Zooplankton Sampling Program: December 2018 to December 2019

Technical Report A - Annexure C

AGL Gas Import Jetty Project

CEE Technical Report
Zooplankton Sampling Program
Lower North Arm, Western Port

December 2018 to December 2019

February 2020

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Report to:
[redacted]

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1 Background

AGL Wholesale Gas Pty Ltd (AGL) and APA jointly propose to develop a Liquid Natural Gas (LNG) import terminal at Crib Point in the Lower North Arm of Western Port in Victoria, Australia. They propose to moor a floating storage and regasification unit (FSRU) at Crib Point Jetty Berth 2, install gas offloading facilities on the jetty and construct a transfer pipeline between Crib Pt and Pakenham. AGL proposes to engage a contractor to supply and operate the FSRU facility, while APA will develop and operate the gas transfer pipeline.

The Victorian Minister for Planning (the Minister) decided that based on the referral documentation an Environmental Effects Statement under the EES Act was required. The Victorian EES process is an accredited assessment process under the EPBC Act. The Minister issued scoping requirements (Ministerial Guidelines) for the EES in February 2018. The Ministerial Guidelines along with the EES referral documents were used to design technical studies that fulfil the requirements for the Environmental Effects Statement.

EES referral documents (CEE, 2018a-e) identified the pathways by which the proposal may impact upon the Western Port marine ecosystem. The documents identified that the passage of relatively large volumes of seawater through the heat exchanger of the FSRU would entrain quantities of plankton. The seawater used in FSRU processes would be chlorinated to prevent marine growth developing within the pipework and heat exchangers, and therefore had potential to effect marine communities in Western Port.

One of the recommendations included in the EES referral was that a plankton sampling program be developed to provide information on spatial and temporal variations in plankton populations in Lower North Arm focussing on the proposed location and position of the FSRU intake. This information would be used to inform the evaluation of *"potential for significant short and long-term impacts on marine biota due to entrainment of organisms in seawater for regasification or due to discharge of cooled seawater after use for regasification, including impacts resulting from reduced availability of food for other species, resultant hydrodynamic changes and other impacts such as long-term changes to populations and distribution".*

This technical report describes the plankton community of Western Port from existing information and presents the rationale and methodology for the plankton sampling program, specifically the zooplankton sampling program. Summary results are also presented. It is one of three reports on the plankton, the others being the phytoplankton (microscopic algae) and ichthyoplankton (fish larvae).

Further discussion of the results in the context of hydrodynamic, entrainment and discharge modelling, zooplankton ecology, environmental guideline values and impact assessment are provided in separate EES related documents.

2 Introduction to plankton

Plankton are the microscopic plants and animals that live in the water column. Plankton communities, including the community in the North Arm of Western Port, comprise:

- Phytoplankton, which are the microscopic plants that photosynthesise and one of the key sources of primary production and food for small animals in Western Port and
- Zooplankton, which are the small animals of various feeding groups that provide a source of food for other filter feeding animals including other plankton, invertebrates on the seabed, jellyfish, larval fish and small fish.

Plankton comprise holoplankton that are the plants and animals that spend their entire life cycle drifting in the water columns, while meroplankton are the propagule or larval stages of larger plants or animals that are attached to the seabed or are free swimming.

Most plankton are weak swimmers and are carried horizontally by ambient water currents. Some plankton move vertically through the water column in response to time of day, this in known as diurnal migration. Others maintain themselves at a certain depth range in waters that are stratified by temperature or salinity layers. Others may be associated with certain seabed habitats, such as seagrass or mudflats in shallow water and have strategies to maintain their position on, in or close to those habitats.

The geographic differences in the combination of physical, chemical and biological character of Western Port were recognised by interdisciplinary marine scientists during the Western Port study in the 1970s (Harris *et al,* 1979, Hinwood 1979, Marsden 1979) who partitioned of Western Port into the arms, zones and segments shown in Figure 1. These areas remain relevant to environmental understanding and discussion 40 years later.

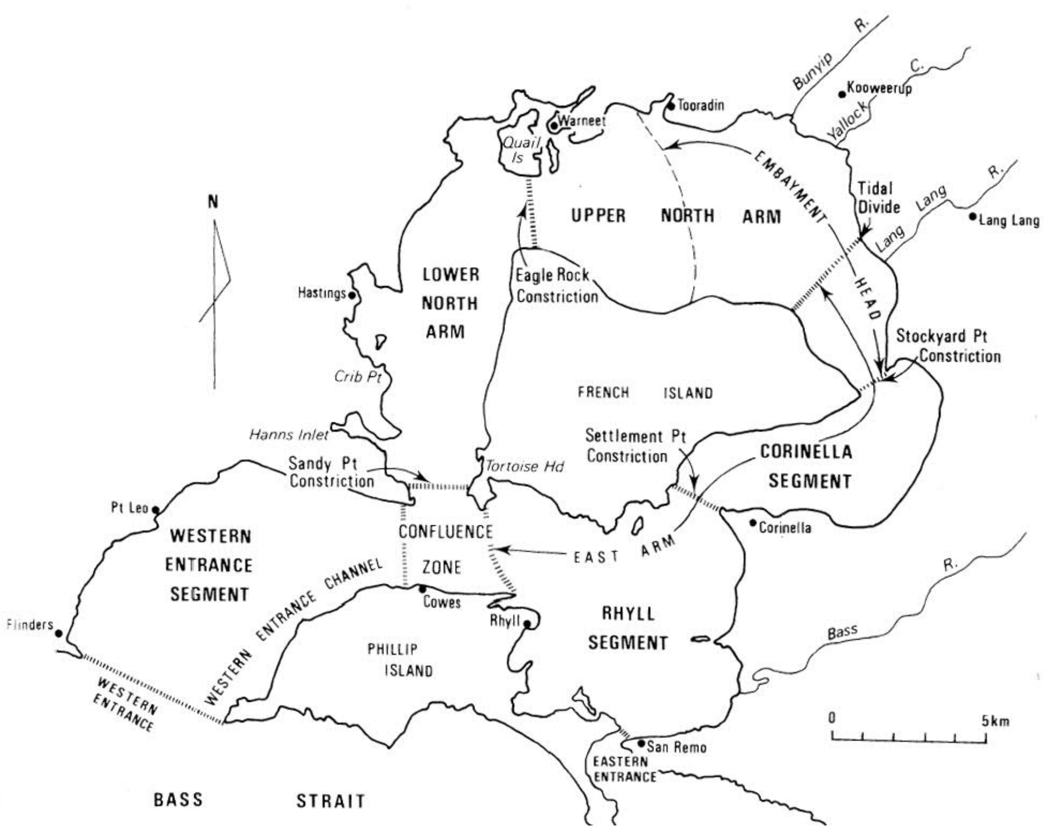


Figure 1. Environmental zone and features of Western Port

(Harris *et al* 1979, Marsden 1979)

The strong tidal water currents in the deeper main channels at Crib Point and throughout most of Western Port, result in thorough mixing of the water column and the planktonic biota it contains. The plankton in the mixed water column are transported back and forth for kilometres along the channels over each tide.

Wave action on the shallow intertidal mudflats and seagrass detritus from the extensive intertidal and subtidal seagrass beds results in relatively high amounts of suspended sediments and organic detritus in the water column in northern and eastern Western Port. Suspended material is highest in the shallow waters of the tidal divide in the northeast of the Bay, and reduces through North Arm and the Corinella and to very low concentrations at the Western Entrance near Flinders and Cape Grant as it mixes with the clear oceanic waters of Bass Strait (Kimmerer and McKinnon 1987, Longmore 1997).

2.1 Background to plankton in Western Port

A range of studies have documented the plankton community in Western Port. Zooplankton were studied in Western Port in 1971-72 (Macreadie 1972), 1973-74 (Arnott 1974 and Min Con 1975) and 1982 -84 (Kimmerer and McKinnon various). Phytoplankton were also studied during the 1973-74 Ministry for Conservation Western Port Study (Min Con 1975). Fish eggs and larvae have been surveyed episodically and usually associated with the southern part of the bay and the shallow and intertidal habitats (Acevedo *et al* 2010, Edgar and Shaw 1995, Hoedt and Dimmlich 1995, Robertson 1978, Robertson and Howard 1978). There have been no documentative studies of phytoplankton or zooplankton in North Arm since 1974. Studies of zooplankton in the 1980s focussed on the Corinella Rhyll and Western Entrance Segments, and although some samples were collected in North Arm, the results were not reported.

In recognition of the gap in information on plankton communities in North Arm and the potential effects of the operation of an FSRU at Crib Point and the potential effects of entrainment on the planktonic community of North Arm, a comprehensive program to sample plankton in North Arm was recommended and developed during the referral process in 2018. The monthly phytoplankton, chlorophyll-a, zooplankton and fish eggs and larvae (ichthyoplankton) sampling program was initiated in December 2018, two months prior to the release of the Ministerial Guidelines for the EES.

This technical report provides the results of a 13-month study on zooplankton in the project area. It is one of three reports on the plankton, the others being the phytoplankton (microscopic plants) and ichthyoplankton (fish larvae).

2.2 Previous zooplankton studies in Western Port

A range of studies have documented the plankton community in Western Port (Macreadie 1972, Arnott 1974 and Min Con 1975, Kimmerer and McKinnon 1985, 1987). All studies found that although all species found in Western Port were found throughout to Bass Strait and Port Phillip Bay and that all communities were dominated by copepods, the proportions of the key species were substantially different in northern Western Port. The key difference between Lower North Arm and Bass Strait, and Port Phillip was the numerical and ecological dominance of the zooplankton community in Western Port by a pair of *Acartia* species: *A. fancetti* and *A. tranteri* (McKinnon et al 1992). The two species are difficult to separate taxonomically and appear to occupy the same ecological position, so they are treated throughout the EES as a single entity, *Acartia* spp. While *Acartia* spp. dominate the upper arms of Western Port, the copepod *Paracalanus indicus* was more numerous than *Acartia* in Port Phillip and Bass Strait.

Western Port was sampled comprehensively by Kimmerer and McKinnon (1985) in 1982-1983, and further into 1984 (Kimmerer and McKinnon 1987a). During that period the bay ranged in temperature from 9.9 °C to 22 °C and in salinity from 33.4 to 37.8, leading to the conclusion that Western Port was not strongly estuarine. The high turbidity of the bay was highlighted by Secchi depths as shallow as 1.2 m in some areas; chlorophyll-a concentration was correlated inversely with Secchi depth. Residence times were calculated to be up to 60 days. Zooplankton were sampled at a group of 'central' stations in the north of the Rhyll Segment and southwest of the Corinella Segment. Samples were collected using a zooplankton net with a 0.5 m diameter mouth and 200 μm mesh size that was towed vertically from 1 m above the seabed - bottom to the surface. Populations that could live mostly close to the seabed (demersal) were not sampled. Initial analysis of variation in data resulted in spreading sampling effort over many stations instead of counting replicates from individual stations (Kimmerer and McKinnon 1985).

The zooplankton community was characterised by Kimmerer and McKinnon (1985) as comprising species that were either euryhaline marine or open coastal in nature, rather than showing estuarine affinities. Calanoid copepods, particularly *Acartia tranteri* (previously identified as *A. clausi*, Arnott 1974, cited in Kimmerer and McKinnon 1985) were the dominant group. The organisms identified as *Acartia tranteri* were likely to be a combination of two species, *A. tranteri* and *A. fancetti*, the latter representing up to 77% of *Acartia* spp. *Acartia* spp. contributed over 50% to total zooplankton abundance and they were particularly common at the 'central' stations. The second most abundant copepod species, which contributed less than 10% to total zooplankton, was *Paracalanus indicus* (previously identified as *P. parvus*); this species was common in waters north of Cowes, on the northwestern side of Phillip Island. Other less abundant copepods included *Pseudodiaptomus cornutus*, *Calanus australis* and *Bestiolina similis*.

Groups other than copepods generally occurred in lower numbers; for example, cladocerans were only represented by a few records of *Podon*, viz. *P. intermedius* and *P. polyphemoides* (Kimmerer and McKinnon 1985). Notably, gastropod larvae represented as high as 25% of the total, while crab larvae reached 4% of the total (Macreadie 1972). The water column above the seagrass-covered mudflats at Crib Point were common habitat for crab zoea and larvae of callianassid and carid shrimps (Robertson and Howard 1978), and larvae of the barnacle *Elminius covertus* were observed near Rhyll, on the northwestern edge of Phillip Island (Satumanatpan and Keough 2001). Planktonic carnivores occurred in low numbers. These included the copepod *Tortanus barbatus*, chaetognaths, ctenophores and medusae (Kimmerer and McKinnon 1985). The jellyfish *Catostylus mosaicus* was sampled in Westernport Bay and Port Phillip Bay in April and May 1998 (Hudson and Walker 1998).

The key findings of the previous studies were that:

- Zooplankton within Western Port were cosmopolitan species that were widely distributed in Southeastern Australia;
- Populations were strongly seasonal;
- Zooplankton populations (non-demersal) were distributed over the water column;
- The zooplankton community of inner Western ort was dominated by the *Acartia* group of copepods;
- *Acartia* spp. were well-adapted to the relatively high suspended solids concentrations within Western Port;
- The *Acartia* spp. population in Western Port was limited by food and adults may prey on early stages of its own species (cannibalism) and other zooplankton species at times;
- Predation pressure on *Acartia* spp. was generally low, although episodic occurrences of some predators may affect populations from time to time (years);

- The physical shape, geomorphology and hydrological characteristics of Western Port, particularly tidal flushing, were key factors in the spatial distribution of zooplankton along the Western Entrance, East and North Arms of Western Port.

3 Sampling for EES

The studies for the EES were designed to optimise integration of the hydrodynamic modelling, particle entrainment modelling and understanding of plankton community spatial and temporal variability and dynamics to assess the effects of entrainment on plankton populations from Berth 2 at Crib Point Jetty situated in the main channel in Lower North Arm, and implications for the Western Port ecosystem.

The key interest of the studies was to:

1. Characterise the key components of the North Arm Plankton community
2. Identify spatial patterns along or across the main channel of North Arm where the FSRU will be located that may indicate sensitivity of local populations to entrainment or cold-water discharge
3. Identify seasonal patterns that may inform assessment of impacts of the project under differing seasonal intake and discharge scenarios

The EES plankton studies recognised that water depth, water exchange, current speed, turbulence and proximity of seabed habitats are strong influences on the composition of plankton likely to pass the FSRU intake. The FSRU berthed at Crib Point Berth 2 would be located approximately 600 m offshore from the low tide mark, more than 500 m from the 2 m depth contour and approximately 450 m and 330 m offshore from the 5 m and 10 m depth contours (Chart Datum), respectively. The lower boundary of the nearest saltmarsh-mangrove community southeast and northeast of the Jetty would be more than 1,100 m from of the FSRU intake. The intake on an FSRU at Crib Point jetty would be located approximately 450 m offshore from the likely lower limit of subtidal seagrasses at Woolies Beach at Crib Point.

The studies aimed to document the planktonic character of the water mass of the main North Arm Channel that would be entrained by the FSRU. The methods used were those typically used to quantitatively sample phytoplankton, mesozooplankton (including some meroplankton) and ichthyoplankton (including larger invertebrate meroplankton). The equipment, methods and timing did not target particular species. All plankton sampling used depth integrated samples to sample the same depth band of the water column that would be drawn into the FSRU heat exchange intakes.

The study design was based on the 1982 to 1984 zooplankton investigations of Western Port and Port Phillip Bay (Kimmerer and McKinnon 1985, 1987a, b, c), which provide spatial and temporal information on zooplankton in East Arm and the Western Entrance.

In the EES study, plankton sampling was designed to provide spatial and temporal information comparable between different trophic levels. Samples of phytoplankton, zooplankton and ichthyoplankton were collected monthly for a 13-month period (December 2018 to December 2019) along approximately 19 km of the Lower North Arm Channel.

In addition to the monthly sampling, zooplankton and phytoplankton samples were collected at the Berth 2 site during downloading of the water temperature logger at Crib Point jetty, which occurred at intervals approximately half-way between monthly plankton surveys. These data are not included in this report, so that data are consistently based on monthly data for all sites.

Samples were collected at approximately monthly intervals using standard methods (see Section 3.3) at eight locations in spring and seven in summer, autumn and winter from December 2018 to December 2019. A total of 4 surveys were conducted in summer and 3 surveys in spring, autumn and winter, to provide seasonal replicates at sampling sites. These seasonal replicates allowed for a seasonal analysis of the plankton community in the Lower North Arm.

3.1 Sites

The location of monthly sampling sites is shown Figure 2. Sites were distributed along a central north-south axis from the north of Lower North Arm southward to the Confluence Zone; and a west-east axis from the 10 m depth contours on the west of Lower North Arm at Crib Point eastward to the 10 m contour on the eastern side of the main channel.

The north-south axis sites were positioned to document spatial variability along the tidal gradient in Lower North Arm: waters in the south of Lower North Arm are exchanged with Bass Strait water on a shorter time-scale than those in the north of Lower North Arm. These sites documented the plankton community at sites from near the extensive intertidal and shallow subtidal seagrass beds in Upper North Arm, to sites near the wave and current exposed deep channels in the Confluence Zone.

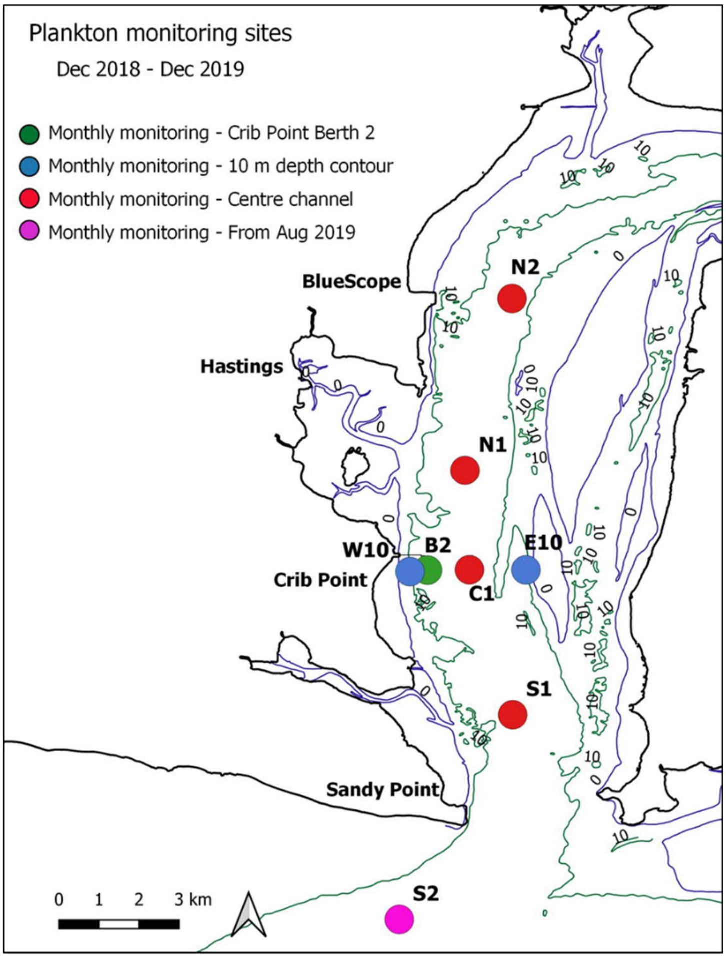


Figure 2. Plankton monthly sampling sites in Lower North Arm 2018-19, Western Port

Sites along the north-south axis were CPN2, CPN1, CPC1, CPS1 and CPS2. Site CPN1 is near a long-term water quality monitoring site used by EPA Victoria (Hastings) while site CPC1 is in the middle of the channel directly east of Crib Point Jetty Berth 2.

Site CPS1 at the south end of lower north arm was expected to show Bass Strait influence, particularly at high tide, due to its proximity to the Confluence Zone and Western Entrance segments. The first six months of the sampling program showed conditions at CPS1 were quite similar to other lower north arm sites regardless of tide. Therefore, site CPS2 in the confluence zone was added from August 2019 to assess plankton with greater Bass Strait influence.

Sites on the east-west axis were designed to document spatial variability between waters over different benthic habitats across the main North Arm channel at Crib Point. Sites on the 10 m contour east (CPE10) and west (CPW10) of Crib Point are each around 100 m from shallow subtidal and intertidal seagrass beds. The Crib Point Berth 2 site is at the location of the proposed FSRU where entrainment will occur and is adjacent to the jetty habitat created by the jetty piles. CPC1 represents mid-channel habitat. Selection of the 10 m depth contour for the east and west sites also considered extent of discharge plumes from the FSRU predicted during preparation of the EES referral: the cooler-water FSRU discharge will form a seabed or mid-water plume at depths greater than 10 m.

As discussed below, the timing of surveys was not synchronised with tides, so that the water body sampled at any of the sites on any sampling occasion could have originated from up to 7 km kilometres over the six hours prior to sampling. This essentially randomised the spatial horizontal position of individual samples and was consistent with the approach of Kimmerer and McKinnon (1985, 1987a).

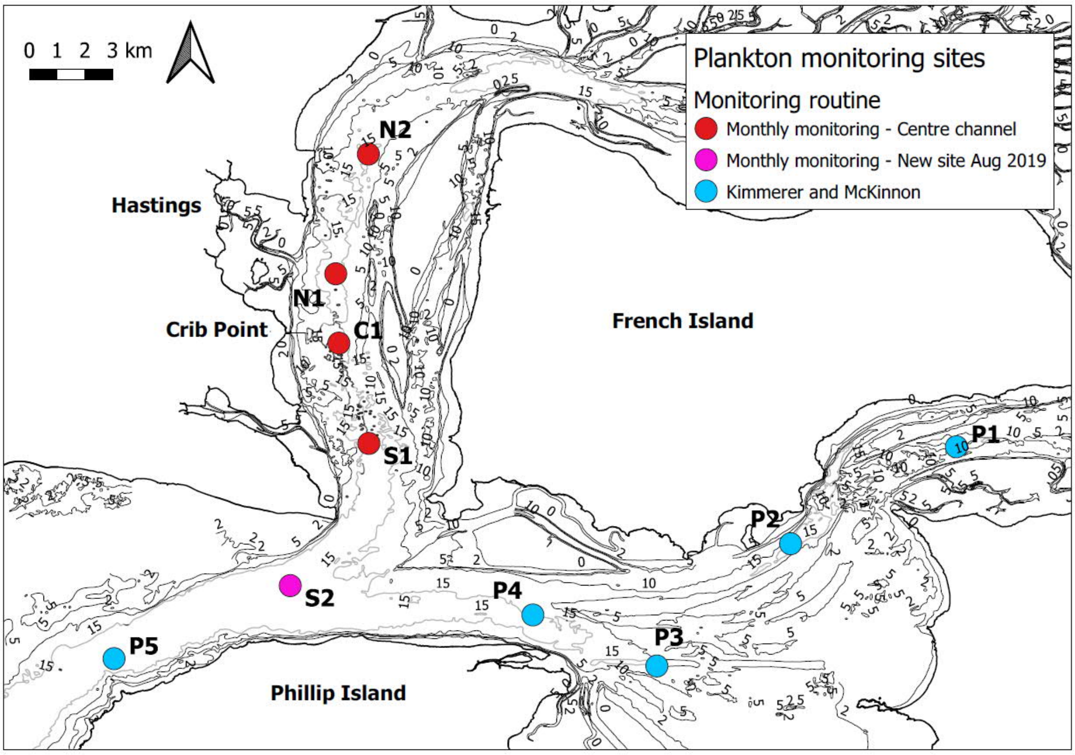


Figure 3. Plankton sampling sites North and East Arms Western Port, October 2019

3.1.1 Broad Scale Survey

An additional broad-scale, 'snapshot' survey in October 2019 was used to characterise the phytoplankton, zooplankton and water quality along two long transects from the Western Entrance up into East Arm (as far as Corinella) and North Arm (as far as the BlueScope wharves). Sites used in the broadscale study are shown in Figure 3. Sites CPP1 to CPP5 are in the same locations as those used by Kimmerer and McKinnon (1985) for which there is existing data on zooplankton communities. Sites CPS2 to CPN2 were the same sites as those used in regular sampling.

3.2 Timing

Phytoplankton, zooplankton and ichthyoplankton were sampled at each monthly site visit. Plankton at all sampling sites were sampled at approximately monthly intervals from December 2018 and December 2019 inclusive (13 surveys).

Monthly samples were collected during daytime only, when weather was suitable within approximately one week of the change in month. Mobilising to site, launching, sampling all sites, preserving samples and demobilising took a whole day per survey. Surveys or sampling were not synchronised with tides in any way.

Individual samples (phytoplankton, zooplankton, ichthyoplankton were collected during the same site visit. Phytoplankton and zooplankton samples were usually collected simultaneously. The vessel was usually relocated back to the approximate sample site position between the ichthyoplankton sample collection and the phytoplankton and zooplankton samples due to drift during sampling.

Each monthly survey was separated by a minimum of 3 and a maximum of 6 weeks. The sampling schedule is shown in Table 1.

Table 1. Plankton sampling summary, December 2018 to December 2019

Monthly Survey	Date	S2	S1	B2	W10	E10	C1	N1	N2
Survey 1	11/12/2018		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 2	10/01/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 3	4,11/02/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 4	07/03/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 5	04/04/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 6	03/05/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 7	07/06/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 8	03/07/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 9	02/08/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 10	03/09/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 11	1/10/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 12	30/10/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 13	11/12/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Total number of surveys		5	13	13	13	13	13	13	13

z = zooplankton, i = ichthyoplankton, p = phytoplankton

3.3 Zooplankton sampling methods

The zooplankton sampling equipment and collection method followed Kimmerer and McKinnon (1985, 1987a), so that results could be compared directly with the 1982 to 1984 sampling program. Following the approach of Kimmerer and McKinnon (1985), plankton sampling effort was spread over stations and frequency rather than replicates from individual stations in each survey.

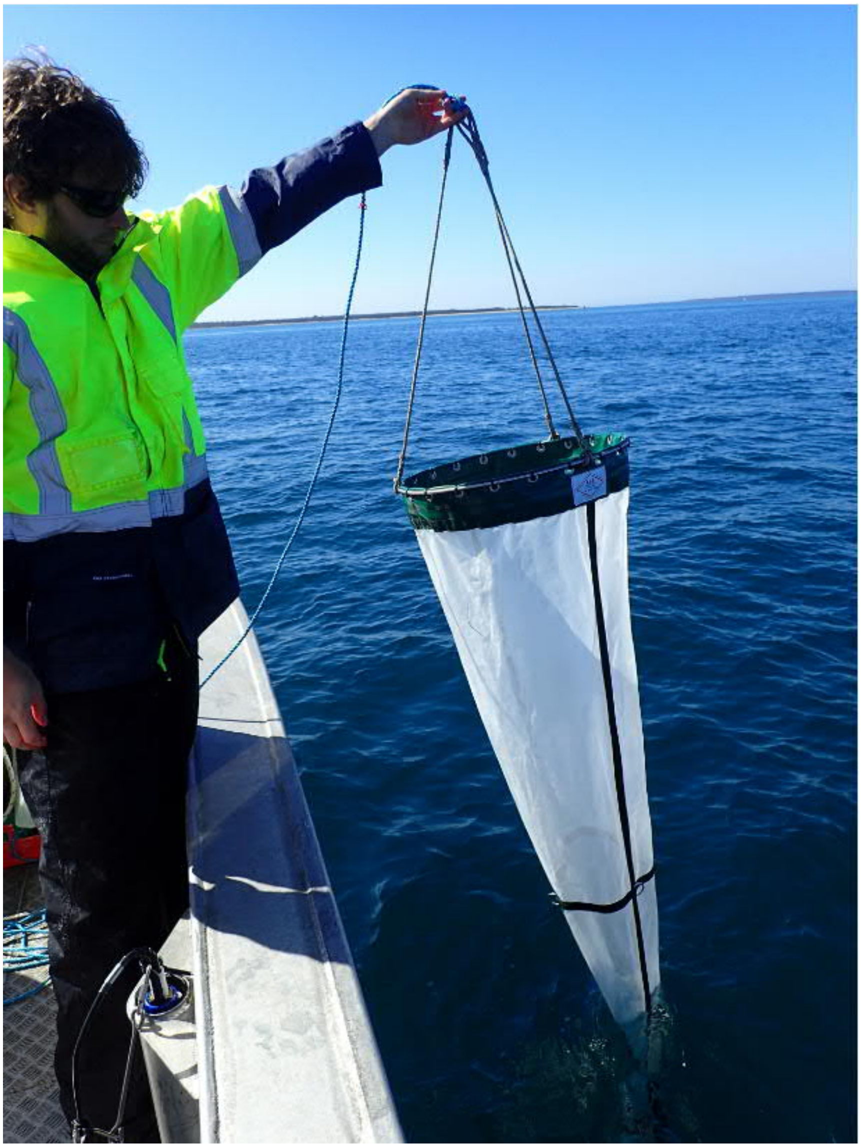


Figure 4. Zooplankton collection net

Kimmerer and McKinnon (1985) sampled zooplankton only, but in our case, effort on sampling and analysing phytoplankton, zooplankton and ichthyoplankton increased the integrated approach to data interpretation and assessment. Zooplankton and ichthyoplankton samples were collected at the same sites and on the same days for all surveys. Phytoplankton were collected from the central sites only. Monthly sampling provided triplicate seasonal samples at each site for spatial comparisons and sampling at seven and eight sites provided 7 and 8 replicates for monthly temporal abundance comparisons.

All zooplankton samples were collected using a 3 m long and 0.5 m diameter conical net made with 210 µm mesh, the same as Kimmerer and McKinnon (1985). A 90 mm diameter by 150 mm long cod-end and a 1.5 kg lead weight were fitted to the bottom of the net.

Vertical hauls from approximately 1 m above the seabed to the surface (Kimmerer and McKinnon 1985) provided a depth integrated sample over the whole water column. The vertical distance of each haul was recorded, typically 15 m for central channel sites and 10-12 m for shallower east and west sites (depending on tide height). The net was hauled steadily by hand at around 1 m/s. Any plankton adhering to the inside sides of the net were rinsed to the cod-end by washing gently but thoroughly from top to bottom and from the outside after each haul. Samples were concentrated by draining excess water through the side of the net and rinsing zooplankton back into the cod-end.

One zooplankton sample was collected at every site in every survey as discussed above. All samples were initially preserved in 2% v/v buffered formalin for fixing and transport to the Institute of Marine and Antarctic Studies, University of Tasmania, for analysis of species abundance. Sorted samples were washed and preserved in alcohol.

An additional sample was collected in each survey at Crib Point Berth 2 and stained with 0.15% v/v vital stain (10 mg/L Neutral Red, Elliott and Tang 2009) for 10 minutes prior to preservation in 2% v/v buffered formalin. The vital stained samples data can be used to assess zooplankton viability at Crib Point Jetty as the proportion of live:dead zooplankton. These data are not reported here, but are available to inform development of baseline and operational monitoring studies during a Works Approval stage of the project.

3.4 Subconsultant laboratory processing of samples and report

Dr. K. Swadling at the Institute of Marine and Antarctic Science, University of Tasmania, provided advice on sampling methods, analysed collected samples and provided advice on the ecology of zooplankton. Zooplankton samples were sorted to the lowest practical taxonomic level and counted by Dr. K. Swadling. Sorted samples were washed and preserved in alcohol and archived. Dr. Swadling's informative Technical Report on the ecology of the zooplankton collected during the 2018-19 sampling program is appended to this report.

3.5 Data analysis

Zooplankton counts were standardised to number per cubic metre of water. The volume of seawater that passed through the zooplankton net while collecting each sample was calculated using:

$$v = (pi*r^2)*d$$

where v = volume, r = radius of net mouth and d = water depth.

3.5.1 Monthly community composition

The monthly monitoring program at the array of sample sites is shown in Table 1. Mean monthly abundance and standard error of the mean (mean± SEM) of phyto-, zoo-, and ichthyo- plankton taxa in Lower North Arm was estimated for thirteen months using the number of samples shown in Table 2. The table shows that the number of samples (n) for calculation of mean and standard error ranges from 5 for the first eight months of monitoring phytoplankton to 8 for the last five months of monitoring zooplankton and ichthyoplankton.

Table 2. Number of samples (n) for monthly mean and SEM calculations

Lower North Arm Dec 2018 to Dec 2019

Plankton	Dec 2018 to Jul 2019	Aug 2018 to Dec 2019
Phytoplankton	5	6
Zooplankton	7	8
Ichthyoplankton	7	8

3.5.2 Spatial patterns in Lower North Arm

Annual spatial pattern at monitoring sites

Spatial patterns between monitoring sites in Lower North Arm were demonstrated for key biota from annual mean and standard errors calculated from monthly data (Table 1). Table 3 shows that the number of samples (n) for calculation of mean annual abundance and standard error of the mean (mean± SEM) of phyto-, zoo-, and ichthyo- plankton taxa at monitoring sites in Lower North Arm ranged from 5 at site S2 to 13 at the major monitoring sites.

Table 3. Number of samples (n) for annual mean and SEM calculations

Lower North Arm monitoring sites Dec 2018 to Dec 2019

Plankton	S2	S1	B2	W10	E10	C1	N1	N2
Phytoplankton	5	13	13			13	13	13
Zooplankton	5	13	13	13	13	13	13	13
Ichthyoplankton	5	13	13	13	13	13	13	13

Seasonal spatial pattern at monitoring sites

Seasonal spatial patterns between monitoring sites in Lower North Arm were demonstrated for key biota from seasonal mean and standard errors calculated from monthly data (Table 1). The table shows that the number of samples (n) for calculation of mean annual abundance and standard error of the mean (mean± SEM) of phyto-, zoo-, and ichthyo- plankton taxa at monitoring sites Lower North Arm was n=3 for autumn, winter and spring and n=4 for summer.

3.5.3 Further data presentation and use

Environment Effects Statement

Further discussion of the results in the context of hydrodynamic, entrainment and discharge modelling, zooplankton ecology, environmental guideline values and impact assessment are provided in separate EES related documents. The assessment of impacts on marine ecosystem components including plankton communities, is a risk-based, 'likelihood X consequence' process informed by statistically determined environmental guidance values (for temperature, chlorine concentration and entrainment proportion with respect to natural flushing), hydrodynamic, entrainment and exposure modelling and understanding of ecological characteristics documented in the technical studies.

Baseline documentation and impact assessment monitoring

The environmental data collected during EES studies, such as those presented in this report, will inform selection of environmental indicators, and the design and statistical power of baseline and operational compliance monitoring programs if the project proceeds.

3.6 QAQC

Quality assurance processes samples collected during this task included:

- Sampling equipment was rinsed with fresh seawater prior to sampling, and sampling equipment was rinsed with fresh water following each survey to prevent cross-contamination of samples
- Only new sample containers were used
- The time, date, GPS position and sampling depth was recorded for each sample, along with details of tide state, weather and sea-state
- Samples were delivered to the analysing laboratory along with chain of custody documentation detailing the sampling dates, sites and sampling depths for each sample
- Field data were compiled into a database within a few days of sampling
- Laboratory procedures were carried out by academic specialists

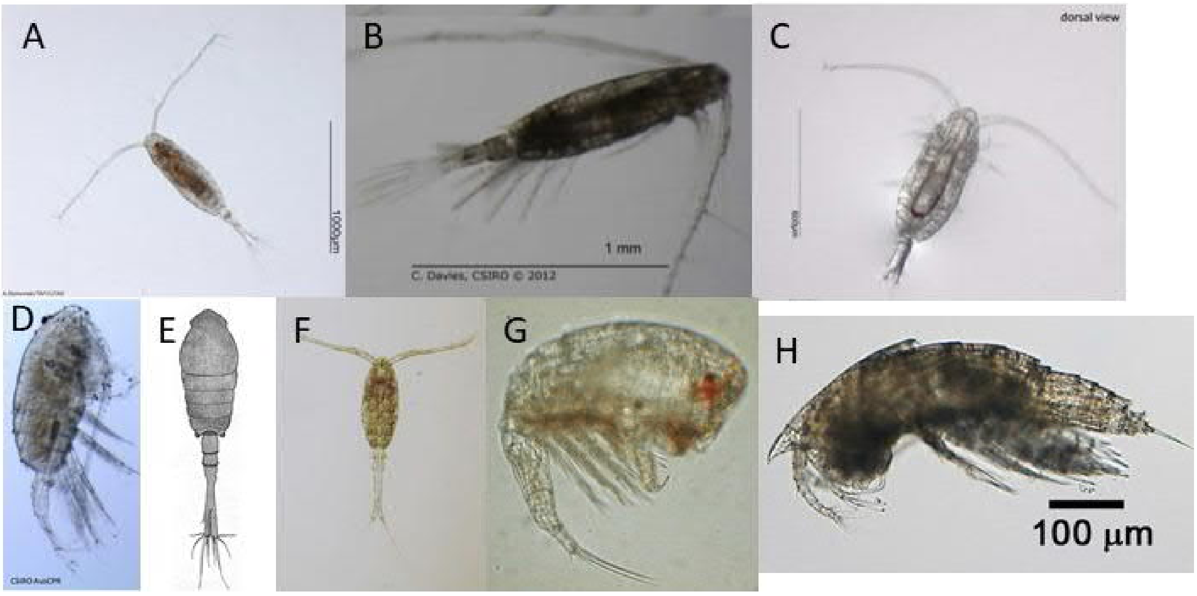
Quality control for data collected during this task included:

- Checks that the field recorded GPS positions for each sample matched the planned (regular) site location
- Data returned by the laboratory were cross checked against field records and compiled into a database
    - Checks to ensure that the same number of data provided by the laboratory were entered into the database
    - Checks for consistency of data coding (site and sample identifications, taxonomic nomenclature, units)

4 Results

More than 40 taxa of zooplankton were present in 96 net-tows collected at seven to eight sites over the 13-month sampling period from December 2018 to December 2019. The mean density of zooplankton was 2,895 individuals per m^3 and a mean monthly number of taxa of 24. More than 80% of the zooplankton collected were represented by seven species of copepod. Images of some key copepod species are shown in Figure 5.

The zooplankton community was numerically dominated by copepods, which are typically the most abundant zooplankton in the sea and are a key trophic link in planktonic and pelagic food webs (Kimmerer and McKinnon 1990). More than 60 percent of the individual plankton collected over the sampling period were a single copepod species complex, *Acartia* spp., which was present in all samples in all surveys. The copepod *Paracalanus indicus* was the only other taxon collected in all months of the program. It was the second-most abundant taxon, but its numbers represented only 6% of the total zooplankton collected. Copepods *Euterpina acutifrons* and *Pseudodiaptomus cornutus* each represented almost 5% of the total zooplankton.



A. *Acartia* spp.; **B.** *Acartia danae*; **C.** *Paracalanus indicus*; **D**. *Bestiolina similis*; **E.** *Tortanus barbatus*; **F.** *Oithona* sp.; **G.** *Oncaea* sp.; **H.** *Euterpina acutifrons*

Figure 5. Example of copepods collected from Western Port Bay

(Photos: AUSCPR, Swadling 2020)

Table 4 summarises groups and taxa that contributed to the mean sample density by more than 1%. All species of zooplankton identified were common to marine waters in Southeastern Australia including Bass Strait and Port Phillip Bay. The table shows that more than 70% of the zooplankton collected were represented by five species of copepod.

Table 4. Taxa comprising more than 1% of total zooplankton (n/m^3)

Taxon	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Mean	% of the Mean
Acartia spp. (C)	586	947	734	469	219	243	1532	1180	2430	2918	4752	4426	1850	1714	59
Noctiluca scintillans (O)	14	125	63	0	0	0	0	0	0	0	11	1079	2668	305	11
Paracalanus indicus (C)	23	89	60	83	165	148	253	570	280	93	82	6	15	144	5
Small gastropod (M)	110	833	429	193	72	35	0	0	0	0	0	0	0	129	4
Euterpina acutifrons (C)	2	6	2	0	0	0	156	6	178	673	368	60	4	112	4
Pseudodiaptomus cornutus (C)	0	79	124	35	2	4	172	64	100	289	157	226	107	105	4
Bestiolina similis (C)	0	0	0	338	81	23	62	21	90	113	0	0	0	56	2
Decapod larva (O)	30	27	83	39	5	6	19	0	0	7	5	10	319	42	1
Crab zoea (O)	22	33	90	20	4	11	0	4	1	127	15	23	42	30	1
Other (¬30 taxa)	139	234	205	343	226	126	696	221	108	522	382	45	388	280	10
All Zooplankton	927	2366	1799	1519	774	586	2889	2066	3186	4484	5772	5875	5393	2895	100
Number of taxa	24	30	30	33	23	22	19	25	18	22	30	15	19	24	

Colour	Plankton descriptor
(orange)	Holoplankton
(green)	Meroplankton
(light yellow)	Benthic biota
(light pink)	Mixed

Colour	Plankton descriptor
(blue)	Present in samples, n/m^3
(light blue)	Not present in samples

Letter code ( )	
C	Copepods
M	Molluscs
O	Other

Copepods are small crustaceans, usually 0.5 to 3 mm in length, with a teardrop-shaped body and a pair of antennae. Marine copepods have high tolerance to salinity and temperature variations and are found in all depths and biogeographical zones of the marine environment. Copepods spend their entire life cycle as plankton and are thus referred to as holoplankton. The copepod life history from the egg stage includes six, small nauplius stages and five larger copepodite stages before reaching the final, large reproductive adult stage. Nauplius and early copepodite stages are small and pass through standard mesoplankton nets and may represent more than 90 percent of the total copepod population when abundances are highest. Hence, the total population numbers of copepod species during peak months (October through March) may be up to 10 times higher than indicated by the number of adults shown in this report.

Spatial and temporal patterns of the 11 most abundant mesozooplankton taxa and groups are described in detail in the following sections of this chapter. Other groups under 1% abundance that occurred in low numbers but consistently over a period of the year were other copepods such as *Corycaeus speciosus* (Jul-Nov), *Gladioferens* spp. (Mar-Nov), *Oncacea* spp. (Mar-Nov), *Microsetella norvegica* (Jun-Sep), *Temora* sp. (all year round) and *Oithona* spp. (all year round) as well as *Oikopleura* spp. and salps (Tunicata, salps and sea-squirts), barnacle nauplii and cyprids (larval stages), and sea jellies (Cnidaria).

4.1 Spatial and Temporal Patterns in taxonomic richness

As discussed above, approximately 40 distinguishable taxonomic groups (species or higher groups) of zooplankton were collected over the 13-month sampling period. However, not all taxa were collected in any one sample or survey at any time, so the number of species or taxa varied between site and survey.

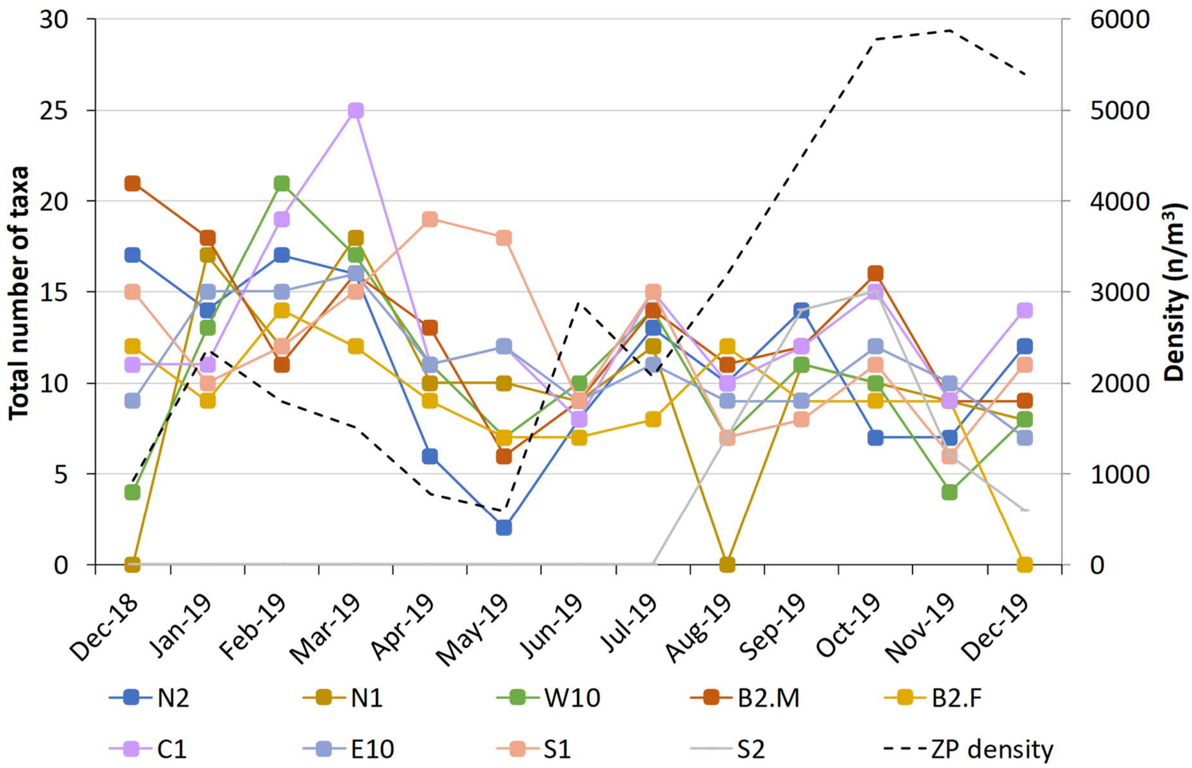


Figure 6. Number of zooplankton taxa at monthly sampling sites over time

Figure 6 shows the number of taxa for each site over the sampling period. Generally, species richness did not follow any significant seasonal patterns, however there is a slight trend to a decrease in species richness with higher densities of total zooplankton.

Figure 7 shows the average number of taxa at 7 sampling sites over the entire sampling period (December 2018 – December 2019). Site CPS2 was excluded from this graph as it was only sampled from August 2019 – December 2019.

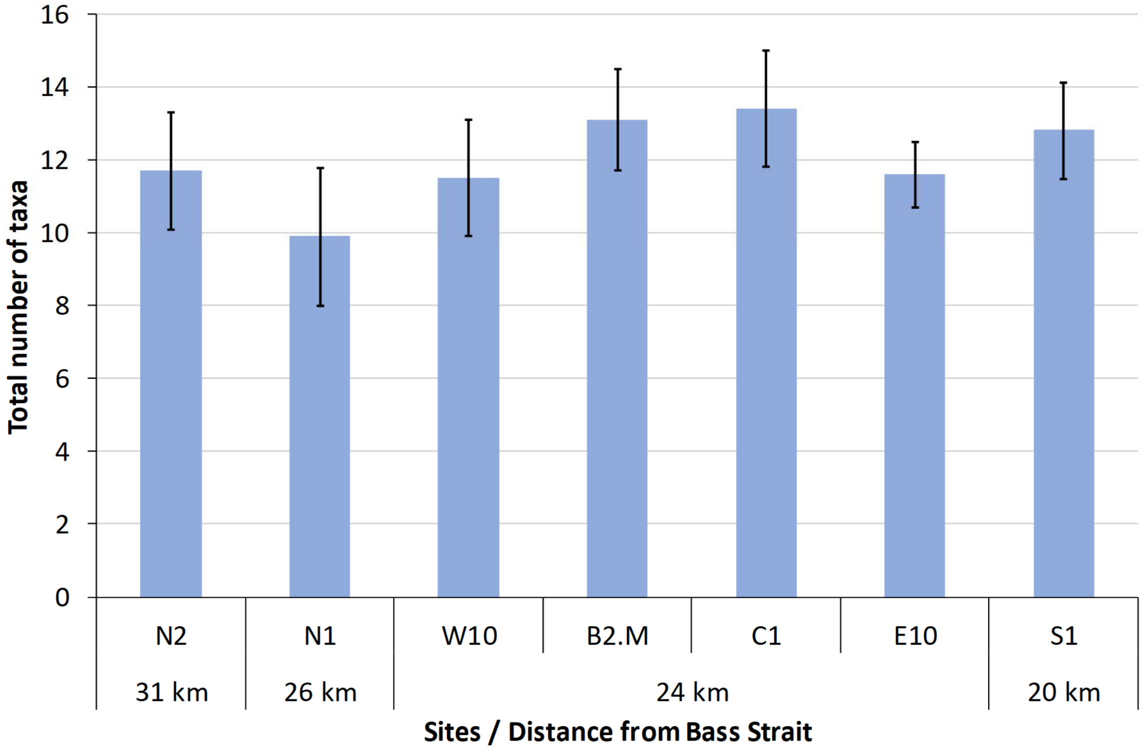


Figure 7. Average species richness at sampling sites over the sampling program

Species richness was similar between sites and did not follow any distinctive spatial patterns. Site CPB2 of the fortnightly sampling routine (B2.F) had a slightly lower number of taxa than its monthly sampling routine and other sites (Figure 6). However, this difference appears to be due to general sample variability. Data from all sites (including CPS2) sampled between August 2019 and December 2019 did not show any differences in numbers of taxa (Figure 24). Overall, the variation in species richness demonstrates spatial patchiness (variation between sites) of zooplankton populations during any survey and variation between surveys due to seasonal successions and natural variation as discussed further in following sections.

4.2 Temporal Patterns in Major Zooplankton taxa

Zooplankton species populations vary strongly according to water temperature, daylength food availability (phytoplankton, organic detritus, smaller zooplankton), competition with other zooplankton species, loss due to predation by other zooplankton and fish and nutrient availability. These factors are interdependent as the biological factors rely on the same physical and chemical factors. The temporal patterns of major taxa and groups sampled during this study over a 13-months period (December 2018 to December 2019) are below.

Figure 8 shows monthly average densities of total zooplankton and key classes over the 13-months sampling period. Copepods dominated all but December 2019 monthly zooplankton samples and comprised more than 90% of total zooplankton in most surveys. Figure 8 shows that copepod abundance fluctuated slightly between 500 and 1000 individuals per m^3 between December 2018 and May 2018 but increased dramatically from an annual low of 500 per m^3 in May to average of > 5,000 individuals per m^3 in November 2019. The initial increase in copepod numbers in June appears to be related to daylength rather than water temperature.

Small gastropods are molluscs, which are a separate class of organisms from copepods, which are crustaceans. They peaked in numbers in January 2019, but slowly declined to be close to 0 individuals per m^3 by May. These gastropods are likely to be seasonal populations that are washed-off their habitat and dispersed in the water column by the tidal currents with the drifting seagrass leaves and fine suspended sediments.

Other zooplankton classes were generally low in numbers. The only exception was observed in the heterotrophic *Noctiluca scintillans*. A slight increase in November (~1000/m^3) followed by a significant increase in December 2019 (~15000//m^3) was observed for this bioluminescent dinoflagellate, which as mostly due to a spring bloom (Figure 13).

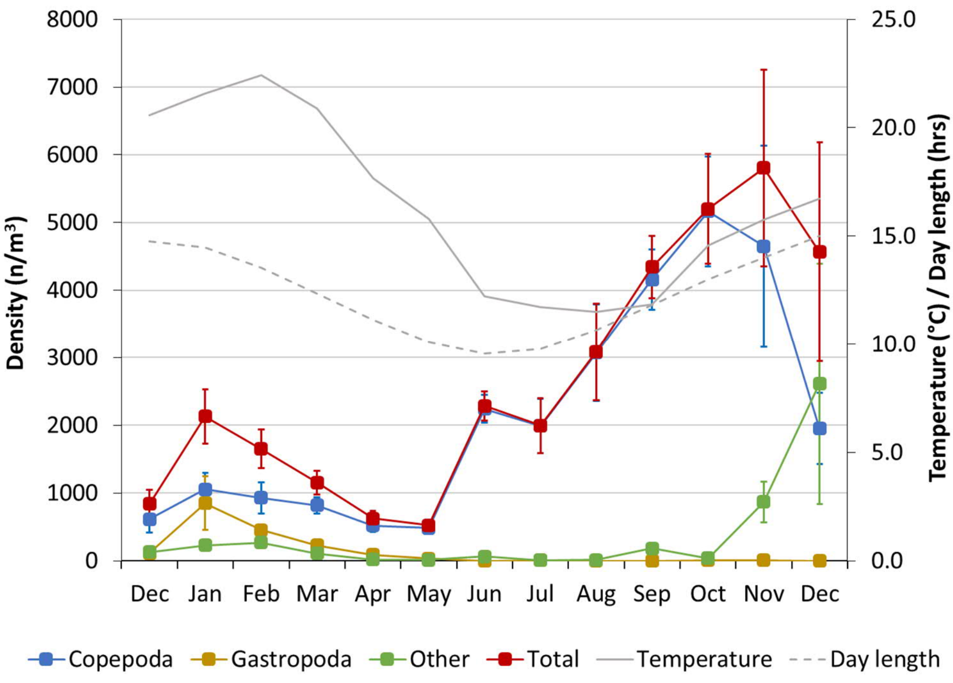


Figure 8. Monthly average abundance of key zooplankton classes

4.2.1 Copepods

The most abundant class of zooplankton identified in North Arm, Western Port were Copepoda of three main orders: Calanoida, Cyclopoida and Harpactoida.

Calanoid copepods were the largest group recorded in North Arm and included *Acartia* spp., *Paracalanus indicus*, *Bestiolina similis*, *Euterpina acutifrons*, *Pseudodiaptomus cornutus* and *Tortanus barbatus*. The cyclopoid copepod *Dioithona rigida* was also present in winter and early spring samples. All these species are common in marine waters of south-eastern Australia. The abundance of copepods at all sites over the monthly surveys from Deecember 2018 to December 2019 is shown in Figure 9.

Acartia (mostly *A. fancetti*) dominated the zooplankton communities in North Arm and East Arm of Western Port and are typically found in nearshore habitats (estuaries) as well as in the open ocean around the globe. Their relatively high tolerance to high particulate densities provides an advantage over other species in the turbid Western Port environment.

Acartia fancetti numerically dominated the zooplankton in all surveys, with the lowest numbers in autumn and the highest densities (up to 14000 individuals per m^3) in late spring (Figure 9). Variability among sites was generally low, however increased in October and November when numbers were highest.

The second most abundant copepod species identified during the program was *Paracalanus indicus* (Figure 9), an epipelagic coastal species that is common in Bass Strait and Port Phillip Bay. *P. indicus* abundances peaked in winter months of 2019 (up to 1000 individuals per m^3 in July). Numbers dropped significantly from August to November, whereas *Acartia* peaked over this period. The decrease in *Paracalanus* is likely due to predation by higher numbers of *Acartia* over the spring to summer period.

Another species of the *Paracalanidae* family is *Bestiolina similis,* which is an epipelagic species that is commonly found in inshore regions and estuaries of the tropics and temperate regions. *Bestiolina similis* occurred in high numbers in North Arm in March (up to 650 individuals per m^3) and in moderate densities between April and September (~50/m^3). *B. similis* was absent from samples in late spring and summer months (Figure 9).

Another copepod species that showed a summer minimum, was *Euterpina acutifrons* (Dana 1847), a harpacticoid copepod that occurs in tropical and subtropical waters of all oceans. It tolerates a large salinity range and mainly feeds on phytoplankton. In Western Port, abundances peaked in September and October (~1000/m^3) and dropped off sharply in November. Samples were devoid of *E. acutifrons* from December to May (Figure 9).

Pseudodiaptomus cornutus, a calanoid warm water species, showed a spring maximum with high variability among sites (up to 600/m^3) and variable moderate densities for the remainder of the year (0-300/m^3, Figure 9).

The carnivorous copepod *Tortanus barbatus* was common in autumn and winter (up to 200/m^3) with high variability among sites, however, did not occur in spring and summer (Figure 9).

The cyclopoid copepod *Dioithona rigida* followed a similar pattern to *E. acutifrons* and *P. cornutus* with higher densities observed between June and October (varying around ~60/m^3) and lower densities observed between November and May (Figure 9).

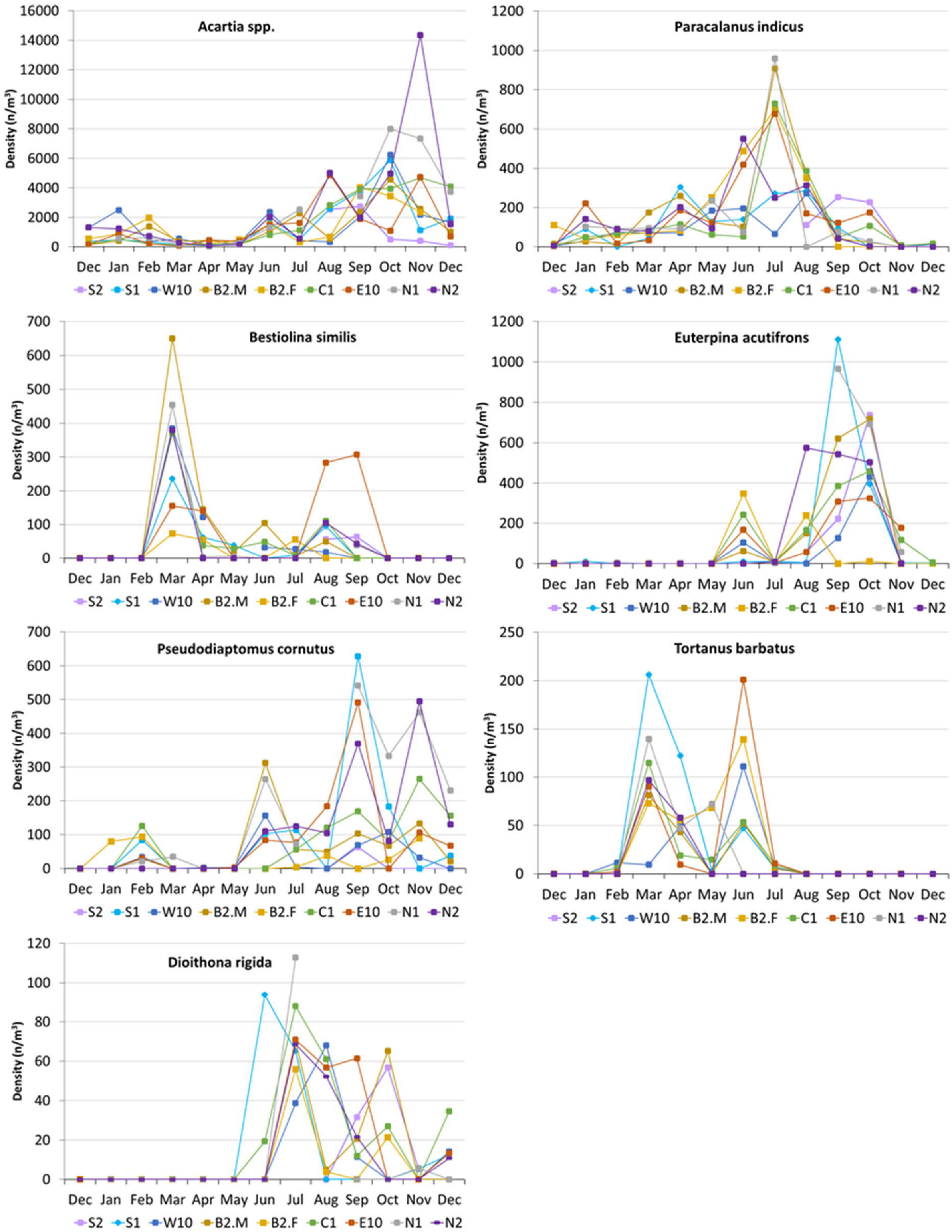


Figure 9. Copepod densities in North Arm, Western Port (Dec-2018 to Dec-2019)

4.2.2 Molluscs

Small gastropods were the fourth most common group observed in the zooplankton sampling program. Their overall abundance was predominantly due to very high numbers in samples collected during the summer months, when numbers up to 3000/m^3 peaked in January 2019 and slowly declined to be close to 0 individuals per m^3 by May (Figure 10). Most of these gastropods were identified as benthic. These small gastropods were absent from samples between June and November.

The small gastropods present in the samples were not planktonic forms and are incapable of maintaining themselves in the water column in the lack of turbulence. They were recognised as species that may be found grazing on microalgae that grow on seagrass leaves and on, or close to, the surface of the sediments of the intertidal mudflats.

Their presence in the summer and autumn period likely corresponds to shed of seagrass leaves or suspension of intertidal sediments during peak growing season for seagrass and microalgae Hence, they are likely to be seasonal populations that are washed-off their habitat and dispersed in the water column by the tidal currents with the drifting seagrass leaves and fine suspended sediments. There is no consistent pattern between the surveys to indicate a local source of the gastropods along the either the north-south or east-west arrangement of sites.

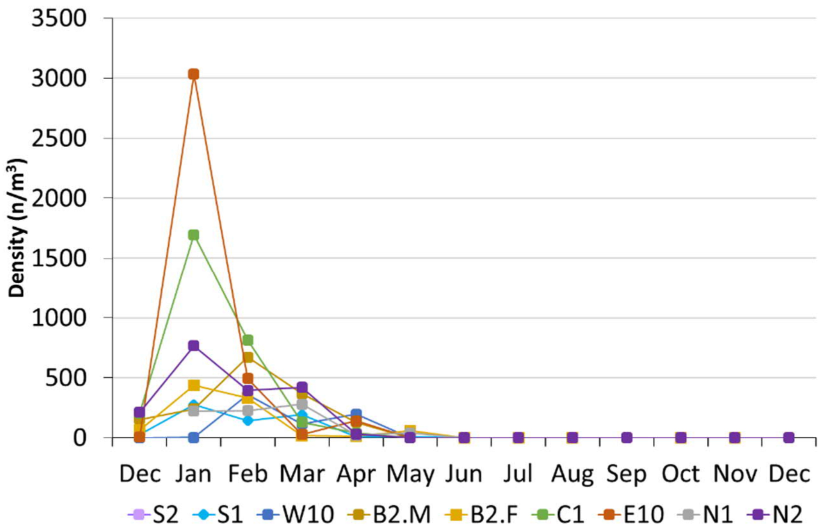


Figure 10. Small gastropods abundance in North Arm, Western Port (Dec-2018 to Dec -2019)

4.2.3 Other taxa

Other groups occurring with a proportion of over 1% of the total over the entire survey period were mainly meroplanktonic species such as crab zoea and polychaete larvae that spend their larval stages as plankton and settle to the seabed or seagrass beds in later larval stages of their life cycle or as adults.

Crab zoea, planktonic crustacean larvae, were most abundant during spring and summer months with generally 50-150 individuals per m^3 with the highest counts documented in September at South 1 (~350/m^3). Densities were close to zero during the winter months (Figure 11).

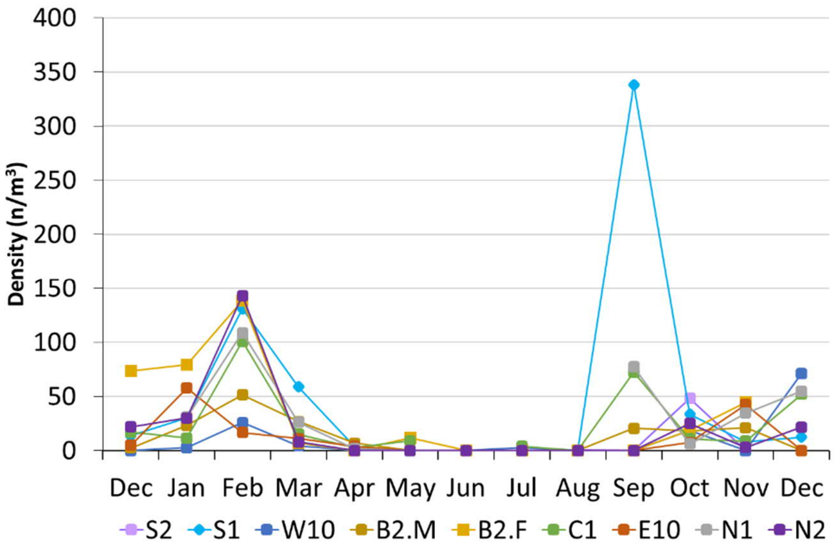


Figure 11. Crab zoea abundance (Dec-2018 to Dec-2019)

Polychaete larvae densities were highest in June (up to 200/m^3), August (up to 50/m^3) and September (up to 250/m^3) with high variability among sites in June and September (Figure 12). Techniques to further taxonomically identify these larvae have not been established.

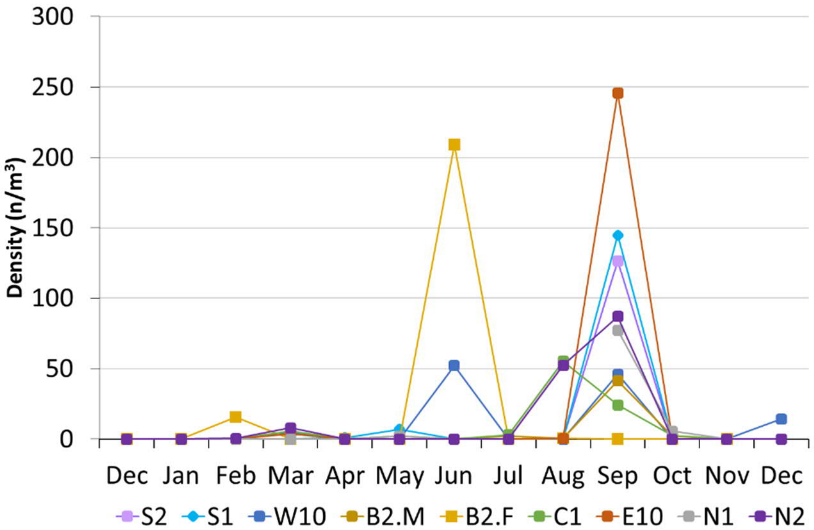


Figure 12. Polychaete larvae abundance (Dec-2018 to Dec-2019)

Noctiluca scintillans, a dinoflagellate, was present in warmer months from November to February, with a peak abundance of 15000/m³ in December 2019 (Figure 13). The distribution of *N. scintillans* in the peak month shows a strong spatial gradient along the north-south sampling axis with highest concentration in the south at site CPS2 and a consistent reduction along the sampling axis and absence at sites CPN1 and CPN2 in the north. This indicates that the high density observed may have originated from Bass Strait. *Noctiluca* it is known for spring blooms and patchy distribution in coastal and estuarine environments

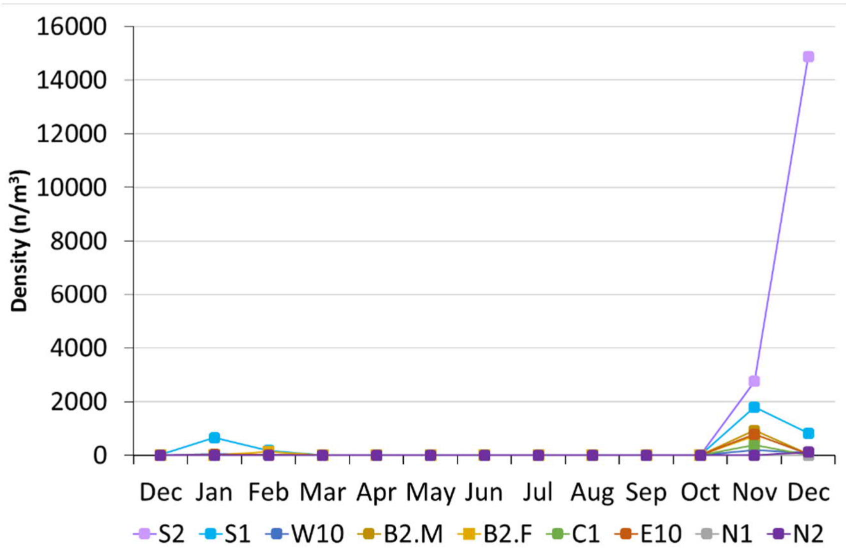


Figure 13. *Noctiluca scintillans* abundance (Dec-2018 to Dec-2019)

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4.3 Spatial patterns in Major Taxa

As discussed previously, zooplankton were sampled along a longitudinal and a lateral axis in North Arm, Western Port:

1) Five sites along 17 km of a north-south axis extending from 31 km (CPN2) to 14 km (CPS2) north of the Bass Strait entrance.
2) Four sites along a west-east axis approximately spanning the 2.3 km width from the 10 m depth contours on either side of the main North Arm channel at Crib Pt Jetty, located 24 km north of the Bass Strait entrance.

The following section describes spatial patterns in abundances of selected zooplankton taxa along these axes. Column graphs represent average zooplankton densities per season`

4.3.1 Acartia spp.

Acartia spp. density was generally highest in the north to lowest in the south during spring when numbers were high (Figure 14). *Acartia* is well-adapted to living in the northern and eastern Western Port environments where particulate loads are high compared to its density in bays where particulate concentrations are relatively low.

The north to south: high to low density gradient is consistent with a core growing population located in Upper North Arm area that is progressively diluted with oceanic water entering Western Port from Bass strait. This pattern is discussed further in the next section of this report.

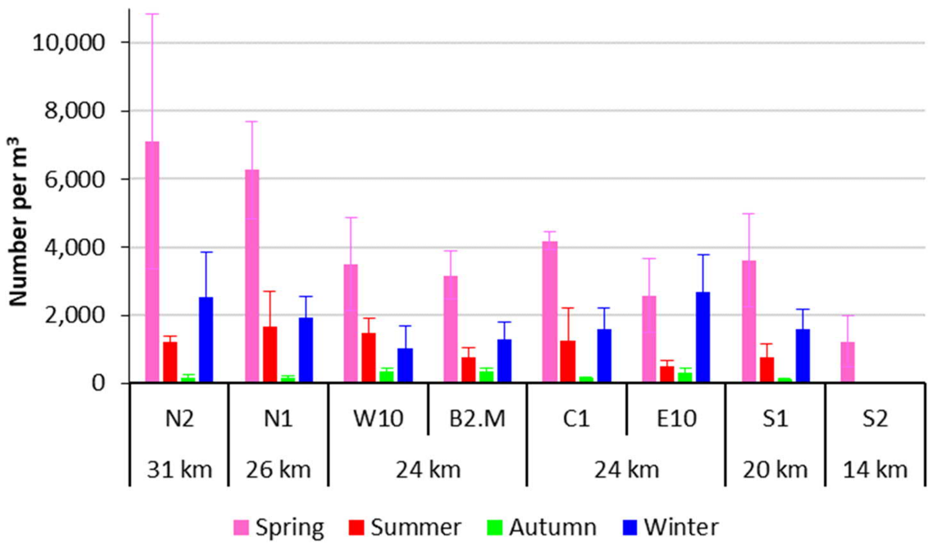

Figure 14. Spatial distribution of *Acartia* spp. (Dec-2018 to Dec-2019)

4.3.2 *Paracalanus indicus*

The highest abundances of *Paracalanus indicus* were observed during winter (Figure 15). The spatial distribution of *P. indicus* was somehow similar to *Acartia* spp. where high densities were registered at north (CPN1, CPN2), central (CPB2, CPC1) and east (CPE10) sites.

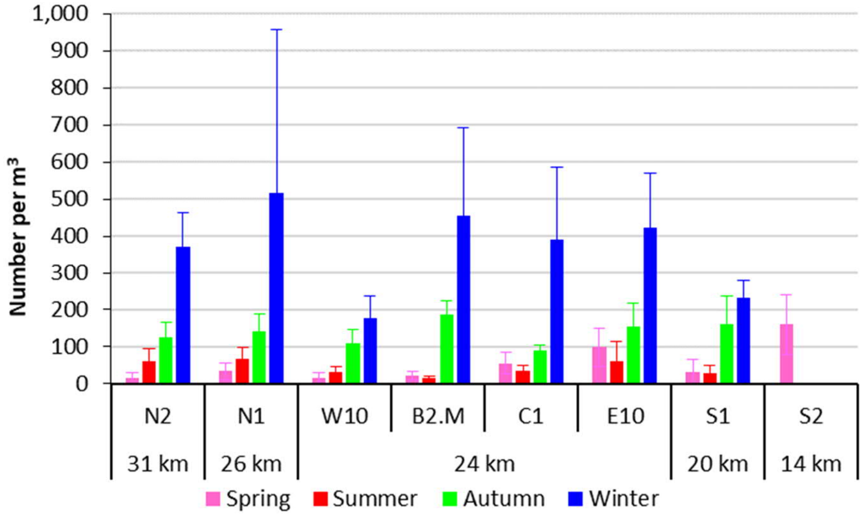

Figure 15. Spatial distribution of Paracalanus indicus (Dec-2018 to Dec-2019)

4.3.3 *Noctiluca scintillans*

Noctiluca scintillans represented 11 per cent of the total zooplankton collected during the program. However, it was only found in late spring and summer. *N. scintillans* followed a reversed pattern to *Acartia* and *Paracalanus* with highest densities at the two south sites, medium densities at Crib Pt and no individuals at N1 and N2 (Figure 16). At site S2 a significant increase in *N. scintillans* abundance was observed in December 2019 reaching a density higher than 14000 individuals/m^3.

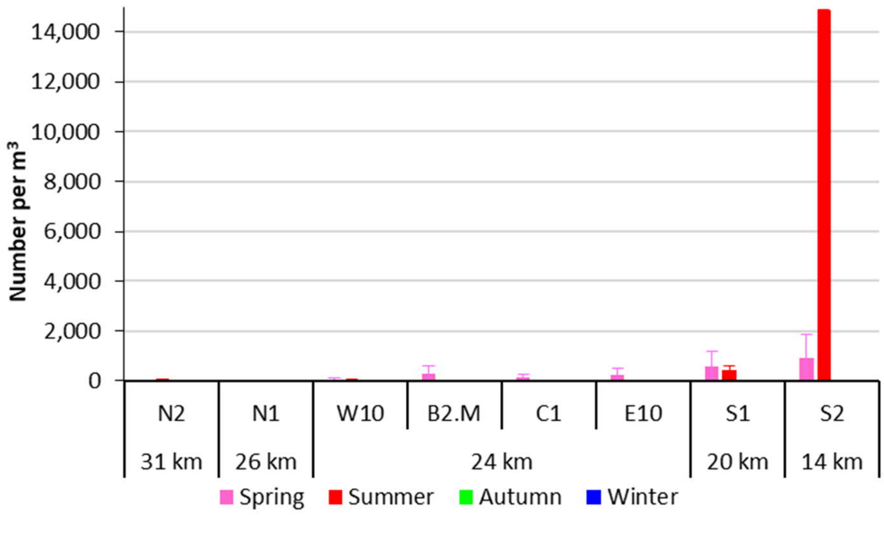

Figure 16. Spatial distribution of *Noctiluca scintillans* (Dec-2018 to Dec-2019)

5 Key indicator species of zooplankton community

The results presented in the previous section demonstrate that the plankton community of Lower North Arm comprises a small number of holoplankton species that are present all year round.

5.1 Snapshot comparison of Lower North Arm and East Arm

As discussed above, previous studies by Kimmerer and McKinnon in the 1980s focussed on East Arm, whereas the EES studies focussed on the Lower North Arm. During October 2019, sites in both Lower North Arm and East Arm were sampled to provide a snapshot of spatial patterns in the zooplankton and phytoplankton communities along both arms and into the confluence zone. The sites included those sampled monthly by CEE in North Arm (N2 to S2) and those sampled in East Arm P1 to P5 by Kimmerer and McKinnon (1985) along a transect from the entrance of Bass Strait up to 31 km in Lower North Arm and 39 km along East Arm (Figure 3).

Samples taken in October 2019 showed a north-south downward gradient in *Acartia* spp. density at the routinely sampled sites (Figure 17). The additional set of sites (P1 to P5) showed the highest densities near the shallow basin bordered by the northeast of Phillip Island, the south of French Island and southeast border of Western Port (P2-P4). Site P1 and P5 on the outer ends of the transect and the regular sampling site CPS2 had similar and substantially lower numbers of *Acartia* spp. (Figure 17). The longer water residence times and low current speeds that characterise the area of the basin could be an explanation for the higher densities of *Acartia* spp. at sites P2 to P4.

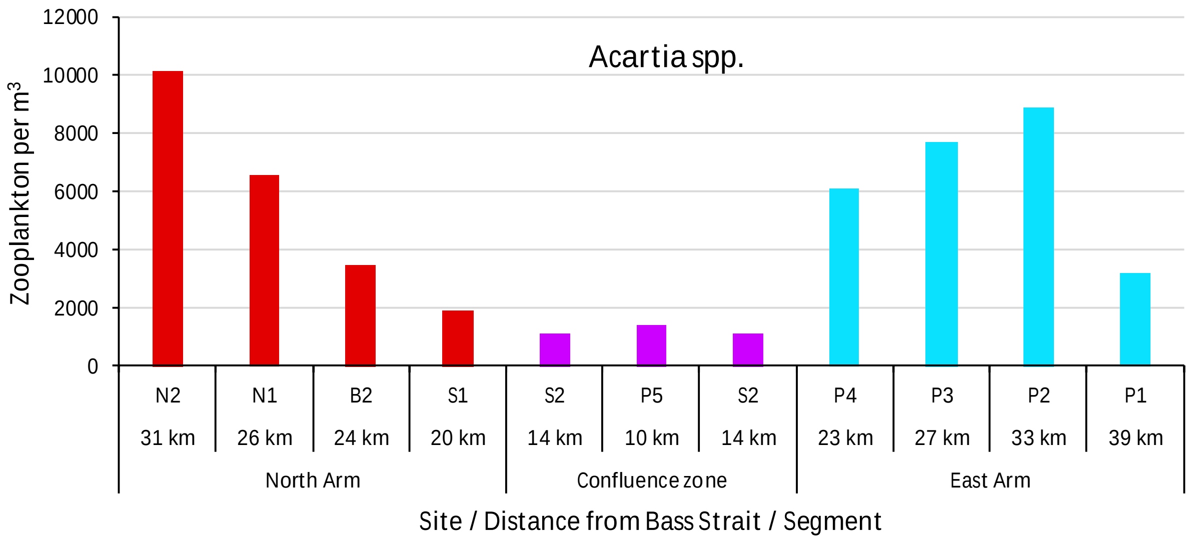

Figure 17. Spatial distribution of *Acartia* spp., October 2019

Similarly to *Acartia* spp., *Euterpina acutifrons* occurred in higher densities with distance from the Bass Strait entrance on both transects (CPN2-CPS2 and P1-P5, Figure 18)

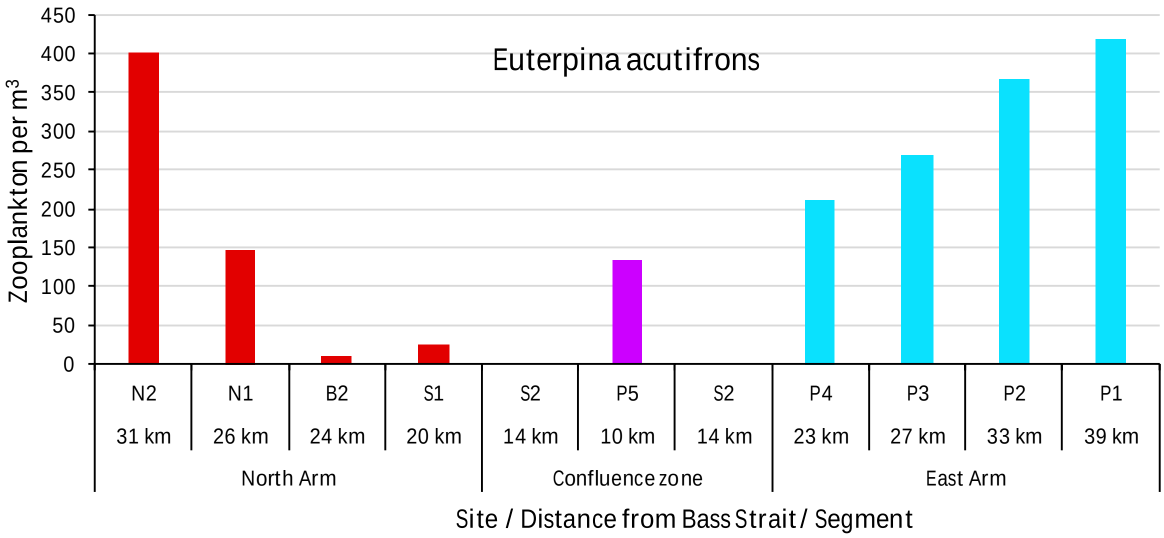

Figure 18. Spatial distribution of *Euterpina acutifrons,* October 2019

Other taxa did not follow this distinctive pattern, although *Pseudodiaptomus cornutus* concentrations were higher overall in the upper arms compared to the confluence zone (Figure 19, Appendix Figure 28).

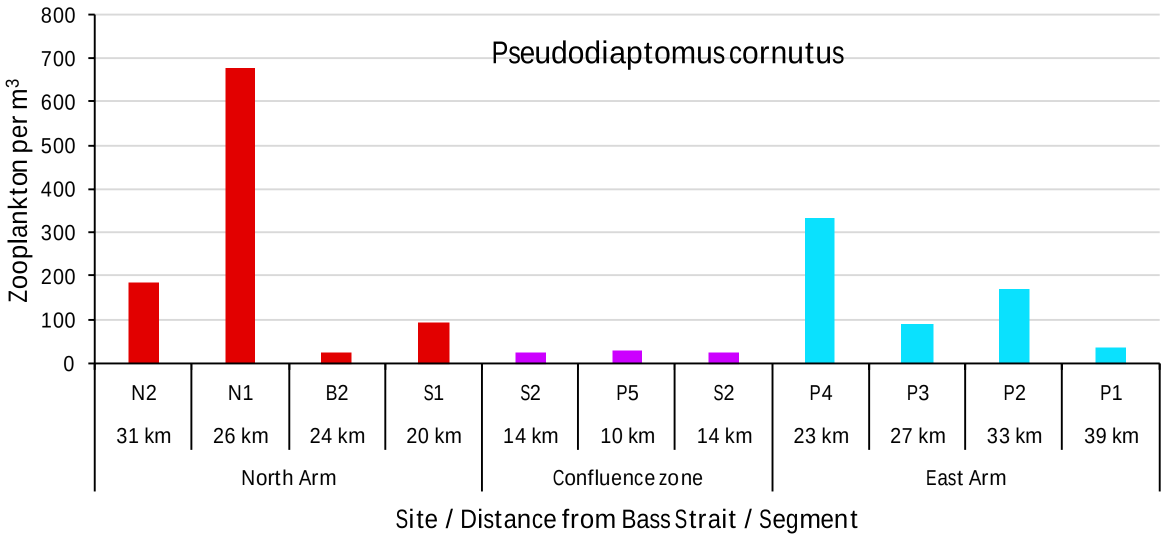

Figure 19. Spatial distribution of *Pseudodiaptomus cornutus,* October 2019

5.1.1 Comparison of zooplankton community: time and location

The composition of the zooplankton community sampled by CEE in North Arm in 2019 was very similar to the composition of the zooplankton community sampled in East Arm in 1982-83 (Kimmerer and McKinnon 1985), with the abundance rank of the six most numerous zooplankton species collected being very similar (Table 5).

Table 5. Species abundance rank in 2018-19 and 1982-83

Zooplankton species*	Western Port		Port Phillip
	CEE 2019	K&Mc 1983	K&Mc 1983
Acartia spp.**	1	1	5
Paracalanus indicus	2	3	1
Euterpina acutifrons**	3	2	6
Pseudodiaptomus cornutus**	4	4	Present
Bestiola similis**	5	6	Present
Tortanus barbatus **	6	Present	3
Oikopleaura dioica	Present	5	2
Lucifer Hannseni**	Present	Present	4

*excludes larvae, diatoms and benthic species

**nominated as bay residents Kimmerer and McKinnon (1985)

The monthly mean *Acartia* concentrations of the 1982-83 East Arm program (Kimmerer and McKinnon 1985) and the 2018-19 North Arm program are shown in Figure 20. The two sets of data show notably similar patterns of variation and abundance for independently collected data that are 38 years apart and from distinct segments of Western Port. The key features of comparison of the data sets are:

- The two data sets show annual peak abundance in summer and annual low in autumn.
- Both data sets show very similar measured abundances, particularly from mid-autumn to mid-winter.
- Both sets show the obvious commencement of the annual population increase from April to July.
- The January to March 1983 abundances were substantially higher than the January to March 2019 abundances. However, the trajectory August to November data was very similar for both years indicating that *Acartia* abundance over the 2018/19 summer was low compared to 82/83 and possibly 2019/20.
- The 1982-83 data show greater variance as demonstrated by the wider SE bars in the 1982-83 compared to the 2018-19 data. This is probably due to wider spatial separation of the1982-83 sampling sites, which included a site close to the confluence zone.
- There is strong similarity and likely to be connectivity between the zooplankton populations in North Arm and East Arm.

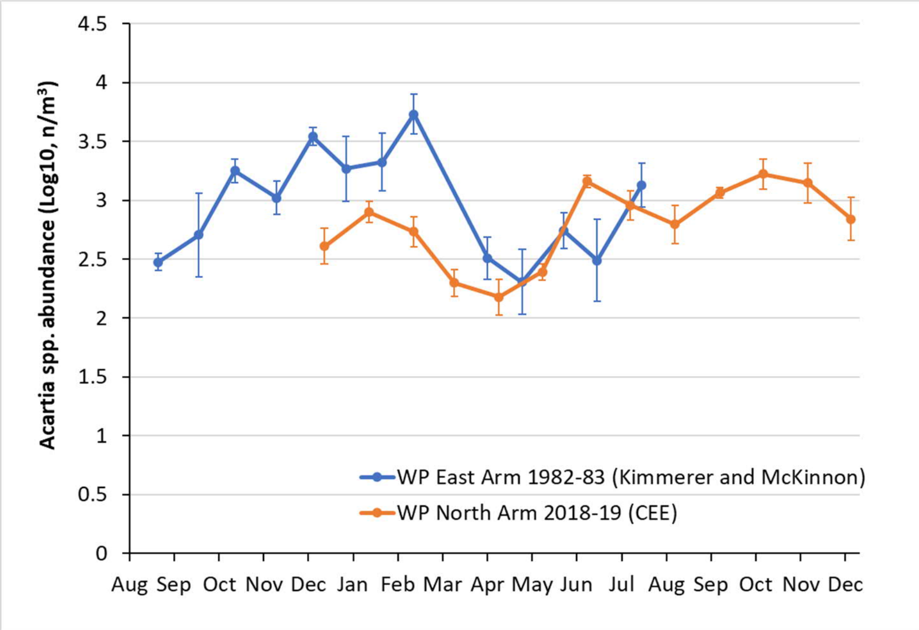

Figure 20. *Acartia* spp. abundance in East Arm (1982-83) and Lower North Arm (Dec-2018 to Dec-2019)

(1982-83 mean and SE were published as Log_{10}. 2018-19 data transformed similarly)

In summary, *Acartia* numerically dominated all North Arm sites during all surveys during the 2018-19 program and dominated all East Arm sites during the 1982-83 program. These were also the only species present at all 2018-19 surveys. *Euterpina acutifrons* was the third most abundant zooplankton species present in the 2018-19 program but was strongly seasonal and absent or in very low abundance in 6 of the 12 surveys. The six most abundant zooplankton species present in the 2018-19 surveys were classified as “Bay residence” by Kimmerer and McKinnon (1985).

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7 Appendices

7.1 Additional Charts and Tables

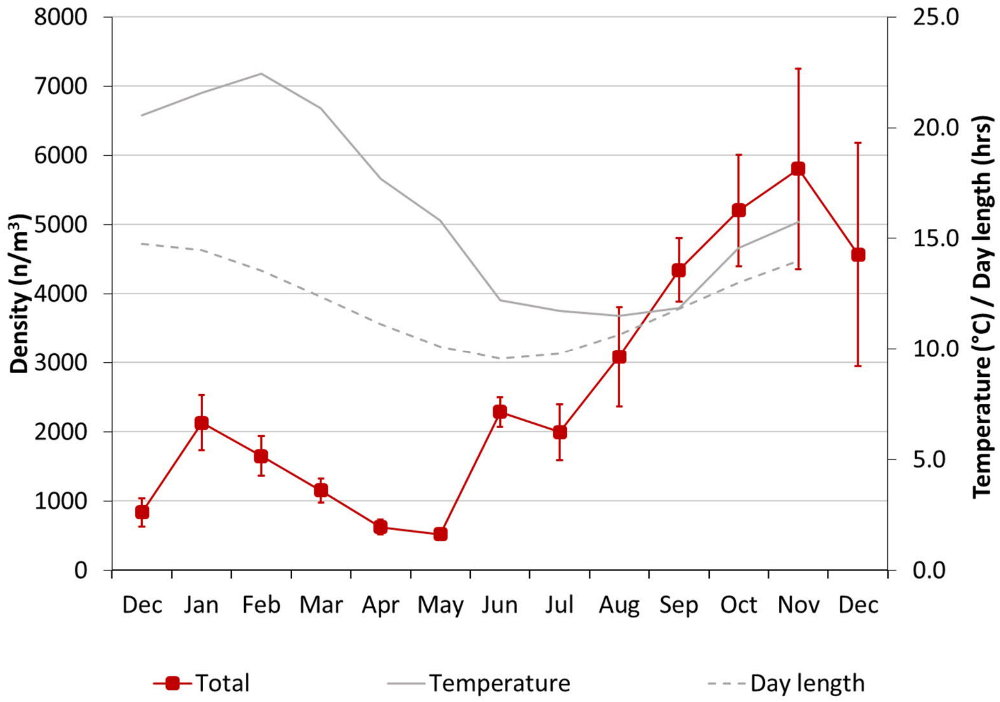

Figure 21. Total zooplankton abundance over time

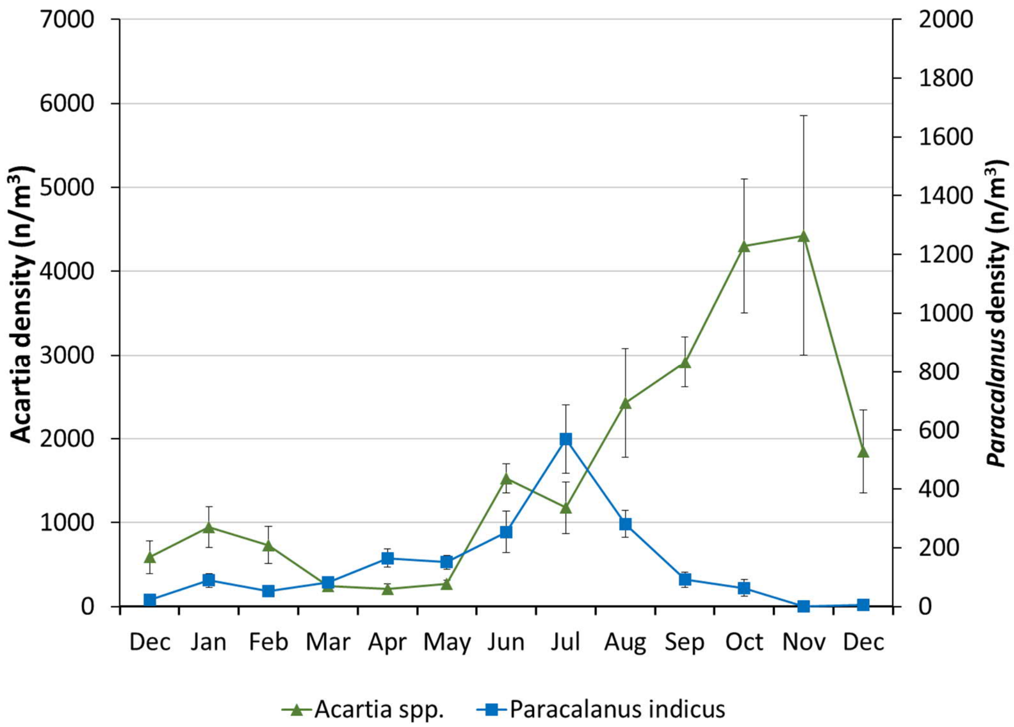

Figure 22. *Acartia* spp. and *P. indicus* average abundance (Dec-2018 to Dec-2019)

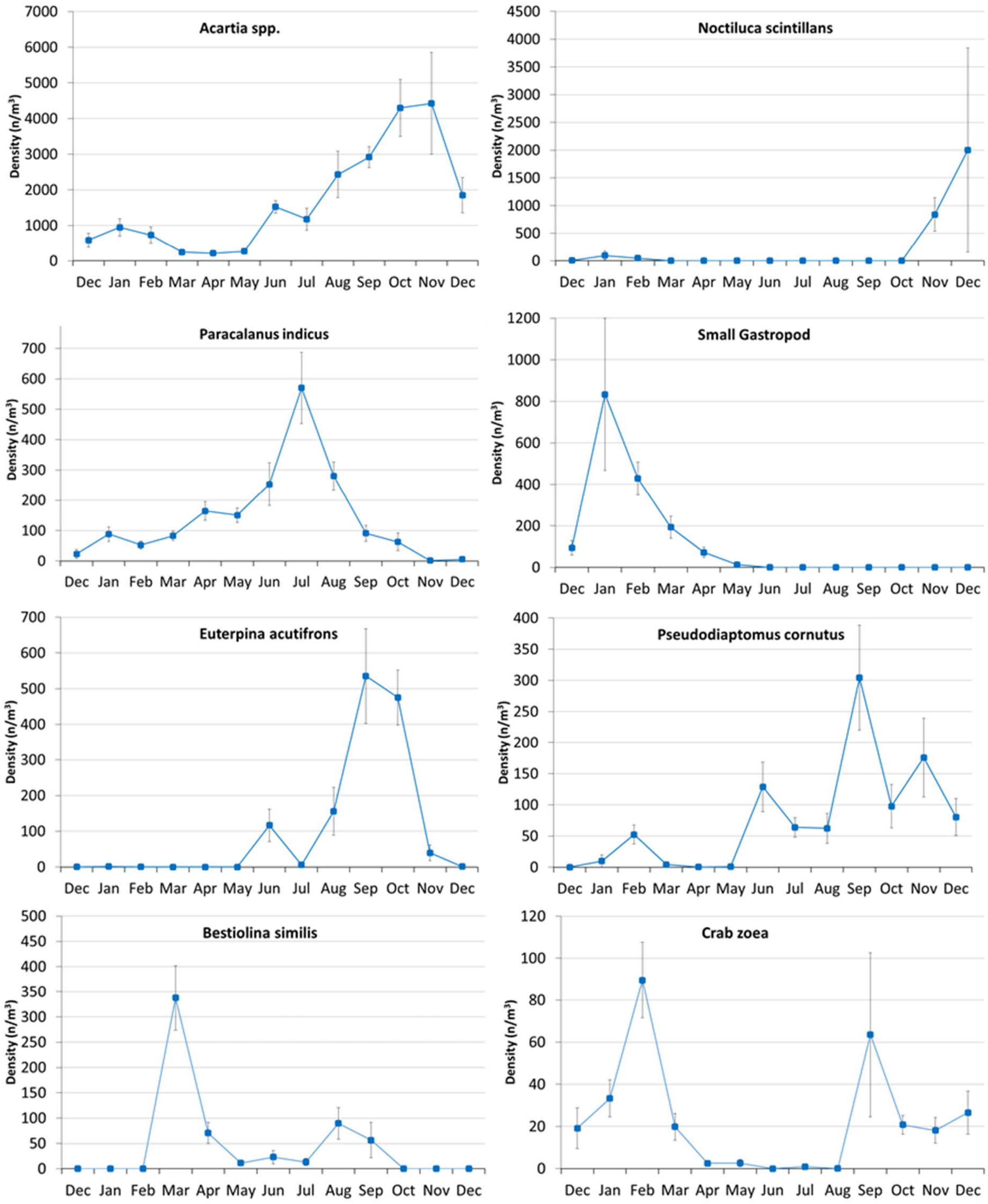

Figure 23. Average abundance of top 11 species (Dec-2018 to Dec-2019)

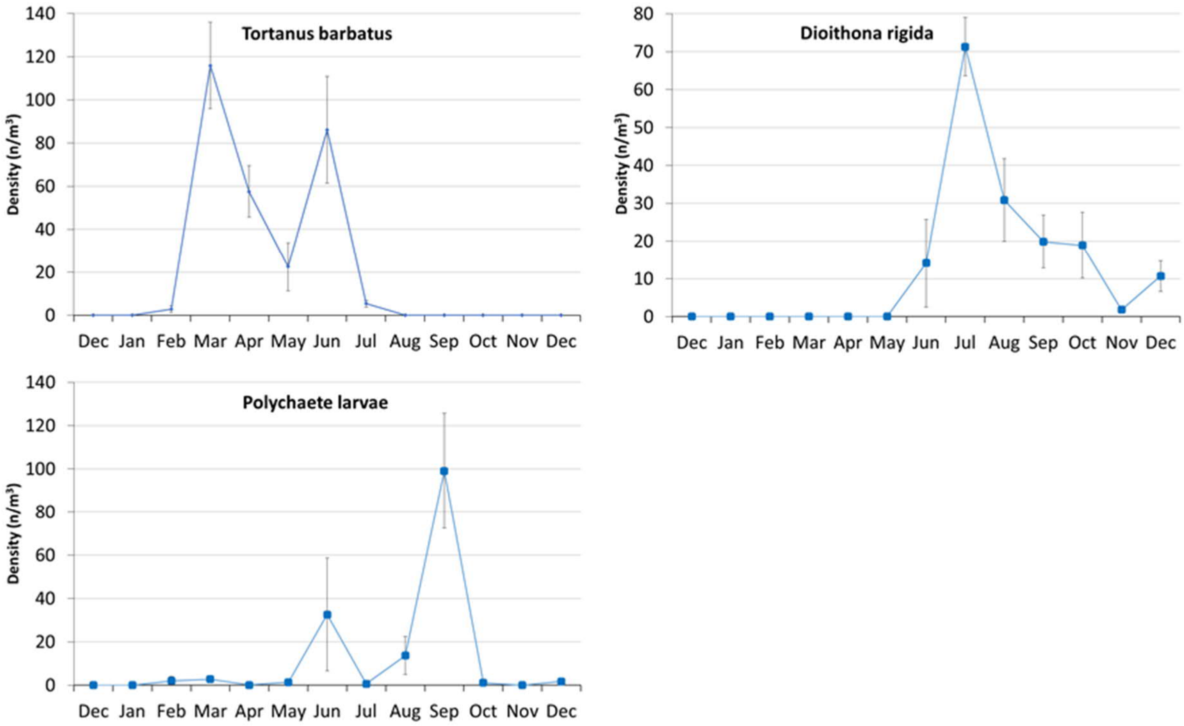

Figure 23 (*cont.*). Average abundance of top 11 species (Dec-2018 to Dec-2019)

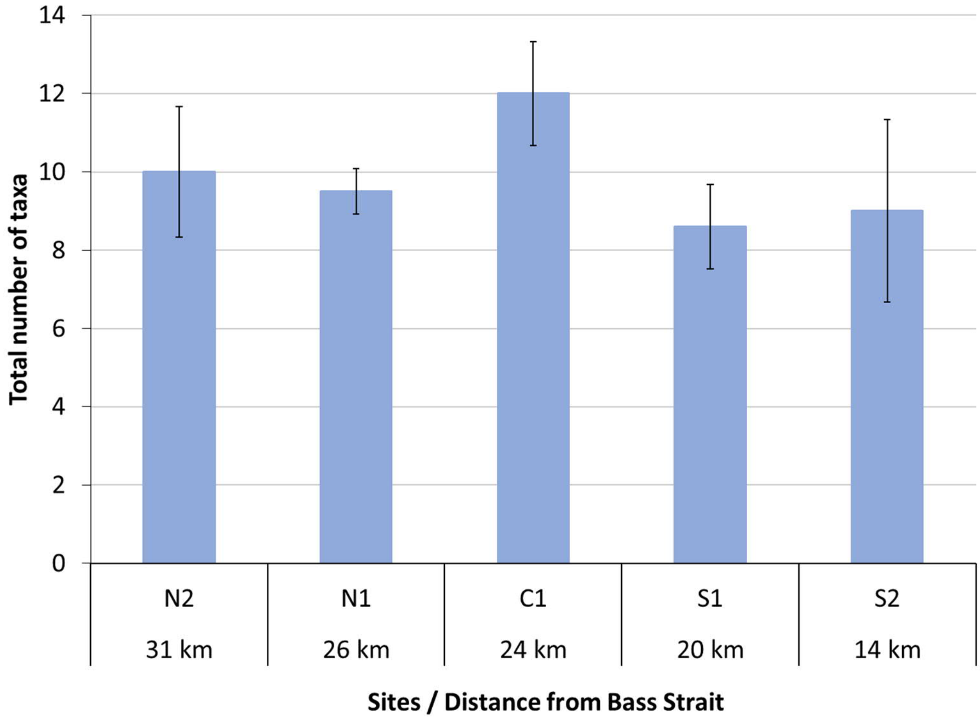

Figure 24. Average species richness on north-south transect including S2 (Dec-2018 to Dec-2019)

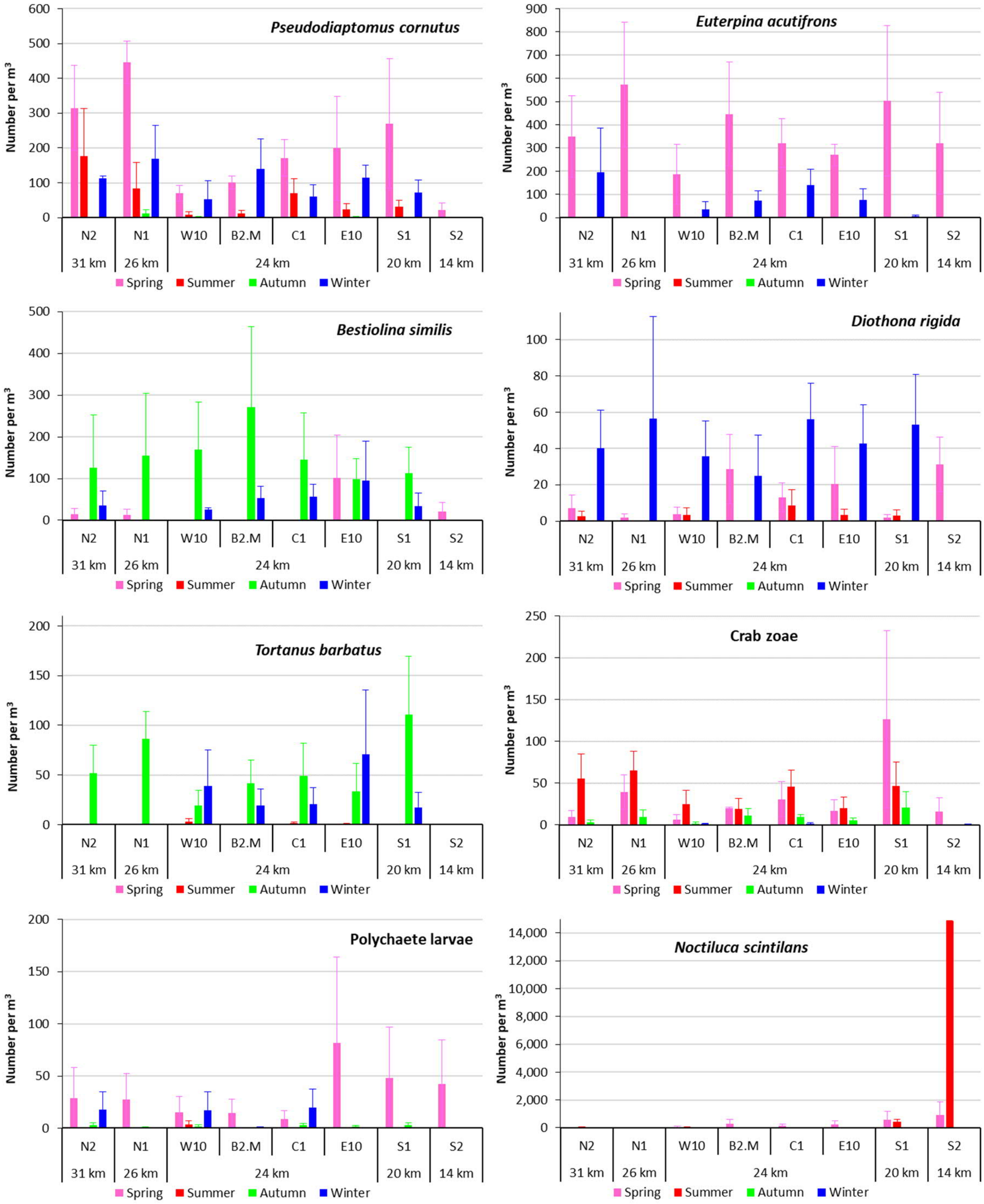

Figure 25. Spatial distribution of highly abundant zooplankton species (Dec-2018 to Dec-2019)

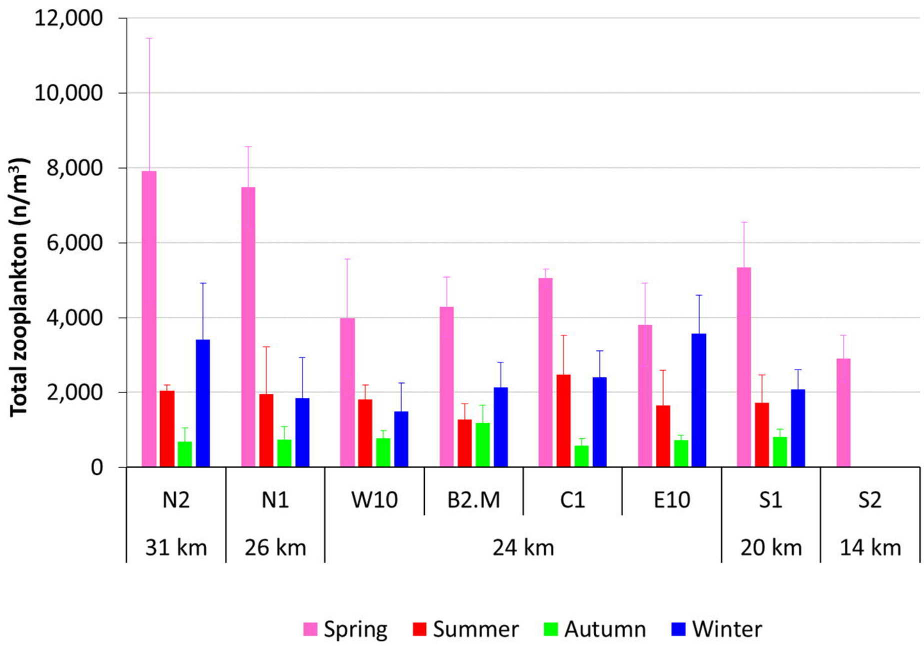

Figure 26. Seasonal abundance of total zooplankton per site (Dec-2018 to Dec-2019)

**Excludes August and December 2019 surveys at S2.*

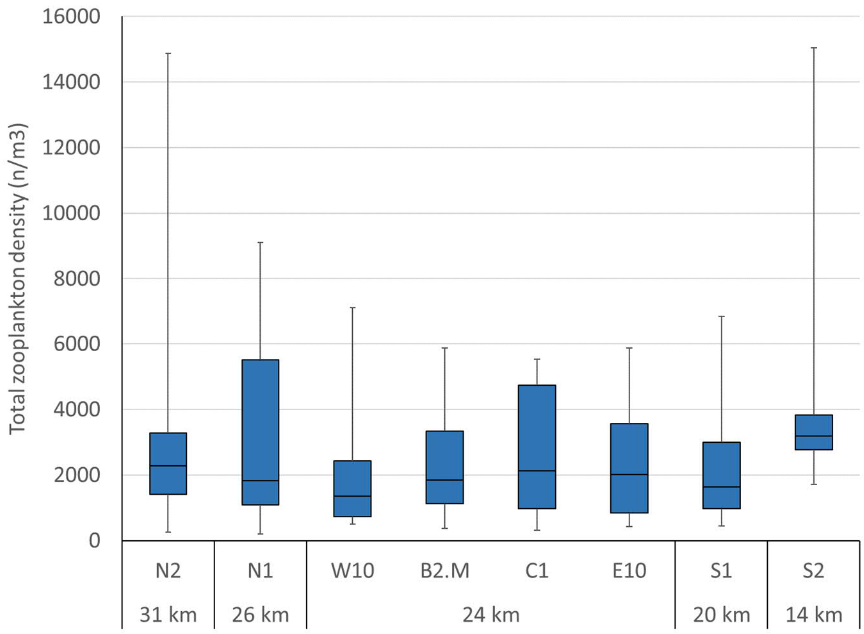

Figure 27. Spatial density of total zooplankton (Dec-2018 to Dec-2019)

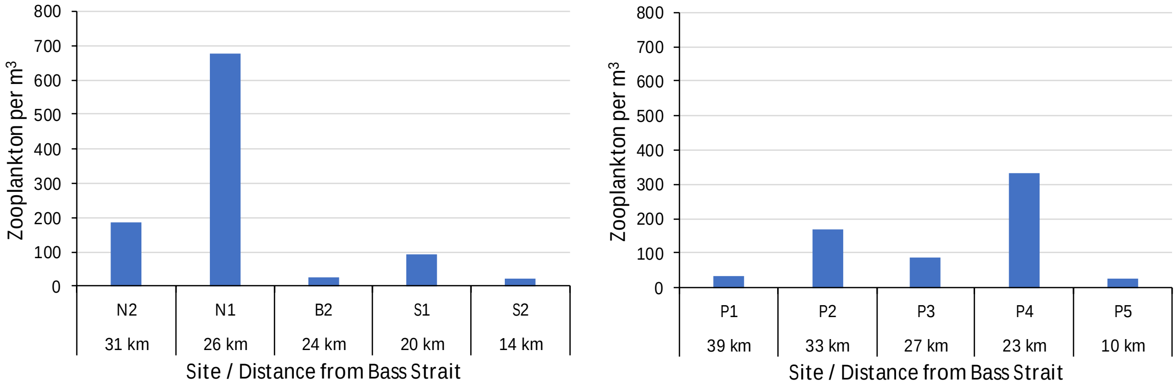

Figure 28. Spatial distribution of *Pseudodiaptomus cornutus*, October 2019

Table 6. Monthly zooplankton density (n/m^3) at site N2

Taxon \ Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					87	159	2035	562	5015	1977	4978	14353	1536
Acartia danae			6										
Acartia spp.	1329	1245	742	290									
Ascidian tadpole								5		43			1
Barnacle cyprid	6	5	2	16									
Barnacle nauplius	54	9	25	8						22			22
Bestiolina similis				379					104	43			
Bivalve			2										
Centropages	1												
Centropages australiensis										22			
Copepod nauplius	2												
Corycaeus speciosus								1					
Crab zoea	22	30	143	8							25	3	22
Ctenocalanus vanus										22			
Decapod larva	58	31	255									3	11
Dioithona rigida								69	52	22			11
Euphausiid larvae		4											
Euterpina acutifrons	2							8	575	543	503		
Fish egg	1												
Gammarid amphipod								1					
Gladioferens				16			55	6					
Gladioferens inermis			15										
Harpacticoid											8		
Leptomedusae	6	18	15	16								1	1
Lucifer	1												
Lucifer hanseni							11						
Microsetella norvegica							55	62	3	22			
Mollusc juvenile											8	9	11
Noctiluca scintillans			1										119
Oikopleura sp.			12	24	14								
Oithona			6	8									
Oithona (Fiona)		11											
Oncaea							110	1	4	43			
Paracalanus indicus	7	142	89	81	203	95	550	250	313	43	2		
Polychaete larva			1	8					52	87			
Polychaete trochophore larva	2												
Pseudodiaptomus cornutus			575				110	125	104	369	81	495	130
Pteropod	2	17		28	4			6					
Sagitta	28	2	2									2	10
Small gastropod	211	766	394	420	30								
Stomatopod larva				1									
Temora							6	18	7	22			
Temora turbinata	2	8											
Tortanus barbatus				97	58								
Total zooplankton	1732	2287	2285	1401	395	255	2932	1113	6231	3280	5606	14866	1873
Total number of species	17	13	17	15	6	2	8	13	10	14	7	7	11

Table 7. Monthly zooplankton density (n/m^3) at site N1

Taxon / Month	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)				24	272	1322	2537	3440	8009	7340	3737
Acartia danae		2									
Acartia spp.	596	607	166								
Ascidian tadpoles								77			
Barnacle cyprid	2		9	2	9						
Barnacle nauplius		25	9	2							
Bestiolina similis			454	4	6			39			
Centropages	1										
Corycaeus speciosus							1	39	2		
Crab zoea	31	109	26	2				77	6	35	55
Decapod larva	19	43	26			19				14	143
Dioithona rigida							113			6	
Euphausiid calyptopsis			13								
Euphausiid larvae	1										
Euterpina acutifrons	2						2	966	693	58	
Fish larva			1								
Gladioferens			17	5	8	38	5			9	
Gladioferens inermis		1									
Harpacticoid	1								11		1
Leptomedusae	20	15	1		1		1		8		1
Lucifer	1										
Lucifer hanseni			8			19					
Microsetella norvegica						76	6				
Mollusc juvenile										6	1385
Noctiluca scintillans	3										
Oikopleura sp.		10		6	1						
Oithona			44								
Oithona (Fiona)	4										
Oithona cf. similis							7	39	6		
Oncaea							2	39			
Paracalanus indicus	105	94	96	94	235	76	958	77	28		
Penilia sp.			9								
Polychaete larva					2			77	6		
Pseudodiaptomus cornutus		21	35			264	73	541	333	462	231
Pteropod	19		58								
Sagitta	2	1				8					77
Small gastropod	221	225	279	21	39						
Temora						11	14				
Temora turbinata	3										
Tortanus barbatus			140	47	72						
Total zooplankton	1030	1153	1390	207	644	1832	3718	5412	9100	7930	5629
Total numbers of species	17	12	18	10	10	9	12	11	10	8	8

Table 8. Monthly zooplankton density (n/m^3) at site W10

Taxon / Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					147	295	2348	427	340	2055	6240	2204	1667
Acartia danae					14	7	7						
Acartia spp.	1329	2501	367	561									
Ascidian tadpoles										11			
Barnacle cyprid		1	4										
Barnacle nauplius		1	10	5				4					
Bestiolina similis				385	122		33	27	18				
Bivalve			2										
Copepod nauplius		1											
Corycaeus speciosus							3	8		11	297		
Crab megalopa		1	2										
Crab zoea		3	26	5				3			19		71
Ctenocalanus vanus										11			
Cumacean									1				
Decapod larva	5		8	5	9	7					3		200
Dioithona rigida								39	68	11			14
Euphausiid calyptopsis			4		2	3							
Euphausiid furcilia				2									
Euphausiid larvae											4		
Euterpina acutifrons			2				104	3		126	432		
Gladioferens				9								1	
Harpacticoid								2		23			
Leptomedusae		54	10	5			20				22		
Lucifer hanseni				3									
Mollusc juvenile													57
Noctiluca scintillans		45	30									194	100
Oikopleura sp.			4	5									
Oithona			17	5									
Oithona (Fiona)		4											
Oithona cf. similis								3	1	11			
Oncaea								1	36				
Paracalanus indicus	4	32	77	70	73	184	196	67	272	46			14
Pipefish		3											
Polychaete larva			1	5			52			46			14
Porcellanid				2									
Pseudodiaptomus cornutus			34		2	4	157	4		69	108	32	
Pteropod			22	9									
Radiolarians					3								
Sagitta	25												
Salpa		73											
Small gastropod		1	358	116	196								
Temora			6		4	1		87					
Tortanus barbatus			12	9	49		111	7					
Veliger			2										
Total zooplankton	1363	2721	996	1198	621	501	3028	682	735	2422	7125	2432	2138
Total numbers of species	4	13	21	17	11	7	10	14	7	11	8	4	8

Table 9. Zooplankton density (n/m^3) at site B2 (monthly)

Taxon / Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					460	189	1040	2269	550	2359	4581	2581	1034
Acartia spp.	161	412	1396	393									
Barnacle cyprid	2	1	22	41									
Barnacle nauplius	1	3		14	13	11							
Bestiolina similis				650	145	17	104	6	50				
Centropages	1												
Corycaeus speciosus								5	5	41	79		
Crab megalopa		1											
Crab zoea	2	23	52	27	7					21	18	21	
Cumacean								1					
Decapod larva	19	10	11	54	3						4	8	517
Dioithona rigida								70	5	21	65		
Euphausiid calyptopsis				20									
Euphausiid larvae	1												
Euterpina acutifrons	2						62	7	150	621	719		
Fish egg	1												
Fish larvae	1	1											
Gammarid		1											
Gladioferens				14	3		109	19		2	22	3	
Harpacticoid	6									41	4		
Leptomedusae	2	17	17								11	3	1
Lucifer	1												
Lucifer hanseni				16	23		1						
Mollusc juvenile								1	1		2	8	11
Noctiluca scintillans	2	2	15									931	43
Oikopleura sp.				27									
Oithona			20		21								
Oithona (Fiona)	1												
Oithona cf. similis										21			
Oncaea								2	5				11
Paracalanus indicus	15	28	15	176	259	125	104	908	350	41	24	3	
Pipefish		2											
Polychaete larva								2	1	41	2		
Polychaete trochophore larva	1												
Porcellanid		1		7									
Pseudodiaptomus cornutus			30				312	57	50	103	67	133	22
Pteropod	1	2	14	29	11	14							
Sagitta	4	12											11
Salpa		63											
Small gastropod	152	239	672	366	129								
Temora				122	3	32	52	57	5	21	269		
Temora turbinata	1	12											
Tortanus barbatus				81	43		52	6					
Total zooplankton	375	833	2262	2037	1120	389	1836	3408	1171	3333	5869	3691	1650
Total numbers of species	21	18	11	16	13	6	9	14	11	12	14	9	8

Table 10. Zooplankton density (n/m^3) at site B2 (fortnight)

Taxon / Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19
Acartia (fancetti, tranteri)				219	220	505	1532	327	685	4046	3444	2356
Acartia danae							8					
Acartia spp.	554	894	1970									
Barnacle cyprid		40										
Barnacle nauplius	12			6	8							
Bestiolina similis				73	55			56	1			
Copepod nauplius			8									
Corycaeus speciosus							6		27	138	53	
Crab megalopa			1									
Crab zoea	74	79	139	7		12					19	45
Decapod larva	31	40	187							2		30
Dioithona rigida								56	4		21	
Euphausiid calyptopsis				7	3							
Euterpina acutifrons							348	4	239	1775	11	1
Farranula		10										
Gladioferens				19		19						3
Harpacticoid									1		3	
Leptomedusae	6		47						1		2	3
Lucifer hanseni				11								
Microsetella norvegica										3		
Noctiluca scintillans	12		140									716
Oithona			47			18						
Oithona (Fiona)	6											
Oithona cf. similis								4				
Oncaea								70	3			
Paracalanus indicus	111	40	61	73	83	252	488	700	353	106		
Polychaete larva			16				209		1	14		
Porcellanid larvae			3									
Pseudodiaptomus cornutus		79	93					4	39	170	27	89
Pteropod	12		8	5	28							
Sagitta	6	99										15
Salpa	154											
Small gastropod	62	437	331	18	14	57						
Temora				16	28				45	43	53	
Tortanus barbatus				73	55	68	139					
Total zooplankton	1040	1719	3049	527	492	931	2729	1221	1397	6297	3632	3259
Total numbers of species	12	9	14	12	9	7	7	8	12	9	9	9

** August 19 values are averaged from 4 replicate samples*

Table 11. Monthly zooplankton density (n/m^3) at site C1

Taxon / Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					191	175	825	1146	2823	3910	3947	4705	4089
Acartia danae			5										
Acartia spp.	187	540	210	139									
Ascidian tadpole										36	1		
Barnacle cyprid	1	4	8	2									
Barnacle nauplius	4	4	17	2	7	5		5					17
Bestiolina similis				370	38	29	49	9	111				
Copepod nauplius		4											
Corycaeus speciosus								8	3	12	189	29	
Crab megalopa			8	2									
Crab zoea	17	12	101	15	3	9		4		72	11	9	52
Ctenocalanus vanus									5				
Decapod larva	32	4	59	17	4	3				12	3		806
Dioithona rigida							19	88	61	12	27		35
Doliolid	2												
Euphausiid calyptopsis			64	4									
Euphausiid larvae											1		
Euterpina acutifrons							243	8	166	386	460	118	5
Farranula			1										
Fish egg				2									
Fish larvae			1										
Gammarid amphipod											3		
Gladioferens				23									5
Harpacticoid				2							3		1
Leptomedusae	1	23	22	6				2		24	8		3
Lucifer	1												
Lucifer hanseni				2		3	34						
Microsetella norvegica							63						
Mollusc juvenile												7	156
Noctiluca scintillans		16										382	
Oikopleura sp.			42	8	7	2							
Oithona			17	4	15	12							
Oithona cf. similis								21					
Oncaea				6				2	11				
Paracalanus indicus	5	50	67	90	115	63	53	729	387	48	108	9	17
Penilia sp.				4									
Polychaete larva				6		2		3	55	24	3		
Porcellanid				2									
Pseudodiaptomus cornutus			126					57	121	169	81	265	156
Pteropod		35	17	15	3	2							
Sagitta												3	87
Salpa	5												
Small gastropod	206	1697	815	130	38								
Temora			50	2				31		24	81		
Tortanus barbatus			6	115	19	15	53	9					
Total zooplankton	461	2388	1635	966	441	319	1339	2122	3743	4731	4925	5527	5429
Total numbers of species	11	11	19	24	11	12	8	15	10	12	15	9	13

Table 12. Monthly zooplankton density (n/m^3) at site E10

Taxon \ Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					465	386	1507	1627	4879	1905	1100	4741	712
Acartia danae			2										
Acartia spp.	173	903	221	53									
Ascidian tadpole			1										
Barnacle cyprid		14			5	5							
Barnacle nauplius		5		4				5					
Bestiolina similis				155	140				284	307			
Copepod nauplius		5		4			126						
Corycaeus speciosus								9	5	61	50		
Crab zoea	5	58	17	11	4						8	42	
Decapod larva	61	58	17	57	1	7						4	94
Dioithona rigida								71	57	61			13
Doliolid	3												
Euphausiid calyptopsis			7			3							
Euphausiid larvae		5									1		
Euterpina acutifrons							167	5	57	307	325	177	
Fish larvae	3												
Gammarid amphipod											2		
Gladioferens							10	5				2	
Gladioferens inermis			1										
Leptomedusae		29	3	4						61	25	11	5
Microsetella norvegica							8		1				
Mollusc juvenile												1	13
Noctiluca scintillans		29	20									778	40
Oikopleura sp.		19	3	15	1								
Oithona				8	2	2							
Oithona (Fiona)		5											
Oithona cf. similis											3		
Oncaea								3			1	3	
Paracalanus indicus	3	222	17	34	186	244	418	678	170	123	175		
Penilia sp.				6									
Polychaete larva				4					1	246			
Polychaete trochophore larva		10											
Pseudodiaptomus cornutus			31			4	84	77	184	492		106	67
Pteropod		29	17	17	9	13							
Sagitta	3												
Salpa	165												
Small gastropod	5	3032	493	26	140								
Temora						27	17	47			325		
Tortanus barbatus			2	90	9		201	11					
Total zooplankton	419	4422	850	486	963	690	2538	2536	5636	3565	2014	5865	946
Total numbers of species	9	15	15	15	11	9	9	11	9	9	11	10	7

Table 13. Monthly zooplankton density (n/m^3) at site S1

Taxon / Month	Dec 18	Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)					92	161	1594	543	2608	3817	5888	1139	1925
Acartia danae			1		2	2							
Acartia spp.	372	486	337	147									
Ascidian tadpole				1									
Barnacle cyprid	4			15	1	2							
Barnacle nauplius	2		26			3							13
Bestiolina similis				236	62	39		9	95				
Centropages	1												
Copepod nauplius	1												
Corycaeus speciosus							47	7	3		244		
Crab zoea	14	30	131	59	4					338	34	8	13
Ctenocalanus vanus								3					
Cumacean					1	1			1		1		
Decapod larva	6	30		74	6							3	725
Dioithona rigida							94	65				5	13
Euphausiid calyptopsis			2		9	5							
Euphausiid larvae		10											
Euterpina				15	2								
Euterpina acutifrons		10					9	10	4	1111	397	3	3
Farranula			8										
Gladioferens				88	1	12	9	11					
Harpacticoid	1		14								3		
Leptomedusae	6	41	26			2					9		
Lucifer hanseni					7	1							
Microsetella norvegica							23	22					
Mollusc juvenile													138
Noctiluca scintillans	27	658	175									1790	825
Oikopleura sp.				88									
Oithona				29	31	22							
Oithona (Fiona)	2												
Oithona cf. similis								5		48	3		
Oncaea					92	7		1					
Paracalanus crassifrostris								6					
Paracalanus indicus	18	91		44	306	129	141	272	284	97			13
Penilia sp.				9									
Polychaete larva					1	7				145			
Pseudodiaptomus cornutus			84				103	114		628	183		38
Pteropod		10		4	6	9							
Sagitta	1										2		113
Salpa	9												
Small gastropod	25	273	143	192	9	10							
Temora			26		7	32		81	4	48	73		
Tortanus barbatus				206	122	3	47	5					
Total zooplankton	488	1640	973	1208	761	448	2068	1153	2999	6233	6837	2948	3815
Total numbers of species	15	10	12	15	19	18	9	15	7	8	11	6	11

Table 14. Monthly zooplankton density (n/m^3) at site S2

Taxon \ Month	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Acartia (fancetti, tranteri)	2537	2753	511	416	97
Barnacle nauplius		32	7		
Bestiolina similis	56	63			
Centropages australiensis		32			
Corycaeus speciosus		95	54	3	
Crab zoea	1		48		
Ctenocalanus vanus	3				
Cumacean		32			
Decapod larva			6		55
Dioithona rigida		32	57	5	
Euphausiid larvae			2		
Euterpina acutifrons	56	221	738	1	
Gladioferens				3	
Microsetella norvegica		32			
Mollusc juvenile			15		
Noctiluca scintillans				2758	14883
Oithona cf. similis			4		
Oncaea	13	63			
Paracalanus indicus	113	253	227		
polychaete larva		127			
Pseudodiaptomus cornutus		63			
Temora		32	28		
Total zooplankton	2779	3829	1697	3186	15034
Total numbers of species	7	14	12	6	3

7.2 Subconsultants Report

"*Westernport Bay Zooplankton"*
Report to CEE Pty Ltd Environmental Scientists and Engineers.
January 2020

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Dr. Kerry Swadling
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Report follows

Westernport Bay Zooplankton
CEE Technical Report
Kerrie Swadling

10 January 2020

1. Marine zooplankton

The term zooplankton describes heterotrophic planktonic organisms that are generally weak swimmers and cannot move effectively against currents. Zooplankton are found in almost all water bodies, both freshwater and marine, and throughout the major ocean realms down to the deep sea. Zooplankton are critical to the functioning of marine food webs due to their large numbers and vital ecosystem roles. One of these roles is as grazers of the primary producers in aquatic foodwebs, making zooplankton a key conduit for energy transfer from phytoplankton to higher trophic levels such as fish, marine mammals and seabirds. Zooplankton are also crucial components of the biological carbon pump, as their grazing supports remineralisation of nutrients in surface waters and their products (carcasses, moults, faecal pellets) transfer carbon to the sediments, where they can be sequestered over geological time-scales. Over millennia carbon from plankton accumulates to become oil and natural gas deposits.

Representatives of most marine phyla are found in the zooplankton, either spending their entire life cycle in the plankton (‘holoplankton’) or spending part of their life span, ranging from hours to many months (‘meroplankton’). Examples of holoplankton are common crustaceans such as copepods, euphausiids (krill) and cladocerans (water fleas), and gelatinous species (e.g. salps, jellyfish). Meroplankton represent those animals that often have a planktonic larval phase before settling to the benthos as adults (e.g. echinoderms, bryozoans, crabs) or grow into free-swimming nekton (e.g. fish, prawns). Zooplankton are mostly small and measure from millimetres to centimetres. However, some jellyfish can measure up to 2 m and weigh many kilograms.

Because of their weak swimming ability zooplankton are dependent on currents for their dispersal and geographical positioning, making them vulnerable to the effects of warming seawater temperatures and other environmental changes. Nutrient input to coastal waters, e.g. from agricultural runoff, sewage outflows, can also affect zooplankton, by altering the community composition if there is a sudden influx of nutrients. For example, an increase in nutrients from terrestrial sources might lead to a spike in numbers of protists, cladocerans and small copepods; i.e., small, rapidly reproducing taxa. If the event is episodic then small-bodied colonisers will give way to larger species. However, if the increase in nutrients becomes persistent then there is a chance that the community will persist indefinitely as smaller species, thereby altering the mean

size of the zooplankton assemblage. Zooplankton are poikilotherms (internal temperature varies with the environment), so their physiology is dependent on the surrounding conditions, which dictates their possible habitat range. This feature makes some species good indicators of specific water bodies. Biological indicators can be used to define environmental characteristics that can be followed over time and space to quantify and identify shifts from normal conditions. For example, finding warm water zooplankton species in samples can imply the presence of a warm water mass and might facilitate predictions about future climate change scenarios. Zooplankton might be better indicators than larger nekton due to several features: they are rarely, if ever, targeted by commercial fisheries, their life spans are short, and their metabolism is coupled to water temperature. This last feature means that the habitat ranges of planktonic animals expand and retract in size depending on the conditions in the water column and/or the movements of currents.

Zooplankton are distributed patchily, both vertically and horizontally, a result of both behavioural traits and the environmental conditions of their habitat. Individuals can form large aggregations, often in response to locating a concentrated food source, but also as a means of predator avoidance and for purposes of reproduction. Aggregations can also be the result of temperature and salinity gradients within the water column acting as barriers to dispersal. Understanding the aggregation and migration behaviour of zooplankton is important for interpreting their population dynamics in both space and time. Diel vertical migration (DVM) is a behaviour common to many zooplankton species, where they ascend to surface waters at night and live deeper in the water during daylight hours. By feeding in the surface waters at night the organisms can avoid visual predators, predominantly planktivorous fish.

2. Early studies of the zooplankton community in Westernport Bay.

The waters of Westernport Bay are warm and shallow, with regions of mudflats and seagrass beds. These features provide zooplankton with protection from predators and a reliable food supply. The waters are also used as nursery grounds for several fish species. Westernport Bay is ~680 km^2 in area and the water column averages 5 m depth. It has a wide western entrance and a narrow entrance east of Phillip Island, where tidal currents are strong. Many channels carve through and drain the mudflats and seagrass beds, resulting in a turbid habitat that generates large quantities of particulate organic matter (POM) in the form of detritus.

Zooplankton in Westernport Bay were first studied in the early 1970s (Arnott 1974, cited in Kimmerer and McKinnon 1985), while nearby Port Phillip Bay was first sampled for zooplankton during the period 1969-1970 (Axelrad et al. 1981). Westernport Bay was sampled repeatedly by Kimmerer and McKinnon (1985) in 1982-1983. During that period the bay ranged in temperature from 9.9 °C to 22 °C and in salinity from 33.4 to 37.8, leading to the conclusion that Westernport Bay was not strongly estuarine. The high turbidity of the bay was highlighted by Secchi depths as shallow as 1.2 m in some areas; chlorophyll a concentration (as a proxy for phytoplankton biomass) was correlated inversely with Secchi depth. Residence times were calculated to be 60 days. Sampling was undertaken at a group of 'central' stations in the basins south and east of French Island and 'outer' stations north of Phillip Island.

To collect the zooplankton Kimmerer and McKinnon (1985) deployed a small net (0.5 m mouth area, 200 μm mesh size) vertically from the near-bottom to the surface. The zooplankton community was characterised as comprising species that were either euryhaline marine or open coastal in nature, rather than showing estuarine affinities. Calanoid copepods, particularly *Acartia tranteri* (previously identified as *A. clausi*, Arnott 1974, cited in Kimmerer and McKinnon 1985) were the dominant group. The organisms identified as *Acartia tranteri* were likely to be a combination of two species, *A. tranteri* and *A. fancetti*, the latter representing up to 77% of *Acartia* spp. counted in Westernport Bay. *Acartia* spp. contributed over 50% to total zooplankton abundance and they were particularly common at the 'central' stations. The second most abundant copepod species, which contributed less than 10% to total zooplankton abundance, was *Paracalanus indicus* (previously identified as *P. parvus*); this species was common in waters north of Cowes, on the northwestern side of Phillip Island. Other, less abundant copepods included *Pseudodiaptomus cornutus*, *Calanus australis* and *Bestiolina similis*.

Groups other than copepods generally occurred in lower numbers; for example, cladocerans were only represented by a few records of *Podon*, viz. *P. intermedius* and *P. polyphemoides* (Kimmerer and McKinnon 1985). Notably, gastropod larvae contributed as high as 25% to the total on some occasions, while crab larvae reached 4% (Macreadie 1972). The water column above the seagrass-covered mudflats at Crib Point were common habitat for crab zoea and larvae of callianassid and carid shrimps (Robertson and Howard 1978), and larvae of the barnacle *Elminius covertus* were observed near Rhyll, on the northwestern edge of Phillip Island (Satumanatpan and Keough 2001). Planktonic carnivores occurred in low numbers. These included the copepod *Tortanus barbatus*, chaetognaths, ctenophores and medusae (Kimmerer and McKinnon 1985). The jellyfish *Catostylus mosaicus* was sampled in Westernport Bay and Port Phillip Bay in April and May, 1998 and March to May, 1999 (Hudson and Walker 1998, 1999).

3. General characteristics of the zooplankton community in Westernport Bay, 2018 - 2019

In Westernport Bay the total average zooplankton abundance ranged from a low of 464 individuals m^{-3} in early May to a high of 7100 individuals m^{-3} in November. The zooplankton followed a common pattern for temperate coastal areas, where high abundance occurs in summer then decreases through autumn and winter (Figure 1A), though it was interesting to see numbers begin to rise again well before the onset of spring. However, there was considerable variation around each mean, with maximum values up to double that of the mean and minima less than half of the mean. Over all samples and dates copepods represented ~ 74% of the total abundance. Molluscs, primarily small gastropods, accounted for 17%, decapod larvae ~ 5%, gelatinous groups 1% and the remainder 3%. The 'other' group consisted mainly of chaetognaths and polychaete larvae (Figure 1B).

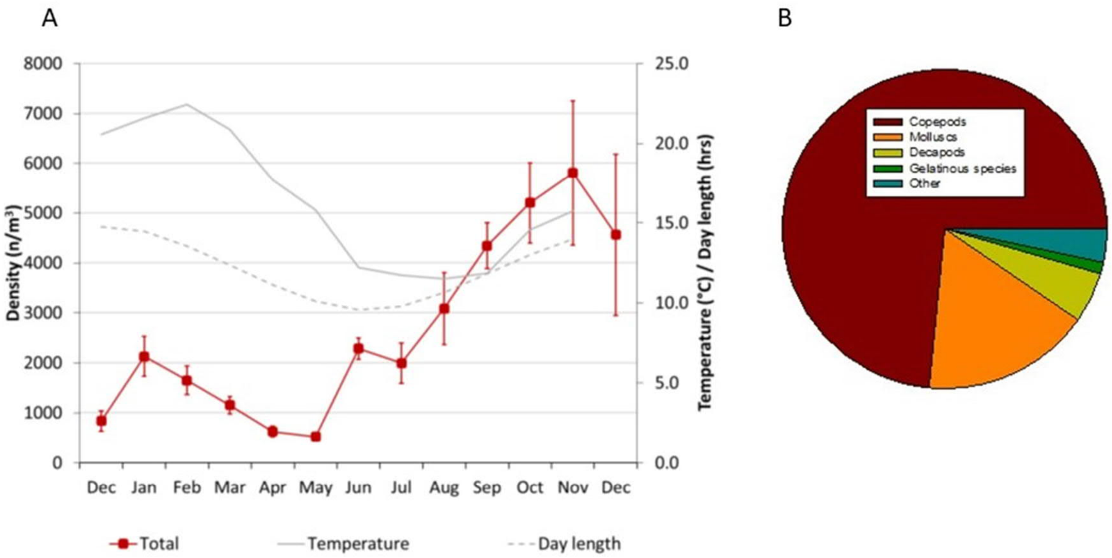

Figure 1. A. Average abundance (circles) of zooplankton in Westernport Bay. Error bars show range (minimum – maximum) of recorded values for each month. B. Percentage contribution of the major zooplankton groups sampled from Westernport Bay. The 'other' category represents chaetognaths and polychaete larvae.

The contribution from copepods to total abundance ranged from 51% in January to 93% in May. This likely reflects less contribution from meroplanktonic fauna as the temperatures start to cool. To date, more than forty taxa have been identified as occurring in the survey region over the sampling period. Species in the genus *Acartia*, namely *A. tranteri*, *A. fancetti* and *A. danae*, were dominant in the months of December, January and February, while species in the Family Paracalanidae, *Paracalanus indicus* and *Bestiolina similis* were common from March to May. The

carnivorous copepod *Tortanus barbatus* was also common in the months March to July, with high numbers of adults present. Cyclopoid and poecilostomatoid copepods, *Oithona* spp., *Oncaea* spp. and *Corycaeus* sp., were low in the samples (~3%), as were harpacticoid copepods. The planktontic harpacticoid *Euterpina acutifrons* was present in low numbers during most months (< 1%). Decapod larvae, including zoea and megalopa of crabs, were consistently present, with relative abundance reaching ~10% in February, probably as a result of these animals timing their breeding to the increased food availability in summer. Small gastropods were common in most samples and might have been the result of the shallow water depth whereby resuspension of the sediments stirred these organisms into the water column. Gelatinous species, including salps, doliolids and appendicularians, were never prominent, though salps were observed in reasonable numbers (up to 167 individuals m^{-3}) in December. Finally, the heterotrophic dinoflagellate *Noctiluca scintillans*, a species that is increasingly being transported southwards in the East Australia Current (McLeod et al. 2012), was only observed in small numbers and rarely in the large numbers encountered in other coastal regions.

4. Key taxonomic groups

4.1 Copepods

The three main Orders of free-living copepods have been observed in Westernport Bay: Calanoida, Cyclopoida and Harpacticoida. Calanoid copepods were the dominant group to-date, with only sporadic occurrences of cyclopoids and harpacticoids.

(i) *Acartia* spp., the main contributor to the zooplankton community in Westernport Bay, are found globally in nearshore plankton communities, including estuaries, and open ocean habitats. They often dominate abundance year-round. Many species in this genus are both eurythermal and euryhaline and this strong tolerance of environmental fluctuations facilitates their successful colonisation of coastal waters. This genus is generally omnivorous, with individuals capable of feeding on phytoplankton, small zooplankton and detritus. They often dominate regions with high particulate loads, making them particularly successful in Westernport Bay. *Acartia* spp. are known predators of the calanoid copepods *Paracalanus indicus* and *Gladioferens inermis* in Westernport Bay. The three species in this genus that have been observed in Westernport Bay are *A. tranteri*, *A. fancetti* and *A. danae*.

Acartia (*Acartiura*) *tranteri* Bradford, 1976; length is 0.97 – 1.11 mm (female), 0.9 – 1.0 mm (male); Figure 2A: This species is epipelagic and found in estuarine, inshore coastal and coastal waters. It has been reported previously from Moreton Bay, the Swan River Estuary, Port Phillip Bay and Westernport Bay. It often dominates plankton hauls in nearshore waters and has a strong

tolerance for salinity and temperature fluctuations and waters with high particulate loads. It reproduces year-round with overlapping generations, if sufficient food is available. Development is nearly constant throughout its life and turnover rates have been estimated to be between 3 and 30 days. Adults of *A. tranteri* are known to prey on *Paracalanus indicus* and *Gladioferens inermis*.

Acartia (*Acartiura*) *fancetti* Kimmerer, McKinnon & Benzie, 1992; length is 0.72 – 1.08 (female), 0.75 – 0.96 (male): Little is known about this species. It was previously identified as *A. clausi* or *A. tranteri* from Westernport and Port Phillip Bays. McKinnon et al. (1992) used allozyme electrophoresis to separate the individuals and erected the new species, *A. fancetti*. It appears to be the characteristic species of the 'inner' bay stations as described by Kimmerer and McKinnon (1985).

Acartia (*Acartia*) *danae* Giesbrecht, 1889; length is 0.90 – 1.34 (female), 0.70 – 1.10 (male); Figure 2B: This species occurred only in small numbers in Westernport Bay. It is epipelagic, and one of two species of *Acartia* that primarily inhabit oceanic waters. It has been identified previously from Moreton Bay, Port Hacking, and offshore from New South Wales. It is a cosmopolitan species, found generally in subtropical and tropical waters between 40 ^{o}N and 40 ^{o}S. It has been used as an indicator species of warm water intrusion into cooler southern Australian regions (e.g. Johnson et al. 2012). It functions as both a suspension feeder and a raptorial carnivore.

(ii) Family Paracalanidae: Two species from this Family have been observed in Westernport Bay: *Paracalanus indicus* Wolfenden, 1895 and *Bestiolina similis* (Sewell, 1914). The more common species is *P. indicus*, which often co-dominates with *A. tranteri* in inshore waters. *Paracalanus indicus* (Figure 2C; length 0.85 – 0.95 female, 0.85 – 1.02 male) is an epipelagic coastal species that is widespread in tropical and subtropical waters of the three major oceans and is also found in subantarctic waters. It is common around Australia. *Paracalanus indicus* are suspension feeders, making the turbid waters of Westernport Bay a less favourable habitat. It often has red pigmentation, which makes it common prey for planktivorous fish in shallow estuaries. *Bestiolina similis* (Figure 2D; length 0.72 – 0.81 female, 0.80 male). Like *P. indicus* it is an epipelagive species that is common in inshore waters and estuaries of the tropics; however, it is also found in temperate waters along the east coast of Australia. *Bestiolina similis* can produce up to 50 eggs female^{-1} day^{-1}, and its eggs are spawned directly into the water column. Naupliar development is usually complete in less than four days. This species is also important prey for larval fish.

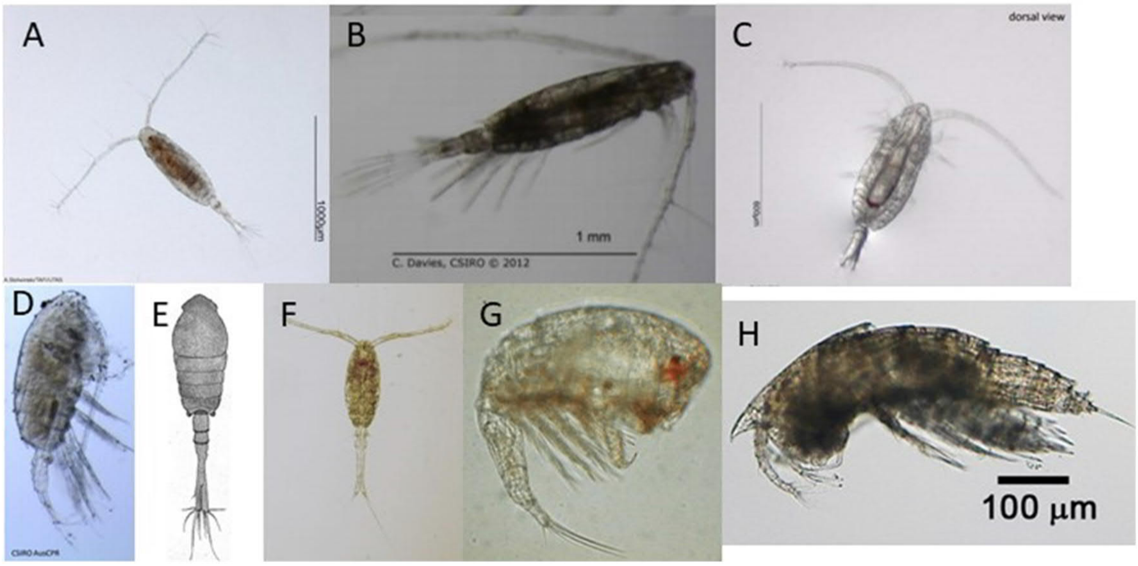

Figure 2. Examples of copepods collected from Westernport Bay. A. *Acartia tranteri*; B. *Acartia danae*; C. *Paracalanus indicus*; D. *Bestiolina similis*; E. *Tortanus barbatus*; F. *Oithona* sp.; G. *Oncaea* sp.; H. *Euterpina acutifrons.* Photos: AUSCPR, Razouls et al. 2019 (E)

(iii) *Tortanus barbatus* (Brady, 1883); length is 1.15 – 2.10 (female), 0.90 – 1.20 (male); Figure 2E: This species is carnivorous and is coastal and epipelagic (Razouls et al. 2019). It often occurs in eutrophic waters. Species in the genus *Tortanus* lay resting eggs in sediments that survive until conditions become favourable for hatching. Not much is known of the behaviour or ecology of *T. barbatus* though it has been recorded undertaking diel vertical migration (Tranter et al. 1981).

(iv) Cyclopoid and Poecilostomatoid copepods: These are generally small copepods, often measuring less than 0.5 mm. The genus *Oithona* (Figure 2F) is a cosmopolitan group that is found in both coastal and oceanic habitats including in the high latitudes of the Southern Ocean. It is important prey for small mesopelagic fish, as well as surface feeders in coastal regions. Members of the genus carry their egg sacs until conditions are favourable for spawning. They have a broad range of feeding strategies, including ingesting motile prey such as ciliates, as well as feeding on faecal pellets of other zooplankton. Many species within *Oithona* are difficult to distinguish and there are now efforts to use molecular genetics to resolve some of the issues with identification.

Oncaea spp. (Figure 2G) were once part of the Order Cyclopoida, but recent work has relegated them to a separate Order, the Poecilostomatoids. *Oncaea* spp. are small, often pigmented and cryptic. In some cases they can only be identified to groups or clades. To date, they have only been observed in low numbers in Westernport Bay during the cooler months. The species in this genus are epipelagic to mesopelagic and they found in inshore, coastal and oceanic waters. They tend to be more diverse in subtropical and tropical regions, though a small number of species are found in high numbers in subantarctic and Antarctic waters. They carry their eggs in paired sacs, with up to 50 eggs per sac. Members of this genus are known to feed on small zooplankton and the mucous

houses of appendicularians, which attract phytoplankton and bacteria to their sticky surfaces. Some species are also parasitic or semi-parasitic.

(v) Harpacticoid copepods: Two species of planktonic harpacticoids, *Euterpina acutifrons* Dana, 1947 (Figure 2G) and *Metis* sp. have been observed in Westernport Bay, with *E. acutifrons* the more numerous. They are small, measuring 0.5 mm in for males and 0.75 mm for females. Their distribution is epipelagic and coastal, and they are widespread in tropical and subtropical waters of all oceans. They can tolerate a wide range in salinity and are non-selective herbivores. The females carry a single egg sac. The generation times range from 23 – 85 days, with the length of time depending on water temperature and food availability. *Metis* sp. is pigmented bright red and is also small. Less than 10 specimens have been observed in Westernport in the present study.

4.2 Other crustaceans

The decapod larvae present in the samples were a diverse group, represented mainly by zoea of crabs (Figures 3A, B), prawn larvae (Figure 3D) the ghost shrimp *Lucifer hanseni* (Figure 3E) and the nauplii (Figure 3G) and cyprids (Figure 3H) of barnacles. Crab zoea were the most common of the decapods observed, though a small number of the megalopa (Figure 3C), a more advanced development stage, was also seen. Euphausiids (Figure 3F) can be distinguished from other crustaceans by their external gills that are visible near the front appendages. Only larval euphausiids were observed in Westernport Bay, with two stages, calyptopsis and furcilia, identifiable.

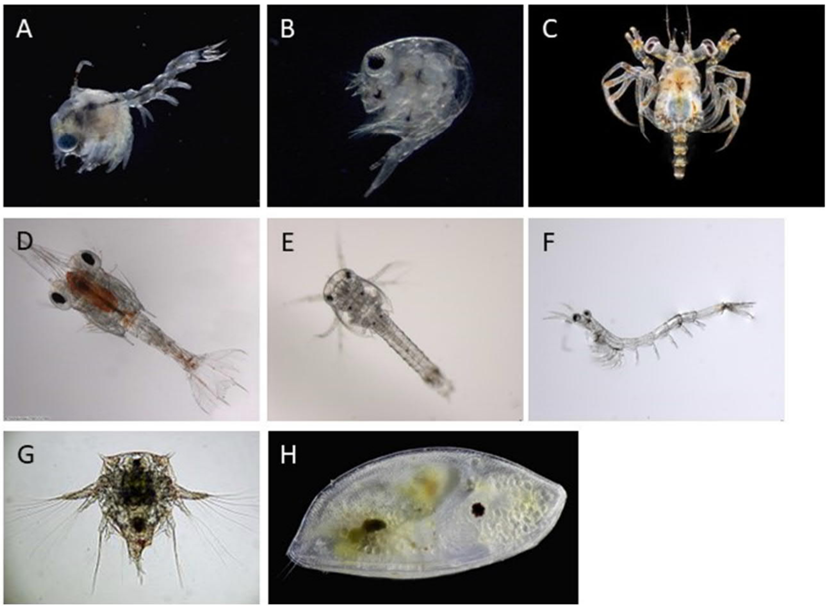

Figure 3. Examples of other crustaceans collected from Westernport Bay. A. Crab zoea; B. Crab zoea; C. Crab megalopa; D. Larval shrimp; E. Euphausiid larva; F. *Lucifer hanseni*; G. Barnacle nauplius; H. Barnacle cyprid. Photos: AUSCPR

4.3 Molluscs

Molluscs were common in many of the samples, possibly as a result of sediment resuspension in the shallow waters of Westernport Bay. Two species (Figure 4A, B) were observed, along with some pteropods (Figure 4C). At present the molluscs remain unidentified to higher taxonomic levels.

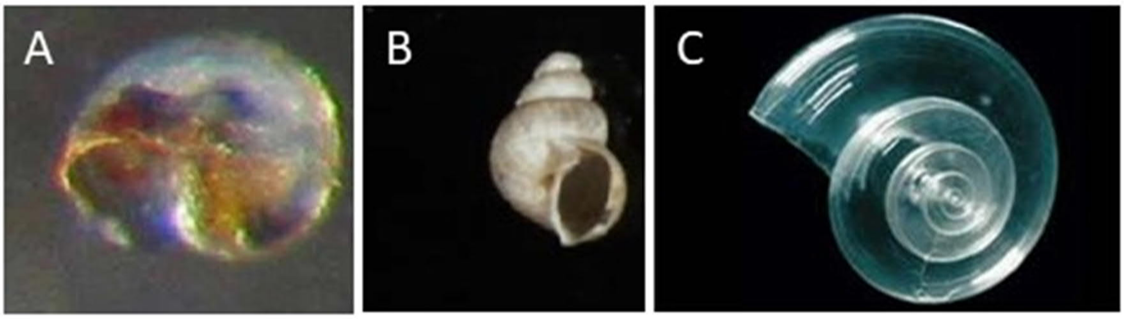

Figure 4. Examples of molluscs collected from Westernport Bay. A. Small gastropod; B. Small gastropod; C. Pteropod shell.

4.4 Other taxa

Several groups were recorded in either low abundances or on only one or two occasions. These groups included thaliaceans (salps and doliolids), appendicularians, polychaete larvae, chaetognaths and *Noctiluca scintillans*. The salp *Thalia democractica* was present in its aggregate form, especially east of Crib Point (167 individuals m^{-3}). Doliolids were also present at that site, though in much lower numbers (3 individuals m^{-3}). These thaliaceans tend to be common in southeastern Australian waters in summer, when water temperatures are higher and phytoplankton is abundant. Appendicularians, also called larvaceans, were represented by *Oikopleura* sp. and were never higher than 1.5% of total abundances. Polychaetes were present as unidentified larvae, and were also low in number. Chaetognaths, also called arrow-worms, are a gelatinous, planktonic group of predators. They prey on a large range of other zooplankton, including copepods, euphausiids and decapod larvae. They were also rare in Westernport Bay, rarely reaching > 1% of the total abundance. Finally, the dinoflagellate *Noctiluca scintillans* was sampled from December to February, in keeping with the higher abundances that are observed along the coast of southeastern Australia in summer.

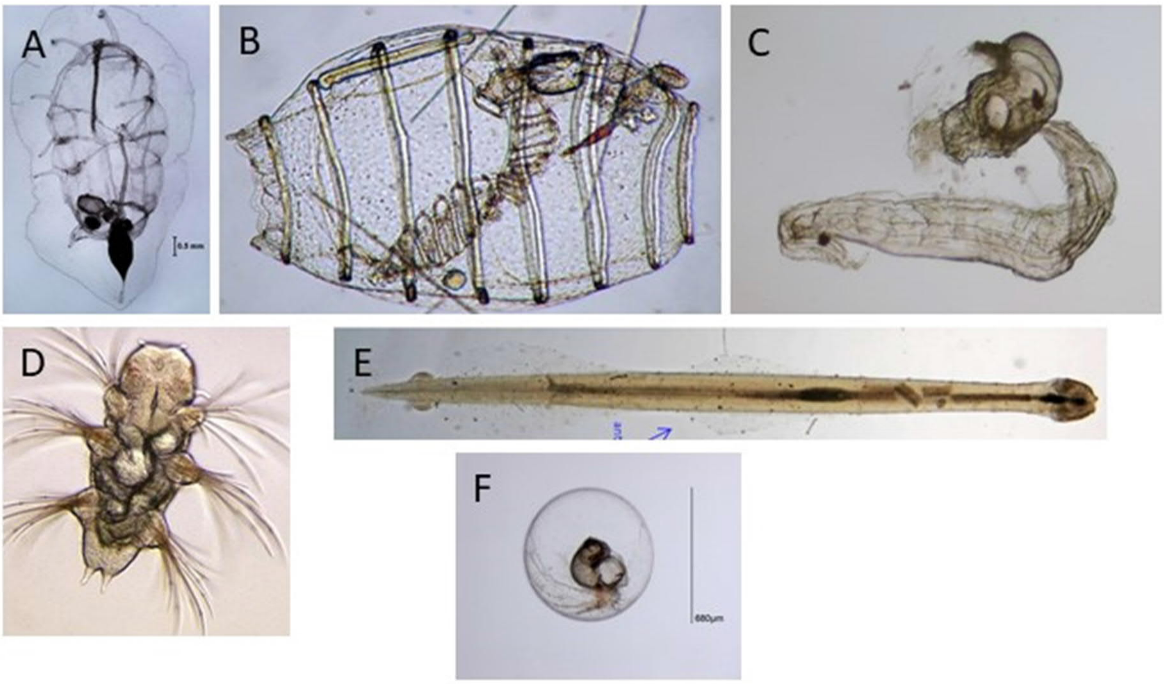

Figure 5. Examples of other organisms collected from Westernport Bay. A. *Thalia democratica*; B. Doliolid; C. *Oikopleura* sp.; D. polychaete larva; E. *Sagitta* sp.; F. *Noctiluca scintillans*. Photos: AUSCPR

5. Comparison of North Arm zooplankton community with other locations

The zooplankton community in North Arm was similar to the broader patterns that have been observed for Westernport Bay in the past (Kimmerer and McKinnon 1985). The dominance of *Acartia* spp. and the lower numbers of *Paracalanus indicus* reflect the samples collected in the early 1980s. The large quantities of detritus that are generated from the mudflats and seagrass beds in Westernport contrast with the environment of nearby Port Phillip Bay, where *P. indicus* shows seasonal dominance. In the deeper waters of Port Phillip Bay, the influence of mudflats and seagrass, and consequently detritus, is reduced. Therefore *P. indicus* can thrive and reach abundances that are similar to or higher than *Acartia* spp. *Paracalanus indicus* appeared to be an invader in Westernport rather than a resident and was more abundant at the 'outer' stations (Kimmerer and McKinnon 1985). Notably, in a year with higher than average rainfall *Acartia* spp. were more abundant than normal in Port Phillip Bay (Arnott 1974, cited in Kimmerer and McKinnon, 1985), possibly resulting from the extra rainfall creating turbulence and stirring up particulate organic matter in the bay.

Both Westernport Bay and Port Phillip Bay debouche into Bass Strait, with Westernport having greater exchange with Bass Strait due to it wider entrance. The three water bodies share five species in common: the copepods *P. indicus*, *Oithona similis*, *A. tranteri*, *E. acutifrons*, and the

ghost shrimp *Lucifer hanseni*. *Oithona similis* was present all year in Westernport, as was *Euterpina acutifrons*, though the latter was present all year at the 'outer' stations but was seasonal at the inner stations. *Lucifer hanseni* seemed to be resident in both bays, though more seasonal in Port Phillip Bay. The appendicularian *Oikopleura dioica* was present in Westernport only in summer, apparently invading from Bass Strait. Overall, abundances in this region appear to be low in comparison to other temperate bays, which is in keeping with low abundances in most Australian coastal waters (Kimmerer and McKinnon 1985). Relatively low trophic status implies relatively low nutrient input per unit area.

Residence time (~60 days), suspended particulate matter and water motion are probably more important than temperature and salinity alone in determining the zooplankton community patterns observed in Westernport Bay, along with zooplankton behaviour and predation. The residence time is long compared to turnover times (3 – 30 days for *A. tranteri*), promoting a permanent resident fauna in the central bay. Tidal and shallow wind-driven currents are greater in Westernport Bay and the suspended detritus that results from these explain the reduced diversity observed there. Suspension feeders need to be able to select against the detritus or consume it, though it is regarded as a poor food choice, which might explain why cladocerans and appendicularians (often common in temperate coastal waters) are absent or occur in low abundances.

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