Delta Coal

Mannering & CVC Collieries

Lake Macquarie Benthos Survey

Results No. 21

By Dr Emma Laxton

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Summary of survey findings

In March 2022, 22 benthic stations were sampled. The following is a history of benthos sampling from 2014 to 2022:

- By March 2014, mining beneath Lake Macquarie had proceeded so that two Reference stations (R) had been re-designated Impact Stations (IM), namely:

  R3 became IM5
  R4 became IM6.

- By September 2014, Station R5 had become the impact station 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 27 species of organisms greater than 1mm in size. This list was derived from the 21 samplings undertaken between February 2012 and March 2022. 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 lakebed at 2m depth (the growth limit of seagrasses and macroscopic algae in the Delta Coal study area). At 6m depth, between 2% and 4% of the surface PAR reached the lakebed, not enough light to support the growth of seagrasses or benthic algae.

The 21 samplings of the benthos undertaken at six monthly intervals between February 2012 and March 2022 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 and turbidity of the bottom water had little influence on the species composition of the benthos. Dissolved oxygen concentration, however, can have a major effect on abundance. 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). Low concentrations of dissolved oxygen in the bottom water were also recorded during the March 2020 sampling period. Stations with low abundance of organisms correlated with low concentrations of dissolved oxygen in the bottom waters.

- At the time of sampling, water depth does not determine species composition at a station.

- In the March 2022 survey species diversity or composition was consistent with previous years. A total of 1196 organisms greater than 1mm in size were found, comprising 10 species. This compared with the results from March 2017, March 2018, March 2019, March 2020 and March

2021 where 1031, 1160, 832, 1032 and 797 organisms respectively were recorded representing approximately twelve species.

- As in previous years, polychaete worms and bivalve molluscs were the most frequently encountered animals in the March 2022 survey. Stations were distinguished by the relative abundance of the dominant species.

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

Rainfall effects the salinity of Lake Macquarie. Annual rainfall in the Cooranbong (Lake Macquarie AWS) region was 839.8 mm in 2017; 859.8 mm in 2018; 763.4 mm in 2019; and 1496.4 mm in 2020 (BOM Station Number 061412). This lack of rainfall in the Lake Macquarie catchment had the effect of raising the concentration of salinity in the water column of Lake Macquarie. In March 2019, salinity was over 39 parts per thousand and almost uniform from surface to bottom.

The Lake Macquarie region received relatively heavy rainfall in August (111.2 mm) and September (64.8 mm) 2019; and January (79.6 mm), February (335.4 mm), March (173.0 mm), July (184.0 mm), October (150.8 mm) and December (220.6 mm) 2020. The catchment also received rainfall in January (104.8 mm) and February (155.8 mm) 2021 (BOM Station Number 061412). This rainfall lowered the salinity of water in the lake to around 36 parts per thousand in 2019, 33 parts per thousand in March 2020, and 32 parts per thousand in August 2020. Monthly rainfall for the Cooranbong region in January and February 2022 was 152.2 mm and 247.6 mm respectively. At the time of sampling, a further 268.8 mm had fallen in the catchment. Mean salinity of Lake Macquarie bottom waters is currently 32.89 parts per thousand.

Rainfall also influences water clarity. During periods of low rainfall, the water profile of the lake becomes very clear. Long periods of high water clarity effected 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, red and brown algae were found on mussels at depths between 4.5 and 6 m of water in September 2018 at stations C4 and IM2, and on mussels at stations R3 and IM2 in March 2021. Recent heavy rainfall, however, has increased the turbidity and greatly reduced water clarity in the lake. The water is brown in colour. A combination of freshwater, lower dissolved oxygen and possibly an increase in sediment is likely responsible for the smaller than usual number of living mussels collected during the March 2022 survey.

In general, water temperature, conductivity, salinity, and pH were found to be uniform from surface to bottom. During the March 2021 sampling period, for instance, water temperature throughout the water column ranged from 24.18^{o}C to 27.04^{o}C; conductivity ranged from 51.68 ms/cm to 52.04 ms/cm; salinity ranged from 33.96 parts per thousand to 34.23 parts per thousand; and pH ranged from 7.90 to 8.06.

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. In March 2020, changes were again detected. Sediments at stations C5 and C7 comprised mostly of course black sand. In August 2020, sediment was mostly fine grey/black silt. The sediment collected during the March 2022 survey was largely fine grey silty mud with some shell fragments.

Note: AWS - Automatic Weather Station

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 lakebed 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 lakebed sufficiently remote from previous or proposed mining.
- Reference stations – R, areas of lakebed above subsidence areas of previous mining.
- Impact stations – IM, areas of lakebed 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 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 (March 2022) presents the results of the just completed 21st 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 twenty surveys (February 2012 to September 2021). The benthic survey was conducted between the 5th and 18th March 2022. Water quality variables were measured on 5th and 18th March 2022. The work in March 2022 was supervised by Mr Lachlan McWha of Delta Coal.

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 October 2019. **Table 1** provides the exact location of each sampling station by latitude and longitude and by eastings and northings using WGS84 datum. **Figure 2** shows the extent of mining from March 2021 to March 2022.

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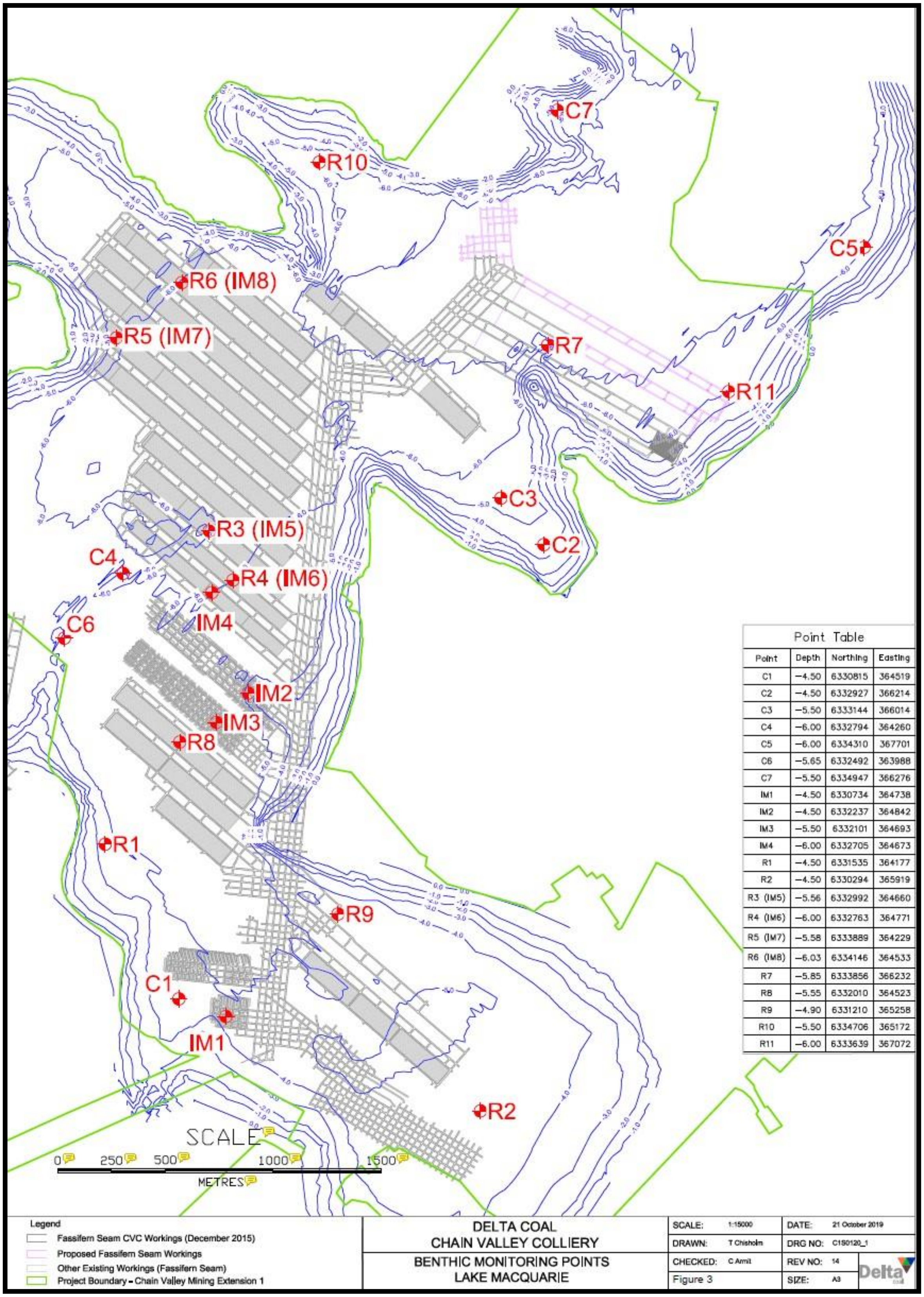


Point Table

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 1. Location of Benthos Sampling Stations (March 2022).

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

Station	Sample depth (m) AHD	Latitude	Longitude	MG-56 Easting	MG56 Northing
C1	-4.50	S33º 09' 10.69"	E151º 32' 50.11"	364519	6330815
C2	-4.50	S33º 08' 02.89"	E151º 33' 56.65"	366214	6332927
C3	-5.50	S33º 07' 55.78"	E151º 33' 49.05"	366014	6333144
C4	-6.00	S33º 08' 06.35"	E151º 32' 41.17"	364260	6332794
C5	-6.00			367701	6334310
C6	-5.50			363988	6332492
C7	-5.50			366276	6334947
IM1	-4.50	S33º 09' 13.44"	E151º 32' 58.51"	364738	6330734
IM2	-4.50	S33º 08' 24.67"	E151º 33' 03.34"	364842	6332237
IM3	-5.50	S33º 08' 29.02"	E151º 32' 57.52"	364693	6332101
IM4	-6.00	S33º 08' 09.42"	E151º 32' 57.04"	364873	6332705
R1	-4.50	S33º 08' 47.18"	E151º 32' 37.31"	364177	6331535
R2	-4.50	S33º 09' 28.23"	E151º 33' 43.87"	365919	6330294
R3 (IM5)	-5.50	S33º 08' 00.10"	E151º 32' 56.72"	364660	6332992
R4 (IM6)	-6.00	S33º 08' 07.58"	E151º 33' 00.88"	364771	6332763
R5(IM7)	-5.50	S33º 07' 30.78"	E151º 32' 40.55"	364229	6333889
R6 (IM8)	-6.00	S33º 07' 22.56"	E151º 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

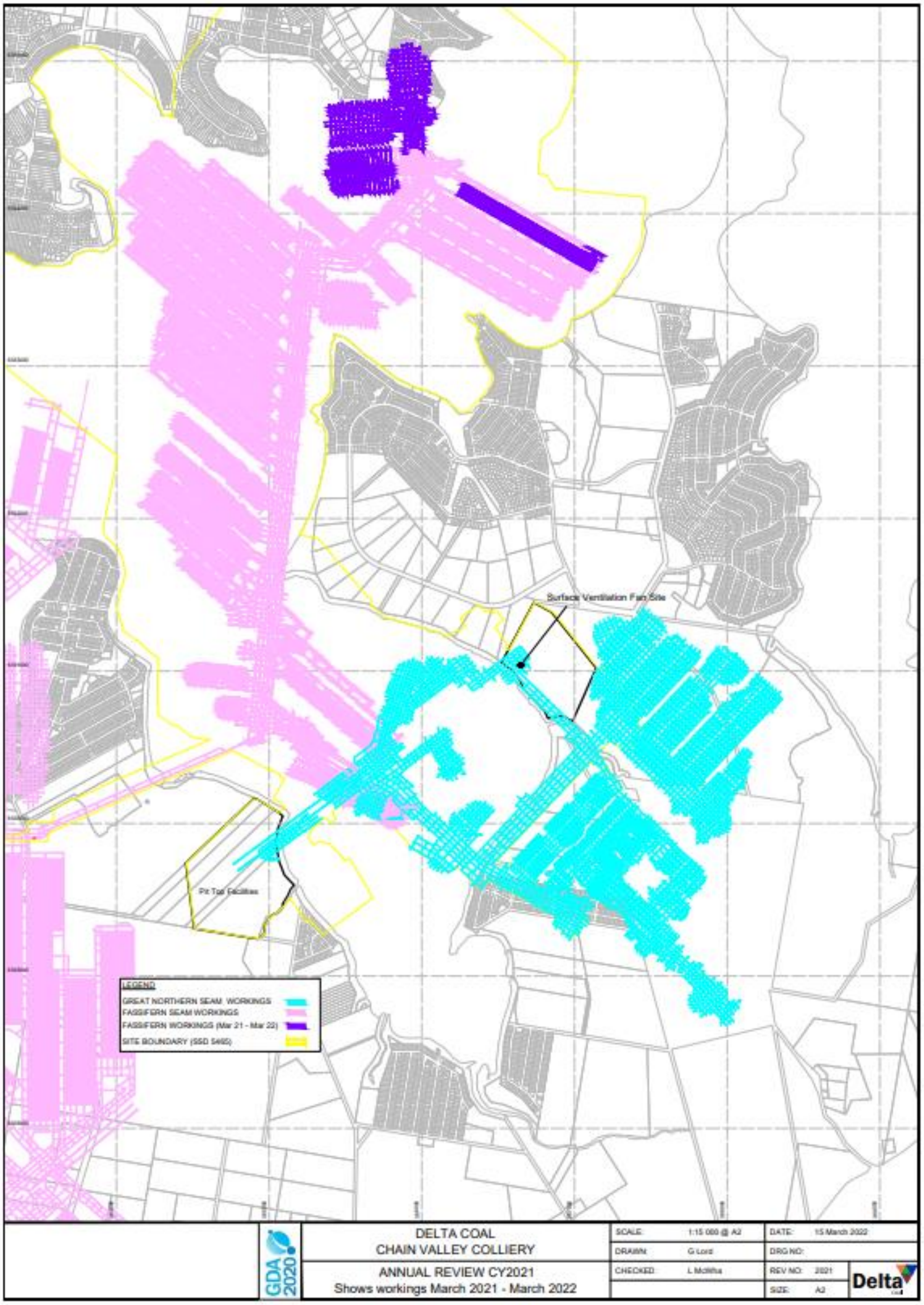


Figure 2. Extent of Fassifern Seam Workings from March 2021 – March 2022 (purple)

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, Dr 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.

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 180º 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 seabed. 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 lakebed. 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 2021, 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 March 2022. 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 overboard as the boat drifted into position.
- The diver descended to the lakebed 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.
- Water quality of bottom waters was measured using a calibrated Yeo-Kal 618 Water Quality Analyser. Water temperature, conductivity, salinity, pH, dissolved oxygen, turbidity and depth 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 freshwater.

- The cylinders were stoppered and shaken vigorously to suspend the sediment in the freshwater.
- The cylinders were then placed on the laboratory bench to allow the fractions of the sediment to settle.
- Once settled 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 final volume of sediment collected.

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 lakebed varied greatly (**Figure 3**).

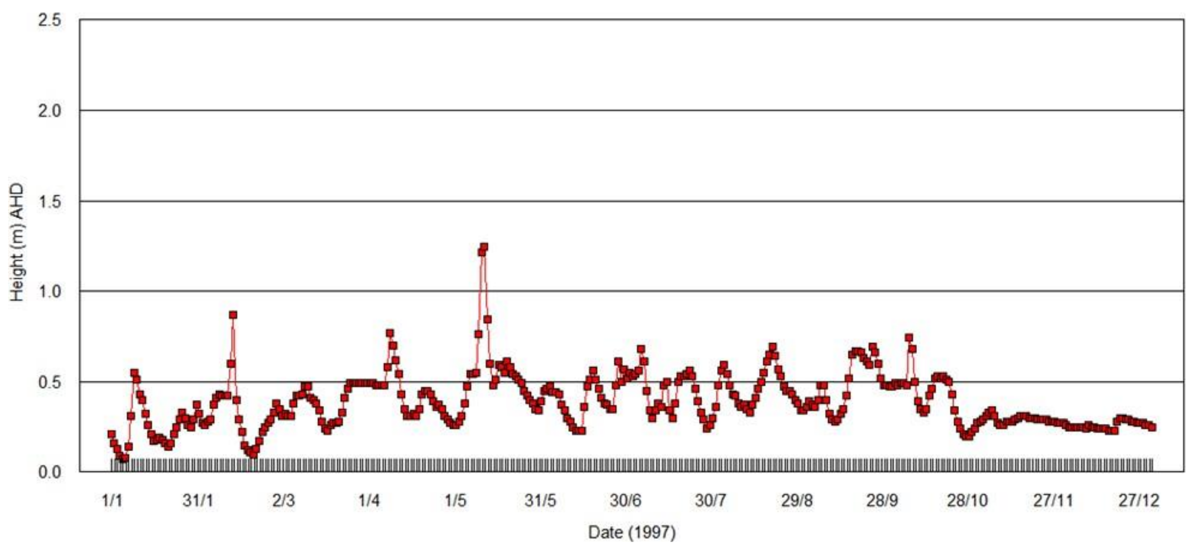


Figure 3. Water level changes in a coastal lagoon with an entrance open to coastal waters.

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

- The body of Lake Macquarie is 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 is reached, the tidal prism has been reduced to around 0.05m.

- The height of coastal waters and coastal lakes are influenced by changes in atmospheric pressure. The Tasman Sea acts as a huge barometer. When the atmospheric pressure is high the sea surface is depressed. This causes 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 is low, the surface of the sea bulges upwards. This raising of sea level causes water to flow into Lake Macquarie, increasing the water depth.

- Low pressure systems in the Tasman Sea almost always generate strong winds and coastal rainfall. The strong winds cause large swells to form that impact the coast. Wave setup at the entrance to Lake Macquarie causes the water level in the lake to rise as large volumes of seawater enter the system.

- Rainfall during a period of low atmospheric pressure causes runoff into catchment rivers and streams to increase. When this extra water reaches the body of Lake Macquarie, the water level rises in proportion to the runoff volume. This water is 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 can rise to heights of a meter or more above AHD (**Figure 3**).

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
Transmision 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	0.10	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)				

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 4** and **Figure 5**.

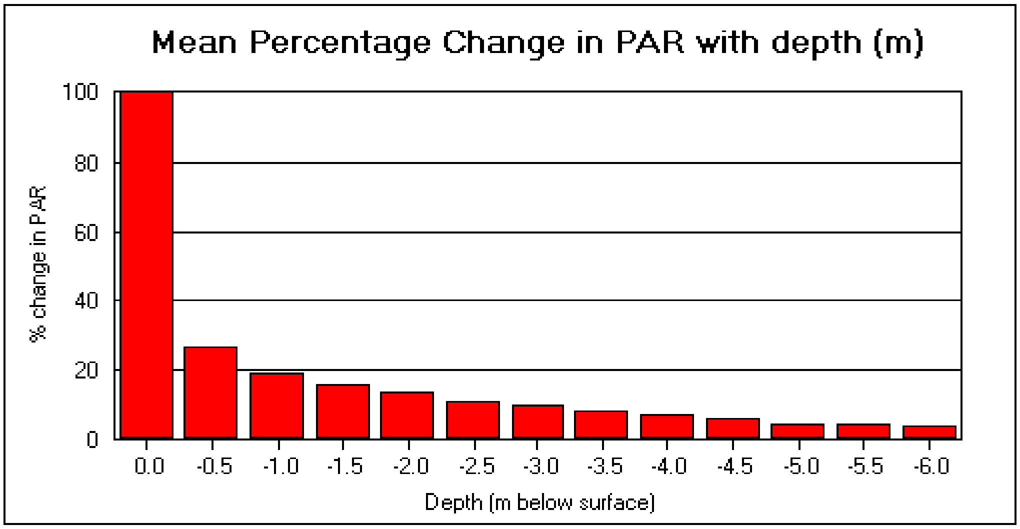


Figure 4. Mean percentage changes in PAR with depth at Station 1 - Wyee Point over 12 months.

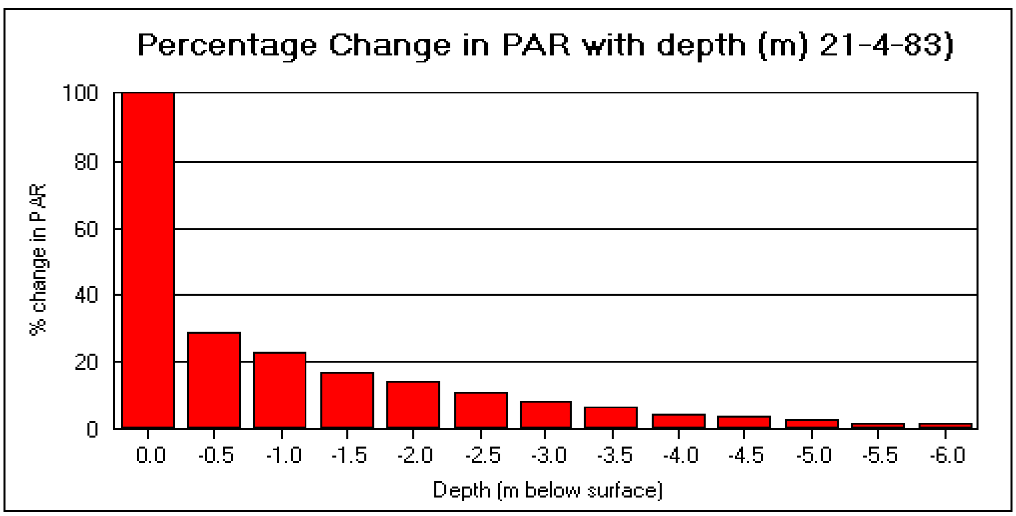


Figure 5. Actual percentage changes in PAR at Station 1 - Wyee Point on the morning of 21-4- 83.

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 March 2022

The following organisms were found in the sediment samples collected off Summerland Point and in Chain Valley Bay between February 2012 and March 2022:

Designated name	Family or Species	Comments
Anemone	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*	Uncommon. (Brown or pink bivalve)
Bivalve	*Anadara trapezia*	Uncommon.
Bivalve	*Dosinia sculpta*	Many juveniles found in sandy sediment in September 2019.
Bivalve	*Trichomya hirsuta*	Common as dead shells. Found in large clumps at C2, C6, R3, R7, IM2 and IM3.
Bivalve	*Saccostrea glomerata*	Found on mussels at C4 and C6 in 2021.
Ophuroid	Brittle star	Uncommon. Found amongst mussel clumps and on mud.
Echinoid	Sea urchin	Uncommon. Found at C5 and C7 in 2021.
Sponge	White calcareous sponge	Specimen found associated with mussels.
	Pink sponge	Small species found on mud surface.
	Red sponge	Several specimens found in 2019.
Crabs	Small	Uncommon.
Prawn	Small	One specimen taken in March 2013 at R3 and one specimen in September 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 **1f** 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 (February 2012 – March 2022).

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 many simple elongate filaments along the body. The genera are poorly defined.

Plate 1b. Gastropod species found in the benthos of Lake Macquarie (February 2012 – March 2022).

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 (February 2012 – March 2022).

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 found amongst the mussel beds of Lake Macquarie, NSW.

Phylum: Echinodermata

Class: Ophiuroidea

Order: Ophiurida

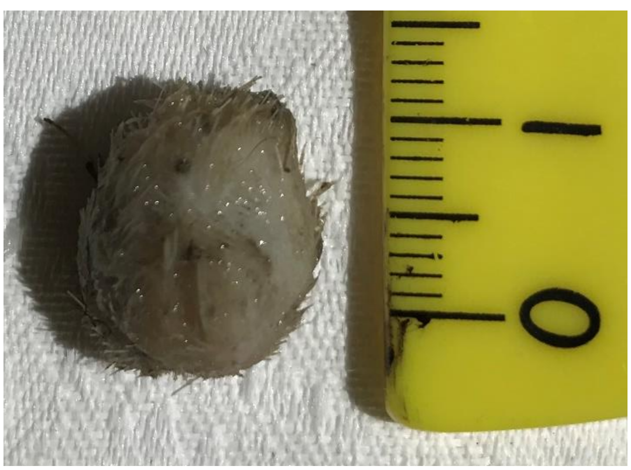
Family: Ophionereididae

Genus: *Ophionereis*

Species: *Ophionereis schayeri*

Remarks: Largest and most common brittle star found in Sydney waters. 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.

Plate 1e Sand dollar sea urchins found in Lake Macquarie, NSW



Phylum: Echinodermata

Class: Echinoidea

Order: Clypeasteroida

Remarks: Sand dollars are small in size. They possess a rigid skeleton called a test. The test consists of calcium carbonate plates arranged in a fivefold symmetric pattern.

Plate 1f Crab species found in Lake Macquarie, NSW

Phylum: Arthropoda

Class: Malacostraca

Order: Decapoda

Molluscs found as dead shells

Benthic organism samples collected between February 2012 and March 2022 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 **2f** 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 March 2022 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 March 2022:

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.

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.

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, NSW.

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 - March 2022

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 March 2022.

Table 3. Organisms found at Sampling Stations from 5th to 18th March 2022.

Control Station C1 Depth -4.50m AHD 56 364519 6330815 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
C1.1	0	0	2	0	0	1	2	0	0	0	0	0	0	0	0
C1.2	1	1	0	0	0	1	15	0	0	0	0	0	0	0	0
C1.3	4	0	3	0	0	3	8	0	0	0	0	0	0	0	0
C1.4	0	0	4	0	0	2	5	0	0	0	0	0	0	0	0
C1.5	1	0	2	0	0	0	15	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.2	0.2	2.2	0.0	0.0	1.4	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	30	5	55	0	0	35	225	0	0	0	0	0	0	0	0

No. species (box) **5** **Total Organisms at Station** **70**

Control Station C2 Depth -4.50m AHD 56 366214 6332927 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Planaria
C2.1	0	1	0	0	0	20	4	0	0	0	0	0	0	0	0
C2.2	0	1	0	0	0	0	5	0	0	0	0	0	0	0	0
C2.3	0	0	0	0	0	6	12	0	0	1	0	0	0	0	0
C2.4	1	2	1	0	0	0	14	0	0	0	0	0	0	0	0
C2.5	0	1	5	0	0	3	4	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.2	1.0	1.2	0.0	0.0	5.8	7.8	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	5	25	30	0	0	145	195	0	0	5	0	0	0	0	0

No. species (box) **6** **Total Organisms at Station** **81**

Control Station C3 Depth -5.50m AHD 56 366014 6333144 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Planaria	Sponge
C3.1	0	1	0	0	0	2	7	0	0	0	0	0	0	0	0
C3.2	0	1	3	0	0	0	29	0	0	0	0	0	0	0	0
C3.3	0	1	2	0	0	2	15	0	0	0	0	0	0	0	0
C3.4	0	0	0	0	0	2	14	0	0	0	0	0	0	0	0
C3.5	0	1	0	0	0	2	11	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.0	0.8	1.0	0.0	0.0	1.6	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	0	20	25	0	0	40	380	0	0	0	0	0	0	0	0

No. species (box) **4** **Total Organisms at Station** **93**

Control Station C4 Depth -5.50m AHD 56 364260 6332794 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Oyster *Saccostrea*	Ophuroid	Fish
C4.1	2	1	1	0	0	0	1	0	0	0	0	0	0	0	0
C4.2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C4.3	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
C4.4	0	1	0	0	0	0	6	0	0	0	0	0	0	0	0
C4.5	2	1	1	0	0	0	4	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.0	0.8	0.6	0.0	0.0	0.0	2.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	25	20	15	0	0	0	55	5	0	0	0	0	0	0	0

No. species (box) **5** **Total Organisms at Station** **54**

Control Station C5 Depth -5.50m AHD 56 367701 6334510 Sampled 5th to ?? March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Echinoid	Fish
C5.1	1	6	1	0	0	0	1	0	0	0	0	1	5	0	0
C5.2	0	1	2	0	0	0	1	0	0	0	0	0	8	0	0
C5.3	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0
C5.4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C5.5	0	4	1	0	0	0	0	0	0	0	0	0	3	0	0
Mean/station (boxes)	0.2	2.8	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0
no./m2 (box)	5	70	20	0	0	0	10	0	0	0	0	5	85	0	0

No. species (box) **6** **Total Organisms at Station** **39**

Control Station C6 Depth -5.50m AHD 56 363988 6332492 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Oyster *Saccostrea*	Ophuroid	Barnacle
C6.1	0	0	0	0	0	0	7	1	0	0	0	0	0	0	0
C6.2	0	1	0	0	0	3	7	0	0	0	0	0	0	0	0
C6.3	0	0	1	0	0	3	10	0	0	0	0	0	0	0	0
C6.4	0	0	0	0	0	4	8	0	0	0	0	0	0	0	0
C6.5	2	0	1	0	0	3	2	1	0	0	0	0	0	0	0
Mean/station (boxes)	0.4	0.2	0.4	0.0	0.0	2.6	6.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	10	5	10	0	0	65	170	10	0	0	0	0	0	0	0

No. species (box) **7** **Total Organisms at Station** **55**

Control Station C7 Depth -5.50m AHD 56 364736 6334947 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Echinoid	Barnacle
C7.1	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
C7.2	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
C7.3	3	2	1	0	0	0	0	0	0	0	0	1	0	0	0
C7.4	2	2	0	0	0	0	0	0	0	0	0	1	0	0	0
C7.5	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	3.0	3.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
no./m2 (box)	75	75	5	0	0	0	0	0	0	0	0	10	0	0	0

No. species (box) **4** **Total Organisms at Station** **33**

Station R1 Depth -4.50m AHD 56 364177 6331535 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
R1.1	0	2	2	0	0	1	8	0	0	0	0	0	0	0	0
R1.2	0	1	2	0	0	2	2	0	0	0	0	0	0	0	0
R1.3	2	2	0	0	0	0	4	0	0	0	0	0	0	0	0
R1.4	2	2	6	0	0	0	9	1	0	0	0	0	0	0	0
R1.5	1	3	0	0	0	1	8	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.0	2.0	2.0	0.0	0.0	0.8	6.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	25	50	50	0	0	20	155	5	0	0	0	0	0	0	0

No. species (box) **6** **Total Organisms at Station** **61**

Station R2 Depth -4.50m AHD 56 365919 6330294 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Fish
R2.1	0	0	8	0	0	5	10	0	0	0	0	0	0	0	0
R2.2	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
R2.3	1	0	0	0	0	2	10	0	0	0	0	0	0	0	0
R2.4	1	0	3	0	0	4	14	0	0	0	0	0	0	0	0
R2.5	0	0	2	0	0	3	17	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.4	0.0	2.6	0.0	0.0	3.2	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	10	0	65	0	0	80	265	0	0	0	0	0	0	0	0

No. species (box) **4** **Total Organisms at Station** **84**

Station R3 (now IM5) Depth -5.50m AHD 56 364660 6332992 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Fish	Crab
R3.1	3	3	1	0	0	1	1	1	0	0	6	0	0	0	0
R3.2	1	11	0	0	0	0	0	0	0	0	2	0	0	0	0
R3.3	0	4	0	0	0	0	0	0	0	0	0	0	1	0	0
R3.4	3	5	0	0	0	2	1	0	0	0	8	0	0	0	0
R3.5	0	2	0	0	0	0	0	1	0	1	2	0	0	0	0
Mean/station (boxes)	1.4	5.0	0.2	0.0	0.0	0.6	0.4	0.4	0.0	0.2	3.6	0.0	0.2	0.2	0.0
no./m2 (box)	35	125	5	0	0	15	10	10	0	5	90	0	5	5	0

No. species (box) **9** **Total Organisms at Station** **60**

Station R4 (now IM6) Depth -6.00m AHD 56 364771 6332763 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
R4.1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0
R4.2	0	4	0	0	0	0	5	1	0	1	0	0	0	0	0
R4.3	1	1	0	0	0	2	0	1	0	0	0	0	0	0	0
R4.4	1	1	0	0	0	1	5	0	0	0	0	0	0	0	0
R4.5	0	3	3	0	0	0	2	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.4	1.8	0.8	0.0	0.0	0.8	2.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	10	45	20	0	0	20	65	10	0	5	0	0	0	0	0

No. species (box) **7** **Total Organisms at Station** **35**

Station R5 (now IM7) Depth -6.00m AHD 56 364229 6333889 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
R5.1	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0
R5.2	0	0	2	0	0	1	4	0	0	0	0	0	0	0	0
R5.3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
R5.4	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
R5.5	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.4	0.0	0.8	0.0	0.0	0.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	10	0	20	0	0	20	40	0	0	0	0	0	0	0	0

No. species (box) **4** **Total Organisms at Station** **18**

Station R6 (now IM8) Depth -6.00m AHD 56 364533 6334146 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
R6.1	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0
R6.2	0	1	1	0	0	0	2	0	0	0	0	0	0	0	0
R6.3	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0
R6.4	0	2	0	0	0	1	2	0	0	0	0	0	0	0	0
R6.5	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.0	0.8	0.4	0.0	0.0	0.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	0	20	10	0	0	15	45	0	0	0	0	0	0	0	0

No. species (box) **4** **Total Organisms at Station** **18**

Station R7 Depth -6.00m AHD 56 366232 6333856 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Prawn
R7.1	0	7	7	0	0	0	3	2	0	1	6	0	0	0	0
R7.2	2	4	2	0	0	0	2	1	0	0	3	0	0	0	0
R7.3	2	3	0	0	0	0	2	0	0	0	15	0	0	0	0
R7.4	0	0	1	0	0	0	0	0	0	0	9	0	0	0	1
R7.5	2	3	1	0	0	0	0	0	0	1	0	0	0	0	0
Mean/station (boxes)	1.2	3.4	2.2	0.0	0.0	0.0	1.4	0.6	0.0	0.4	6.6	0.0	0.0	0.0	0.2
no./m2 (box)	30	85	55	0	0	0	35	15	0	10	165	0	0	0	5

No. species (box) **8** **Total Organisms at Station** **80**

Station R8 Depth -6.00m AHD 56 364323 63322010 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Fish
R8.1	0	0	0	0	0	5	4	0	0	0	0	0	0	0	0
R8.2	0	0	0	0	0	5	4	0	0	0	0	0	0	0	0
R8.3	0	0	1	0	0	8	5	0	0	0	0	0	0	0	0
R8.4	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
R8.5	0	0	0	0	0	2	7	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.0	0.0	0.2	0.0	0.0	4.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	0	0	5	0	0	100	130	0	0	0	0	0	0	0	0

No. species (box) **3** **Total Organisms at Station** **47**

Station R9 Depth -6.00m AHD 56 366232 6331210 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Fish
R9.1	2	0	0	0	0	3	11	0	0	0	0	0	0	0	0
R9.2	1	0	1	0	0	0	6	1	0	0	0	0	0	0	0
R9.3	1	0	0	0	0	1	9	0	0	0	0	0	0	0	0
R9.4	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0
R9.5	10	0	0	0	0	0	23	1	0	0	0	0	0	0	0
Mean/station (boxes)	2.8	0.0	0.6	0.0	0.0	0.8	10.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	70	0	15	0	0	20	255	10	0	0	0	0	0	0	0

No. species (box) **5** **Total Organisms at Station** **74**

Station R10 Depth -6.00m AHD 56 365172 6334708 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Fish
R10.1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R10.2	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0
R10.3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
R10.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R10.5	1	0	1	0	0	0	2	0	0	1	0	0	0	0	0
Mean/station (boxes)	0.2	0.2	0.6	0.0	0.0	0.2	0.8	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	5	5	15	0	0	5	20	0	0	5	0	0	0	0	0

No. species (box) **6** **Total Organisms at Station** **11**

Station R11 Depth -6.00m AHD 56 367072 6333638 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Fish
R11.1	0	4	1	0	0	1	0	0	0	0	0	0	1	0	0
R11.2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
R11.3	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
R11.4	1	4	2	0	0	1	0	0	0	0	0	0	0	0	0
R11.5	3	3	0	0	0	0	1	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.8	2.6	0.8	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
no./m2 (box)	20	65	20	0	0	10	10	0	0	0	0	0	5	0	0

No. species (box) **6** **Total Organisms at Station** **26**

Station IM1 Depth -4.50m AHD 56 364738 6330734 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Barnacle	Sponge
IM1.1	4	1	0	0	0	0	5	0	0	0	0	0	0	0	0
IM1.2	0	4	1	0	0	0	1	0	0	0	0	0	0	0	0
IM1.3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0
IM1.4	4	1	0	0	0	0	1	0	0	0	0	0	0	0	0
IM1.5	0	4	1	0	0	0	1	0	0	0	0	0	0	0	0
Mean/station (boxes)	2.0	2.4	0.4	0.0	0.0	0.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	50	60	10	0	0	5	40	0	0	0	0	0	0	0	0

No. species (box) **5** **Total Organisms at Station** **33**

Station IM2 Depth -4.50m AHD 56 364842 6332237 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Saccostrea*	Ophuroid	Sponge	Prawn
IM2.1	7	0	0	0	0	0	1	0	0	0	10	0	0	0	0
IM2.2	1	3	0	0	0	0	0	0	0	0	3	0	0	0	0
IM2.3	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0
IM2.4	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0
IM2.5	5	4	0	0	0	0	1	0	0	0	2	0	0	0	1
Mean/station (boxes)	3.8	2.4	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	3.4	0.0	0.0	0.0	0.2
no./m2 (box)	95	60	0	0	0	0	10	5	0	0	85	0	0	0	5

No. species (box) **6** **Total Organisms at Station** **52**

Station IM3 Depth -5.50m AHD 56 364693 6332101 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Ophuroid	Barnacle	Fish	Crab
IM3.1	0	0	0	0	0	3	11	0	0	0	0	0	0	0	0
IM3.2	1	1	0	0	0	1	11	0	0	0	0	0	0	0	0
IM3.3	1	0	0	0	0	1	6	0	0	0	0	0	0	0	0
IM3.4	2	0	1	0	0	2	5	0	0	0	0	0	0	0	0
IM3.5	0	1	0	0	0	0	9	0	0	0	0	0	0	0	0
Mean/station (boxes)	0.8	0.4	0.2	0.0	0.0	1.4	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
no./m2 (box)	20	10	5	0	0	35	210	0	0	0	0	0	0	0	0
No. species (box)	**5**										**Total Organisms at Station**				**56**

Station IM4 Depth -6.00m AHD 56 364673 6332705 Sampled 5 - 18 March 2022

Replicates	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Dosinia*	Bivalve *Anadara*	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Paphia*	Ophuroid	Barnacle	Fish
IM4.1	0	0	1	0	0	1	3	0	0	0	0	0	0	0	0
IM4.2	0	0	1	0	0	2	6	0	0	0	0	1	0	0	0
IM4.3	0	4	4	0	0	1	2	0	0	0	0	0	0	0	0
IM4.4	3	2	0	0	0	0	2	0	0	0	0	0	0	0	0
IM4.5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean/station (boxes)	1.0	1.8	1.2	0.0	0.0	0.8	2.6	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
no./m2 (box)	25	45	30	0	0	20	65	0	0	0	0	5	0	0	0
No. species (box)	**6**										**Total Organisms at Station**				**38**
												Total organisms			**1196**

A total of 1196 benthic marine organisms greater than 1 mm in size were captured in the study area of Lake Macquarie during the March 2022 survey of 22 stations (**Table 3**). Ten species of benthic marine organisms were found in the samples. The fauna included three species of polychaete worm (**Plate 1a**); six species of bivalve (**Plate 1c**); and one species of brittle star (**Plate 1d**).

In March 2022, the greatest numbers of organisms were collected at stations C3 (93 organisms), R2 (84 organisms), C2 (81 organisms), R7 (80 organisms), and C1 (70 organisms). The stations with the least numbers of organisms were R10 (11 organisms), R5 now IM7 (18 total), R6 now IM8 (18 total), R11 (26 total), IM1 (33 total), C7 (33 total), and R4 now IM6 (35 total) (**Table 3**).

Polychaete worms were common in the benthos, with means ranging from 0.2 to 3.8 organisms in each sample (**Table 5**). *Soletellina alba* and *Corbula truncata* were the most commonly occurring bivales in the benthic muds during the March 2022 survey (**Plate 1c**, **Table 3**). Small numbers of the bivalves *Paphia undulata* and *Dosinia sculpta* were also collected at several stations. The mussel *Trichomya hirsuta* was found alive at station R3 (now IM5), R7 and IM2 only (**Table 3**). The low water clarity, inflow of freshwater, and lower concentrations of dissolved oxygen are the likely causes of mussel mortality in the lake.

Table 4 shows the number of species found at each station between February 2012 and March 2022. It shows diversity has not changed significantly compared to previous years, and that diversity between Control, Reference and Impact stations do not vary greatly.

Table 4. Number of species found at each Station from February 2012 to March 2022

Station	C1	C2	C3	C4	C5	C6	C7	R1	R2	R3	R4
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
Sept 2014	3	4	4	8				6	5	6	6
March 2015	3	3	5	3				5	3	6	5
Sept 2015	5	4	4	3				5	3	4	6
March 2016	6	4	5	5	5			6	5	6	4
Sept 2016	7	3	6	5	4	8		8	4	5	6
March 2017	2	4	5	3	5	5		4	5	4	5
Sept 2017	4	4	4	4	4	5		4	3	6	5
March 2018	4	4	8	4	4	3	5	7	8	5	4
Sept 2018	3	4	4	6	5	5	5	4	4	5	5
March 2019	6	3	4	4	6	5	3	4	5	7	3
Sept 2019	5	6	5	5	4	5	6	4	3	7	4
March 2020	5	6	6	4	7	3	6	6	6	7	4
August 2020	6	5	4	4	3	5	5	4	5	7	4
March 2021	5	6	3	4	5	2	2	5	4	7	4
Sept 2021	4	4	7	6	7	7	6	5	4	8	3
March 2022	5	6	4	7	6	7	4	6	4	9	7

Station	R5	R6	R7	R8	R9	R10	R11	IM1	IM2	IM3	IM4
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	4	3						5	9	4	5
Sept 2014	3	3						5	6	3	6
March 2015	3	3						5	4	4	5
Sept 2015	5	4						5	5	4	4
March 2016	4	4	8					6	6	3	4
Sept 2016	6	7	7	5	8			6	4	6	3
March 2017	4	4	4	3	5			3	4	3	4
Sept 2017	4	4	4	5	4			5	5	5	5
March 2018	6	3	4	3	4	4	4	5	7	3	4
Sept 2018	5	4	6	4	5	4	4	4	8	4	4
March 2019	5	4	4	4	4	6	6	5	5	2	4
Sept 2019	4	4	5	4	4	4	3	6	5	7	5
March 2020	4	4	8	3	4	4	4	7	7	4	4
August 2020	7	5	8	4	5	5	4	5	6	4	6
March 2021	5	5	5	4	6	5	8	7	7	5	7
Sept 2021	4	4	7	3	4	6	7	3	7	4	4
March 2022	4	4	8	3	5	6	6	5	6	5	6

Table 5 shows the mean number of marine benthic organisms for each station and species sampled in March 2022. The table includes depths relative to AHD for each station.

Table 5 **Mean number of marine benthic organisms at Control (C), Reference (R) and Impact Stations (IM)**

	Depth (m)	Polychaete thin	Polychaete mud	Polychaete thick	Gastropod *Nassarius*	Gastropod *Bedeva*	Bivalve *Corbula*	Bivalve *Soletellina*	Bivalve *Paphia*	Bivalve Anadara	Bivalve *Cyamiomactra*	Bivalve *Trichomya*	Bivalve *Dosinia*	Ophuroid	Fish	Crab
C1	-4.5	1.2	0.2	2.2	0.0	0.0	1.4	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2	-4.5	0.2	1.0	1.2	0.0	0.0	5.8	7.8	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
C3	-5.5	0.0	0.8	1.0	0.0	0.0	1.6	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C4	-6.0	1.0	0.8	0.6	0.0	0.0	0.0	2.2	0.2	0.0	0.0	0.0	0.8	0.0	0.0	0.0
C5	-6.0	0.2	2.8	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0
C6	-5.5	0.4	0.2	0.4	0.0	0.0	2.6	6.8	0.4	0.0	0.0	0.0	0.2	0.0	0.2	0.0
C7	-5.5	3.0	3.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
R1	-4.5	1.0	2.0	2.0	0.0	0.0	0.8	6.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R2	-4.5	0.4	0.0	2.6	0.0	0.0	3.2	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R3 (IM5)	-5.5	1.4	5.0	0.2	0.0	0.0	0.6	0.4	0.4	0.0	0.2	3.6	0.0	0.2	0.0	0.0
R4 (IM6)	-6.0	0.4	1.8	0.8	0.0	0.0	0.8	2.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0
R5 (IM7)	-5.5	0.4	0.0	0.8	0.0	0.0	0.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R6	-6.0	0.0	0.8	0.4	0.0	0.0	0.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R7	-6.0	1.2	3.4	2.2	0.0	0.0	0.0	1.4	0.6	0.0	0.4	6.6	0.0	0.0	0.2	0.0
R8	-5.5	0.0	0.0	0.2	0.0	0.0	4.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R9	-4.5	2.8	0.0	0.6	0.0	0.0	0.8	10.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R10	-5.5	0.2	0.2	0.6	0.0	0.0	0.2	0.8	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
R11	-6.0	0.8	2.6	0.8	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IM1	-4.5	2.0	2.4	0.4	0.0	0.0	0.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IM2	-4.5	3.8	2.4	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	3.4	0.0	0.0	0.0	0.0
IM3	-5.5	0.8	0.4	0.2	0.0	0.0	1.4	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IM4	-6.0	1.0	1.8	1.2	0.0	0.0	0.8	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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

<u>Sample Points</u>

- 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 and stations

Figure 6 shows a biplot representing the relationship between marine benthic organisms and stations for the March 2022 survey.

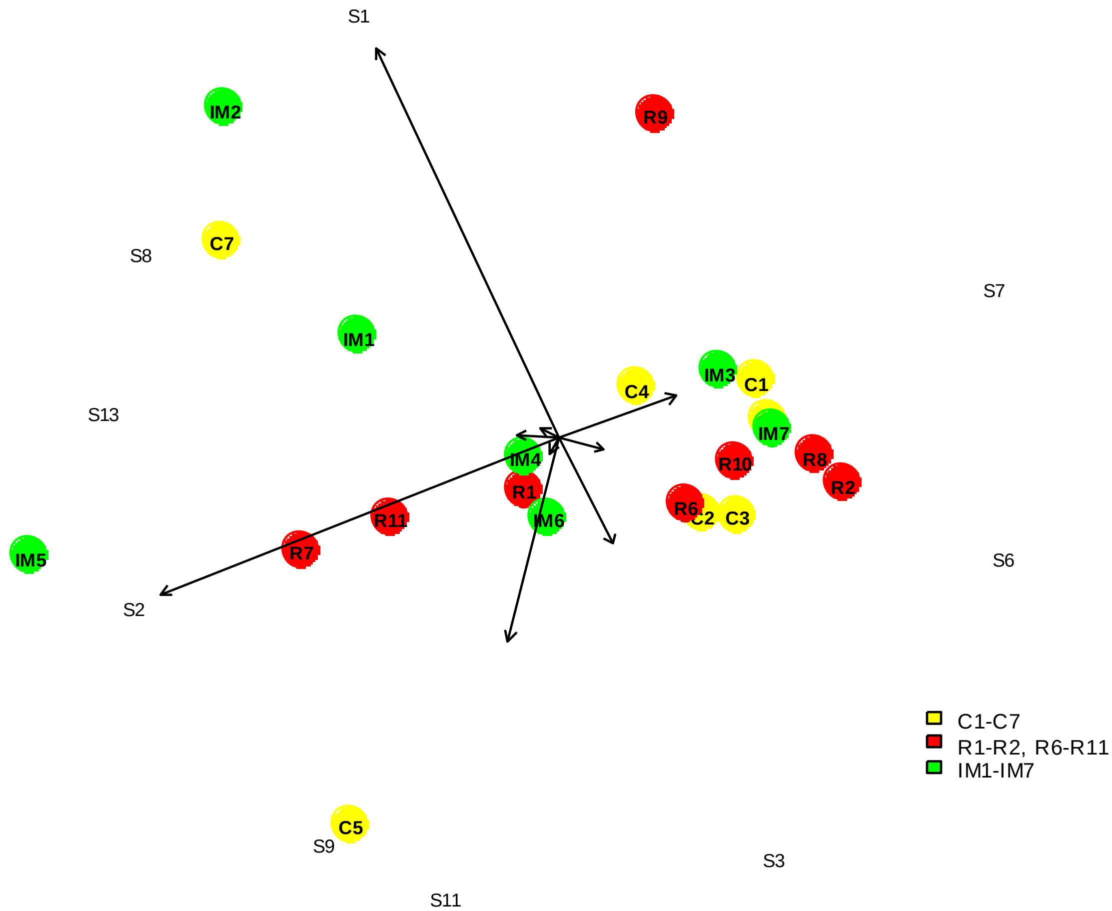


Figure 6. Relationship between benthic organisms and sampling stations – Lake Macquarie benthos survey March 2022 (PC biplot goodness-of-fit: 73.72%)

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	S3 Polychaete thick
C4 – Control Station C4	R11 – Reference Station R11	S6 *Corbula truncata*
C5 – Control Station C5	IM1 – Impact Station IM1	S7 *Soletellina alba*
C6 – Control Station C6	IM2 – Impact Station IM2	S8 *Paphia undulata*
C7 – Control Station C7	IM3 – Impact Station IM3	S9 *Cyamiomactra mactriodes*
R1 – Reference Station R1	IM4 – Impact Station IM4	S11 *Ophionereis schayeri*
R2 – Reference Station R2	IM5 – Impact Station IM5	S13 *Trichomya hirsuta* (mussels)
R6 – Reference Station R6	IM6 – Impact Station IM6	
R7 – Reference Station R7	IM7 – Impact Station IM7	

Six species differentiated sampling stations during the March 2022 sampling period (**Figure 6**):

- The Polychaete *Sthenelais petitiboneae* (S1) characterised the Control Station C7; the Impact Stations IM1 and IM2; and the Reference Station R9.
- The Polychaete mud worm designated S2 characterised stations IM4, IM5, R7 and R11.
- The bivalve *Soletellina alba* (S7) defined the Control Stations C1, C2, C3, C4; the Reference Stations R2, R8, R9, R10; and the Impact Stations IM3 and IM7.
- The bivalve *Corbula truncata* (S6) defined Stations C2, C3, R2 and R8.
- The bivalve *Trichomya hirsuta* differentiated the Reference Station R7 and the Impact Stations IM5.
- The Control Station C5 was characterized by the brittle star *Ophionereis schayeri*.

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/ black silty mud that was mildly plastic in nature (able to be molded into a coherent shape) or was very fine and fluid. Shell fragments were present in the sediment at most stations. The sediment at C5 consisted of fine to medium grey/black sand.

A description of the sediment samples collected in March 2022 is shown in **Table 6**.

Table 6. Description of Sediment collected from Sampling Stations in March 2022.

Station	Description	Volume (mL)
C1	Fine grey silty mud with some shell	250
C2	Fine grey silty mud	250
C3	Fine grey silty mud	250
C4	Fine grey silty mud	250
C5	Grey sand and silt	250
C6	Fine grey silty mud with some shell	250
C7	Fine grey silty mud with grey sand and some shell	250
R1	Fine grey silty mud with some grey sand	250
R2	Fine grey silty mud with shell fragments	250
R3 (IM5)	Fine grey silty mud with some shell fragments	250
R4 (IM6)	Fine grey silty mud with some shell fragments	250
R5 (IM7)	Fine grey silty mud with some shell fragments	250
R6	Fine grey silty mud with some shell fragments	250
R7	Fine grey silty mud	250
R8	Fine grey silty mud with some shell fragments	250
R9	Fine grey silty mud with some shell fragments	250
R10	Fine grey silty mud with some shell fragments	250
R11	Fine grey silty	250
IM1	Fine grey silty mud with some shell fragments	250
IM2	Fine grey silty mud with some shell fragments	250
IM3	Fine grey silty mud with some large shell fragments	250
IM4	Fine grey silty mud with some shell fragments	250

Table 7 shows the percentage of silt in the sediment at each station from February 2012 to March 2022.

Table 7. Percent mud in sediment from each station – February 2012 to March 2022

	Sep-16	Mar-17	Sep-17	Mar-18	Sep-18	Mar-19	Sep-19	Mar-20	Aug-20	Mar-21	Sep-21	Mar-22
	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud	% Mud
C1	90	68	94	80	80	80	100	94	90	75	95	95
C2	80	92	80	80	64	70	100	86	95	94	95	100
C3	90	80	100	92	80	100	100	96	100	82	100	99
C4	75	98	100	80	40	80	100	92	100	60	95	100
C5	90	92	80	92	64	60	80	29	80	35	70	75
C6	80	92	100	84	60	70	100	100	95	75	98	95
C7				80	60	80	100	29	90	61	80	90
R1	70	96	100	80	80	80	96	96	70	55	100	95
R2	90	80	92	80	84	84	80	80	80	60	90	90
R3 (IM5)	90	96	100	80	96	92	80	92	95	60	52	95
R4 (IM6)	90	96	100	78	92	80	84	98	75	79	95	95
R5 (IM7)	90	88	100	70	80	80	100	94	100	95	95	95
R6	98	98	80	80	78	96	100	92	85	95	85	95
R7	90	94	92	50	80	98	84	92	95	94	90	100
R8	80	98	100	80	82	92	100	92	90	95	95	99
R9				80	84	70	100	80	95	60	90	90
R10				80	96	80	84	80	80	75	85	95
R11				80	30	50	92	100	90	75	98	100
IM1	90	76	96	80	60	80	80	70	95	90	70	80
IM2	98	98	98	92	70	60	80	80	80	95	95	94
IM3	99	96	100	92	96	80	92	90	95	95	98	95
IM4	99	84	92	100	80	80	92	92	90	95	98	90

Water Quality Profiles – March 2022

At each station, water quality was determined using a calibrated Yeo-Kal 618RU Analyser. 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 Turbidity (TURB) - NTU (**Table 8**).

Up until recently, little significant rain has fallen in the catchments of Lake Macquarie. Annual rainfall in the Cooranbong (Lake Macquarie AWS) region was 839.8 mm in 2017; 859.8 mm in 2018 and 763.4 mm in 2019 (BOM Station Number 061412). The lack of rainfall caused the salinity of the water column to become very high (over 39 parts per thousand by March 2019) and almost uniform from surface to bottom. The Lake Macquarie region has since received relatively heavy rainfall in August (111.2 mm) 2019; February (335.4 mm), March (173.0 mm), July (184.0 mm), October (150.8 mm) and December (220.6 mm) 2020 (BOM Station Number 061412); and January (104.8 mm), February (155.8 mm) and March (421.6 mm) 2021. This rainfall lowered the salinity of water in the lake to around 36 parts per thousand in 2019, 33 parts per thousand in March 2020, and 32 parts per thousand in August 2020. Monthly rainfall for the Cooranbong region in January and February 2022 was 152.2 mm and 247.6 mm respectively. At the time of sampling, a further 268.8 mm had fallen in the catchment. Mean salinity of Lake Macquarie bottom waters is currently 32.89 parts per thousand (**Table 8**).

The physical characteristics of the bottom waters of Lake Macquarie in March 2022 were as follows:

- Water Temperature ranged from 24.73ºC to 27.26ºC. Mean water temperature was 25.41ºC.
- Conductivity ranged from 43.99 mS/cm to 52.76 mS/cm. Mean conductivity was 50.05 mS/cm.
- Salinity ranged from 28.63 ppt to 34.77 ppt. Mean salinity was 32.89 ppt.
- Turbidity ranged from 8.9 NTU to 15.9 NTU. Mean turbidity was 11.46 NTU.
- pH ranged from 7.44 and 7.99. Mean pH was 7.83.
- Dissolved oxygen (% saturation) ranged from 4.2% to 114.1%. Mean dissolved oxygen was 67.8% saturation.
- Dissolved oxygen (mg/L) ranged from 0.28 mg/L to 7.76 mg/L. Mean dissolved oxygen was 4.60 mg/L (**Appendix 1**).

The physical characteristics of the bottom water are shown in **Table 8**.

Table 8 Physical characteristics of the bottom water – March 2022

Station	Temperature °C	Conductivity mS/cm	Salinity ppt	Dissolved Oxygen % sat	Dissolved Oxygen mg/L	pH	Turbidity NTU	Depth m
C1	27.26	44.36	28.63	113.8	7.70	7.98	9.2	3.22
C2	25.58	51.30	33.68	84.1	5.67	7.97	11.7	4.41
C3	25.48	51.34	33.73	86.0	5.81	7.99	12.1	4.91
C4	24.73	51.89	34.1	4.2	0.28	7.44	8.9	6.13
C5	24.88	52.65	34.67	65.4	4.47	7.93	13.1	6.09
C6	25.28	52.17	34.35	72.0	4.84	7.93	12.8	4.82
C7	25.34	46.75	30.39	62.2	4.30	7.76	11.1	3.62
R1	25.84	51.11	33.54	87.0	5.86	7.94	10.9	3.05
R2	24.98	43.99	31.79	43.6	3.12	7.54	11.9	4.37
R3 (IM5)	25.19	52.49	34.57	63.7	4.32	7.9	9.2	6.80
R4 (IM6)	25.07	52.68	34.7	57.9	3.93	7.88	10.2	6.91
R5 (IM7)	25.53	47.43	30.74	53.7	3.69	7.64	12.7	4.14
R6	25.02	49.80	32.58	29.1	1.71	7.51	12.9	5.54
R7	24.9	52.76	34.77	61.9	4.19	7.9	12.5	7.17
R8	25.34	52.53	34.59	58.6	3.94	7.87	15.9	5.72
R9	25.92	44.79	28.92	105.5	7.28	7.99	9.3	2.30
R10	25.02	49.55	31.59	50.7	3.48	7.63	10.3	4.38
R11	24.91	52.44	34.52	73.3	4.98	7.97	12.4	6.30
IM1	26.9	44.72	28.78	114.1	7.76	7.98	9.1	3.81
IM2	25.68	51.25	33.65	84.2	5.71	7.97	10.9	3.86
IM3	25.17	52.58	34.63	55.6	3.75	7.85	9.7	6.17
IM4	25.09	52.50	34.57	64.9	4.40	7.79	15.3	5.95
Mean	25.41	50.05	32.89	67.8	4.60	7.83	11.46	4.99
Min	24.73	43.99	28.63	4.2	0.28	7.44	8.9	2.30
Max	27.26	52.76	34.77	114.1	7.76	7.99	15.9	7.17

Conclusions

The results from the March 2022 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 display nil to minor environmental consequences due to underground mining.

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

Conditions from SSD-5465 – Mod 3	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. Measures Methods fully described.	Compliant – See section 4 and 5 Compliant – See section 4 and 5

In March 2022, 22 benthic stations were sampled in the study area. A total of 1196 organisms greater than 1mm in size were found, comprising 10 species. This compares with the results from March 2017, March 2018, March 2019, March 2020 and March 2021 where 1031, 1160, 832, 1032 and 797 organisms respectively were recorded representing approximately twelve species. As in previous years, polychaete worms and bivalve molluscs were the most frequently encountered animals. 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 and turbidity of the bottom water had little influence on the species composition of the benthos. Dissolved oxygen concentration, however, can have a major effect on abundance. 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) and low dissolved oxygen levels were measured during the March 2020 benthic survey. In March 2022, dissolved oxygen levels of Lake Macquarie ranged from 4.2% saturation to 114.1% saturation. Surface waters had higher concentrations of dissolved oxygen than the bottom waters.

Bottom sediment in the study area was composed of fine black mud with varying proportions of black sand and shell fragments. In March 2020 some changes to the composition of the upper 100mm of the bottom sediments were detected. At Stations C5 and C7 the sediment comprised mostly sand where previously it was fine black silt. In March 2022, sediment comprised mostly of fine grey/black silty mud with some shell.

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

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