
- Physical Water Quality profiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- NH_4/NO_x/FRP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- TN/TP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- TOC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- TSS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- Chla	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- PAH/TPH	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- H_2S						✓								✓		
- Phytoplankton		✓				✓				✓				✓		
Sediment quality sampling																
- TN/TP						✓								✓		
- TOC/DOC						✓								✓		
- Trace Metals						✓								✓		
- PAH/TPH						✓								✓		
- pH/ORP						✓								✓		
- PSD						✓								✓		
- Infauna						✓								✓		
Single-beam hydroacoustic mapping		✓														
Drop video habitat sampling				✓				✓				✓				✓
Acoustic Doppler Current Profiling		In		Out		In		Out		In		Out		In		Out

Table 2: Sample requirements for water quality analyses during baseline studies of the MWADZ.

Total Suspended Solids (TSS) (inc Loss on ignition)	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	Using a pre-weighed GFC filter paper, filter the 1L sample using a Nalgene Vacuum Filter Flask. Rinse filter with deionized water after filtering sample.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	1 mg/L
Hydrogen Sulphide (H_2S)	Sample volume	250mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Completely fill sample bottle to exclude air. Preserve with Zinc acetate.
	Maximum sample holding time and storage conditions	1 week, chilled sample
	Required Reporting limit	1 mg/L
Total Organic Carbon (TOC)	Sample volume	40mL
	Sample bottle	glass bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample

	Required Reporting limit	1 mg/L
Total Nitrogen (TN) Total Phosphorus (TP)	Sample volume	125mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	0.005 mg/L (TP), 0.01 mg/L (TN)
Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace) Total Petroleum Hydrocarbons (TPH)	Sample volume	1L
	Sample bottle	Amber glass bottle
	Preservation technique	None
	Maximum sample holding time and storage conditions	14 days, chill sample and keep in dark
	Required Reporting limit	0.001 µg/L (1 ng/L)
Chlorophyll-a	Sample volume	1L
	Sample bottle	Polyethylene bottle
	Preservation technique	Filter the 1L sample using a Nalgene Vacuum Filter Flask.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	0.001 mg/L
Ammonium (NH_4) Nitrate + Nitrite (NO_X) Orthophosphate (FRP)	Sample volume	2 x 10mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Filter sample through 0.45µm filter. Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	3 µg/L (NH_4), 2 µg/L (NO_2 + NO_3), 2 µg/L (FRP)
Phytoplankton Community Composition	Sample volume	200mL
	Sample bottle	Polyethylene bottle
	Preservation technique	Add Lugols solution to final concentration of 1% (2.5mL of Lugols stock solution)
	Maximum sample holding time and storage conditions	1 month, chilled sample and kept in dark

2.2. Sediment Quality

At each monitoring site, sediment samples were collected and delivered to ChemCentre for the determination of:

- Total Phosphorus (TP)
- Total Nitrogen (TN)
- Total Organic Carbon (TOC)
- Trace Metal: Silver (Ag), Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Antinomy (Sb), Selenium (Se), Zinc (Zn), Iron (Fe), Manganese (Mn), Lithium (Li), and Mercury (Hg)
- Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace Level)
- Total Petroleum Hydrocarbons

Other data was either collected on site or samples were submitted to other laboratories for testing, these included:

- pH/Redox Potential (ORP)[6]
- Particle Size Distribution[7], including wet/dry weight ratio
- Infauna community composition[8]

Sediment was taken from the sandy covering above the rocky platform; using a Petite Ponar sediment grab (used a number of times at each site to get a sample of adequate volume).

Three (3) replicate samples were collected at each sample site. Each of the three (3) replicate samples at a site were combined and homogenised (within inert bowl), with sediment aliquots being collected from the homogenised sample for each of the required analyses listed in **Error! Reference source not found.** (as per the sea water samples) these were stored initially on ice during sampling, but they were frozen prior to transportation to the appropriate laboratory for analysis with its associated Chain of Custody form.

Table 3: Sample requirements for sediment quality analyses during baseline studies of the MWADZ.

Total Organic Carbon (TOC)	Sample volume	125g
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	0.05%
Total Nitrogen (TN) Total Phosphorus (TP)	Sample volume	125g
	Sample bottle	Polyethylene bottle
	Preservation technique	Fill sample bottle ¾ full.
	Maximum sample holding time and storage conditions	1 month, frozen sample
	Required Reporting limit	10 mg/kg (TP), 0.005% (TN)
Trace Metals (Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Se, Zn, Hg, Fe, Li, Mn)	Sample volume	250g (250g for Hg)
	Sample bottle	Acid washed Polyethylene bottle Hg – plastic jar with Teflon lid
	Preservation technique	
	Maximum sample holding time and storage conditions	1 month, chilled sample 6 months, frozen sample
	Required Reporting limit	0.001 (Ag, As, Cd, Co, Cu, Pb, Se, Sb); 0.005 (Cr); 0.01 (Ni, Zn); and 0.0001 (Hg) mg/L
Polycyclic Aromatic Hydrocarbons (PAH) (Ultra Trace) Total Petroleum Hydrocarbons (TPH)	Sample volume	100 g
	Sample bottle	Glass jar
	Preservation technique	None
	Maximum sample holding time and storage conditions	14 days, chill sample and keep in dark
	Required Reporting limit	0.001 mg/kg (1 µg/kg)
Particle Size Distribution	Sample volume	200 g
	Sample bottle	Ziplock bag (triple bagged)
	Preservation technique	None
	Maximum sample holding time and storage conditions	Chill sample and keep in dark
	Required Reporting limit	0.02µm and greater (binned by size classes)

[6] Data gathered at time of sediment collection
[7] Analysed by Murdoch Universities Marine and Freshwater Research Laboratory
[8] Analysed by Aquenal Laboratories

Infauna Community Composition	Sample volume	200mL
	Sample bottle	Plastic Jar
	Preservation technique	Sieved to 1mm
	Maximum sample holding time and storage conditions	Preserved with 10% Formalin
	Required Reporting limit	Lowest recognisable taxonomic unit and associated abundance

2.3. PAH Analysis Methods

The method used to extract the PAHs is dependent on the matrix (sediment or seawater). A copy of the two methods is given below.

Waters

(a) Aqueous samples are collected in 1 L amber glass bottles with Teflon-lined screw caps. Mark the level of the sample on the bottle and measure the volume after the sample has been removed to obtain the volume of the sample.

(b) Transfer the aqueous contents (1000 mL) to a clean separating funnel. (Note: Sample volumes can be adjusted according to circumstances.)

(c) Add 20 mL of DCM to the sample bottle and swirl to rinse the inner walls of the container. Add this solvent to the separating

(d) Funnel, seal and invert carefully. Release the pressure immediately, with the stopcock pointing away from other staff. Make sure that all work is performed in a fumehood.

(e) Shake the separating funnel vigorously for two minutes, periodically releasing the pressure.

(f) Place a Whatman 540 filter paper containing sodium sulphate into a filter funnel. Filter the extract through the filter paper and collect in a schott bottle.

(g) Repeat steps **Error! Reference source not found.** to **Error! Reference source not found.** two more times collecting the extract in the same schott bottle.

(h) Quantitatively transfer the extract to a 16 × 150 mm glass test tube

Sediments

a) Weigh 15 g of sample in a Schott bottle. Record the weight to the nearest 0.01g.

b) Add 30 mL of DCM/methanol to the mixture, cap the vial, and sonicate for 20 minutes.

c) Filter the extract through a filter funnel into a 200 mL separating funnel.

d) Repeat steps **Error! Reference source not found.** and **Error! Reference source not found.** twice more, and collect all three extracts in the same separating funnel.

e) Add around 80 mL of water to the extract and gently shake to move methanol from extract to water phase.

f) Drain DCM layer through a filter funnel packed with a little sodium sulfate into a schott bottle.

g) Quantitatively transfer the extract to a test tube, and blowdown to 1.0 mL.

h) Transfer the extract to a pre-conditioned clean-up column.

i) Elute the clean-up column with 3 mL of a pentane/DCM mixture.

Analysis

a) Concentrate the extract under a gentle stream of nitrogen.

b) Transfer the extract to a GC vial, making sure to rinse the test tube with at least one portion of DCM. Make up to the final volume with DCM.

c) To the GC vial add 10 µL of PAH internal standard.

d) Run the final extracts by GC-MS, this method requires a large volume syringe in the injector tower, a PTV inlet with cryogenic cooling in solvent-vent mode, a DB-5MS column or equivalent, and SIM detection capability.

3. Results

Seawater and sediment samples were collected over four and two sampling campaigns respectively. These were submitted to the laboratory within a week of collection. This is summarised in **Error! Reference source not found.** below.

Table 4: MWADZ Sample Submission Details.

Initial Sampling Date	Lab Submission Date	Laboratory Number	Number of Samples	Sample Type
20 May 2014	26 May 2014	13B0821	59	Seawater
19 June 2014	23 June 2014	13B0895	59	Seawater
18 August 2014	25 August 2014	14B0125	59	Seawater
18 August 2014	25 August 2014	14B0125	35	Sediments
18 September 2014	22 September 2014	14B0184	59	Seawater
10 November 2014	13 November 2014	14B0321	59	Seawater
9 December 2014	15 December 2014	14B0378	59	Seawater
14 February 2015	20 February 2015	14B0498	59	Seawater
14 February 2015	20 February 2015	14B0498	35	Sediments
10 March 2015	16 March 2015	14B0564	59	Seawater

Data for each of the analyses is supplied in the Excel File 2012_738 MWADZ Seawater and Sediment Data. Not all of the analyses were carried out for each sample set. Some samples were not collected e.g. the total and volatile suspended solid samples were not collected during the first sampling campaign. ChemCentre was unable to achieve the desired detection limits for Chlorophyll a, after the first two sets of analyses, subsequent samples were sent to an alternative laboratory. Other miscellaneous samples were not received or were not suitable for analysis. One half of one set of seawater PAH data (collected on 10 March 2015) did not pass its QA/QC and was not reported. For this batch of samples the back ground level of all of the naphthalene data was high, 0.002-0.006 ng/L, rather than the expected < 0.001 ng/L. We believe that the sealed extracts were contaminated whilst awaiting GC/MS analysis by diffusion of an oil sample that was being stored in a nearby location.

In the majority of instances the results for the sea water samples were either below the detection limits (DL) of the methods used or were within a factor of 5 of the DL. The exception was nitrogen which was typically in the range 0.04-0.17 mg/L (DL of 0.01 mg/L). Even with the improved detection limits for the analysis of the PAHs, only naphthalene was routinely detected, between 0.001 and 0.004 ng/L, though figures greater than 0.1 ng/L were reported at three sites, one of these being a reference site (R2A_S). It is unclear why these results were considerably higher than the samples collected at other times from the same sites. The data for the other analytes from the duplicate samples taken at the same time were

within the bounds considered acceptable for these samples, i.e. within a factor of 5 of the detection limits.

The sediment samples had almost no detectable levels of TRH, nitrate, nitrite, or PAH; even at the lower detection limits. Unsurprisingly there were moderate amounts of aluminium, barium, chromium, cobalt, iron, lead, lithium and manganese detected in both sets of sediment samples. Total organic carbon, nitrogen and phosphorus were present in each sediment sample analysed.

4. Discussion

4.1. Seawater Samples

Samples were submitted to the laboratory between May 2014 and March 2015. Some analytes were not able to be determined due to insufficient sample, incompatibility issues with the analytical process, or QA/QC failures. All the seawater data is in the excel file labelled MWADZ_Seawater.

Half of the nitrogen (N) results were less than 0.1 mg/L, (DL = 0.01 mg/L) and 96% of the results were less than 0.2 mg/L. Half of the total organic carbon (TOC) results were less than the detection limit (1 mg/L), and almost every result was < 2 mg/L. Over 60% of the phosphorus (P) data was less than the detection limit (0.05 mg/L), with over 98% of the remainder of the data less than 0.2 mg/L.

To normalise the N data, the results from this test were divided by the results from the TOC test and multiplied by 100. This normalisation will allow the data to be compared across the sampling time more easily. Where the TOC was less than detection limit (1 mg/L), the detection limit was applied. Selected sites are summarised in **Error! Reference source not found.** below.

Table 5: Summary of Select Samples for Ratio of total Nitrogen to Total Organic Carbon (TOC)

Site	Lowest Nitrogen to TOC Ratio (Sampling Campaign)	Highest Nitrogen to TOC Ratio (Sampling Campaign)
L1DS	4.6 (August 2014)	15 (November 2014)
L1GB	5.8 (September 2014)	13 (June 2014)
L1HS	6.0 (May 2014)	15 (June 2014)
L2BB	4.3 (August 2014)	17 (November 2014)
L2FB	5.3 (August 2014)	12 (November 2014)
L2CS	7.1 (September 2014)	18 (June 2014)
L2DS	3.8 (September 2014)	21 (March 2015)
R2AB	4.3 (September 2014)	16 (June 2014)
R2BS	6.2 (August 2014)	14 (June 2014)
R3BB	4.3 (September 2014)	16 (December 2014)
R4BS	5.4 (September 2014)	19 (March 2015)
R4CB	5.7 (September 2014)	18 (June 2014)

It is apparent from these ratios that there was generally 3-5 times more nitrogen in the water column (relative to TOC) from the samples collected in March and June than from those collected in August and September.

The maximum, minimum and average total nitrogen abundance (relative to TOC) is given in **Error! Reference source not found.**, note the two highest readings (generally, considerably higher than the other data) from each campaign have been removed to improve statistical analyses. This data supports

the findings above, where the average abundance is generally higher in the campaigns carried out in November (14B0321), December (14B0378) and February (14B0498 and 14B0564) than in the other campaigns, though the June 2014 data appears significantly higher than the other cooler months.

Table 6: Maximum, Minimum and Average Ratios of Nitrogen relative to TOC for Sea Water samples, (note this is unit less measure)

Season	May 2014	Jun 2014	Aug 2014	Sept 2014	Nov 2014	Dec 2014	Feb 2015	Feb 2015
Job No	13B0821	13B0895	14B0125	14B0184	14B0321	14B0378	14B0498	14B0564
Maximum	11.0	22.7	16.0	10.0	18.0	12.0	16.4	24.0
Minimum	5.0	2.0	2.6	2.9	8.2	2.0	1.0	1.0
Average	7.7	12.5	7.3	6.3	13.3	7.8	9.3	12.1

Sixteen sets of PAH samples were analysed, one set of PAH data (half of the final set of samples collected on 10 March 2015) could not be reported as this batch failed its QA/QC. We believe this occurred during storage of the extracts while they were waiting to be analysed. The back ground level of all of the naphthalene data from this set of samples was high, 0.002-0.006 ng/L, rather than the expected < 0.001 ng/L. Though the point of contamination has not been confirmed, we believe it occurred when oil stored in the same room as the sealed containers diffused into the extracts. The very low analytical levels reached have made previously routine laboratory practises now a potential source of contamination. We were unable to repeat this analysis as the entire sample was extracted during the laboratory work, this is part of our standard protocol when trying to achieve these ultra low detection limits.

As was expected the majority of the organic (total recoverable hydrocarbons (TRH) and polycyclic aromatic hydrocarbons (PAHs)) data were either at or below the practical quantitation limits (PQL). All of the TRH fractions were below the PQL for each seawater sample tested. This is not unexpected as the sources of TRH are limited and the ocean currents in the Zeewijk Channel (averaging around 0.2 m/s^{-1}, with some variability through the water-column)[9] would ensure that any anthropogenic TRHs are removed relatively quickly. With the significantly more sensitive polycyclic aromatic hydrocarbons (PAHs) testing regime, a small number of compounds were detected in both the sample and reference sites. Naphthalene was generally found at levels between 0.001 and 0.005 µg/L. Though there were a few results greater than 0.01 µg/L, these were spread evenly between the sample and reference sites, interestingly all of the sites with the higher readings were sampled in duplicate and the duplicate returned readings less than 0.005 µg/L. This inconsistency may be a function of either the sampling; or of the immature analytical testing regime and will need investigation. Interestingly this effect did not occur with samples collected during February and March of 2015. The effected naphthalene data is given in **Error! Reference source not found.**. Those cells with the same colour are samples supplied in duplicate. Only duplicates that varied by more than 0.008 µg/L are reported here.

For these samples it is apparent that one of the duplicate results was much greater than the norm and that there was a significant variation between each of the duplicates analysed. The variation is distributed between the two samples and reference sites and over each of the sampling campaigns, apart from the final February and March 2015 programs. Some of the samples (L2F_S and R2A_S) were analysed in duplicate during other campaigns and the results for each duplicate were found to be < 0.01 µg/L. Approximately ten other samples (L1H_S, L1I_S, L2C_S (x 3), R1C_S (x 2), R3A_S, R3B_S) were collected in duplicate and there was no noticeable disparity in their results. If there was a consistent problem with the sampling or the analysis, it would be reasonable to expect that all the results would be

[9] Maslin, 2005.

variable, however this is not the case. It is possible that there is variation within the samples that is causing the variation, though this would not explain some very significant variations e.g. L1E_S where 0.31 and <0.001 µg/L were reported in duplicate analyses. This disparity was not noticed in the February and March 2015 duplicate sample data.

Table 7: Comparative non-repeatable Naphthalene duplicate testing data.

ChemCentre ID	Client ID	Sampled	Naphthalene µg/L
13B0821/006	L1C_S	20/05/2014	0.047
13B0821/007	L1C_S	20/05/2014	0.002
13B0821/024	L2B_S	20/05/2014	0.042
13B0821/025	L2B_S	20/05/2014	0.002
13B0895/002	L1A_S	20/06/2014	0.034
13B0895/003	L1A_S	20/06/2014	0.003
14B0125/056	R4B_S	18/08/2014	0.002
14B0125/057	R4B_S	18/08/2014	0.025
14B0125/011	L1E_S	18/08/2014	0.31
14B0125/012	L1E_S	18/08/2014	<0.001
14B0378/042	R2A_S	9/12/2014	0.002
14B0378/043	R2A_S	9/12/2014	0.88
14B0378/032	L2F_S	10/12/2014	0.76
14B0378/033	L2F_S	10/12/2014	0.003

For these samples it is apparent that one of the duplicate results was much greater than the norm and that there was a significant variation between each of the duplicates analysed. The variation is distributed between the two samples and reference sites and over each of the sampling campaigns, apart from the final February and March 2015 programs. Some of the samples (L2F_S and R2A_S) were analysed in duplicate during other campaigns and the results for each duplicate were found to be < 0.01 µg/L. Approximately ten other samples (L1H_S, L1I_S, L2C_S (x 3), R1C_S (x 2), R3A_S, R3B_S) were collected in duplicate and there was no noticeable disparity in their results. If there was a consistent problem with the sampling or the analysis, it would be reasonable to expect that all the results would be variable, however this is not the case. It is possible that there is variation within the samples that is causing the variation, though this would not explain some very significant variations e.g. L1E_S where 0.31 and <0.001 µg/L were reported in duplicate analyses. This disparity was not noticed in the February and March 2015 duplicate sample data.

There are two possible sources of error, the laboratory work and sampling. To ensure comparative data was available at the end of the project, neither the laboratory or sampling processes were varied during the course of this program. Examining the duplicate samples will be the starting point to determine why these discrepancies may be occurring. The first step will be to identify if the laboratory process needs refining and the second step will be to eliminate any impact that the sample may have on the results. Only a sub sample of the sediments is analysed and repeat replicate work can be carried out on this matrix as required. The entire water sample (1L) is consumed during analysis, the challenge with this

matrix will be to split and analyse subsequent / spare samples without impacting the detection limit. The focus will be on:

- Analysing duplicate samples in replicate, this will assist in the identification of possible sources of error within the analytical regime. This may involve spiking the extracted sample with naphthalene and determining recoveries.
- Greater homogenisation of the sediment and to a lesser extent seawater samples prior to initial extraction.

Once this data is available it is anticipated that the source of the error/s will be identified and new processes adopted to mitigate this analytical uncertainty.

Phenanthrene was found in approximately one third of the samples at levels between 0.001 and 0.005 µg/L, the remainder were < 0.001 µg/L. In a small number of samples, 0.001 µg/L of some PAHs (fluorene, fluoranthene, anthracene, pyrene etc) were also detected.

4.2. Sediment Samples

Sediment samples were collected in August 2014 (Winter) and February 2015 (summer), these were submitted to the laboratory immediately after collection. Some analytes were not able to be determined due to insufficient sample or there was some incompatibility with the analytical process. All the data is in the Excel file labelled MWADZ_Sediment. No TRH was detected and no significant levels of PAH were detected in any sample. Traces levels of naphthalene were detected in some Winter samples, two samples SL4-A and SL2-2-C contained trace levels of some PAHs other than naphthalene. Though the levels were very close to the detection limits and should not be considered significant.

All of the results, which were above the background level, were normalised against total organic carbon (TOC). TOC was chosen because there was a positive result for every sample collected and its presence in the samples was reasonably consistent across each sampling campaign. A summary of the maximum, minimum and average results for the summer and Winter campaigns are presented in **Error! Reference source not found.**, note some ratios e.g. Cadmium have been multiplied by 1000, to make them more easily evaluated.

Table 8: Ratio of each analyte with a positive result to Total Organic Carbon (TOC), note this is a unit less parameter.

Descriptor	Aluminium / TOC	Ammonium as N / TOC	Barium / TOC	Cadmium / TOC
Season	Winter / Summer	Winter / Summer	Winter / Summer	Winter / Summer
Maximum	452 / 459	8.8 / 3.5	53 / 37	696 / 455
Minimum	72 / 91	2.6 / 1.3	11 / 12	224 / 128
Average	265 / 270	4.5 / 2.8	31 / 26	375 / 208

Descriptor	Chromium / TOC	Cobalt / TOC	Iron / TOC	Lithium / TOC
Season	Winter / Summer	Winter / Summer	Winter / Summer	Winter / Summer
Maximum	71 / 62	10 / 10*	484 / 541	5.2 / 4.5
Minimum	4.5 / 5.1	1.3 / 1.1	97 / 58	2.2 / 1.1
Average	31 / 27	3.1 / 3.2*	252 / 215	3.5 / 3.3

* One extraneous ratio of 48 from SR1A was excluded from this calculation

Descriptor	Manganese / TOC	Nitrogen / TOC	Phosphorus / TOC	Vanadium / TOC
Season	Winter / Summer	Winter / Summer	Winter / Summer	Winter / Summer
Maximum	39 / 38	124 / 291	1957 / 1400	3.9 / 3.2
Minimum	5.3 / 3.1	83 / 89	580 / 325	0.9 / 0.5
Average	14 / 12	95 / 137	1079 / 964	2.0 / 1.8

For each of the metals (Al, Ba, Cd, Cr, Co, Fe, Li and Mn) reported in **Error! Reference source not found.**, the calculated ratios are consistent across the Winter and summer sampling campaigns, generally the Winter ratios are slightly higher than the summer ratios, the only variation being Cadmium where the Winter values are generally 50 % greater than the summer values.

For the more abundant elements nitrogen, phosphorus and nitrogen as ammonium there are significant differences between the winter and summer ratios e.g. the maximum summer Ammonium as N ratio (3.5) is less than half of its equivalent winter value (8.8) and is less than the average winter value (4.5) (relative to TOC). The Nitrogen / TOC relationship is unusual in that it is the only combination where the summer ratios are all higher than the winter ratios. The ammonium ratios did not track the nitrogen levels. This is interesting because nitrogen is a key ingredient in ammonium. This result does track the availability of nitrogen in the water column (see **Error! Reference source not found.** and **Error! Reference source not found.**), i.e. more nitrogen is in the water column between November and June than August to September (relative to TOC). It is possible that the relatively higher level of nitrogen in the water column in these months is impacting the levels of total nitrogen in the sediment.

The nitrogen, phosphorus and ammonium values, either as absolute amounts or as normalised TOC ratios, should be able to be used to monitor any impacts that an aquaculture industry may have on this environment, particularly the waste from the feeding process, as this material will be high in nitrogen containing nutrients, though it is important to also take into consideration the TOC content as this is also a factor in these calculations.

5. Benefits and Adoption

5.1. Aquaculture Industry:

The ultimate benefit to the aquaculture industry is the establishment of an area of Western Australian waters, selected according to its suitability for large-scale commercial marine finfish aquaculture; with consideration of its environmental, economic and social attributes; and established with an effective management framework, including an efficient approval process, for aquaculture operators within that area. The EPA has identified a number of gaps which limits its capability to assess the likely impacts of aquaculture operations on marine ecosystems. By gathering baseline data it will now be possible for the Department to develop a comprehensive ecosystem model that will address these gaps. The model will support an EIA which will be central in demonstrating to the EPA that the potential impacts of aquaculture on the marine environment at this Mid-West location can be managed within acceptable limits, thereby justifying approval of the Strategic proposal.

Credible ecosystem modelling requires analytes to be present at levels above the detection limit. Though not all compounds determined in this baseline monitoring were above the detection limits of the methods used, some analytes were. These analytes are therefore capable of being used in the development of this model to better inform the EIA.

Nitrogen, total organic carbon, total suspended and volatile solids were detected at levels above the detection limit and can be used in the model. As these elements and phosphorus, are likely to be the major effluent from an aquaculture facility, the on-going monitoring of these should ensure that any impacts from aquaculture industries can now be monitored. This data can also contribute to the adoption of trigger values for aquaculture management make it relatively simple to avoid irreversible environmental impacts. This negates the need for remediation actions and, or, enforced shutdown of operations should unacceptable impacts eventuate.

5.2. Analytical Capability:

ChemCentre has developed new methods for the detection of PAHs from seawater and sediment samples that are more than 100 times more sensitive than the original techniques. Over 500 samples were analysed for PAHs at this new level, however the only two PAHs that were routinely detected at this new limit were naphthalene and phenanthrene. The data shows that levels of anthropogenic TPH and PAH compounds are very low in all of the samples submitted. Though these results may not be as beneficial for modelling as was originally hoped, the baseline levels established for the PAHs and to a lesser extent the TRH, will contribute to the adoption of trigger values for aquaculture management and will assist with minimising the duration and costs of remediation actions and possible enforced shutdown of operations should any unplanned events occur.

6. Further Development

It is important that the variation in the duplicate PAH results, particularly regarding the naphthalene result is investigated. It is difficult to imagine a scenario where the sampling could have such an adverse impact on the data. Sample homogeneity may be a cause for this variation as are laboratory processes, further work will need to be carried out after completion of this project to determine the root cause of this error.

Based on these analyses, on-going monitoring of the total Nitrogen and TOC in both the sediment and seawater columns is very likely to assist regulators when assessing potential environmental impacts from new industries, though the validity of this observation should be verified with longer term studies.

7. Planned Outcomes

7.1. Public Benefit Outcomes

The information generated by this baseline monitoring will be part of the basis on which the aquaculture industry will be able to obtain approvals within the proposed MWADZ. ChemCentre's involvement in the project helps realise the Department goals to develop an aquaculture development zone in the Mid-West and thereby help Western Australia's fledgling finfish aquaculture industry to grow. These are goals sought by both government and industry. Data are now available for the ecological modelling which supports the MWADZ proposal and can be used to complete the EIA's necessary for environmental approval.

The baseline data on selected sediment and water quality parameters are critical to the MWADZ Project and will contribute directly to the:

- comprehensive baseline description of the marine environment at the MWADZ location;
- documentation of the likely environmental impacts of aquaculture operations;
- closing of knowledge gaps;
- determination of optimal finfish production;
- optimal scale of operations for a specific MWADZ location;
- spatial planning for the establishment of aquaculture infrastructure;
- identification of environmental indicators;
- adoption of triggers, standards and best practices in aquaculture management;
- capability to minimise the duration and costs of remediation actions and possible enforced shutdown of operations;
- contingency planning and knowledge of potentially required remediation;
- certainty for the aquaculture industry and
- third party accreditation of the aquaculture industry.

7.2. Beneficial Outcomes to ChemCentre

ChemCentre has improved analytical capabilities, with detection limits for the analysis of PAHs being improved by more than a factor of 100. There do appear to be some anomalies with some data and this will need to be investigated.

Baseline monitoring is critical to any industry that is likely to have an impact on the environment. ChemCentre can now market these new analytical skills to those industries or groups that are working in this area and we plan on providing a cost competitive product to the broader environmental market, offering an accredited analytical service that no other facility in Australia can currently offer.

7.3. Linkages with Seafood CRC Milestones

The Mid West Aquaculture Development Zone proposal, if granted the requisite environmental approvals will be a major accomplishment in the establishment of a multi-million dollar finfish industry in the Mid West of Western Australia.

Off-shore ecosystems are subjected to various threats from petroleum pollution including minor accidental oil spills from vessels, spillage of crude oils from offshore oil fields and anthropogenic activities. The strategic proposal area for the Mid West Aquaculture Development Zone is situated near major shipping routes, frequently traversed by fishing and recreational vessels, and is exposed oil and gas exploration. Mobile sources, such as fishing and recreational vessels can release combusted petroleum compounds (PAHs) to the environment in the form of exhaust and solid residue, which can build up in marine environments.[10]

ChemCentre was able to analyse sediment and seawater samples for a wide range of analytes, including ultra trace levels of PAHs from both of these sample types (sediment and seawater). The inability of any laboratory within Australia to report meaningful PAH data was a potentially limiting factor in the models

[10] Retnama et. al. 2013.

that were required by the Department. The analytical results from these new methods as well as the more routine analytical data will be used, in part, as the basis for an EIA that will be submitted to the EPA, as part of the necessary due diligence to establish a new commercial aquaculture production system within Western Australian waters.

The ultimate proposed benefit will be the establishment of an area in the Mid-West region, selected according to its suitability, for large-scale marine finfish aquaculture; with consideration of its environmental, economic and social attributes; and established with an effective management framework, including an efficient approval process, for aquaculture operators within that area.

Possible applications of new analytical protocols for the analysis of ultra trace levels of PAH may include:

- Identifying and isolating sources of oil pollution in cultured fish, also useful to justify a buffer between a valuable finfish industry and nearby oil and gas industry activities;
- Baseline data as part of a weight of evidence to demonstrate that the industry itself does not contribute to elevated levels PAH in the marine environment, required for third party accreditation (e.g. Aquaculture Stewardship Council (ASC) accreditation) of the finfish aquaculture industry.
- Baseline data as part of a weight of evidence to demonstrate that the industry itself does not contribute to elevated levels PAH in cultured fish, which is extremely important for international marketing purposes and third party accreditations.

8. Conclusion

The ultimate benefit to the aquaculture industry of this project is the generation of data that can be used by the Department to establish an area within Western Australian waters that is suitable for a large-scale marine finfish aquaculture industry. The Department has identified the Abrolhos Islands in the Mid-West as a potential site for this industry. The EPA identified a number of gaps which limits its capability to assess the likely impacts of such an industry and consequently the Department carried out a baseline survey of this area. Samples were collected and analysed at a number of laboratories over one year period. This baseline data will be used by the Department to develop a comprehensive ecosystem model that will address the gaps identified by the EPA. From this model an EIA will be developed which will be central in demonstrating to the EPA that the risk of adverse impact on the marine environment at this Mid-West location can be managed within acceptable limits, thereby justifying environmental approval of the MWADZ proposal.

Defensible baseline data, which is critical to the whole approvals process, has been generated. New methods were developed for the ultra trace analysis of PAHs from seawater and sediment samples. The detection limits reached were more than 100 times lower than existing US EPA methodologies. Over 500 samples were analysed for PAHs at this new level, the only two PAHs that were routinely detected at this new limit were naphthalene and phenanthrene. Though these results may not be as beneficial for modelling as was originally hoped, the baseline levels established for the PAHs could contribute to the adoption of trigger values for the management of industries operating within the Houtman Abrolhos Islands FHPA.

A range of other analytes, nitrogen, phosphorus and total organic carbon were detected at levels above the detection limit, as were suspended and volatile solids. This data can be used in the model and can also be used as environmental indicators for the optimal operation of aquaculture operations. Normalising the seawater and sediment data, that was above the detection limit, against TOC, yielded trends, particularly relative to nitrogen, that could be used to assess the potential impact of any new industries in this zone.

9. References

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