Lake Macquarie Benthos Survey

Prepared for

Great Southern Energy Pty. Ltd. (trading as Delta Coal)

Chain Valley Colliery

Report No. 16

By Dr John H. Laxton, Dr Emma Laxton and Ms Zofia Laxton

September 2019

J.H. & E.S. Laxton - Environmental Consultants P/L
170 Warrimoo Avenue, St. Ives. NSW 2075 Australia
Telephone 0447 653 387 Email john@laxton.nf

Table of Contents

List of Tables

List of Figures

List of Plates

Summary of Findings

In September 2019, 22 benthic stations were sampled. The following is a history of benthos sampling from 2014 to 2019.

By March 2014, mining beneath the lake had proceeded so that two Reference stations (R) had been re-designated Impact Stations (IM). They were:

R3 became IM5
R4 became IM6

By September 2014, Station R5 had also become an impact station, namely IM7.

In March 2016 two more stations were added to the sampling schedule. They were:

C5	GR 367701 6334310
R7	GR 366232 6333856

In September 2016, difficult geology beneath Bardens Bay and along parts of Summerland Point led Lake Coal to begin mining beneath Chain Valley Bay. To accommodate this change in mining direction, three additional benthos sampling stations were added. They were C6, R8 and R9.

C6	GR 363988 6332492
R8	GR 364523 6332010
R9	GR 365258 6331210

The total number of Stations sampled in September 2017 was 19.

In March 2018, three new stations were added to the sampling programme. They were:

C7	GR 366276 6334947
R10	GR 365172 6334706
R11	GR 367072 6333639

The mud basin off Summerland Point, in Chain Valley Bay and Bardens Bay, was found to be inhabited by 24 species of organisms greater than 1mm in size. This list was derived from the 16 samplings undertaken between February 2012 and September 2019. Polychaete worms and bivalve molluscs were the most frequently encountered animals.

Bottom sediment in the study area was composed of fine black mud with varying proportions of black sand and shell fragments.

Water levels in Lake Macquarie can vary by as much as 1.3m over the course of a year due to combinations of the following phenomena:

- Diurnal tidal changes (around 0.05m);
- Changes in atmospheric pressure (up to 0.4m);
- Wave set up at the entrance to Lake Macquarie;
- Inflow of water from the catchment during major rainfall events.

Light attenuation through the water column of Lake Macquarie, measured off Wyee Point, between 1983 and 1985, showed that only 14% of the photosynthetically active radiation (PAR) reached the lake bed at 2m depth (the growth limit of seagrasses and macroscopic algae in the LDO study area). At 6m depth, between 2% and 4% of the surface PAR reached the lake bed, not enough light to support the growth of seagrasses or benthic algae.

The 16 samplings of the benthos undertaken at six monthly intervals between February 2012 and September 2019 revealed the following:

The same suite of organisms dominated each of the 22 sample stations. These were polychaete worms and bivalves.

Stations were distinguished by the relative abundance of the dominant species.
Water depth was not in any way important in determining the species composition at a station.

Physical variables such as salinity (conductivity), dissolved oxygen concentration and turbidity of the bottom water, measured only on the day the benthos was sampled, had little influence on the species composition of the benthos over the period sampled. However, it is clear that major extinction events have occurred in the mud basin of Lake Macquarie. The evidence for this lies in the presence of large numbers of intact but dead bivalve shells entombed in the mud. The cause of extinction events appears to be prolonged dissolved oxygen depletion of bottom water. Prolonged dissolved oxygen depletion of the bottom water was measured during the water quality study conducted by Laxton and Laxton (1983 to 1997).

These results appear to support the notion that increasing the water depth by the predicted 0.8m subsidence has, to date, had no discernible effect on the composition and abundance of organisms making up the benthos of the mud basin.

In September 2018 a total of 1576 organisms were collected at the 22 stations. In March 2019 and September 2019 the total number of organisms found in sediment from the 22 stations was 832 and 815 respectively. This was around half the number of organisms collected in September 2018. This suggests that some extinction events have occurred recently.

Over the past 3 years, little significant rain has fallen in the catchments of Lake Macquarie. Over that period of time the salinity of the water column has become very high (over 39 parts per thousand by March 2019) and almost uniform from surface to bottom. The water of the lake became very clear for long periods. This high water clarity led to some interesting effects on the benthos of the study area. First, the small seagrass, *Halophila sp.* became established as a dense bed in 6m of water at Station R10 (Brightwaters Bay) in September 2018. *Halophila sp* was not recorded at Station R10 in March 2019 but in September 2019 a healthy plant of *Zostera capricorni* was found at this station. Second, at stations C4 and IM2, red and brown algae were found on mussels at depths between 4.5 and 6 m of water in September 2018.

In August and September 2019 some heavy rain fell in the catchment of Lake Macquarie. This rainfall lowered the salinity of water in the lake to around 36 parts per thousand.

In September 2019 some changes to the composition of the upper 100mm of the bottom sediments were detected. At Stations C1-C4 and C6-C7 no sand was present, just fine black silt. This indicated that these sediments had been reworked since March 2019. Sediments at Stations R5, R6 R8 and R9 also appeared to have been reworked.

For the first time in 16 samplings of sediments of Lake Macquarie large numbers of juvenile (3-4mm diameter) were found especially in sandy sediments.

Introduction

In 2012 Lake Coal P/L was seeking a variation to its mining agreement because of proposed changes to its mining methods. They were planning on increasing miniwall panel widths to 85m wide, 97m total extraction, which will result in some additional subsidence above that currently approved. As such, a modification and supporting EA was prepared. The predicted subsidence agreed to by the NSW Government was around 0.406m. The method now proposed will increase subsidence to around 0.468m.

NSW Department of Planning and Infrastructure raised concerns that this increase in depth of water over the existing benthic community of the mud basin of Lake Macquarie may alter the species composition and relative abundances of organisms within that community.

To address these concerns, Lake Coal decided to conduct a benthic survey of the mud basin community to attempt to answer the following questions.

- What is the structure of the benthic community of the mud basin off Summerland Point and in Chain Valley Bay?
- What changes to the benthic community, if any, have taken place in areas of the lake mud basin that have been subjected to subsidence from previous mining activity?
- What changes to the benthic community, if any, may be expected in the mud basin community from the proposed variation to the mining method?

This study had a seasonal component and the benthos could change from year to year without the influence of any subsidence due to mining.

Ms Jemma Sargent of JSA Environmental prepared a formal document entitled:

Benthic Communities Management Plan. Chain Valley Colliery Domains 1 & 2 Continuation. Project (10_0161). 25 June 2012.

The extraction plan required under Condition 6 of Schedule 3 within Project approval (10_0161) requires that a Benthic Communities Management Plan (BCMP) be developed. This BCMP was prepared to provide for the management of the potential impacts and/or environmental consequences of the proposed second workings on benthic communities and includes:

- surveys of the lake bed to enable contours to be produced and changes in depth following subsidence to be accurately measured;
- benthic species surveys within the area subject to second workings, as well as control sites outside the area subject to second workings (at similar depths) to establish baseline data on species numbers and composition within the communities;
- a program of ongoing seasonal monitoring of benthic species in both control and impact sites;
- development of a model to predict the likely impact of increased depth and associated subsidence impacts and effects, including but not limited to light reduction and sediment disturbance, on benthic species number and benthic communities composition, incorporating the survey data collected.

Three types of station were sampled. They were:

- Control stations – C, areas of lake bed sufficiently remote from previous or proposed mining.
- Reference stations – R, areas of lake bed above subsidence areas of previous mining.
- Impact stations – IM areas of lake bed where subsidence is expected from future mining.

Two depth zones within the mud basin were sampled, -4.5m AHD and -5.5 to -6.0m AHD. The locations of the sampling stations were specified by Mr Chris Ellis and Mr Wade Covey, using the results of a recent bathymetric survey of the lake and the known locations of past and proposed mining.

In November 2014, project consent 10_0161 was surrendered. It was replaced by consent SSD-5465 as modified. The remodeled subsidence values were 0.62m for the single seam extraction area (everywhere that is currently being mined) and up to 0.886m for areas where multiseam mining will occur (near Site R2).

This report (September 2019) presents the results of the just completed 16th sampling of the now 22 (previously 19, 16, 14 and 12) stations off Summerland Point, in Chain Valley Bay, Bardens Bay and Sugar Bay. These results will be compared with those obtained from the previous fifteen surveys (February 2012 to March 2019). Field work for the 16th survey was conducted between the 10th and 11th September 2019. The work in September 2018 was supervised by Mr Chris Armit of Chain Valley Colliery.

Location of Sampling Stations

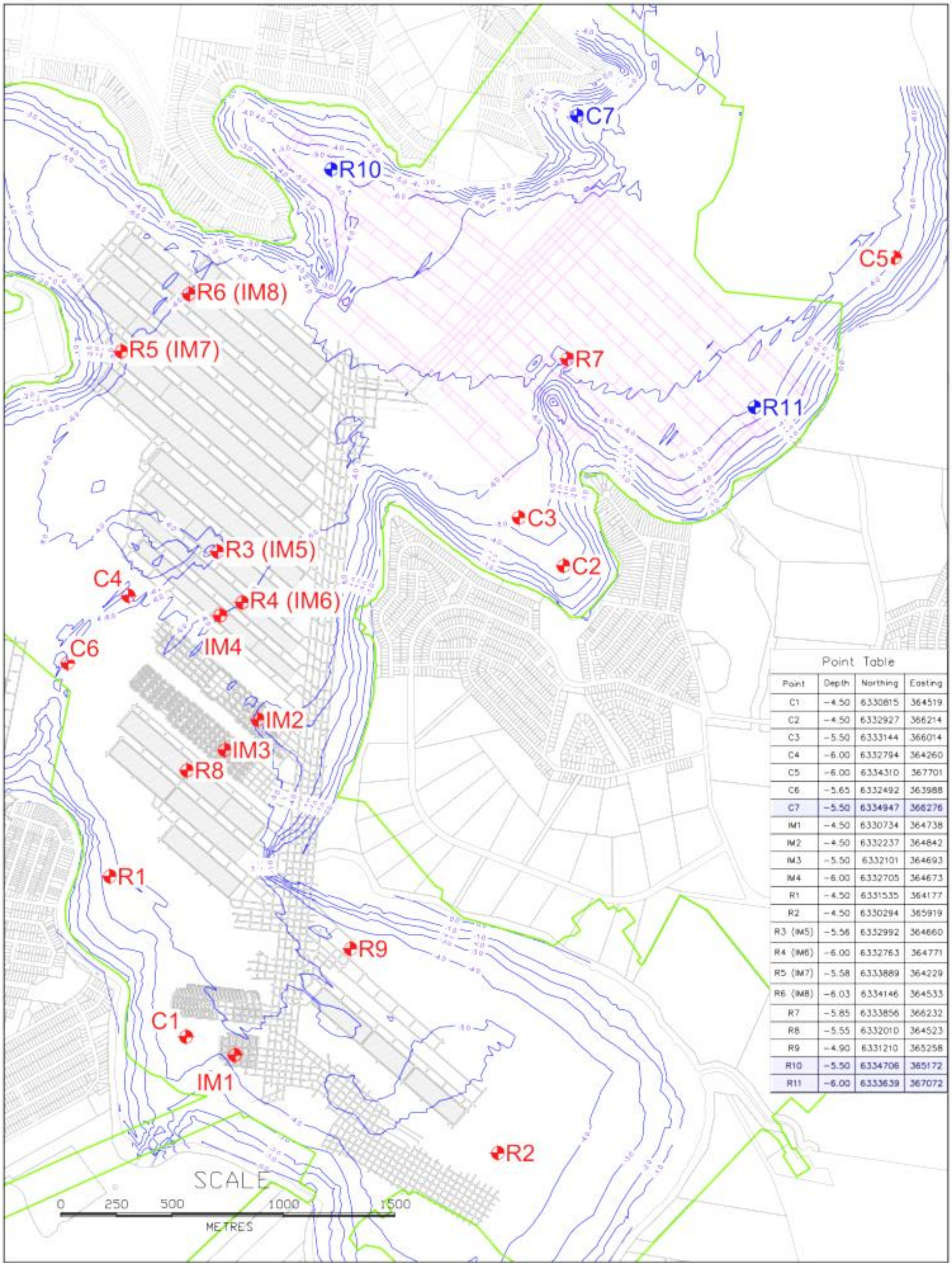
Figure 1 shows the location of sampling stations, depth contours of the lake, and the locations of existing and proposed underground mine workings prepared by Mr Chris Armit and the LDO team in February 2017 and updated in March 2019. **Table 1** provides the exact location of each sampling station by latitude and longitude and by eastings and northings using WGS84 datum.

Selection and Evaluation of the Sampling Method

Methods for sampling benthos of sedimentary bottoms of oceans, coastal waters and saline and freshwater lakes must fulfill the following criteria:

- The area of bottom collected by the sampling device must be appropriate to the types and sizes of organisms inhabiting the substratum.
- The depth that the sampler penetrates the sediment must be sufficient to capture infauna or identifiable parts of more deeply buried species.
- Sufficient samples must be taken within the benthic environment to be certain that more than 95% of the component species of the ecosystem are collected.
- Sufficient samples must be taken to permit the population densities of component species to be calculated.

In 1971 John Laxton was appointed by Dr Frank Talbot, Director of the Australian Museum, to lead a team of scientists to undertake the Shelf Benthic Survey. The purpose of the Shelf Benthic Survey was to provide baseline biological data on the benthos, fish and birds of the Continental Shelf adjacent to Sydney. Baseline oceanographic and biological data for coastal waters adjacent to Sydney were required to evaluate the effects of the proposed deep water ocean outfalls planed by the Metropolitan Water Sewerage and Drainage Board to replace the existing shoreline sewage outfalls. Both rocky bottoms and sedimentary bottoms were present in the study area and water depths ranged from the intertidal zone out to 200m.



Point Table

Point	Depth	Northing	Easting
C1	−4.50	6330815	364519
C2	−4.50	6332927	366214
C3	−5.50	6333144	366014
C4	−6.00	6332794	364260
C5	−6.00	6334310	367701
C6	−5.65	6332492	363988
C7	−5.50	6334947	366276
IM1	−4.50	6330734	364738
IM2	−4.50	6332237	364842
IM3	−5.50	6332101	364693
IM4	−6.00	6332705	364673
R1	−4.50	6331535	364177
R2	−4.50	6330294	365919
R3 (IM5)	−5.56	6332992	364660
R4 (IM6)	−6.00	6332763	364771
R5 (IM7)	−5.58	6333889	364229
R6 (IM8)	−6.03	6334146	364533
R7	−5.85	6333856	366232
R8	−5.55	6332010	364523
R9	−4.90	6331210	365258
R10	−5.50	6334706	365172
R11	−6.00	6333639	367072

Figure 1a. Location of Benthos Sampling Stations (September 2019).

Figure 1b. Extent of mining to September 2019

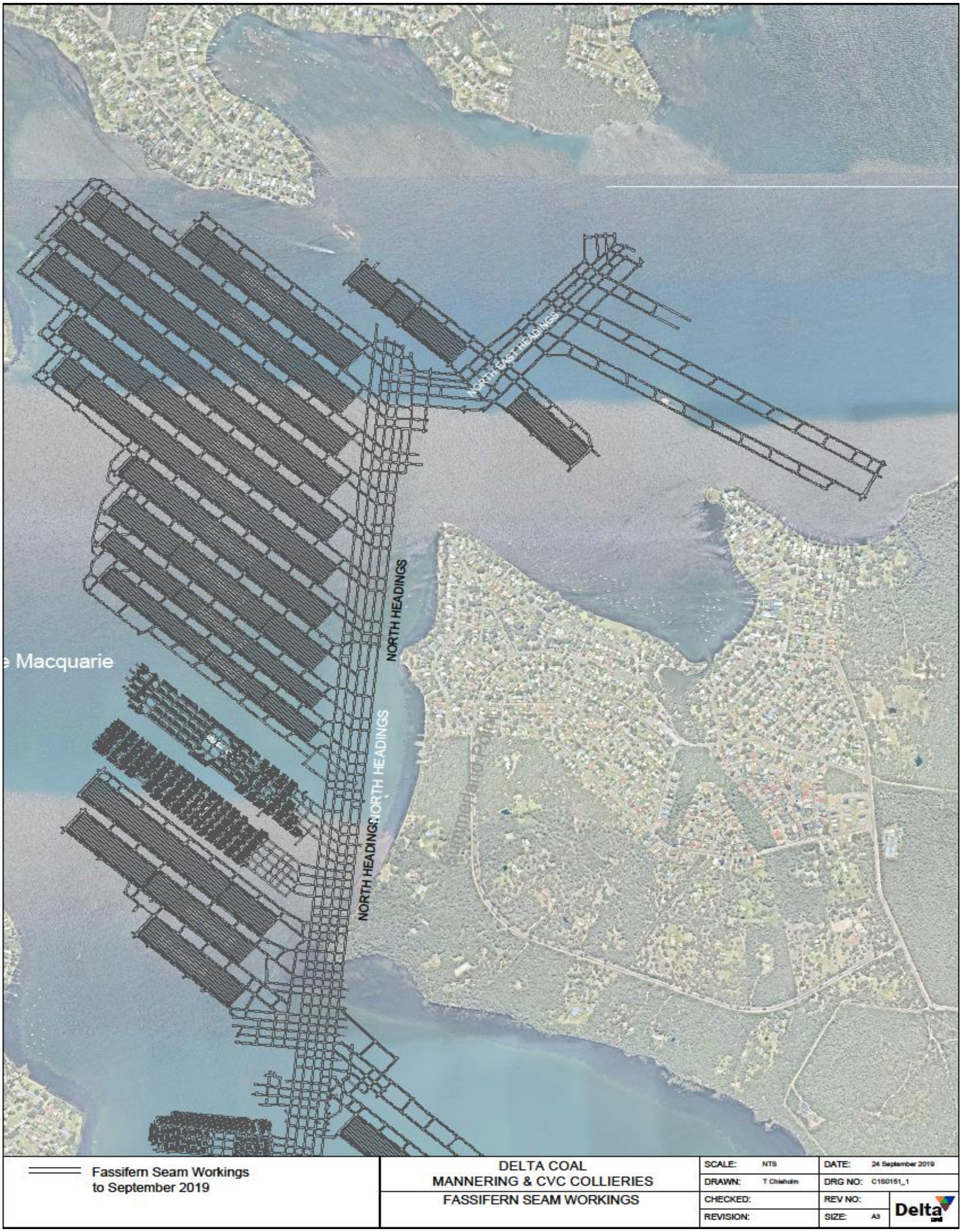


Table 1. Co-ordinates of Benthos Sampling Stations prepared by the LDO team.

Station Co-ordinate Table					
Station	Sample depth (m) AHD	Latitude	Longitude	MG-56 Easting	MG56 Northing
C1	-4.50	S33° 09' 10.69"	E151° 32' 50.11"	364519	6330815
C2	-4.50	S33° 08' 02.89"	E151° 33' 56.65"	366214	6332927
C3	-5.50	S33° 07' 55.78"	E151° 33' 49.05"	366014	6333144
C4	-6.00	S33° 08' 06.35"	E151° 32' 41.17"	364260	6332794
C5	-6.00			367701	6334310
C6	-5.50			363988	6332492
C7	-5.50			366276	6334947
IM1	-4.50	S33° 09' 13.44"	E151° 32' 58.51"	364738	6330734
IM2	-4.50	S33° 08' 24.67"	E151° 33' 03.34"	364842	6332237
IM3	-5.50	S33° 08' 29.02"	E151° 32' 57.52"	364693	6332101
IM4	-6.00	S33° 08' 09.42"	E151° 32' 57.04"	364873	6332705
R1	-4.50	S33° 08' 47.18"	E151° 32' 37.31"	364177	6331535
R2	-4.50	S33° 09' 28.23"	E151° 33' 43.87"	365919	6330294
R3 (IM5)	-5.50	S33° 08' 00.10"	E151° 32' 56.72"	364660	6332992
R4 (IM6)	-6.00	S33° 08' 07.58"	E151° 33' 00.88"	364771	6332763
R5(IM7)	-5.50	S33° 07' 30.78"	E151° 32' 40.55"	364229	6333889
R6	-6.00	S33° 07' 22.56"	E151° 32' 52.42"	364533	6334146
R7	-6.00			366232	6333856
R8	-5.50			364523	6332010

R9	-4.50			365258	6331210
R10	-5.50			365172	6334706
R11	-6.00			367072	6333639

At first, a Shipek grab was employed to collect samples of sediment. The Shipek grab used a spring loaded hemi-cylindrical bucket that rotated through 180^o to collect a half cylinder of sediment nominally 200 x 200 mm in area and cut to a maximum depth of 100mm. On gravel bottoms, the Shipek grab worked consistently to collect 200 x 200 x 100mm samples. On sandy bottoms the grab, when triggered, penetrated the bottom to varying depths, collecting half cylinders of sediment that could range in depth from the full 100mm to as little as 25mm. This meant that the area of the seabed sampled varied greatly between samples taken at the same station and the depth of some samples was so shallow that many species of infauna were not collected. On muddy bottoms the heavy Shipek grab could plunge into the soft mud and emerge untriggered.

The Shipek grab was safe to use from a pitching and rolling vessel but as a scientific sampling device, it had serious deficiencies.

The Shelf Benthic Survey then obtained a Smith-MacIntyre (S-M) grab for evaluation. The Smith-MacIntyre grab used two spring operated clam-shells which swung inwards towards the midline to gather 200 x 200 x 100mm samples of sediment. This grab also had similar limitations to the Shipek grab when used to sample various sediment types. The worst feature of the S-M grab was that the two springs had to be tensioned by a lever separately and then a keeper was placed in position to stop it triggering while on deck or while being lowered to the sea bed. To position the keeper, the operator had to reach in between the two cocked spring loaded clam-shells. These clam-shell jaws were sharp and the action was violent enough to remove a hand. The Captain of the vessel banned its use on the project and undoubtedly saved someone's hand.

Following completion of the Shelf Benthic Survey, John Laxton joined an engineering firm that was commissioned to design wastewater outfalls for Gosford City, Wyong Shire and the Hunter Area. Baseline data on water quality and biology were again required and the seabed in the discharge and mixing zones was either rocky or sedimentary. As the maximum water depth in sedimentary areas was 30m, diver operated sample collection devices could be used to sample sedimentary bottoms. It was decided to build a diver operated benthic sampler that would overcome the difficulties and deficiencies of the available grab samplers. It should collect a 200 x 200 x 100mm section of sediment consistently and be easy to operate in conditions of zero underwater visibility.

To collect a 200 x 200 x 100mm sample of sediment consistently an aluminium box was designed that could be slid sideways into the sediment, whether gravel, sand or mud, and be filled completely before it was lifted clear of the bottom and the door closed and locked to retain the sediment. The top of the box included a panel of 1.0mm stainless steel mesh. Thus each box contained its own sieve to permit particles less than 1mm in size to be removed from the box leaving only large particles and organisms.

Tests of this box revealed that in all sediments (gravel, sand and mud) between 3 and 5 replicate samples were required to capture 95% of the species present. Once the maximum number of replicates required had been determined, five sieve boxes were manufactured along with a carry case to contain the boxes on the journey between the surface and the bottom and back. These devices permitted samples of consistent area and depth to be collected. Five replicates were always collected regardless of the sediment type or the environment being studied so that individual species/area curves were not required for each new area being investigated.

Five sieve boxes sample an area of 0.20 m^2. This sampling device has been used in all J.H. & E.S. Laxton - Environmental Consultants P/L benthos studies since 1980.

In an attempt to make the Summerland Point/Chain Valley Bay study results comparable with other studies, the BCMP required two cores of 100mm diameter and 200mm depth to be taken along with the 5 sieve box samples. These two cores covered an area of 0.015 m^2. There was no requirement in the BCMP to determine how many cores of these dimensions were needed to capture 95% of the benthic species inhabiting the lake bed. However, it is unlikely that sampling 0.015 m^2 of bottom sediment will provide a more realistic picture of the structure of the benthic community than sampling 0.20 m^2 of bottom sediment.

Sampling Procedure

Between September 2012 and September 2019, five replicate samples of basin mud were collected at each station using 200 x 200 x 100mm sieve boxes (1mm mesh). Two 100 x 200mm core samples were also collected at each station on each date sampled.

Twenty-two stations were sampled in September 2019. At each station the following procedure was carried out:

- A GPS unit was used to locate the sampling station. The boat was positioned upwind of the station and was then allowed to drift back to the exact location. When the wind strength was 0-5km/h, the boat stayed on position. When the wind strength increased from 5 to 25km/h, the boat yawed on its anchor warp, causing the distance from the boat to the station to vary greatly and the sampling difficulty to increase. This was mitigated by working in calm conditions only.
- A line with five sieve boxes, two 100 x 200mm core samplers and a mesh bag containing a 250mL jar for whole sediment was cast over board as the boat drifted into position.
- The diver descended to the lake bed to fill the 250mL jar, the two core samplers and five sieve boxes with sediment.
- The samplers were then hauled to the surface, and the contents of each sampler placed in a clean, labeled zip-lock plastic bag.
- Processing of samples occurred in the laboratory.
- A water quality profile from surface to bottom (at 0.5m depth intervals) was taken using a calibrated Yeo-Kal 611 Water Quality Analyser. Water temperature, conductivity, salinity, pH, dissolved oxygen and turbidity were measured. Each line of data was stored in the memory of the machine.

In the laboratory the marine benthic samples were treated in the following way:

- Each sample was tipped into a 1 mm mesh sieve and washed free of mud.
- The washed material from each sample was then placed into an enamel dish and sorted for animals.
- Organisms and parts of organisms were removed, counted, identified and the results entered into a spread sheet. This process was repeated until the debris of the entire sample had been examined.
- Sorted organisms were preserved in formaldehyde solution.
- All shell remaining in the sample was kept for later examination.

The 250mL samples of whole sediment were treated in the following way:

- Each sample was tipped into a 1L clear glass measuring cylinder and the volume made up to 600mL with seawater.
- The cylinders were stoppered and shaken vigorously to suspend the sediment in the seawater.
- The cylinders were then placed on the laboratory bench to allow the fractions of the sediment to settle.
- Once settled the sediment profiles were photographed and the volumes of each fraction (shell and coarse sand, fine sand, mud and fine silt) were calculated and recorded. Results were displayed relative to the initial volume of sediment collected in the 250mL jar.

Factors Affecting the Depth of Water in Lake Macquarie

The bathymetric chart of Lake Macquarie shows water depths relative to AHD. The actual depth of water above the lake bed varied greatly (**Figure 2**).

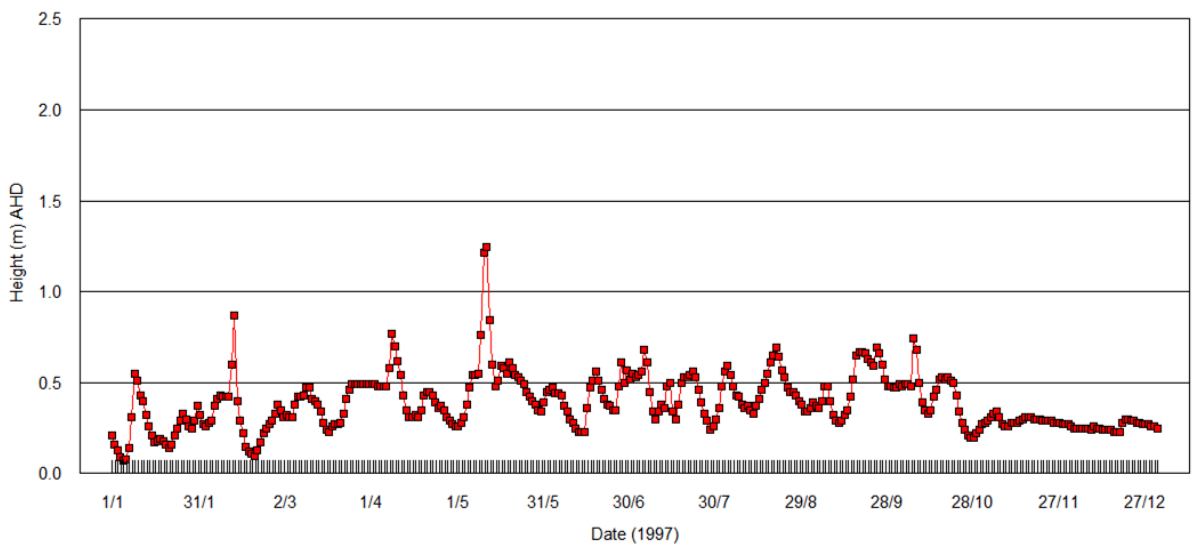


Figure 2. Water level changes in a coastal lagoon with an entrance open to coastal waters.

The actual water depth above the lake bed varied between 0 and 1.3m above AHD over a year. Water depths in coastal saline lakes with an open entrance to coastal waters varied due to combinations of the following factors:

- The body of Lake Macquarie was subject to tidal influence. The height of the tidal prism at Swansea Head may reach almost 2m (during spring tides) but by the time the body of the lake was reached, the tidal prism had been reduced to around 0.05m.
- The height of coastal waters and coastal lakes were influenced by changes in atmospheric pressure. The Tasman Sea acted as a huge barometer. When the atmospheric pressure was high the sea surface was depressed. This caused water to drain from Lake Macquarie causing the depth of water in the body of the lake to decrease. When the atmospheric pressure over the Tasman Sea was low, the surface of the sea bulged upwards. This raising of sea level caused water to flow into Lake Macquarie, increasing the water depth.

- Low pressure systems in the Tasman Sea almost always generated strong winds and coastal rainfall. The strong winds caused large swells to form that impact the coast. Wave setup at the entrance to Lake Macquarie caused the water level in the lake to rise as large volumes of seawater entered the system.
- Rainfall during a period of low atmospheric pressure caused runoff into catchment rivers and streams to increase. When this extra water reached the body of Lake Macquarie, the water level rose in proportion to the runoff volume. This water was prevented from exiting the lake by wave setup at the entrance and the state of the tide. Under these circumstances, the level of the lake rose to heights of a meter or more above AHD (**Figure 2**).

Water Quality of Lake Macquarie (April 1983 – March 1997)

In 1983 the Hunter District Water Board (later Hunter Water Corporation) commissioned J.H. & E.S. Laxton – Environmental Consultants P/L to carry out a water quality study of Lake Macquarie in conjunction with their plans to sewer the western shore of the lake. The study commenced in April 1983 with monthly sampling of the lake and ended in March 1997. The water quality results for the body of Lake Macquarie (as opposed to the creeks) are summarized and presented in **Table 2**.

Table 2. Water Quality of the body of Lake Macquarie (1983-1997)

Variable		Mean	Maximum	Minimum
Water Temperature (^oC)	Surface	20.56	33.77	10.95
	Bottom	20.06	29.17	11.45
Water Salinity (ppt)	Surface	32.61	37.96	1.00
	Bottom	33.92	37.95	21.06
PH	Surface	8.28	9.28	7.19
	Bottom	8.26	8.90	7.55
Dissolved Oxygen (% saturation)	Surface	101.6	177.7	71.9
	Bottom	89.5	147.0	0.9
Turbidity (NTU)	Surface	3.0	32.8	0.0
	Bottom	5.1	77.7	0.0
Transmission of light through water (%)	Surface	94.2	99.9	7.3
	Bottom	88.1	99.4	2.0
Total Suspended Solids (mg/L)	Surface	4.8	123.5	0.5
Chlorophyll-a (µg/L)	Surface	2.953	112.900	0.000
Ammonia-nitrogen (mg-N/L)	Surface	0.071	1.500	0.006
	Bottom	0.075	0.813	0.010
Organic-nitrogen (mg-N/L)	Surface	0.355	9.691	0.000

	Bottom	0.361	3.357	0.002
Oxidized-nitrogen (mg-N/L	Surface	0.010	0.459	0.000
	Bottom	0.008	0.142	0.000
Total-nitrogen (mg-N/L)	Surface	0.436	9.749	0.033
	Bottom	0.445	3.918	0.027
Orthophosphate phosphorus (mg-P/L)	Surface	0.0191	0.4148	0.0006
	Bottom	0.0188	0.1386	0.0003
Total phosphorus (mg-P/L)	Surface	0.0450	0.8922	0.0025
	Bottom	0.0489	0.3534	0.0022
Faecal coliform bacteria (No./100mL)	Surface	55	5000	0

Blue shading in Table 2 indicates variables of interest to this study of the benthos of Lake Macquarie.

Light attenuation in Lake Macquarie (1983 – 1997)

Observations made over many years (Laxton, 2007) show that photosynthetic benthic organisms (seagrasses and algae) are confined to the shallow water areas around the perimeter of Lake Macquarie. In Chain Valley Bay, Bardens Bay and off Summerland Point, seagrasses and benthic algae grow between 0 and -1.89m below AHD (except in September 2018 when *Halophila* and some algae were found in 4.5 to 6m of water at some stations due to low rainfall and clear water).

The water quality study of Lake Macquarie, carried out between 1983 and 1997, measured Photosynthetically Active Radiation (PAR) changes with depth monthly at twelve stations throughout the lake during the years 1983 to 1985. Data for Station 1 off Wyee Point are presented in **Figure 3** and **Figure 4**.

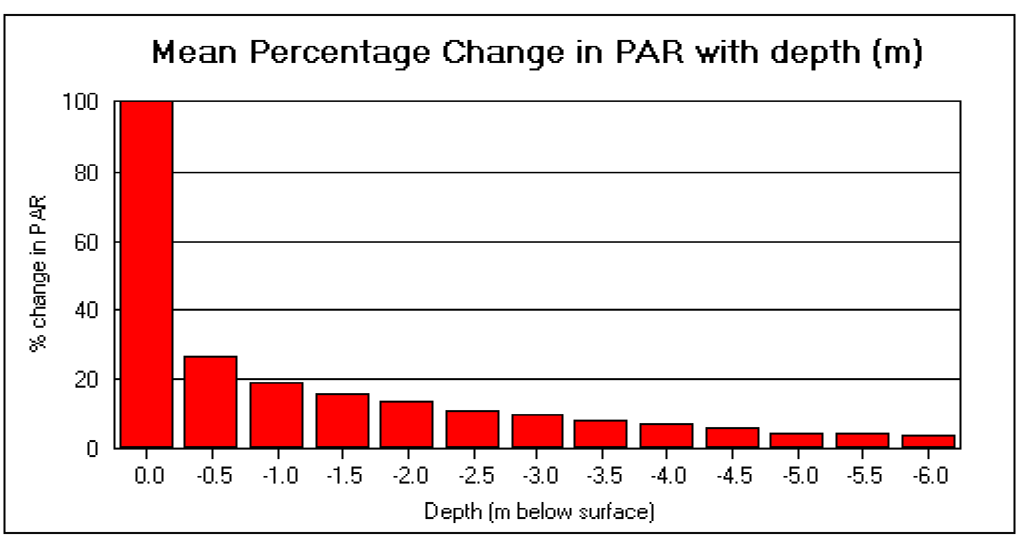


Figure 3. Mean percentage changes in PAR with depth at Station 1 - Wyee Point over 12 months.

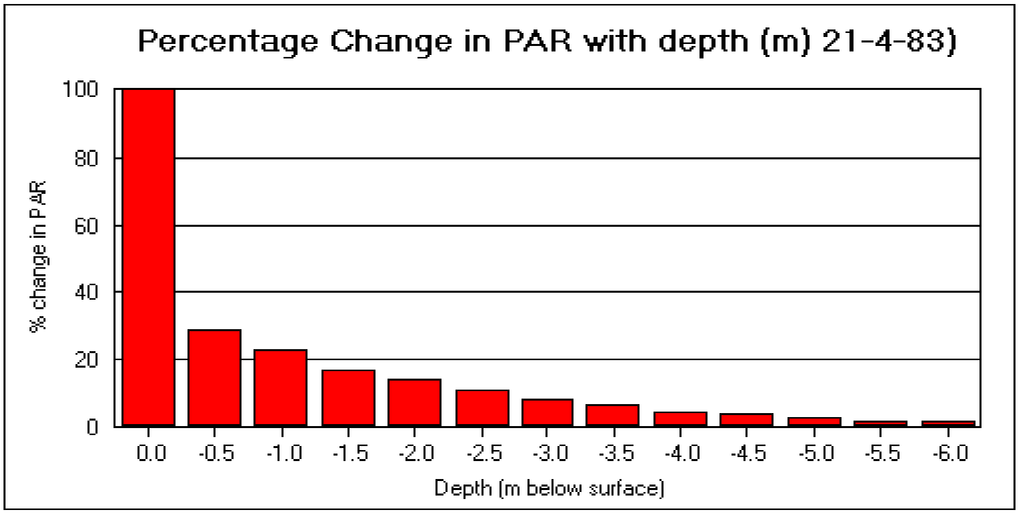


Figure 4. Actual percentage changes in PAR at Station 1 - Wyee Point on the morning of 21-4-83.

It was found that only 14% of the light present at the surface reached a depth of 2.0m below the surface. By 6m below the surface only between 2% and 4% of PAR remained. Seagrasses and algae just manage to survive at 14% of the surface radiation but have no chance of survival at 6m below the surface. The mud basin of Lake Macquarie was devoid of macroscopic benthic algae and seagrasses except at some stations in September 2018.

Results

Benthos of the Study Area – February 2012 to September 2019

The following organisms were found in the sediment samples collected off Summerland Point and in Chain Valley Bay between February 2012 and September 2019:

Designated name	Family or Species	Comments
Anenome	Coelenterata	Found associated with mussel shells.
Planaria (Flat worm)	Platyhelminthes	2 specimens found in 2017.
Polychaete thin	*Sthenelais pettiboneae*	Most common polychaete present.

Polychaete (thick)	Cirratulidae	Present in small numbers.
Polychaete (mud tube)	Not yet identified	Present in small numbers.
Polychaete	Terebellidae	Present at Stations C1, C6, R1 and IM2.
Pectinaria sp. Polychaete	Terebellidae	First found in March 2019
Gastropod	*Nassarius jonasii*	Present in small numbers.
Gastropod	*Lepsiella* (*Bedeva*) *hanleyi*	Present in small numbers.
Gastropod	Bullimorph slug	One specimen found in August 2014.
Bivalve	*Corbula truncata*	Common as live animals and dead shells.
Bivalve	*Soletellina alba*	Common
Bivalve	*Paphia undulata*	Uncommon as live animals. Common as dead shells.
Bivalve	*Cyamiomactra mactroides* (Brown or pink bivalve)	Uncommon
Bivalve	*Anadara trapezia*	Uncommon.
Bivalve	*Dosinia sculpta*	Many juveniles found in sandy sediment in September 2019. Common as dead shells.
Bivalve	*Trichomya hirsuta*	Found in large clumps at C2, C6, R3, R7, IM2 and IM3.
Ophuroid with	Brittle star	Uncommon, found associated mussel clumps and on mud.
Sponge	White calcareous sponge	Specimen found associated with mussels.
	Pink sponge	Small species found on mud surface.
	Red sponge	Several specimens found in 2019.
Crab	Small	Uncommon.
Prawn 2013 at September	Small	One specimen taken in March R3 and one specimen in 2013 at C4.
Shrimp	Small	Found at IM2 in March 2014.
Fish	Small (35mm)	One specimen taken at C3 (September 2012), at R1 (September 2013) and at IM4 in March 2017. 1 specimen in C6 in 2019.

Plates 1a to **1d** provide information about the benthic organisms present in the basin mud of Lake Macquarie, NSW.

Plate 1a. Annelid species found in the benthos of Lake Macquarie (Feb 2012 - September 2019).

Phylum : Annelida
Class: Polychaeta
Subclass: Errantia
Order: Phyllodocida
Family: Sigalionidae
Genus: Sthenelais
Species: *Sthenelais pettiboneae*

Remarks: Found in marine environments.

Phylum : Annelida
Class: Polychaeta
Subclass: Canalipalpata
Order: Terebellida
Family: Cirratulidae

Remarks: Cirratulids vary in size from 1-20 cm long. They are mostly burrowers in soft sediments but some live in rock crevices. The head is conical or wedge-shaped and has no antennae. The body is generally cylindrical, tapering at both ends. Cirratulids are characterised by a large number of simple elongate filaments along the body. The genera are poorly defined.

Plate 1b. Gastropod species found in the benthos of Lake Macquarie (Feb 2012 - September 2019).

	**Phylum :** Mollusca **Class:** Gastropoda **Superfamily:** Buccinoidea **Family:** Nassariidae **Genus:** *Nassarius* **Species:** *Nassarius jonasii* **Remarks:** Endemic to Australia; Noosa Heads, Qld, to SA. Inhabit sand and mud flats in estuaries and lagoons, intertidal down to 100 m. Most *Nassarius* species are very active scavengers. They often burrow into marine substrates and then wait with only their siphon protruding, until they smell nearby food.
	**Phylum :** Mollusca **Class:** Gastropoda **Order:** Neogastropoda **Family:** Muricidae **Genus:** *Lepsiella* (*Bedeva*) **Species:** *Lepsiella hanleyi* **Remarks:** Common name mussel drill. Shell up to 32 mm, with angulated whorls, a high spire and moderately long anterior canal and with both spiral threads and axial ribs. Endemic to Australia. Found in temperate and southern parts of tropical Australia. Lives mainly on sheltered shores, including estuaries and often in association with mangroves. Feeds by drilling holes in bivalves. Lays lens-shaped capsules and development is direct.

Plate 1c. Bivalve species found in the benthos of Lake Macquarie (Feb 2012 - September 2019).

	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Myoida **Family:** Corbulidae **Genus:** *Corbula* **Species:** *Corbula truncata* **Remarks:** Marine bivalve mollusc.
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Veneroida **Family:** Psammobiidae **Genus:** *Soletellina* **Species:** *Soletellina alba* **Remarks:** Posterior and anterior margins almost parallel. Shell thin and normally bluish, rarely white. Lives intertidally and subtidally in sand and mud, especially in sheltered environments. Occurs all around Australia; not recorded elsewhere.
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Veneroida **Family:** Veneridae Genus: *Paphia* **Species:** *Paphia undulata* **Remarks:** Saltwater clam, marine

	bivalve mollusc. Inhabits inshore shallow sandy seabeds.
 	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Veneroida **Family:** Veneridae **Genus:** *Dosinia* **Species:** *Dosinia sculpta* **Remarks:** *Dosinia* is a genus of saltwater clams, marine bivalve molluscs in the family Veneridae, (subfamily Dosiniinae). The shell of *Dosinia* species is disc-like in shape, usually white, and therefore is reminiscent of the shells of Lucinid bivalves. Typically found in the intertidal zone at the water's edge at a mean distance from sea level of -15 meters (-50 feet).
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Veneroida **Family:** Cyamiidae **Genus:** *Cyamiomactra* **Species:** *Cyamiomactra mactroides*

	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Arcoida **Family:** Arcidae **Genus:** *Anadara* **Species:** *Anadara trapezia* **Remarks:** Sydney cockle, or ark cockle is an estuarine filter-feeding bivalve. Its calcareous, heavily-ribbed, shell can grow to approximately 7 to 8 cm across. Its current range is along the east coast of Australia, from Queensland to Victoria. It has been used as an indicator species to study levels of the metals selenium, copper and cadmium.
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Mytiloida **Family:** Mytilidae **Genus:** *Trichomya* **Species:** *Trichomya hirsuta* **Remarks:** The hairy mussel is a major part of the megafauna of Lake Macquarie. It is tolerant of low oxygen levels in the water and its temperature tolerance range has been researched in connection with using the waters of the lake for cooling power stations. Hairy mussels have been used as bioindicators to monitor concentrations of heavy metals (namely Pb, Cd, Cu, Zn, Co, Ni, and Ag) in marine environments.

Plate 1d. Brittle stars are found amongst the mussel beds of Lake Macquarie, NSW.

<table>
<tr>
<td></td>
<td>

Phylum : Echinodermata

Class: Ophiuroidea

Order: Ophiurida

Family: Ophiotrichidae

Remarks: Brittle stars have five long, slender arms which radiate out from a central disc. The mouth is located in the centre of the underside of the disc. There is no anus. Offshore, brittle stars form dense aggregations. In intertidal zones, they are typically found as single individuals in crevices, under stones and amongst seaweed. They feed by raising their arms above the substrate; extending tube-feet; and removing particles from the water. They pass food along the arms to the mouth. They also scavenge on decaying matter. They inhabit the hairy mussel beds of Lake Macquarie.

</td>
</tr>
</table>

Molluscs found as dead shells

Benthic organism samples collected between February 2012 and September 2019 included a large component of shell. **Plates 2a** and **2b** show the mass of shell obtained from the sixty 200x200x100mm samples of sediment taken in February 2012. **Plate 2c** and **Plate 2d** show the mass of shell collected in September 2012 and **Plates 2e** and 2**f** show the mass of shells collected in March 2013.

Plate 2a. Large shell removed from samples during sorting process - February 2012 survey.

Plate 2b. Small shells removed from samples during sorting process - February 2012 survey.

Plate 2c. Large shells removed from samples - September 2012 survey.

Plate 2d. Small shells removed from samples during sorting in September 2012.

Plate 2e. Large shells removed from samples during sorting in March 2013.

Plate 2f. Small shells removed from samples during sorting in March 2013.

Similar masses of shell were found in the samples of the September 2013 to September 2019 surveys. These masses of shell were photographed for the record but were not included in this report.

The following molluscs were found in the large volume of shell collected during the sampling periods between February 2012 and September 2019:

1. *Paphia undulata*
2. *Anomia sp.*
3. *Dosinia sculpta*
4. *Trichomya hirsuta*
5. *Katelysia rhytiphora*
6. *Pecten sp.*
7. *Chlamys sp.*
8. *Saccostrea glomerata*
9. *Corbula truncata*
10. *Batillaria (Velacumantis) australis*
11. *Conuber sp.*
12. *Anadara trapezia*

Plates 3a and **3b** provide information about bivalve mollusc and gastropod species found as dead shells in the basin mud of Lake Macquarie, New South Wales during the periods of sampling.

Plate 3a. Mollusc species found as dead shells in the benthos of Lake Macquarie, NSW.

<table>
<tr><td></td><td>Phylum : Mollusca
Class: Bivalvia
Order: Ostreoida
Family: Anomiidae
Genus: Anomia

Remarks: Genus of saltwater clam, marine bivalve mollusc. Known as "jingle shells". Common in both tropical and temperate oceans and live primarily attached to rock or other shells via a calcified byssus that extends through the lower valve. Anomia shells tend to take on the surface shape of what they are attached to; thus if an Anomia is attached to a scallop shell, the shell of the Anomia will also show ribbing.</td></tr>
<tr><td></td><td>Phylum : Mollusca
Class: Bivalvia
Order: Veneroida
Family: Veneridae
Genus: Katelysia
Species: Katelysia rhytiphora
Remarks: Commonly known as mud cockles, this group of commercially important bivalves often represents a major faunal component of shallow estuarine and marine embayments. K. rhytiphora is broadly distributed around Australia’s temperate coastline from Augusta, Western Australia to Port Jackson, New South Wales.</td></tr>
</table>

	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Ostreoida **Family:** Pectinidae Genus: Pecten **Remarks:** Genus of large saltwater clams or scallops. Marine bivalve mollusc.
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Ostreoida **Family:** Pectinidae **Genus:** *Chlamys* **Remarks:** Genus of saltwater clams or scallops. Marine bivalve mollusc.
	**Phylum :** Mollusca **Class:** Bivalvia **Order:** Ostreoida **Family:** Pectinidae **Genus:** *Saccostrea* **Species:** *Saccostrea glomerata* **Remarks:** Sydney rock oysters are endemic to Australia and New Zealand. In Australia it is found in bays, inlets and sheltered estuaries from Wingan Inlet in eastern Victoria, along the east coast of NSW and up to Hervey Bay QLD, around northern Australia and down the west coast to Shark Bay in WA. Sydney rock oysters are capable of tolerating a wide range of salinities (halotolerant). They are usually found in the intertidal zone to 3 metres (9.8 ft) below the low water mark.

Plate 3b. Gastropod species found as dead shells in the benthos of Lake Macquarie, NSW.

	**Phylum :** Mollusca **Class:** Gastropoda **Family:** Naticidae **Genus:** *Conuber* **Species:** Conuber sordidum **Remarks:** Species of predatory sea snail. A marine gastropod mollusc known commonly as the moon snail. Lives on intertidal muddy sand flats near mangroves or sea weed.
	**Phylum :** Mollusca **Class:** Gastropoda **Family:** Batillariidae **Genus:** Batillaria (Velacumantis) **Species:** Batillaria australis **Remarks:** The Australian Mud Whelk is a marine gastropod found on mud flats in estuaries, river mouths and mangrove swamps. The snail has a high resistance to predation and environmental tolerance, which may partially explain its success as an invasive species. This species is one of the hosts for the flatworm parasite *Austrobilharzia*. Larvae of the flatworm are discharged from the snail into the surrounding water. They normally burrow into the legs of wading birds and complete their life cycle, but may burrow though the skin of humans, causing "bathers itch".

Benthic organisms in the Study Area - September 2019

The organisms found living in the sediments of the mud basin off Summerland Point and in Chain Valley Bay and Bardens Bay were entered into an Excel worksheet. **Table 3** shows the organisms found in each replicate at each station sampled in September 2019. Data for sieve box samples were separated from data obtained from core samples.

Table 3. Organisms found at Sampling Stations on 10th and 11th September 2019.

	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*				
C1.1	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0
C1.2	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
C1.3	0	1	0	0	0	3	1	0	0	0	0	0	0	0	0
C1.4	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0
C1.5	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0
C1.6	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
C1.7	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.6	0.4	0.0	0.0	0.0	1.8	1.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Mean cores	0.0	0.5	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	15	11	0	0	0	45	25	0	0	0	0	5	0	0	0
no./m2 (core)	0	10	0	0	0	50	0	0	0	0	0	0	0	0	0
No. species (box)	5														
No. species (core)	2														20

Control Station C2		Depth -4.50m AHD			56 366214	6332927	Sampled September 11-12th 2019								
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Planaria
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*				
C2.1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C2.2	2	0	0	0	0	6	3	0	0	0	0	0	0	0	0
C2.3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
C2.4	2	0	0	0	0	9	7	0	0	0	0	0	0	0	1
C2.5	1	1	0	0	0	10	1	1	0	0	0	0	0	0	0
C2.6	1	1	1	0	0	3	1	0	0	0	0	0	0	0	0
C2.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.4	0.6	0.0	0.0	0.0	5.0	2.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Mean cores	0.5	0.5	0.5	0.0	0.0	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	35	14	0	0	0	125	55	7	0	0	0	0	0	0	5
no./m2 (core)	10	10	10	0	0	30	10	0	0	0	0	0	0	0	0
No. species (box)	6														
No. species (core)	5														49

Control Station C3		Depth -5.50m AHD		56 366014	6333144		Sampled September 11-12th 2019								
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Bivalve	Planaria	Sponge
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*		Dosinia		
C3.1	1	1	0	0	0	4	0	0	0	0	0	0	0	0	0
C3.2	2	1	0	0	0	3	0	0	0	0	0	0	0	0	0
C3.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C3.4	1	0	0	0	0	2	0	0	0	0	0	0	0	1	0
C3.5	2	3	0	0	0	4	1	0	0	0	0	0	0	0	0
C3.6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C3.7	2	1	0	0	0	1	2	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.2	1.0	0.0	0.0	0.0	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Mean cores	1.0	1.0	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	30	25	0	0	0	65	5	0	0	0	0	0	0	5	0
no./m2 (core)	20	20	0	0	0	10	20	0	0	0	0	0	0	0	0
No. species (box)	5														
No. species (core)	4														26

Control Station C4		Depth -5.50m AHD		56 364260	6332794		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Planaria
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
C4.1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
C4.2	4	1	0	0	0	1	0	0	0	0	30	0	0	0	0	0
C4.3	5	5	0	0	0	4	0	0	0	0	0	1	0	0	0	0
C4.4	3	1	0	0	0	6	0	0	0	0	7	1	0	0	0	0
C4.5	7	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0
C4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4.7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Mean/station (boxes)	3.8	1.4	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	7.4	0.4	0.0	0.0	0.0	0.0
Mean cores	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
no./m2 (box)	95	36	0	0	0	90	0	0	0	0	185	10	0	0	0	0
no./m2 (core)	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0

Control Station C5		Depth -5.50m AHD		56 367701	6334510		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	*Dosinia*
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
C5.1	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5.2	0	5	0	0	0	2	1	0	0	0	0	1	0	0	0	0
C5.3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5.4	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
C5.5	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C5.6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5.7	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.4	3.0	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Mean cores	0.0	3.5	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
no./m2 (box)	35	75	0	0	0	15	10	0	0	0	0	10	0	0	0	0
no./m2 (core)	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)	4															
No. species (core)	1														29	

Control Station C6		Depth -5.50m AHD		56 363988	6332492		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
C6.1	2	0	0	0	0	2	0	0	0	0	0	0	0	1	0	
C6.2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	
C6.3	1	3	0	0	0	1	0	0	0	0	0	1	0	0	0	
C6.4	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	
C6.5	2	1	0	0	0	10	0	0	0	0	0	0	0	0	0	
C6.6	0	1	0	0	0	3	0	1	0	0	0	0	0	0	0	
C6.7	0	4	0	0	0	1	0	0	0	0	0	1	0	0	0	
Mean/station (boxes)	1.6	1.2	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	
Mean cores	0.0	2.5	0.0	0.0	0.0	2.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	
no./m2 (box)	40	30	0	0	0	75	0	0	0	0	0	10	0	5	0	
no./m2 (core)	0	50	0	0	0	40	0	10	0	0	0	10	0	0	0	
No. species (box)	5															
No. species (core)	4														32	

Control Station C7		Depth -5.50m AHD		56 364736	6334947		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Planaria	Dosinia
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
C7.1																
C7.2	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	2
C7.3	2	18	0	0	0	0	0	0	0	0	0	0	0	0	0	3
C7.4	4	4	0	0	0	1	1	0	0	0	0	0	0	0	0	0
C7.5	0	14	0	0	0	0	0	1	0	0	0	0	0	0	0	13
C7.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8
C7.7	1	6	0	0	0	1	0	0	0	0	0	0	0	0	0	2
Mean/station (boxes)	1.5	7.8	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
Mean cores	0.5	3.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.0
no./m2 (box)	38	196	0	0	0	6	6	6	0	0	0	0	0	0	0	113
no./m2 (core)	10	60	0	0	0	10	0	0	0	0	0	0	0	0	10	100
No. species (box)	6															
No. species (core)	4														52	

Station R1		Depth -4.50m AHD		56 364177	6331535		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Sponge
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
R1.1	1	5	0	0	0	2	0	0	0	0	0	0	0	0	0	1
R1.2	0	11	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R1.3	1	12	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R1.4	2	13	0	0	0	6	0	0	0	0	0	0	0	0	0	1
R1.5	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R1.6	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R1.7	0	4	0	0	0	5	0	0	0	0	0	1	0	0	0	0
Mean/station (boxes)	1.2	8.2	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Mean cores	0.0	2.5	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
no./m2 (box)	30	205	0	0	0	65	0	0	0	0	0	0	0	0	0	10
Mean cores	0	50	0	0	0	70	0	0	0	0	0	10	0	0	0	0
No. species (box)	4														62	
No. species (core)	2															

Station R2			Depth -4.50m AHD		56 365919	6330294		Sampled September 11-12th 2019									
		Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Sponge
Replicates		thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
R2.1		4	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0
R2.2		1	1	0	0	0	3	0	0	0	0	0	0	0	0	0	1
R2.3		0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0
R2.4		2	2	0	0	0	9	0	0	0	0	0	0	0	0	0	0
R2.5		2	2	0	0	0	6	0	0	0	0	0	0	0	0	0	
R2.6		0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R2.7		0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)		1.8	1.2	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Mean cores		0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)		45	30	0	0	0	132	0	0	0	0	0	0	0	0	0	
no./m2 (core)		0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	
No. species (box)		3															
No. species (core)		1														48	

Station R3 (now IM5)			Depth -5.50m AHD		56 364660	6332992		Sampled September 11-12th 2019								
		Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab
Replicates		thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*				
R3.1	IM5.1	3	2	0	0	0	3	0	0	0	0	0	0	0	0	0
R3.2	IM5.2	3	1	0	0	0	3	0	1	0	0	0	1	0	0	0
R3.3	IM5.3	0	3	0	0	0	4	1	0	0	0	0	1	0	0	0
R3.4	IM5.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R3.5	IM5.5	1	2	0	0	0	1	0	0	0	0	6	0	0	0	0
R3.6	IM5.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R3.7	IM5.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)		1.0	1.6	0.0	0.0	0.0	1.6	0.2	0.2	0.0	0.0	1.2	0.4	0.0	0.0	0.0
Mean cores		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
no./m2 (box)		25	40	0	0	0	39	5	5	0	0	30	10	0	0	0
no./m2 (core)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)		7														36
No. species (core)		0														

Station R4 (now IM6)			Depth -6.00m AHD		56 364771	6332763		Sampled September 11-12th 2019								
		Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab
Replicates		thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*				
R4.1	IM6.1	1	0	0	0	0	3	0	0	0	0	0	1	0	0	0
R4.2	IM6.2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
R4.3	IM6.3	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0
R4.4	IM6.4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R4.5	IM6.5	4	1	0	0	0	1	0	0	0	0	0	0	0	0	0
R4.6	IM6.6															
R4.7	IM6.7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)		1.8	0.4	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Mean cores		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
no./m2 (box)		45	10	0	0	0	25	0	0	0	0	0	15	0	0	0
no./m2 (core)		253	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)		4														
No. species (core)		1														19

Station R5 (now IM7)			Depth -6.00m AHD		56 364229	6333889		Sampled September 11-12th 2019								
		Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab
Replicates		thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*				
R5.1		2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
R5.2		0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
R5.3		3	1	0	0	0	2	0	0	0	0	0	0	0	0	0
R5.4		1	0	0	0	0	6	1	0	0	0	0	0	0	0	0
R5.5																
R5.6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R5.7		0	1	0	0	0	2	0	1	0	0	0	0	0	0	0
Mean/station (boxes)		1.5	0.3	0.0	0.0	0.0	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean cores		0.0	0.5	0.0	0.0	0.0	1.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)		38	6	0	0	0	69	4	0	0	0	0	0	0	0	0
no./m2 (core)		0	10	0	0	0	20	0	10	0	0	0	0	0	0	0
No. species (box)		4														
No. species (core)		3														19

Station R6 (now IM8)	Depth -6.00m AHD			56 364533	6334146		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Planaria
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					
R6.1	4	0	0	0	0	11	0	0	1	0	0	0	0	0	0	0
R6.2	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
R6.3	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
R6.4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R6.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R6.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R6.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.0	0.0	0.0	0.0	0.0	3.8	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean cores	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
no./m2 (box)	25	0	0	0	0	95	0	5	5	0	0	0	0	0	0	0
no./m2 (core)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)	4															
No. species (core)	0														26	

Station R7	Depth -6.00m AHD			56 366232	6333856		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Bivalve
Replicates	thin	mud	Terebellid	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					*Dosinia*
R7.1	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
R7.2	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
R7.3	3	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0
R7.4	4	4	0	0	0	5	0	0	0	0	0	0	0	0	0	0
R7.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R7.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R7.7	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	2.6	1.0	0.0	0.0	0.0	2.2	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Mean cores	0.0	1.5	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
no./m2 (box)	65	25	0	0	0	55	5	0	0	0	0	5	0	0	0	0
no./m2 (core)	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)	5															
No. species (core)	1														30	

Station R8	Depth -6.00m AHD			56 364323	63322010		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Bivalve
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					*Dosinia*
R8.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R8.2	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
R8.3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R8.4	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
R8.5	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
R8.6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R8.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.6	0.4	0.0	0.0	0.0	1.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean cores	0.5	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
no./m2 (box)	15	10	0	0	0	45	4	0	0	0	0	0	0	0	0	0
no./m2 (core)	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)	4															
No. species (core)	1														15	

Station R9	Depth -6.00m AHD			56 366232	6331210		Sampled September 11-12th 2019									
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle	Fish	Crab	Bivalve
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*					*Dosinia*
R9.1	1	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0
R9.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R9.3	2	1	0	0	0	5	0	0	0	0	0	1	0	0	0	0
R9.4	1	2	0	0	0	11	0	0	0	0	0	0	0	0	0	0
R9.5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R9.6	1	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0
R9.7	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.8	0.6	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Mean cores	0.5	2.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	20	15	0	0	0	145	0	0	0	0	0	5	0	0	0	0
no./m2 (core)	10	40	0	0	0	60	0	0	0	0	0	0	0	0	0	0
No. species (box)	4															
No. species (core)	3														37	

Station R10 Depth -6.00m AHD 56 365172 6334708 Sampled September 11-12th 2019

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactr*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab	Bivalve *Dosinia*
R10.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
R10.2	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	16
R10.3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	7
R10.4	0	5	0	0	0	0	0	2	0	0	0	0	0	0	0	30
R10.5	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	52
R10.6	10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8
R10.7	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	10
Mean/station (boxes)	0.8	3.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.8
Mean cores	6.0	0.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
no./m2 (box)	20	95	0	0	0	0	0	10	0	0	0	0	0	0	0	570
no./m2 (core)	120	10	0	0	0	0	0	20	0	0	0	0	0	0	0	180
No. species (box)	4															
No. species (core)	4														139	

Station R11 Depth -6.00m AHD 56 367072 6333638 Sampled September 11-12th 2019

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactr*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab	Bivalve *Dosinia*
R11.1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R11.2	3	6	0	0	0	0	0	0	0	0	0	1	0	0	0	0
R11.3	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R11.4	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R11.5	2	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R11.6	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
R11.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	2.6	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Mean cores	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
no./m2 (box)	65	79	0	0	0	0	0	0	0	0	0	5	0	0	0	0
no./m2 (core)	20	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
No. species (box)	3															
No. species (core)	2														36	

Station IM1 Depth -4.50m AHD 56 364738 6330734 Sampled September 11-12th 2019

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactr*	Bivalve *Trichomya*	Ophuroid	Barnacle	Sponge	Dosinia
IM1.1	3	0	0	0	0	6	1	0	0	0	0	0	0	0	0
IM1.2	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
IM1.3	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1
IM1.4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
IM1.5	0	1	0	0	0	5	0	0	0	0	0	0	0	0	0
IM1.6	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0
IM1.7	3	0	1	0	0	1	0	0	0	0	0	1	0	0	0
Mean/station (boxes)	1.0	0.4	0.1	0.0	0.0	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Mean cores	2.0	0.0	0.5	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
no./m2 (box)	25	10	4	0	0	85	5	0	0	0	0	0	0	0	5
no./m2 (core)	40	0	10	0	0	60	0	0	0	0	0	10	0	0	0
No. species (box)	6														
No. species (core)	4														26

Station IM2 Depth -4.50m AHD 56 364842 6332237 Sampled September 11-12th 2019

Replicates	Polychaete thin	Polychaete thick	Polychaete mud	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactr*	Bivalve *Trichomya*	Ophuroid	Barnacle	Sponge	Crab
IM2.1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
IM2.2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
IM2.3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
IM2.4	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
IM2.5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IM2.6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IM2.7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.3	0.1	0.2	0.0	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean cores	0.5	0.5	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
no./m2 (box)	32	4	5	0	0	15	5	0	0	0	0	0	0	0	0
no./m2 (core)	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
No. species (box)	5														
No. species (core)	2														13

Station IM3		Depth -5.50m AHD		56 364693	6332101		Sampled September 11-12th 2019						
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	*Anadara*	*Cyamiomactr*	*Trichomya*		
IM3.1	2	0	0	0	0	5	0	1	0	0	0	0	0
IM3.2	1	0	0	0	0	1	1	0	0	0	0	0	0
IM3.3	1	2	0	0	0	1	0	0	0	0	0	0	0
IM3.4	3	0	0	0	0	0	0	0	0	0	25	0	0
IM3.5	0	0	0	0	0	0	1	0	0	0	0	0	0
IM3.6	0	1	0	0	0	2	1	0	0	0	0	0	0
IM3.7	1	3	0	0	0	1	0	0	0	0	0	0	0
Mean/station (boxes)	1.1	0.9	0.0	0.0	0.0	1.4	0.4	0.2	0.0	0.0	3.6	0.0	0.0
Mean cores	0.5	2.0	0.0	0.0	0.0	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	29	21	0	0	0	35	10	5	0	0	89	0	0
no./m2 (core)	10	40	0	0	0	30	10	0	0	0	0	0	0
No. species (box)	7												
No. species (core)	4												

Station IM4		Depth -6.00m AHD		56 364673	6332705		Sampled September 11-12th 2019						
	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle
Replicates	thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Dosinia*	*Anadara*	*Cyamiomactr*	*Trichomya*		
IM4.1	1	0	0	0	0	1	0	0	0	0	0	0	0
IM4.2	1	0	0	0	0	2	0	0	0	0	0	0	0
IM4.3	0	0	0	0	0	6	1	0	0	0	0	0	0
IM4.4	0	1	0	0	0	3	0	0	0	0	0	0	0
IM4.5	2	0	0	0	0	0	1	0	0	0	0	0	0
IM4.6	1	1	0	0	0	0	0	0	0	0	0	1	0
IM4.7	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.8	0.2	0.0	0.0	0.0	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Mean cores	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
no./m2 (box)	20	5	0	0	0	60	10	0	0	0	0	0	0
no./m2 (core)	10	10	0	0	0	0	0	0	0	0	0	10	0
No. species (box)	5												
No. species (core)	3												

Twelve species of benthic marine organisms greater than 1 mm in size were recorded in the study area of Lake Macquarie during the 16th sampling period (10th to 11th September 2019). The fauna comprised three species of polychaete worm (Plate 1a); five species of bivalve (Plate 1c); one species of brittle star (Plate 1d); and one crab (**Table 3**). A total of 815 benthic marine organisms were captured by sieve boxes during the September 2019 survey of 22 stations.

In September 2019, the greatest numbers of organisms were taken at stations C2 (49), C4 (86), C7 (52), R1 (62), R2 (48), R10 (139), and IM3 (45).

The marine benthic organisms with the greatest abundance in September 2019 were the bivalves *Corbula truncata, Trichomya hirsuta* and jeuvenile *Dosinia sculpta.* (**Table 3**). Polychaete worms such as *Sthenelais pettiboneae* were also common (**Table 3**).

Table 4 shows the number of species found at each station between February 2012 and September 2019.

Table 4. Number of Species found at each Station from February 2012 to September 2019

Station	C1	C2	C3	C4	C5	C6	R1	R2	R3	R4	R5	R6	R7	R8	R9
Feb 2012	10	5	5	7			8	8	5	5					
Sept 2012	3	6	4	4			6	3	4	5					
March 2013	4	5	7	7			6	5	6	5					
Sept 2013	6	6	3	7			5	6	5	4					
March 2014	4	3	5	5			6	4	5	3	4	3			
Sept. 2014	3	4	4	8			6	5	6	6	3	3			
March 2015	3	3	5	3			5	3	6	5	3	3			
Sept. 2015	5	4	4	3			5	3	4	6	5	4			
March 2016	6	4	5	5	5		6	5	6	4	4	4	8		
Sept. 2016	7	3	6	5	4	8	8	4	5	6	6	7	7	5	8
March 2017	2	4	5	3	5	5	4	5	4	5	4	4	4	3	5
Sept. 2017	4	4	4	4	4	5	4	3	6	5	4	4	4	5	4
March 2018	4	4	8	4	4	3	7	8	5	4	6	3	4	3	4
Sept. 2018	3	4	4	6	5	5	4	4	5	5	5	4	6	4	5
March 2019	6	3	4	4	6	5	4	5	7	3	5	4	4	4	4
Sept. 2019	5	6	5	5	4	5	4	3	7	4	4	4	5	4	4

Station	C7	IM1	IM2	IM3	IM4	R10	R11
Feb 2012		7	4	4	5		
Sept 2012		4	4	3	5		
March 2013		7	5	5	5		
Sept 2013		4	3	4	5		
March 2014		5	9	4	5		
Sept. 2014		5	6	3	6		

March 2015		5	4	4	5		
Sept. 2015		5	5	4	4		
March 2016		6	6	3	4		
Sept. 2016		6	4	6	3		
March 2017		3	4	3	4		
Sept. 2017		5	5	5	5		
March 2018	5	5	7	3	4	4	4
Sept. 2018	5	4	8	4	4	4	4
March 2019	3	5	5	2	4	6	6
Sept. 2019	6	6	5	7	5	4	3

Table 5 shows the mean number of marine benthic organisms for each station and species sampled in September 2019 (Sieve boxes only).

Table 5. **Opposite page** Mean number of marine benthic organisms for Control, Reference and Impact Stations (September 2019). Depths relative to AHD for each station are shown in the Table as well as the total number of organisms taken by the box samplers at each station.

Species not recorded alive during the September 2019 survey were *Nasarius jonasii* and *Bedeva hanleyi*.

The physical characteristics of the bottom water during the sampling period (September 10th and 11th 2019) were not measured successfully because of instrument failure early in the sampling.

Table of Mean Values

Biplot abreviation		1	2	3	4	5	6	7	8	10	9	13	11	12
	Depth (m)	Polychaete	Polychaete	Polychaete	Gastropod	Gastropod	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Bivalve	Ophuroid	Barnacle
		thin	mud	thick	*Nassarius*	*Bedeva*	*Corbula*	*Soletellina*	*Paphia*	Anadara	*Cyamiomactr*	*Trichomya*		
C1	-4.5	0.6	0.4	0.0	0.0	0.0	1.8	1.0	0.0	0.0	0.0	0.0	0.2	0.0
C2	-4.5	1.4	0.6	0.0	0.0	0.0	5.0	2.2	0.3	0.0	0.0	0.0	0.0	0.0
C3	-5.5	1.2	1.0	0.0	0.0	0.0	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0
C4	-6.0	3.8	1.4	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	7.4	0.4	0.0
C5	-6.0	1.4	3.0	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.0	0.4	0.0
C6	-5.5	1.6	1.2	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
C7	-5.5	1.5	7.8	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0
R1	-4.5	1.2	8.2	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R2	-4.5	1.8	1.2	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R3 (IM5)	-5.5	1.0	1.6	0.0	0.0	0.0	1.6	0.2	0.2	0.0	0.0	1.2	0.4	0.0
R4 (IM6)	-6.0	1.0	1.6	0.0	0.0	0.0	1.6	0.2	0.2	0.0	0.0	1.2	0.4	0.0
R5 (IM7)	-5.5	1.5	0.3	0.0	0.0	0.0	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0
R6	-6.0	1.0	0.0	0.0	0.0	0.0	3.8	0.0	0.2	0.2	0.0	0.0	0.0	0.0
R7	-6.0	2.6	1.0	0.0	0.0	0.0	2.2	0.2	0.0	0.0	0.0	0.0	0.2	0.0
R8	-5.5	0.6	0.4	0.0	0.0	0.0	1.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0
R9	-4.5	0.8	0.6	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.2	0.0
R10	-5.5	0.8	3.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
R11	-6.0	2.6	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
IM1	-4.5	1.0	0.4	0.1	0.0	0.0	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0
IM2	-4.5	1.3	0.1	0.2	0.0	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0
IM3	-5.5	1.1	0.9	0.0	0.0	0.0	1.4	0.4	0.2	0.0	0.0	3.6	0.0	0.0
IM4	-6.0	0.8	0.2	0.0	0.0	0.0	2.4	0.4	0.2	0.0	0.0	0.0	0.0	0.0

Sediment Analysis

The sediment in the mud basin of Lake Macquarie off Summerland Point, in Chain Valley Bay and Bardens Bay was largely composed of fine grey or black mud that sometimes was mildly plastic in nature (able to be molded into a coherent shape) or very fine and fluid, with a small amount of medium to fine black sand in some samples. Large amounts of large and small shell fragments were also present in the sediment at most stations sampled.

A description of the sediment samples collected in September 2019 is shown in **Table 7**.

Table 7. Description of Sediment collected from Sampling Stations in September 2019

		Volume mL
C1	Fine black mud	250
C2	Fine black mud with some shell	250
C3	Fine black mud	250
C4	Fine black mud and some shell	250
C5	Fine black mud with some shell	250
C6	Fine black mud and some shell	250
C7	Fine black mud with some shell	250
R1	Fine black mud with some black sand	250
R2	Fine black mud with some shell	250
R3 (IM5)	Fine black mud	250
R4 (IM6)	Fine black mud with some sand and shell	250
R5 (IM7)	Fine black mud	250
R6	Fine black mud with some shell	250
R7	Coarse shell, sand and some fine black mud	250
R8	Fine black mud with some shell	250
R9	Black mud with coarse shell	250
R10	Coarse sand with some black mud and shell	250
R11	Fine black mud with shell	250
IM1	Fine black mud, sand and coarse shell	250
IM2	Fine black mud and large shell fragments	250
IM3	Fine black mud and some shell	250
IM4	Fine black mud, sand and shell	250

Table 8 shows the percentage silt in the sediment at each station from February 2012 to September 2019.

Table 8. Percent mud in sediment from each station – February 2012 to September 2019.

	Feb 2012	Sept. 2012	Mar. 2013	Sept 2013	Mar. 2014	Sept. 2014	Mar. 2015	Sept. 2015	March 2016
	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud
C1	92	76	60	100	80	72	71	80	96
C2	92	80	60	96	76	77	75	100	96
C3	80	76	64	100	80	75	81	74	96
C4	80	78	64	55	80	75	81	70	96
C5									84
C6									
C7									
R1	80	80	88	40	60	82	80	80	96
R2	94	80	88	60	92	84	97	80	99
R3 IM5	80	82	72	80	88	87	84	80	100
R4 IM6	88	80	80	68	60	85	94	80	100
R5 IM7					80	75	88	65	100
R6					76	78	79	76	100
R7									80
R8									
R9									
R10									
R11									
IM1	86	72	68	84	60	77	79	44	100
IM2	80	75	45	60	70	87	78	80	96
IM3	96	75	53	65	72	77	78	75	100
IM4	80	73	56	64	55	86	85	79	98

	Sept. 2016	Mar 2017	Sept 2017	Mar 2018	Sept. 2018	March 2019	Sept. 2019		
	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	%Mud		
C1	90	68	94	80	80	80	100		
C2	80	92	80	80	64	70	100		
C3	90	80	100	92	80	100	100		
C4	75	98	100	80	40	80	100		
C5	90	92	80	92	64	60	80		
C6	80	92	100	84	60	70	100		
C7				80	60	80	100		
R1	70	96	100	80	80	80	96		
R2	90	80	92	80	84	84	80		
R3 IM5	9090	96	100	80	96	92	80		
R4 IM6	90	96	100	78	92	80	84		
R5 IM7	90	88	100	70	80	80	100		
R6	98	98	80	80	78	96	100		
R7	90	94	92	50	80	98	84		
R8	80	98	100	80	82	92	100		
R9	98	98	96	80	84	70	100		
R10				80	96	80	84		
R11				80	30	50	92		
IM1	90	76	96	80	60	80	80		
IM2	98	98	98	92	70	60	80		
IM3	99	96	100	92	96	80	92		
IM4	99	84	92	100	80	80	92		

Water Quality Profiles - September 2019

At each Station, a water quality profile was taken using a calibrated Yeo-Kal 611 Analyser. Measurements were taken at the surface and at 0.5m intervals to the lake bed (**Table 9**). Units of measurement were: Temperature (TEMP) - degrees Celsius; Conductivity (COND) - mS/cm; Salinity (SAL) - Parts per thousand; pH; Dissolved Oxygen - % saturation and mg/L; and Tubidity (TURB) - NTU.

In September 2019 the Yeo-Kal 611 malfunctioned quite early in the benthic sampling programme and gave no reliable data

In September 2019, water quality in the study area (Figure 1) was remarkably uniform. Very low rainfall for many months allowed the salinity of the water column to rise to around 4 parts per thousand above that of coastal waters. The pH was also very high for the same reason. The water column was clear allowing light penetration to the lake bed in some areas of the lake. In September 2018, this high water clarity led to some interesting effects on the benthos of the study area. First, the small seagrass *Halophila sp.* became established as a dense bed in 6 metres of water at Station R10 (Brightwaters Bay). Second, at Stations C4 and IM2, where beds of the hairy mussel *Trichomya hirsuta* are found, red and brown algae were observed to be growing on mussels at depths between 4.5 and 6m. In March 2019, the water column was also clear due to very low rainfall in the catchment but no *Halophila sp.* was found in 6m of water at station R10. No algae was found associated with mussel beds in March 2019.

In September 2019 the water column of Lake Macquarie had a salinity of 36 parts per thousand (down from 39 ppt) due to rainfall in August and September. A single healthy plant of *Zostera capricorni* was found growing in 6m of water at Station R10.

Analysis of Data

Statistics

Principal component (PC) biplots or multivariate scatterplots produced by the R-statistical program were used to explore the relationship between benthos study sites, animal species found in the sediment, and water quality variables at the lake bed. Points in the matrix were obtained by standardizing the data by subtracting the variable (column) mean from the species (cell) mean and dividing the subsequent value by the variable or column mean (Gabriel, 1971; Gabriel and Odoroff, 1990).

Biplots

A biplot is a particular kind of scatterplot used for displaying multivariate data which results from mapping a matrix of field observations, **X**, into a 2-dimensional graphical display. The name derives from the fact that this is a *joint* display of the rows and columns of **X**. Sample units (rows) are shown by points and variables (columns) by arrows. Biplots have several appealing properties. Firstly, they are capable of presenting graphically large amounts of information on composition, structure and relationships with surpassing ease and efficiency. It enables a truly global look at the data.

Interpretation of Biplots

Sample Points

- The proximity of any pair of sample points is directly proportional to their resemblance with respect to all the variables studied, the closer the points the greater the resemblance;
- Points close to the origin tend to be representative of the sample as a whole, that is, they tend to be average samples,
- Points far from the origin are atypical in that they possess usually large or small values of one or more variables.

Variable Arrows

- The origin of the configuration of arrows marks the mean value of each variable, an important reference point.
- Arrows can be extended through the origin (by eye) in either direction to any desired extent.
- With increasing distance from the origin along an arrow in the direction of an arrow, the value of the variable increases steadily above its mean; similarly, with increasing distance from the origin along an arrow extended by eye in the opposite direction, the value of a variable falls increasingly below its mean.
- Arrow length is directly proportional to the correlation coefficient, r, between the two variables. The smaller the angle the stronger the correlation. Variables x and y with arrows subtending an angle of:

  1. 0^o are perfectly correlated $r_{xy} = 1$
  2. 90^o are strictly uncorrelated $r_{xy} = 0$
  3. $0^o \leq$ Angle $< 90^o$ $0 \leq r_{xy} < 1$
  4. $90^o \geq$ Angle $\leq 180^o$ $0 < r_{xy} < -1$

From 3 it follows that variables whose arrows subtend angles less than 90^o are positively correlated, and from 4, that variables whose arrows subtend angles greater than 90^o are negatively correlated; in particular, where the angle is 180^o, $r_{xy} = -1$.

In general, long arrows can be regarded as more useful in interpretation than short arrows. They have greater influence in differentiating sites.

Relationship between benthic organisms, stations and water quality

Figure 5 shows a biplot representing the relationship between marine benthic organisms and stations for the September 2019 survey.

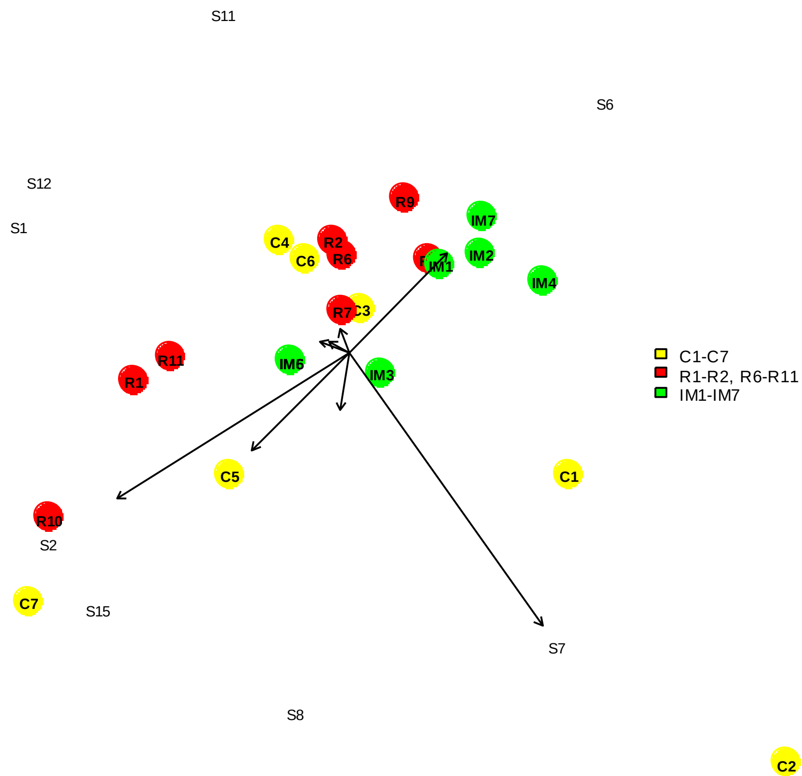


Figure 5. Relationship between benthic organisms and sampling stations – Lake Macquarie benthos survey September 2019 (PC biplot goodness-of-fit: 70.95%)

Station		Organism
C1 - Control Station C1	R8 - Reference Station R8	S1 *Sthenelais pettiboneae*
C2 - Control Station C2	R9 - Reference Station R9	S2 Polychaete mud
C3 - Control Station C3	R10 - Reference Station R10	S6 *Corbula truncata*
C4 - Control Station C4	R11 - Reference Station R11	S7 *Soletellina alba*
C5 - Control Station C5	IM1 - Impact Station IM1	S8 *Paphia undulata*
C6 - Control Station C6	IM2 - Impact Station IM2	S11 *Trichomya hirsuta*
C7 - Control Station C7	IM3 - Impact Station IM3	S12 Ophuroid
R1 - Reference Station R1	IM4 - Impact Station IM4	S15 *Dosinia sculpta*
R2 - Reference Station R2	IM5 - Impact Station IM5	
R6 - Reference Station R6	IM6 – Impact Station IM6	
R7 - Reference Station R7	IM7 – Impact Station IM7	

Five species differentiated sampling stations during the September 2019 sampling period:

- Reference Stations R10, R1, R11; Control Stations C5 and C7; and the Impact Stations IM5 and IM6 were defined by greater numbers of the Polychaete mud worm designated as S2.
- Reference Station R10 and the Control Station C7 were also characterised by relatively large numbers of *Dosinia sculpta*.
- The Impact Station IM3 was characterised by slightly higher numbers of *Paphia undulata* (S8), *Soletellina alba* (S7), and the bivalve *Corbula truncata*.
- The Control Stations C2 and C1 were also differentiated by the greater presence of *Soletellina alba.*
- The Impact Stations IM1, IM2, IM3, IM4, IM7; the Reference Stations R9, R8, R7, R6, R2; and the Control Station C3 were defined by greater numbers of *Corbula truncata.*

Conclusions

The results from the September 2019 benthic communities monitoring results show compliance to the Schedule 4 Environmental Conditions – underground mining of SSD5465 - Modification 2 in the Performance Measures table with respect to the Subsidence Impact Performance Measure for Benthic communities which displays nil to minor environmental consequences due to underground mining.

The below summary of findings outline the historical basis for this compliance statement and the compliance is detailed in the below table

Condition from SSD5465 - Mod 2	**Compliance Status and Comments**
Schedule 4 Environmental Conditions – underground mining Performance Measures - Natural Environment Biodiversity - Benthic Communities Subsidence Impact Performance Measure - Minor environmental consequences, including minor changes composition and/or distribution	Compliant – See section 16 - Conclusions
Measurements undertaken by generally accepted methods	Compliant – See sections 4 and 5
Measurements Methods fully described	Compliant – See sections 4 and 5

In September 2019, 22 benthic stations were sampled. The following is a history of benthos sampling from 2014 to 2019. By March 2014, mining beneath the lake had proceeded so that two Reference stations (R) had been re-designated Impact Stations (IM). They were:

R3 became IM5
R4 became IM6

By September 2014, Station R5 had also become an impact station, namely IM7.

In March 2016 two more stations were added to the sampling schedule. They were:

C5	GR 367701 6334310
R7	GR 366232 6333856

In September 2016, difficult geology beneath Bardens Bay and along parts of Summerland Point led Lake Coal to begin mining beneath Chain Valley Bay. To accommodate this change in mining direction, three additional benthos sampling stations were added. They were C6, R8 and R9.

C6	GR 363988 6332492
R8	GR 364523 6332010
R9	GR 365258 6331210

The total number of Stations sampled in September 2017 was 19.

In March 2018, three new stations were added to the sampling programme. They were:

C7	GR 366276 6334947
R10	GR 365172 6334706
R11	GR 367072 6333639

The mud basin off Summerland Point, in Chain Valley Bay and Bardens Bay, was found to be inhabited by 24 species of organisms greater than 1mm in size. This list was derived from the 16 samplings undertaken between February 2012 and September 2019. Polychaete worms and bivalve molluscs were the most frequently encountered animals.

Bottom sediment in the study area was composed of fine black mud with varying proportions of black sand and shell fragments.

Water levels in Lake Macquarie can vary by as much as 1.3m over the course of a year due to combinations of the following phenomena:

- Diurnal tidal changes (around 0.05m);
- Changes in atmospheric pressure (up to 0.4m);
- Wave set up at the entrance to Lake Macquarie;
- Inflow of water from the catchment during major rainfall events.

Light attenuation through the water column of Lake Macquarie, measured off Wyee Point, between 1983 and 1985, showed that only 14% of the photosynthetically active radiation (PAR) reached the lake bed at 2m depth (the growth limit of seagrasses and macroscopic algae in the LDO study area). At 6m depth, between 2% and 4% of the surface PAR reached the lake bed, not enough light to support the growth of seagrasses or benthic algae.

The 16 samplings of the benthos undertaken at six monthly intervals between February 2012 and September 2019 revealed the following:

The same suite of organisms dominated each of the 22 sample stations. These were polychaete worms and bivalves.

Stations were distinguished by the relative abundance of the dominant species.

Water depth was not in any way important in determining the species composition at a station.

Physical variables such as salinity (conductivity), dissolved oxygen concentration and turbidity of the bottom water, measured only on the day the benthos was sampled, had little influence on the species composition of the benthos over the period sampled. However, it is clear that major extinction events have occurred in the mud basin of Lake Macquarie. The evidence for this lies in the presence of large numbers of intact but dead bivalve shells entombed in the mud. The cause of extinction events appears to be prolonged dissolved oxygen depletion of bottom water. Prolonged dissolved oxygen depletion of the bottom water was measured during the water quality study conducted by Laxton and Laxton (1983 to 1997).

These results appear to support the notion that increasing the water depth by the predicted 0.8m subsidence has, to date, had no discernible effect on the composition and abundance of organisms making up the benthos of the mud basin.

In September 2018 a total of 1576 organisms were collected at the 22 stations. In March 2019 and September 2019 the total number of organisms found in sediment from the 22 stations was 832 and 815 respectively. This was around half the number of organisms collected in September 2018. This suggests that some extinction events have occurred recently.

Over the past 3 years, little significant rain has fallen in the catchments of Lake Macquarie. Over that period of time the salinity of the water column has become very high (over 39 parts per thousand by March 2019) and almost uniform from surface to bottom. The water of the lake became very clear for long periods. This high water clarity led to some interesting effects on the benthos of the study area. First, the small seagrass, *Halophila sp.* became established as a dense bed in 6m of water at Station R10 (Brightwaters Bay) in September 2018. *Halophila sp* was not recorded at Station R10 in March 2019 but in September 2019 a healthy plant of *Zostera capricorni* was found at this station. Second, at stations C4 and IM2, red and brown algae were found on mussels at depths between 4.5 and 6 m of water in September 2018.

In August and September 2019 some heavy rain fell in the catchment of Lake Macquarie. This rainfall lowered the salinity of water in the lake to around 36 parts per thousand.

In August and September 2019 some heavy rain fell in the catchment of Lake Macquarie. This rainfall lowered the salinity of water in the lake to around 36 parts per thousand.

In September 2019 some changes to the composition of the upper 100mm of the bottom sediments were detected. At Stations C1-C4 and C6-C7 no sand was present, just fine black silt. This indicated that these sediments had been reworked since March 2019. Sediments at Stations R5, R6 R8 and R9 also appeared to have been reworked.

For the first time in 16 samplings of sediments of Lake Macquarie large numbers of juvenile (3-4mm diameter) were found especially in sandy sediments.

References

Gabriel, K.R. (1971) The biplot graphical display of matrices with applications to principal component analysis. *Biometrika* 58: 453-525.

Gabriel, K.R. and Odoroff, C.L. (1990) Biplots in biomedical research. *Statistics in Medicine* 9: 469-485.

Laxton, J.H. and Emma Laxton (2007). Aquatic Biology of Chain Valley Bay Lake Macquarie, NSW. Report to Peabody/Lake Coal Chain Valley Colliery.

Lake Coal (20) Benthic Communities Management Plan

Acknowledgements

We wish to acknowledge the help of Mr Chris Ellis, Mr Wade Covey and Mr Chris Armit in facilitating the study.