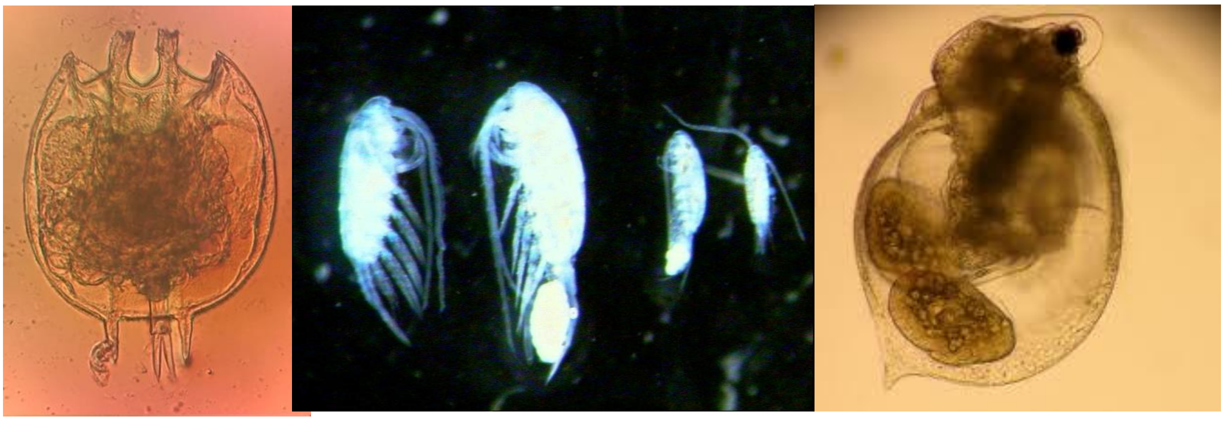
Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth September 2012 – March 2013

Russell J. Shiel & Lor-wai Tan



Report prepared for the Department of Environment, Water and Natural Resources, the Government of South Australia

September 2013

THE UNIVERSITY of ADELAIDE
WRM Wetland Research & Management
Government of South Australia
Department of Environment, Water and Natural Resources

Acknowledgements

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Frontispiece: R. Murray zooplankton – L-R: *Platyias* (Rotifera), *Boeckella*/*Calamoecia* (Copepoda), *Ceriodaphnia* (Cladocera)

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Draft report

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Executive summary

In two consecutive years, 2010-11 and 2011-12, exceptionally high flows from the Murray-Darling basin inundated the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. Studies of the zooplankton assemblages (Lock, 2011, Shiel & Aldridge 2011, Shiel & Tan 2013) during the floods established that a freshwater, rotifer-dominated (riverine) assemblage replaced the microcrustacean-dominated (estuarine) assemblage in the Murray Mouth and North Lagoon sites, with 70% of the zooplankton taxa recorded above the barrages in Lake Alexandrina or the Goolwa Channel in 2010-11, 85% in 2011-12. Halotolerant taxa were recorded from L. Albert and the Goolwa Channel, and longitudinally along the Coorong Nth Lagoon. Very similar zooplankton assemblages, comprising about 200 species, were recorded from the CLLMM sites in both years.

Further monitoring of the zooplankton assemblage from 15 sites approximating the 2010-2012 sites was undertaken by the Environmental Protection Agency SA on four occasions - 10/12 Sept, 11/13 Dec (2012), 13/14 Feb and .18/19 Mar (2013).

122 taxa were recorded from all CLLMM sites during the 2012-13 sampling (L. Alexandrina, 83 taxa, or 54% of 2011-12 assemblage; L. Albert 53/75%; Goolwa Channel 67/50%; Coorong 59/50%. Zooplankton diversity and density was generally lower across most sites than in the preceding Spring-Summer sampling.

Multivariate analysis clearly separated both CLLMM regions and sampling events. The only Coorong site with assemblages comparable to upstream L. Alexandrina or Goolwa Channel zooplankton was at Tauwitcherie, reflecting barrage opening and flows into the Murray Mouth from L. Alexandrina. Conductivity was shown to be a driver for the Coorong assemblages, with an increasing preponderance of halophile taxa longitudinally along the Coorong series.

The decline in diversity/density in the 2012/13 zooplankton assemblage relative to that of the high flow previous years could not be attributed to flow events. Implicated are the protracted (seasonal) sampling interval, which exceeded the life cycle of many of the resident zooplankters, i.e. reduced sampling frequency introduced natural successional species replacements, thereby masking flow-related or environmental perturbation-induced changes. Significant also was the change from shore-based (littoral) sampling to boat-based (open-water) sampling. The 2012/13 samples are generally more indicative of a true lacustrine assemblage, absent the heleoplankters/littoral microfauna of the 2010/11 and 2011/12 series. Notably absent from the 2012/13 samples were the suite of testate amoebae, epiphytic or epibenthic rotifers, and littoral microcrustaceans abundant in both earlier series.

Introduction

Responses of Lower Lakes and Coorong zooplankton assemblages to exceptional Spring (2010) floods in the upper Murray-Darling catchment were reported by Lock (2011) and Shiel & Aldridge (2011). Monitoring the following Spring to determine community responses to continued high water levels and resulting connectivity between the major regions of the Coorong, Lower Lakes and Murray Mouth (CLLMM) was reported by Tan & Shiel (2013). Coincidentally, comparable flows to the millennium floods in 2010-2011 were again recorded during the 2011-12 Spring-Summer sampling period (Fig. 1), when flows over Lock 1 exceeded 50,000 ml/d by late March.

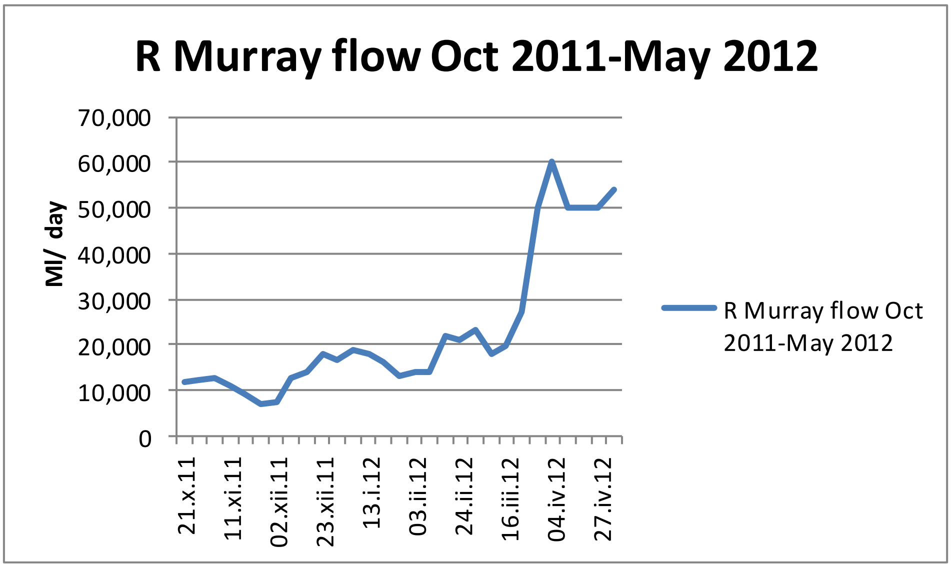


Fig. 1: River Murray flows during the 2011-12 CLLMM zooplankton sampling [Source: https://www.waterconnect.sa.gov.au]

Zooplankton assemblages recorded in the successive years were remarkably similar, both 2010-11 and 2011-12 recording approximately 200 species of Protista, Rotifera, Microcrustacea and planktonic macroinvertebrate stages in the CLLMM region. During both high-flow years the zooplankton community was primarily freshwater in habit, dominated by riverine (Rotifera) assemblages derived from incoming floodwaters, with contributions from littoral/riparian communities (including microcrustaceans). Local heterogeneity of plankton communities was evident, with a halotolerant taxa recorded from Lake Albert, the Goolwa Channel, and along the longitudinal salinity gradient of the Coorong Nth Lagoon.

Further zooplankton sampling was proposed during the Spring-Summer of 2012-13 to evaluate community responses to extended connectivity in the CLLMM region, to flow reductions, and to any resulting return to estuarine conditions in the Coorong. Changes expected from high flow events were:

(i) reduced salinity and improved water quality in the Coorong,

(ii) continued high water level,

(iii) localised restoration of true estuarine character,

(iv) intensified connectivity and possible influx from the Southern Ocean to facilitate (macro)invertebrate recolonisation.

Zooplankton assemblages are sensitive to small changes in water quality, are effective bioindicators. They have short life cycles (4-6 days for Rotifera), can reach high densities in a relatively short time (days to weeks), and are important trophic links between bacteria/algae and higher order consumers, particularly juvenile fish. To evaluate CLLMM zooplankton dynamics during the 2012-13 Spring-Summer, DEWNR proposed that the SA Environment Protection Authority would collect zooplankton samples at 14 sites within the CLLMM region (Table 2; Figures 2 and 3). Each site to be sampled four times, in September and December 2012, February and March 2013. The samples would be provided to Drs Shiel & Tan at the University of Adelaide, with the hypotheses and key questions in Table 1 below to be addressed for the zooplankton assemblages:

Table 1: Objectives, hypotheses and key questions for zooplankton monitoring 2012-13

#	Monitoring Objective	Key Questions	Predictions	Rationale
1	To assess the response of: Zooplankton to: The continued water availability following the recent drought	1. Are there indications of continued system recovery in 2012-2013 following the significant flows of 2010-2011 and further flows in 2012-2013? 2. Will species be able to maintain any range increases observed in 2011-2012 3. Will continued flows be dominated by River Murray or Darling River communities and do they persist in the Lakes? 4. Are there any similarities and/or differences in community structure over differing flow scenarios - How do 2012-2013 zooplankton communities compare to previous monitoring? 5. Relationship between zooplankton, microalgae, nutrients and water quality. 6. Sampling comparison (open water v shore-based).	1. Zooplankton assemblages will increase in diversity and/or biomass over time in response to increased flows and inundation of previously dry margins. 2. Zooplankton communities in the Murray Mouth and Coorong will be dominated by halophiles and communities will change along the salinity gradient. 3. Zooplankton communities in the Goolwa Channel and Lake Albert will be dominated by estuarine/halo-tolerant species whilst Lake Alexandrina will have a more lacustrine and freshwater community. 4. Changes in the zooplankton communities will be observed in relation to differing flows (i.e. drought and higher flow periods).	2010-2011 and 2011-2012 Barrage Flow monitoring

Sites

In order to quantify zooplankton abundance and diversity against that assessed in 2010/2011 and 2011/2012, the sites listed in Appendix 2 and shown in Figs 2 and 3 were sampled on four occasions by EPA staff September 2012 to March 2013. Not all sites sampled in the two previous years were sampled in 2012-2013. The earlier site codes are shown in Appendix 2 for the *closest* station sampled in 2012-2013. Samples were provided to RJS/LWT as soon as possible following sample collection. Samples were collected using the same qualitative net tows and quantitative trap samples as used in 2010-2011 and 2011-2012 sampling.

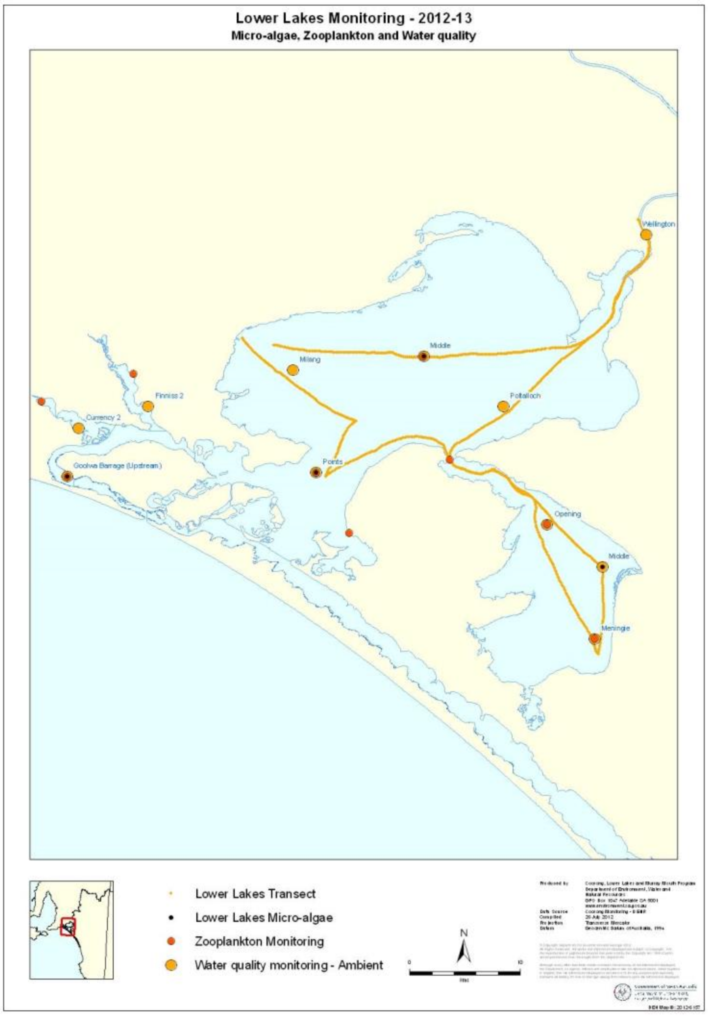


Fig 2: DEWNR Lower Lakes plankton-sampling sites, 2012-13: mid-Lake Alex, Point Sturt, Loveday Bay, Finniss River, Currency Creek, Narrung, NW Lake Albert and Meningie.

Fig. 3: Location of Murray Mouth and Coorong study sites at Goolwa Barrage, Mundoo Channel, Tauwitcherie, Mark Point, Long Point and Villa de Yumpa.

Methods

Field

All sites were sampled in open water, by boat, on 10/12 Sept, 11/13 Dec (2012), 13/14 Feb and .18/19 Mar (2013). Sites selected were as close as practicable to the 2011/2102 sites, which were sampled from the shore (wader depth). The 2010/2011 Lower Lakes sites also were sampled from the shore, while the 2010/2011 Goolwa Barrage and Coorong sites were sampled by boat.

Qualitative Sampling

Standard plankton nets of 230 mm aperture, 35 μm-mesh, were used to collect qualitative plankton samples by oblique hauls (3x5 m tows) from ca.1 m depth to the surface at each site.

Quantitative Sampling

To provide a measure of plankton density at each site both spatially and temporally, volumetric samples were collected with a 4-litre perspex Haney trap. Three 4-l trap samples were pooled by emptying the trap into a plankton net, concentrating 12-litres of filtrate. All collections were fixed in the field with ethanol in 200 ml PET bottles and returned to the laboratory for sorting and enumeration.

Laboratory

Qualitative and quantitative sampling methods were as detailed by Shiel & Tan (2013). In brief, net tow settled contents were decanted, scanned in a gridded Greiner tray on a dark-field Zeiss or Olympus dissecting microscope, and the first 200-300 individual plankters encountered identified and enumerated to provide a proportional composition of the plankton assemblage at each site. Trap volumes were decanted into a 200 ml measuring cylinder, the filtrate volume recorded, the cylinder agitated, and a 1 ml aliquot was extracted by Gilson autopipette to a pyrex Sedgewick-Rafter cell. The plankters in the 1 ml were identified and enumerated on an Olympus compound microscope under Nomarski optics, and the density in 1 ml multiplied up to the filtrate volume to provide an estimate of plankters in 12-litres, from which a density l^{-1} was estimated.

Statistical Methods [by Jess Delaney, WRM]

Zooplankton data were transformed to a log10 abundance scale, whereby 1 = 1 individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000, 5 = >1000, and so on.

Multivariate analysis

Multivariate analyses were performed using the PRIMER package v 6 (**P**lymouth **R**outines **i**n **M**ultivariate **E**cological **R**esearch; Clarke and Gorley 2006) to investigate differences in zooplankton assemblages (log10 abundance) amongst sites and sampling events. The PRIMER package, developed for multivariate analysis of marine fauna samples, has been applied extensively to analysis of freshwater invertebrate data.

Analyses applied to the data included:

- Describing pattern amongst the zooplankton assemblage data using ordination and clustering techniques based on Bray-Curtis similarity matrices (Bray and Curtis 1957). The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped and the groups themselves form clusters at lower levels of similarity. A group average linkage was used to derive the resultant dendrogram.

- To examine whether there were any spatial or temporal differences in zooplankton assemblages, canonical analysis of principal coordinates (CAP) was undertaken within the PERMANOVA add-in in PRIMER. This test finds axes through the multivariate cloud of points that either (i) are the best at discriminating among *a priori* groups (discriminant analysis) or (ii) have the strongest correlation with some other set of variables (canonical analysis) (Anderson and Robinson 2003, Anderson *et al.* 2008). The CAP analysis produced an ordination and vectors corresponding to Spearman Rank Correlations >0.6 (i.e. individual species) were superimposed on this ordination.
- Permutational multivariate analysis of variance (PERMANOVA) was undertaken (two-factor crossed design) to determine whether there was any significant difference in zooplankton assemblages between sites and sampling events (Anderson 2001a, b, McArdle and Anderson 2001, Anderson and ter Braak 2003, Anderson *et al.* 2008).
- For sites which were sampled during the same sampling events for zooplankton and water quality, the relationship between environmental and biotic data was assessed in two ways:
    - Spearman Rank correlations were undertaken between zooplankton assemblages and water quality variables. Results with Spearman Rank correlations of >0.6 were overlain on the zooplankton ordination

The BIOENV routine was used to calculate the minimum suite of parameters that explain the greatest percent of variation (i.e. the parameters which most strongly influence the species ordination).

Results

During the 2012-13 sampling period, there were significant reductions in flows into the CLLMM region (Fig. 4, cf. Fig. 1). The significance of reduced flow to the resident zooplankton community are considered further below.

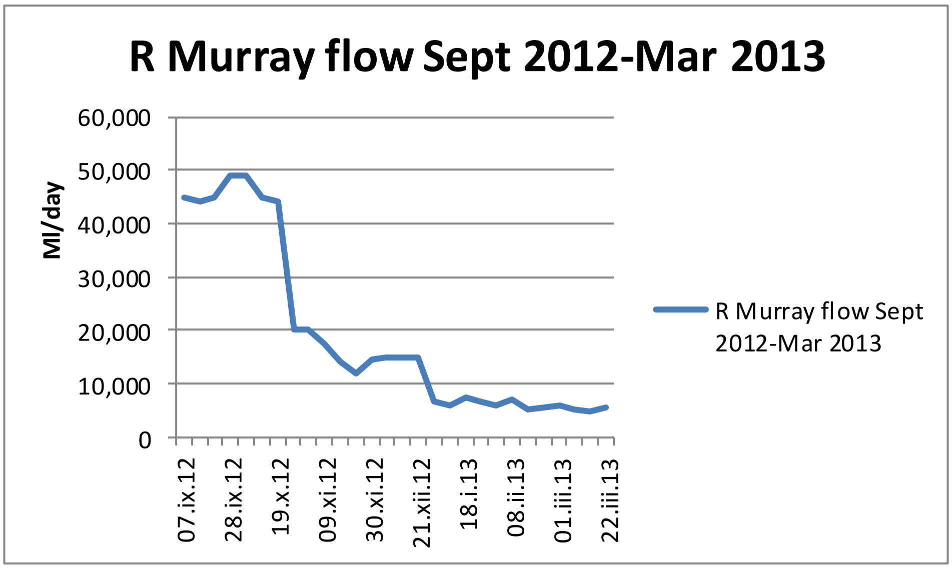


Fig. 4: River Murray flows during the 2012-13 CLLMM zooplankton sampling [Source: https://www.waterconnect.sa.gov.au]

As in previous years, relative proportions of plankters varied widely between sites and dates. Appendix 1 provides a checklist of all taxa identified from the 2010-13 samples. Tables 2 and 3 provide pertinent compositional information for the respective years. 90% of the 2012-2013 zooplankters recorded from the Murray Mouth/Coorong sites also were recorded above the barrages. A reduced suite of halophile rotifers and microcrustraceans than recorded in 2010-2012, less than 10% of the recorded zooplankton assemblage, was again encountered, primarily in Coorong sites, with halotolerant rotifers and calanoid copepods in L. Albert, and a single record of a halotolerant *Daphnia* (nee *Daphniopsis*) in Currency Creek (GCW-10)

Table 2: Zooplankton taxa recorded in successive year sampling

Zoopl. taxa recorded from:	2010-2011	2011-2012	2012-2013
Lake Alexandrina	145	154	83
Lake Albert	48	71	53
Goolwa Channel	109	134	67
Murray Mouth/Coorong	97	117	59
Total taxa	**191**	**207**	**122**

Table 3: Taxonomic composition of zooplankton in successive years

Taxon	2010-2011	2011-2012	2012-2013
Protista	44	51	25
Rotifera	102	101	65
Cladocera	15	14	10
Copepoda	13	16	12
Ostracoda	5	4	2
Macroinvertebrate instars	13	19	8

Zooplankton species richness (diversity) for the 15 sites on four 2012-13 sampling occasions is shown in Fig. 5. Jockwar Rd, the station closest to the R. Murray inflow into L. Alexandrina was not sampled on the first field trip, however was added in subsequent trips to determine the riverine input to the lacustrine zooplankton assemblage. The Jockwar Rd site consistently had the highest zooplankton diversity across the sampling period (25-40 spp.). Diversities were lower (10-20 spp.) at the open water L. Alexandrina/L. Albert sites, with 20-25 species in the Finniss/Currency sites, and a general decrease longitudinally along the Coorong sites to Villa de Yumpa. 'Pulses' at the Goolwa Barrage and Tauwitcherie are discussed below.

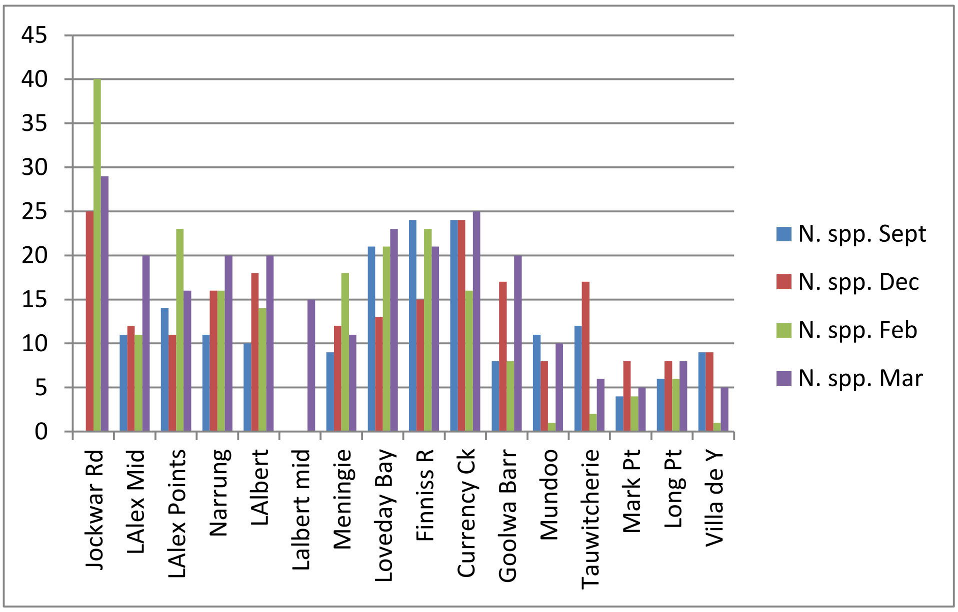


Fig. 5: Zooplankton species richness at 2012-13 sampling sites. Note that L. Albert mid was sampled on only one occasion.

Comparison of the 2012-13 series with both high flow years is shown in Fig. 6.

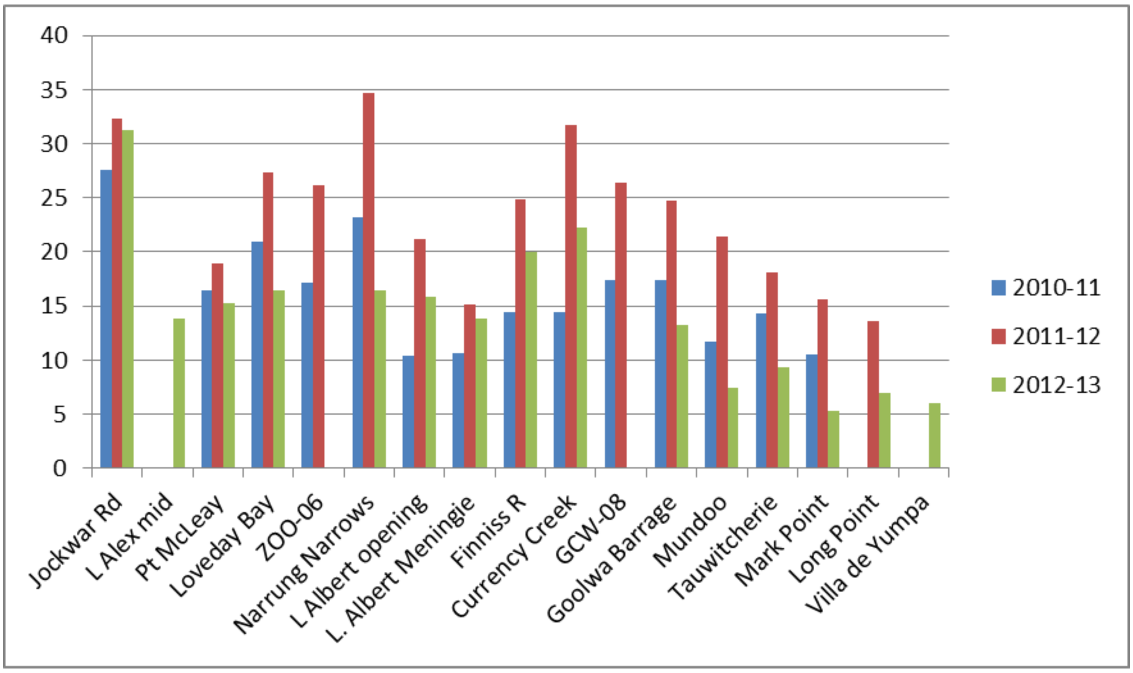


Fig. 6: Zooplankton species richness across all sites 2010-2013. ZOO-06 and GCW-08 were not sampled in 2012-13.

In the 2012-13 sampling period zooplankton diversity was uniformly lower across all sites, significantly so for some sites (e.g. Narrung Narrows, Coorong sites), than for the 2011-12 high flow year, but variable in comparison to the 2010-2011 year.

Mean zooplankton densities (individuals l^{-1}) for all sites for the 2012-13 sampling period are shown in Fig. 7, and for the 2010-13 sampling in Fig. 8.

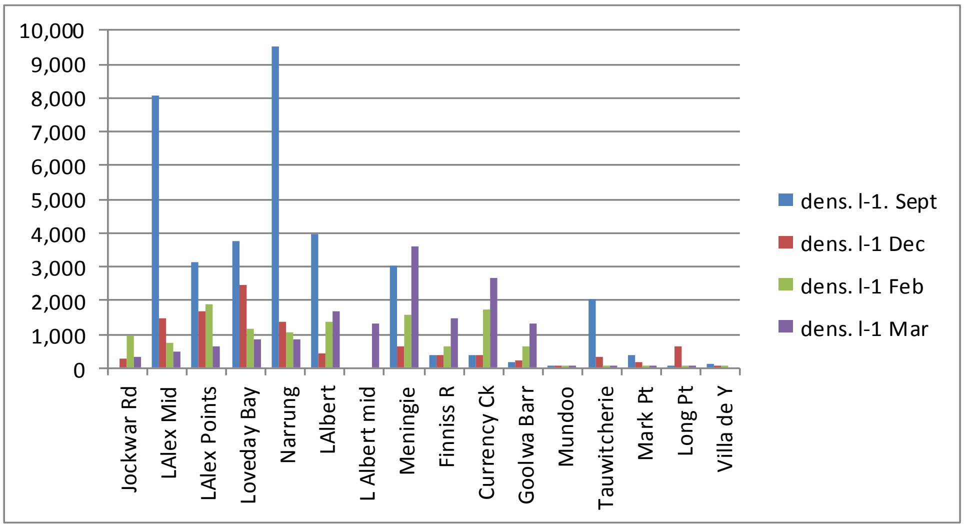


Fig. 7: Mean zooplankton densities (ind. L^{-1}) all sites, 2012-13 sampling.

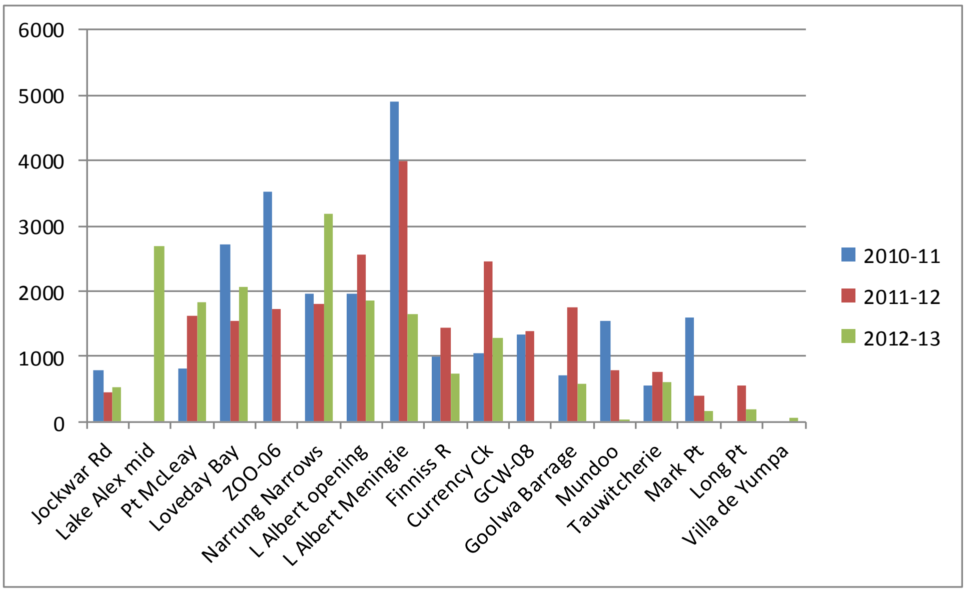


Fig. 8: Mean zooplankton densities (Ind L^{-1}) for all sites, 2010-13 sampling.

Obvious ‘spikes’ in Fig. 7 are September samples from L. Alex Mid and Narrung Narrows, which had 8,000 and 9,500 ind l^{-1} respectively of a bloom of protists (testate ciliate *Stenosemella* mid lake, with an unnamed naked ciliate in Narrung Narrows) and a *Synchaeta* (Rotifera). The same three taxa also were responsible for population peaks at other September 2012 sites.

Species richness and density plots for the 2012-13 sampling are provided below for all sites. Comparative assemblage/density data for the 2011-12 series are given by Shiel & Tan (2013).

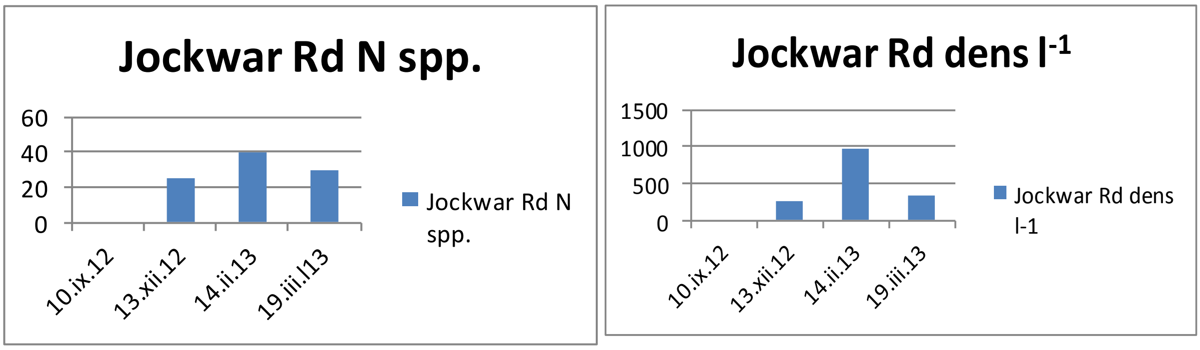


Fig. 9: Jockwar Rd was added after the September sampling to provide more information on riverine input into the L. Alexandrina zooplankton. It provided the most diverse assemblages across the sampling period, 25-40 spp., mean 31, less diverse than this site’s assemblage in 2011-12 (15-55 spp., mean 35.) *Keratella/ Proalides/Synchaeta* dominated in December, *Brachionus/Hexarthra/Synchaeta* and protists in Feb., with *Polyarthra/Synchaeta* and suite of riverine brachionids dominating in March. Microcrustaceans were primarily copepod nauplii. Adults were notably sparse. Densities over the sampling ranged from 264-973/litre (mean: 528).

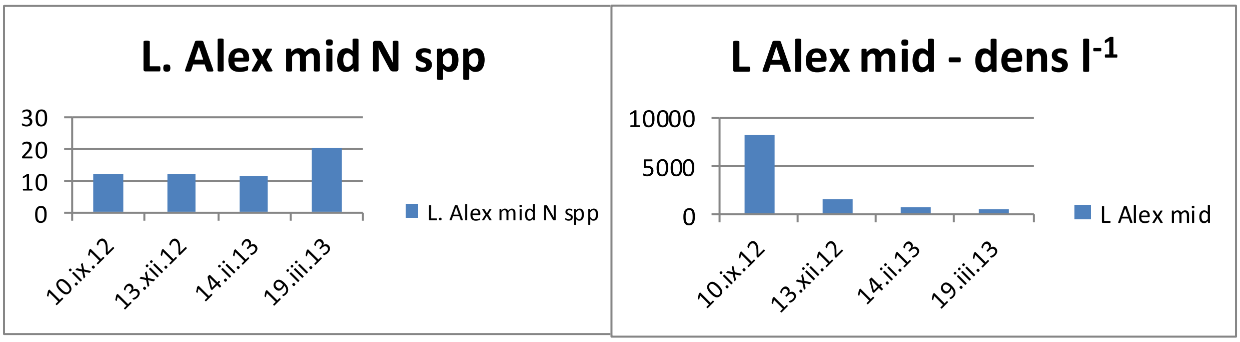


Fig. 10: Lake Alexandrina Middle, a new site in 2012-13, had low diversity (10-11 spp.) until the last sampling event, when 20 taxa were recorded. Cladocerans were abundant in the Sept sample, but the numerically dominant taxon was a pelagic rotifer, *Synchaeta* n. sp. *Daphnia carinata/Synchaeta* predominated in Dec., replaced by *Moina/*mixed rotifers in Feb/March. Copepod nauplii and copepodites were present throughout, but adults were notably sparse or absent. After the initial pulse of *Synchaeta,* densities remained low. Densities over the sampling ranged from 732-8,087/litre (mean: 2,692).

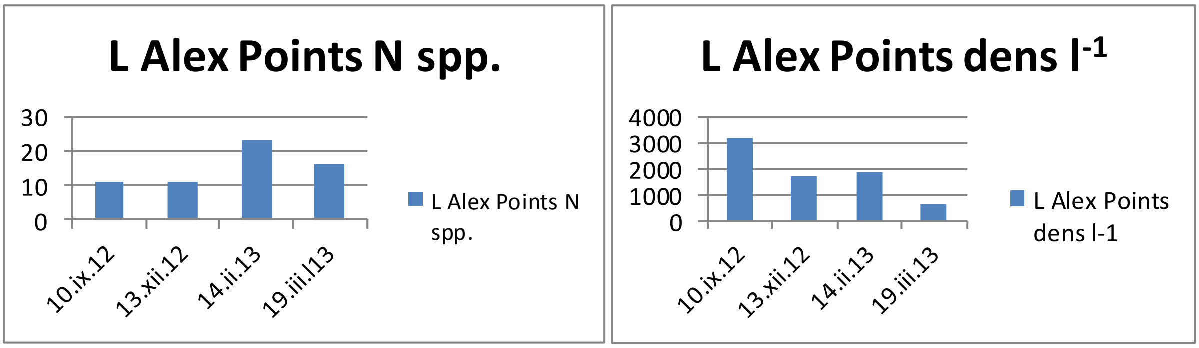


Fig. 11: Lake Alexandrina Point McLeay had low diversity through Sept/Dec (11 spp.), a mix of cladocerans, *Synchaeta* spp. and protists. Feb. brought a flush of riverine rotifers, *Proalides* and *Filinia* predominating, among 23 taxa recorded. *Stenosemella lacustris, Difflugia globulosa* and the suite of rotifers continued through the March sampling. Densities over the sampling ranged from 621-3,140/litre (mean: 1,822). Comparable densities were noted in 2011-2012 samples: 115-3,648/litre (mean 1,634).

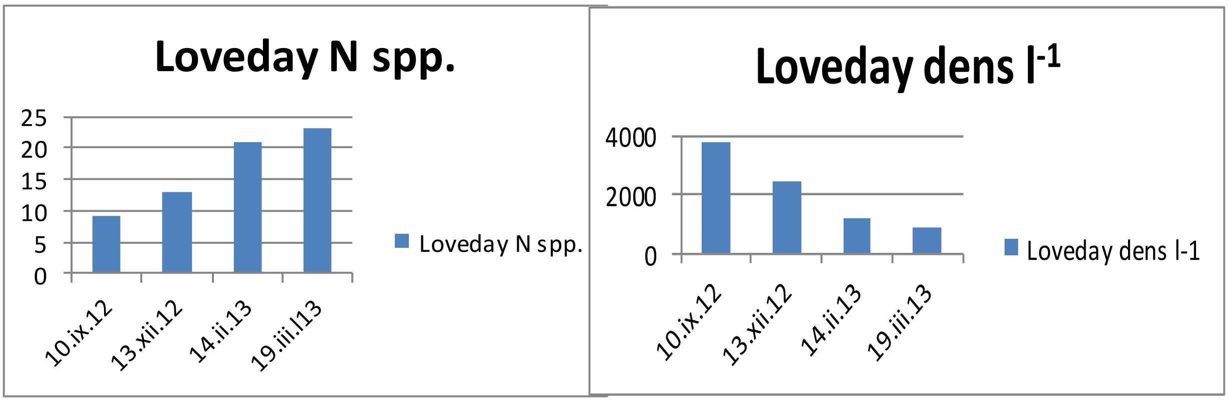


Fig. 12: Lake Alexandrina –Loveday Bay had a similar Sept/Dec zooplankton to that of Point McLeay – *Daphnia/Ceriodaphnia* and copepods, primarily as nauplii, with *Synchaeta* and *Filinia* subdominant. Diversity was low until the Feb/March samples, when protists and rotifers increased diversity to 23 and 25 spp. respectively. Density declined steadily from a high of 3,780/l in Sept to 864/l in Mar (mean: 2,066).

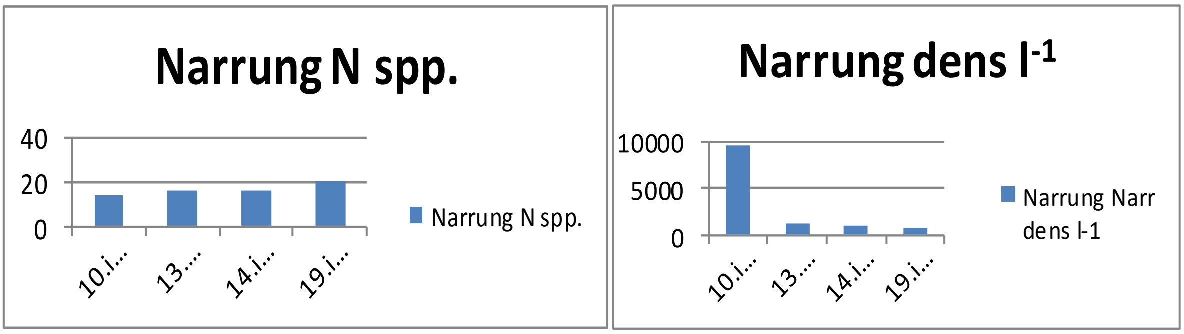


Fig. 13: Narrung Narrows had a suite of microcrustaceans in Spring, principally *Daphnia lumholtzi/Daphnia carinata*, with *Synchaeta oblonga* the only rotifer present in small numbers. The assemblage was swamped by a bloom of ciliates, which together with the *Synchaeta,* produced the highest zooplankton density recorded from 2012-13 CLLMM sites – >9,500 ind l^{-1}. Protists continued in low numbers through Dec, diversity remaining low, with *Stenosemella/Difflugia* again dominant in Feb. Densities over the sampling ranged from 840-9,516/litre (mean: 3,188). Zooplankton density at Narrung in 2011-12 was 224-3,402 (mean 1,812/l).

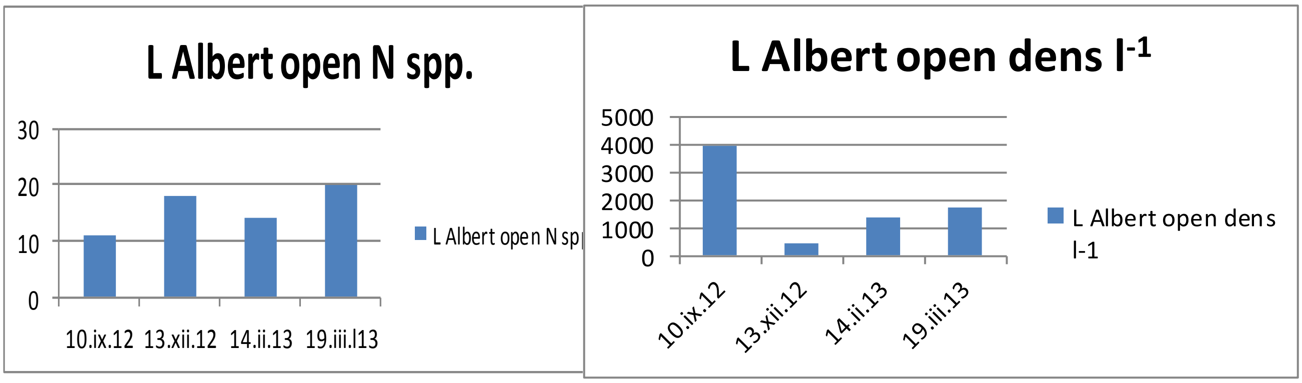


Fig. 14: Lake Albert opening – with 11-20 spp, mean 16, the Sept L. Albert plankton contained a suite of *Daphnia* species, but was numerically dominated by *Synchaeta* n. sp. (>3,000/l), among several rotifers. Rotifers had increased, cladocerans declined, by Dec. In Feb the *Stenosemella/Difflugia* protists predominated, with a suite of rotifers appearing by March. Notably, kinorynchs recorded in 2011-12 were not encountered again. Densities over the sampling ranged from 436-3,950/litre (mean: 1,863). Zooplankton density at L Albert open in 2011-12 was 13-8,732, mean 2,658/l.

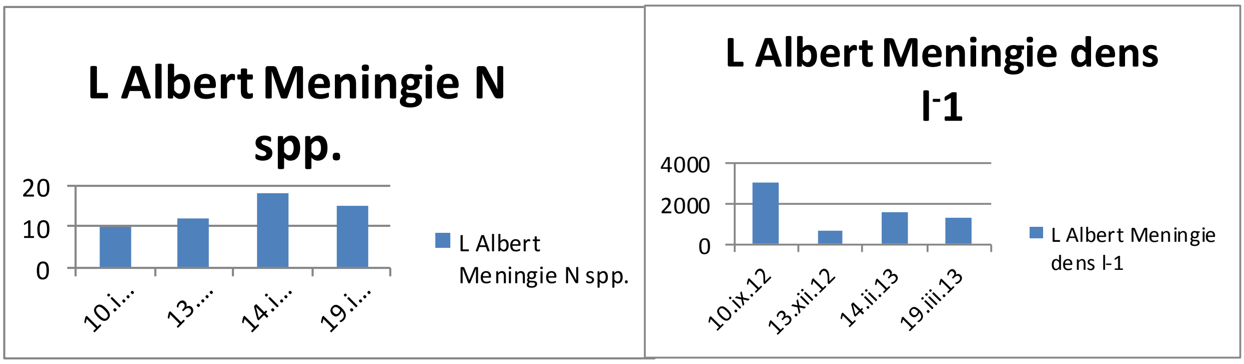


Fig. 15: L. Albert, Meningie had a suite of microcrustaceans in the Sept sample, copepods, cladocerans, but the numerically dominant taxa were indeterminate ciliates, and *Synchaeta* (>3,500/l). Diversity remained low in Dec, and numbers were significantly lower, with rotifers predominant. A pulse of *Stenosemella* was apparent in Feb, which increased through to March, accompanied by a suite of rotifers, primarily *Keratella tropica, Synchaeta* n. sp. and *Filinia* spp. Densities were 616-

3025/1, mean 1636. In contrast, densities at Meningie during the 2011-12 series were 85-12,895, mean 4,001/l), the highest density across all sites in this study.

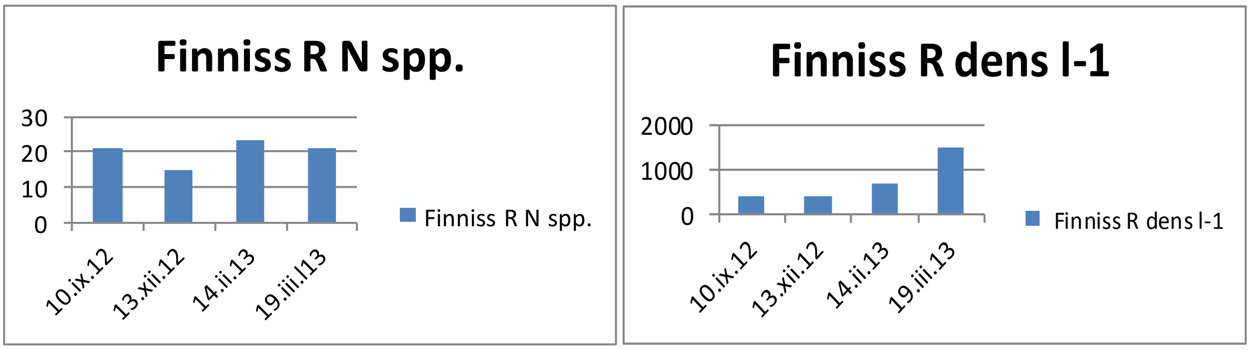


Fig. 16: Finniss River. *Stenosemella* was the dominant plankter in the Sept. samples, with a mixed rotifer/microcrustacean assemblage (21 spp.). Cladocerans predominated in Dec, and again in Feb *Bosmina, Ceriodaphnia* and *Daphnia* were abundant, accompanied by a suite of rotifers. Diverse rotifers appeared through summer, with the *Stenosemella/Difflugia* pair the most abundant protists. Densities were low until the Mar sample - 394-1,480/l (mean 1,295). Comparable zooplankton densities in 2011-12 ranged from 108-3,340/l, mean 1,438.

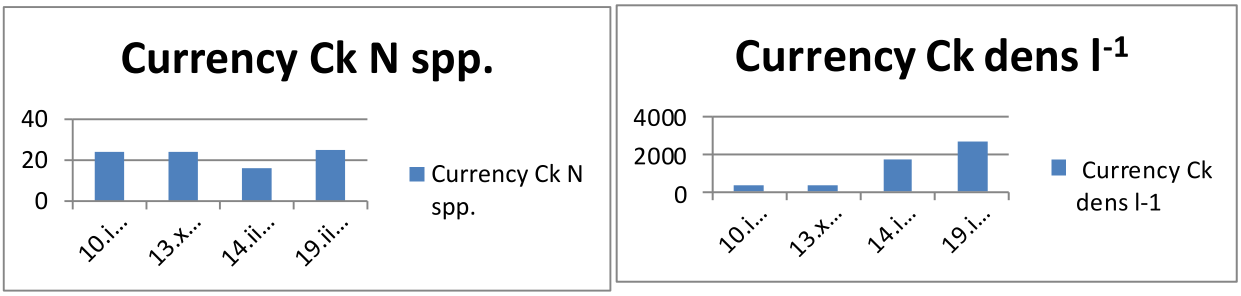


Fig. 17: Currency Creek, Ballast Stone Winery. With a mean of 22 species, an ‘average’ plankton assemblage occurred across the study period. Microcrustaceans and a pulse of *Synchaeta* dominated in Sept. By Dec cladocerans, calanoid copepods and a more diverse suite of rotifers were present. This mixed assemblage persisted through to March, with more rotifers occurring in the last sample, accounting for the density increase from 363-2,679/l (mean 1287). Diversity and

density were lower than in the previous summer: 20-41 spp., mean 31.4. Density 685-4,063, mean 2,447/l

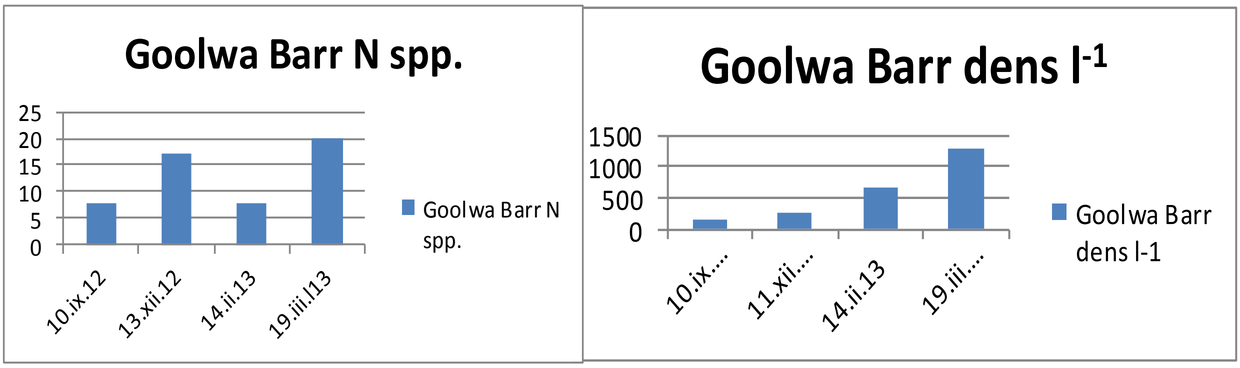


Fig. 18: Goolwa Barrage. A sparse cladoceran/copepod nauplii assemblage in Sept was replaced by more diverse cladocerans/rotifers in Dec. (*Bosmina/Daphnia* dominants). *Daphnia lumholtzi/Moina micrura* increased through to Feb, but had almost disappeared by the Mar sample, when a brachionid dominated (riverine) rotifer plankton was present (20 spp.) Density was low, increasing over the study from 158-1,302 ind./l (mean 593/l). The previous year, zooplankton density across the sampling period was 200-4,883, mean 1,759/l.

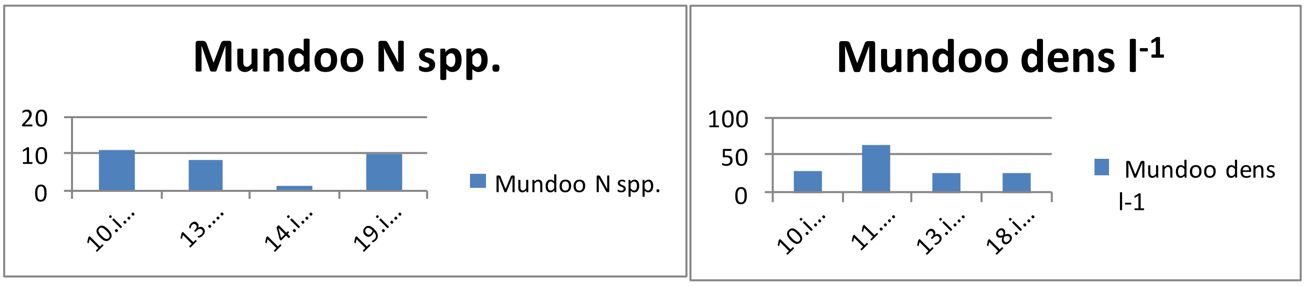


Fig. 19: Mundoo Channel. As for the 2011-12 Mundoo Channel samples, zooplankton diversity and density were low throughout the study period. - <10 spp. and <30 ind/l for three of the four samples. Only protists were present in Sept. The Dec. sample, with 63 ind./l, consisted of small contracted and indeterminate rotifers, likely *Synchaeta* sp. In Feb, a small number of the testate ciliate *Stenosemella*, and *a* solitary juvenile ostracod were recorded. In Mar, *Synchaeta* and copepod nauplii

were sparse. Density ranged from 25-63 ind./l (mean 36/l). During the high flows of 2011-12, diversity ranged from 10-36 spp., mean 20. Density 81-1,967, mean 778/l.

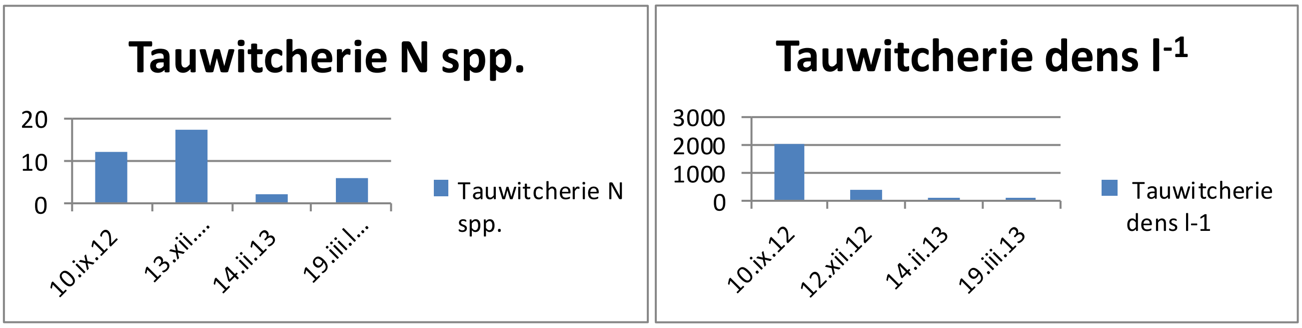


Fig. 20: Tauwitcherie Barrage, Coorong Nth Lagoon. A mixed cladoceran/copepod assemblage (*Bosmina, Ceriodaphnia, Daphnia, Boeckella*) was present in Sept. The only abundant rotifer was a *Synchaeta* sp. Small numbers of a suite of rotifers were present by Dec, with cladocerans/copepods sparse. All were gone by the Feb sampling, when isolated bivalve larvae were recorded. More bivalves occurred in Mar., with sparse calanoid nauplii and tintinnid ciliates. No rotifers or cladocerans were recorded after Dec. Mean diversity was only nine spp., and from a high of 2,035/l in Sep, zooplankton densities declined to 24/l in Mar (mean 619/l). Both diversity and densities were higher in the 2011-12 series: Diversity: 6-32 spp., mean 18.1; density 78-2,817, mean 758/l

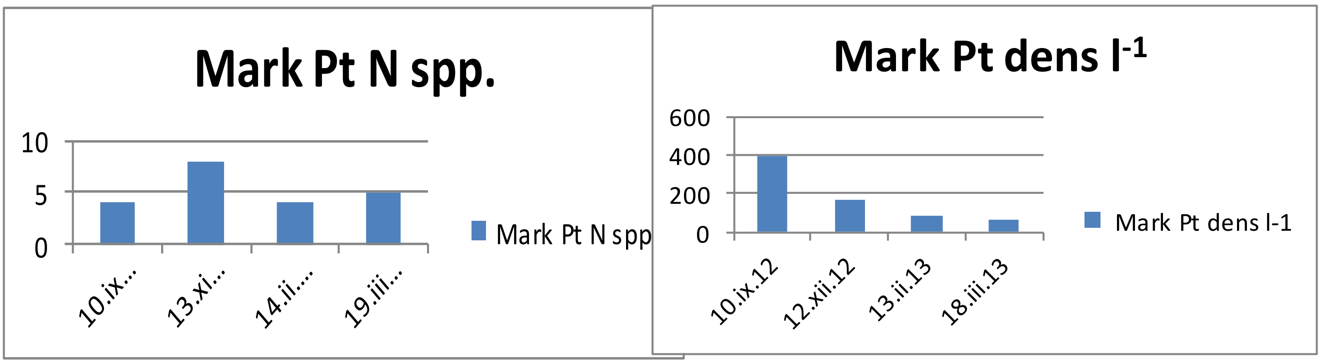
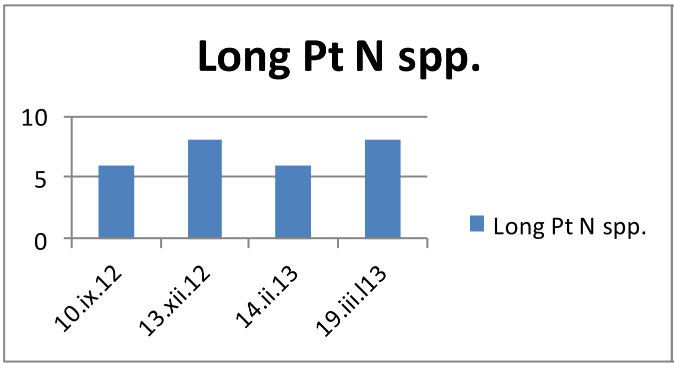


Fig. 21: Mark Point, Coorong Nth Lagoon. Only 4-8 spp. were recorded in the zooplankton at Mark Point over the study. *Synchaeta* spp. were dominant in September, accounting for the density peak of 395 ind./l. Harpacticoid nauplii and

copepodites were sparse. A more diverse plankton was recorded in Dec, with tintinnids, *Synchaeta* spp., the calanoid *Acartia,* harpacticoid copepodites, bivalve larvae and amphipods recorded. A few *Daphnia lumholtzi* also were noted. Calanoids, primarily as copepodites, and bivalves remained by Feb. Tintinnids, *Stenosemella*, *Synchaeta* spp., calanoid juveniles, ostracod juveniles, juvenile gastropods, bivalve larvae and amphipods comprised a more diverse Mar zooplankton. From the initial peak of 395 ind/l. densities declined to 60 ind./l in Mar (mean 177/l). Both density and diversity were lower than in 2011-12: Diversity 4-29 spp., mean 15.6; density 9-1,042, mean 386/l.



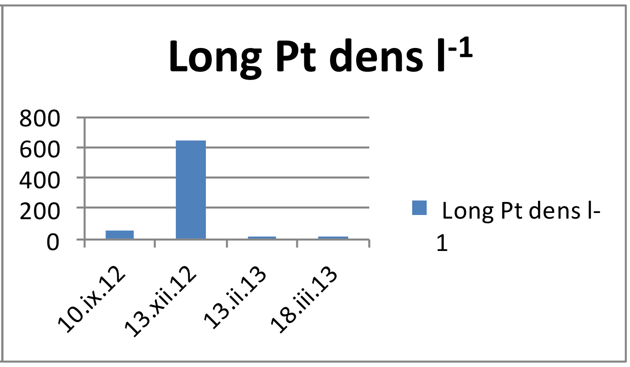


Fig. 22: Long Point, Coorong Nth Lagoon. Only 6-8 zooplankton taxa were recorded at Long Point over the study period (mean = 7). In Sept. *Synchaeta* was the only rotifer recorded, with calanoid and harpacticoid copepodites and nauplii most abundant. Nematodes and amphipods were the only macroinvertebrates present. A bloom of tintinnid ciliates was present by Dec, with a few *Synchaeta* spp. the only other sparse plankter. In Feb bivalve larvae were abundant, with *Daphnia lumholtzi* present in low numbers, as were calanoid nauplii, but rotifers and protists were notably absent. By Mar a few *D. lumholtzii* and nauplii remained. Density was notably sparse (9-57 ind/l) on three of the four sampling occasions. Only in the Dec sample were appreciable numbers of plankters present – 642/l, composed of ciliates and *Synchaeta.* Mean density was 180/l. Both diversity and density were significantly

lower than in the 2011-2012 samples: diversity 5-25 spp., mean 15.6, density 8-915/l, mean 566/l.

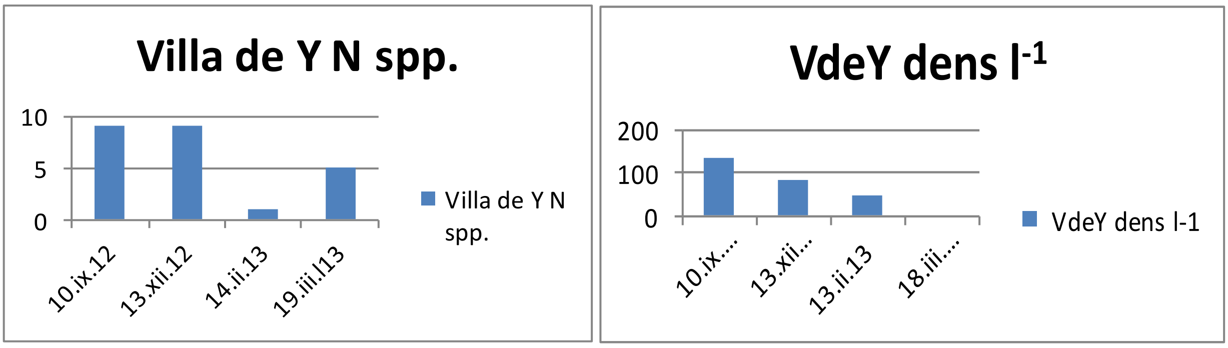


Fig. 23: Villa de Yumpa, Coorong Sth Lagoon. Not sampled previously, Villa de Yumpa had a sparse zooplankton across the study period – only 1-9 (mean 6) species were recorded. Halophile synchaetid rotifers, the estuarine/marine calanoid *Acartia*, and bivalve larvae were dominant in Sept. *Synchaeta* and another halophile rotifer, *Testudinella obscura,* were present in Dec, with harpacticoid and calanoid juveniles predominating. By Feb, only a few calanoids remained – no rotifers or small macroinvertebrates were recorded. In Mar a few *Synchaeta,* nauplii, juvenile ostracods and a mite were present in the net tow, but no plankters were collected in the trap sample. Densities across the study were 0-134/l (mean 65/l).

Multivariate analysis [Jess Delaney, WRM]

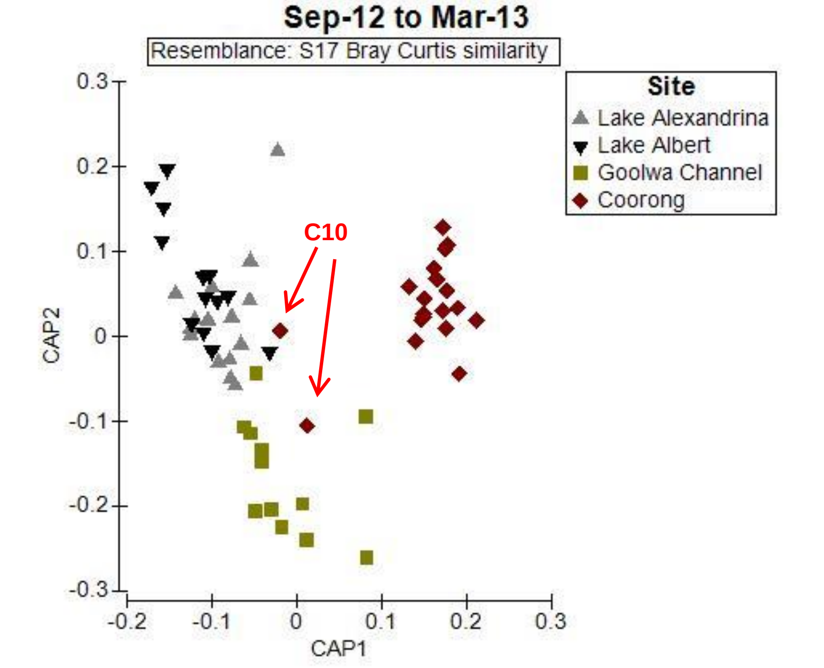


Figure 24. Constrained CAP plot comparing zooplankton assemblages between site.

Multivariate analyses separated Coorong and Goolwa Channel sites from the overlapping L. Alexandrina/L. Albert sites (Fig. 24), with the exception of Tauwitcherie (C-10) which clustered closer to L. Alexandrina and Goolwa Channel assemblages than to the Coorong cluster, reflecting barrage releases containing L. Alexandrina or Goolwa Channel biota. Taxa with significant responses are overlain in the ordination in Fig. 25.

Sampling events are compared in Fig. 26. Sept ‘12 and Mar ‘13 clusters are discrete, with overlap between Dec ‘12 and Feb ’13 clusters indicating shared species. Species contributing to the separations are overlain on the ordination in Fig. 27.

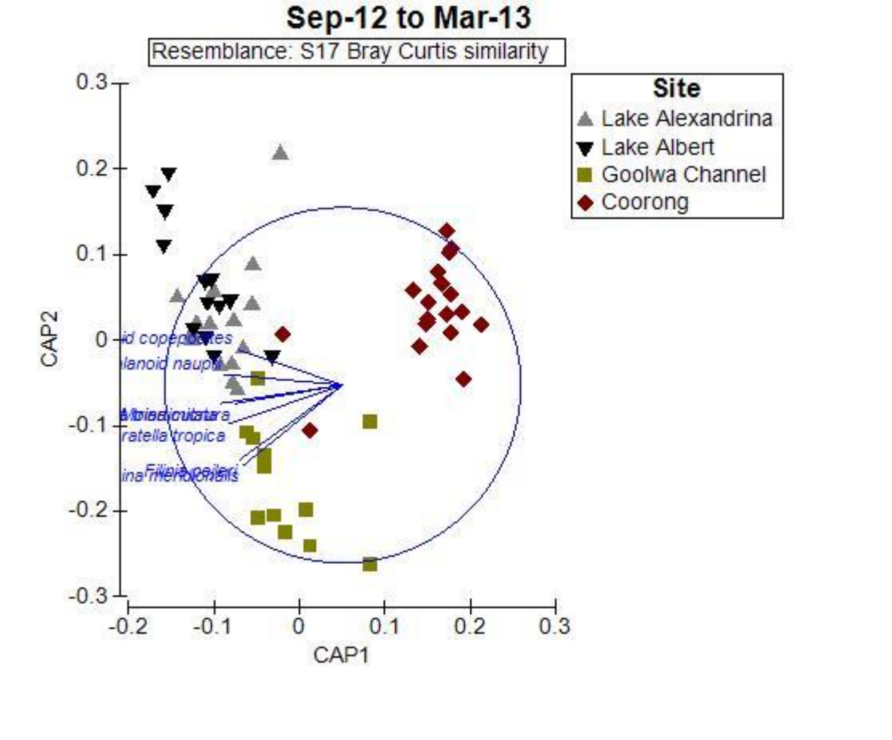


Figure 15. Constrained CAP plot comparing zooplankton assemblages between site. Vectors of Spearman rank correlations >0.6 are overlain on the ordination.

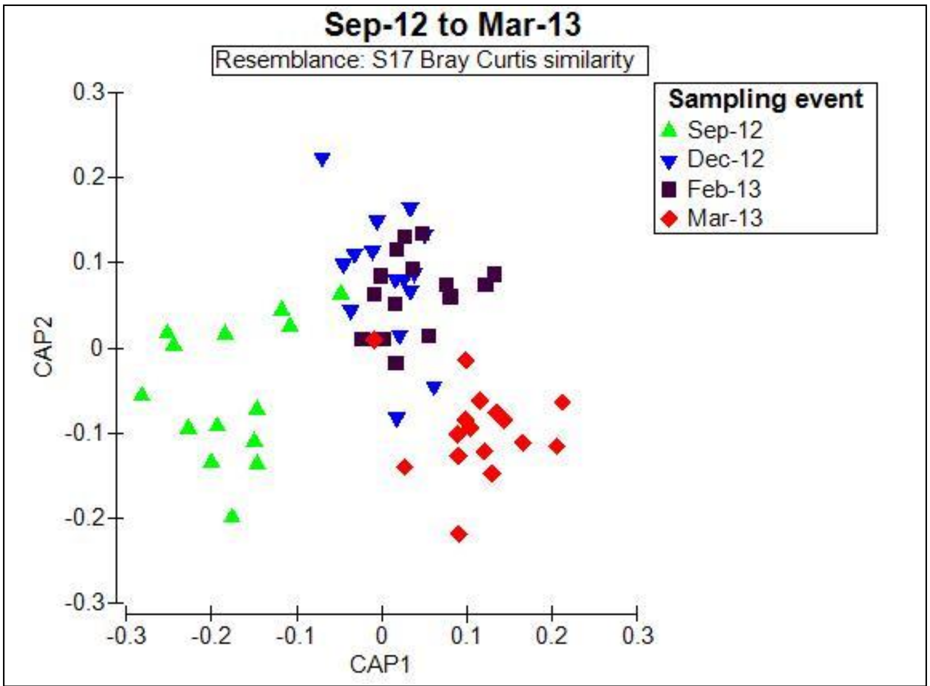


Figure 26. Constrained CAP plot comparing zooplankton assemblages between sampling event.

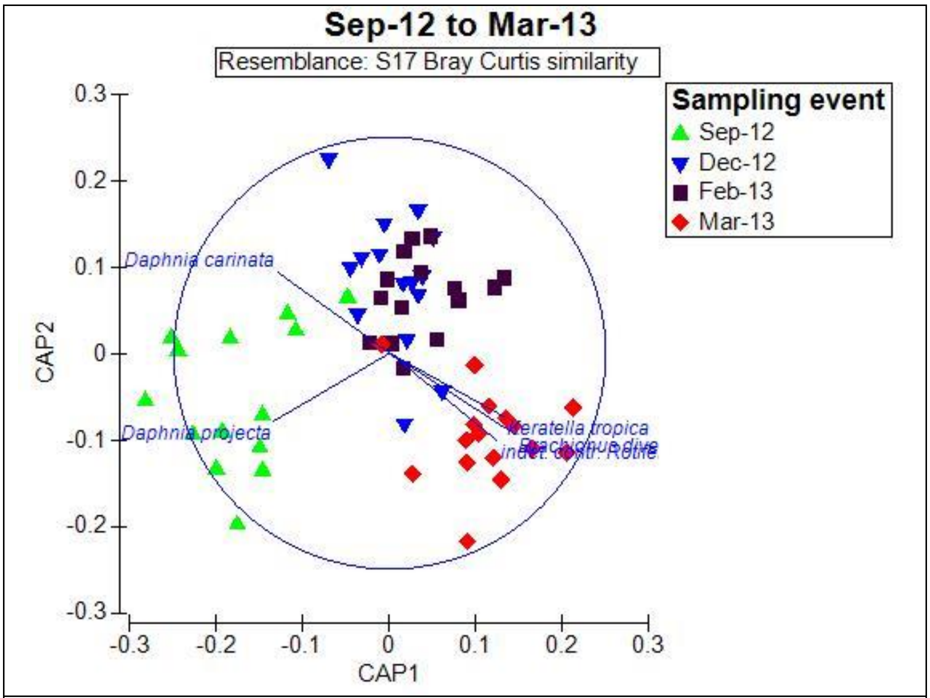


Figure 27. Constrained CAP plot comparing zooplankton assemblages between sampling event. Vectors of Spearman rank correlations >0.6 are overlain on the ordination.

Zooplankton assemblages were significantly different between site and sampling event (see Table 4).

Table 4. Two-Factor PERMANOVA results comparing zooplankton assemblages between site and sampling event.

Source	***df***	***MS***	***Pseudo-F***	***p-stat***
Site	3	14873	9.90	0.0001
Sampling event	3	7309.4	4.86	0.0001
Site*Sampling event	9	2525.2	1.68	0.0002
Residual	44	1502.5		
Total	59			

Sep-12 to Mar-13 – assessment of the influence of water quality

Not all sites/sampling events were sampled for zoopl and water quality, so this analysis includes only comparable sites/sampling events in 2011 and 2012.

BIOENV found that electrical conductivity (EC) contributed to differences in zooplankton assemblages (BIOENV; Rho = 0.75, p = 0.001). Overlaying water quality variables with a Spearman Rank Correlation greater than 0.7 indicated that the separation of the Coorong zooplankton assemblages from other sites was influenced by the higher EC characteristic of this site (Fig. 28). Furthermore, the zooplankton sampling event ordination was shown to be influenced by the higher temperatures recorded during Dec-12 and Feb-13 (Fig. 29).

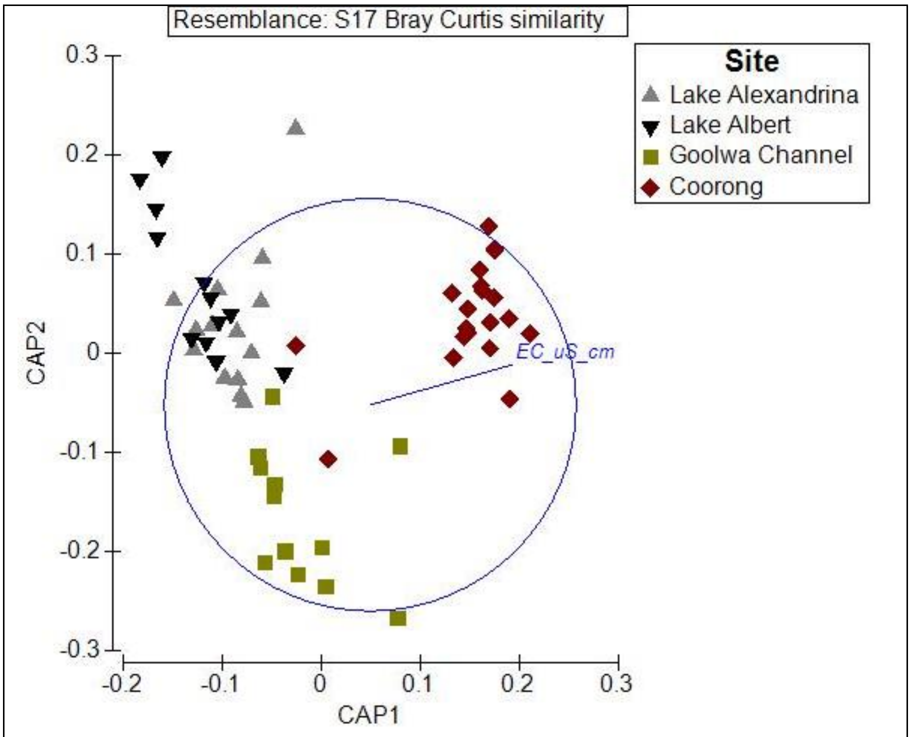


Figure 28. Constrained CAP plot comparing zooplankton assemblages between site. Vectors of water quality variables with Spearman Rank Correlations >0.6 are overlain on the ordination.

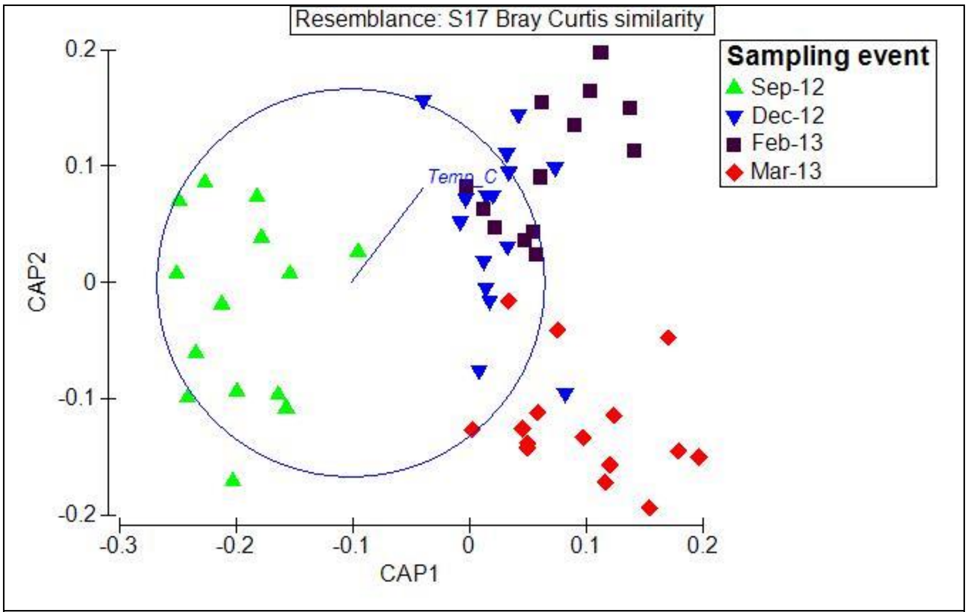


Figure 29. Constrained CAP plot comparing zooplankton assemblages between sampling event. Vectors of water quality variables with Spearman Rank Correlations >0.6 are overlain on the ordination.

All data collected between Nov-10 & Mar-13

Multivariate analyses of all site data for the three consecutive sampling periods are shown in Figs 30-33.

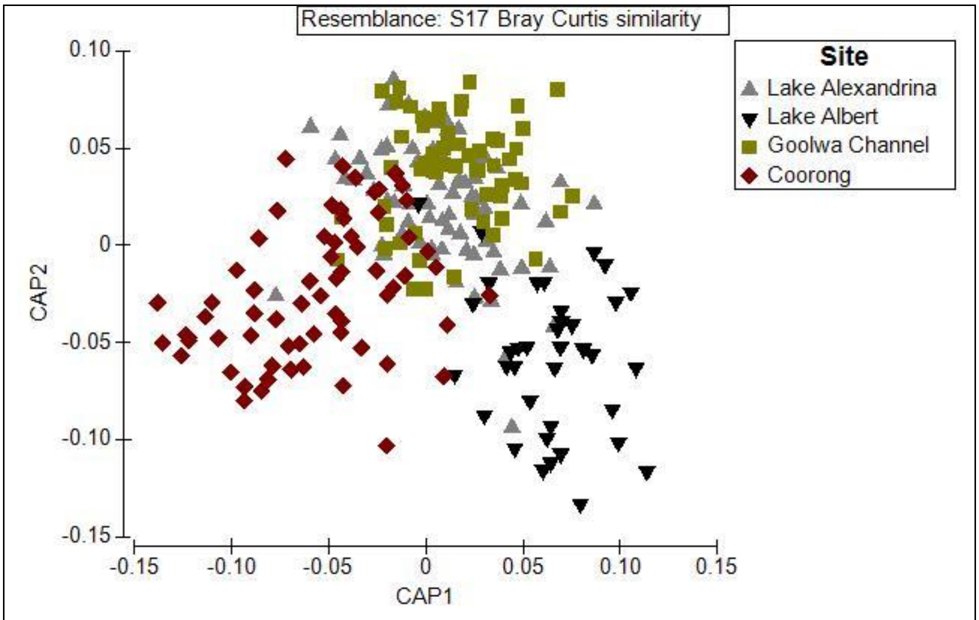


Figure 30. Constrained CAP plot comparing zooplankton assemblages between site using data from all sampling events since Nov-10.

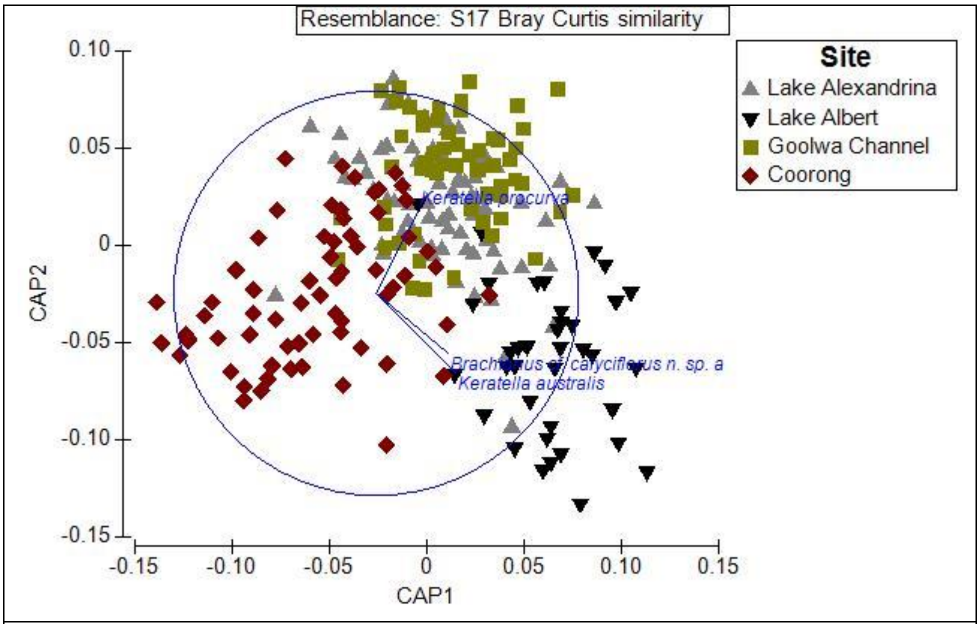


Figure 31. Constrained CAP plot comparing zooplankton assemblages between site using data from all sampling events since Nov-10. Vectors of Spearman rank correlations >0.6 are overlain on the ordination.

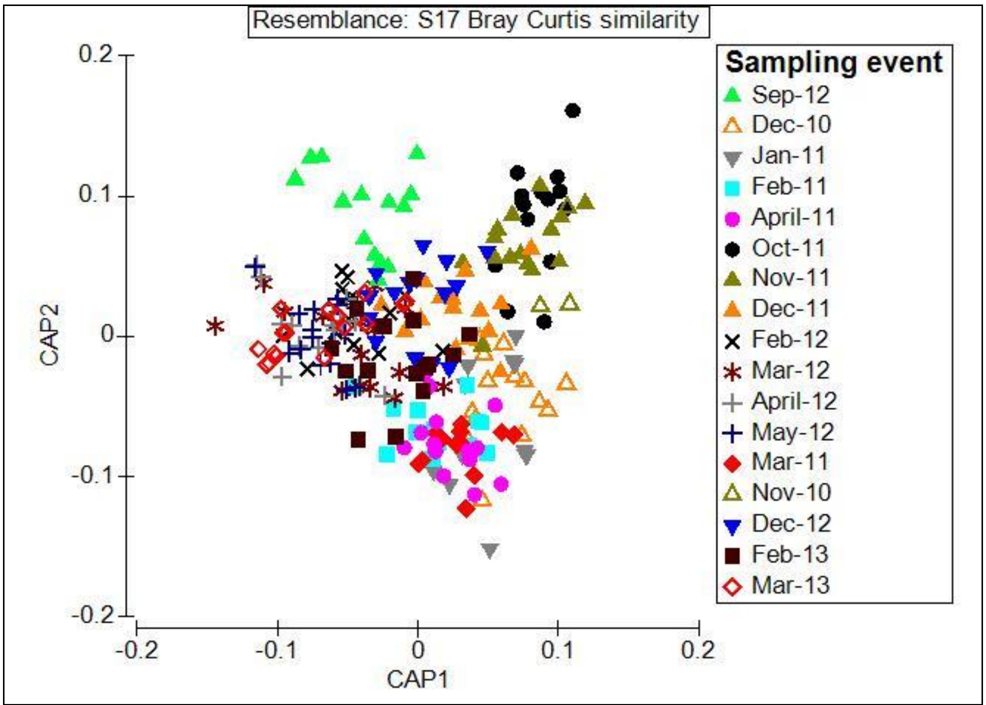


Figure 32. Constrained CAP plot comparing zooplankton assemblages between sampling event using data from all sampling events since Nov-10.

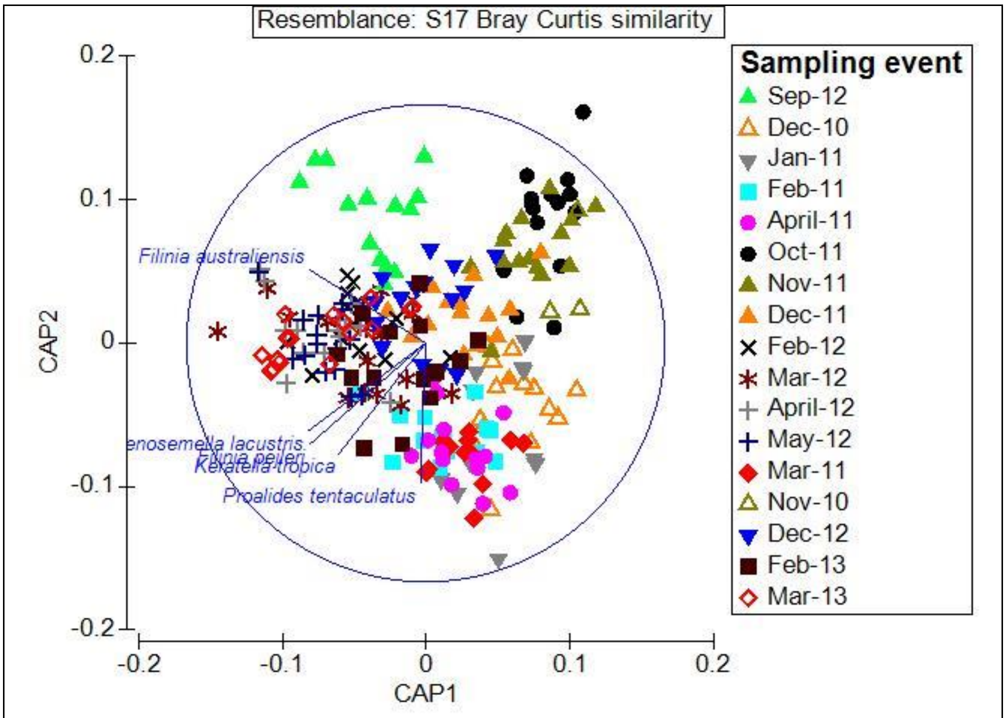


Figure 33. Constrained CAP plot comparing zooplankton assemblages between sampling event using data from all sampling events since Nov-10. Vectors of Spearman rank correlations >0.6 are overlain on the ordination.

Zooplankton assemblages were significantly different between site and sampling event (see Table 5). Post-hoc analyses revealed that all sites were significantly different from one another, but not all sampling events. Sampling events which were not significantly different (i.e. had statistically similar zooplankton assemblages) were:

- Jan-11 and Feb-11
- Feb-11 and Mar-11
- Feb-11 and April-11
- Mar-11 and April-11
- Oct-11 and Nov-11
- Feb-12 and Mar-12

Table 5. Two-Factor PERMANOVA results of all zooplankton data collected between Nov-10 and Mar-13 comparing assemblages between site and sampling event.

Source	*df*	*MS*	*Pseudo-F*	*p-stat*
Site	3	16503	9.57	0.001
Sampling event	16	9937.1	5.76	0.001
Site*Sampling event	45	2996.6	1.74	0.001
Residual	173	1723.8		
Total	237			

Discussion

Qualifiers which must be mentioned before considering the 2012-2013 zooplankton assemblages/dynamics in relation to the key questions (Table 1):

- **In the 2012-13 sampling, there were only four sampling events, vs. seven in 2011-12, and five (LL/GC) or six (Coorong) in 2010-11;**
- **Sampling was in open-water, by boat, whereas sampling in 2011-12 was by wader, from the shore (i.e. littoral), and in 2010-11 by wader (LL/GC) and boat (Coorong);**
- **2012-13 sampling was during a period of reduced flows relative to the exceptionally high flows of the preceding two spring-summers;**

All three factors contributed to the lower diversity of zooplankton assemblages recorded during the 2012-13 monitoring (Table 2). L. Alexandrina produced 54% of the previous year's assemblage, L. Albert 75%, Goolwa Channel 50%, Coorong sites 50%.

Key Questions

1. Are there indications of continued system recovery in 2012-2013 following the significant flows of 2010-2011 and further flows in 2012-2013?

As there was no baseline to begin with – the 2010-11 sampling was during a 1:200 yr flood event, and the following year brought another exceptional flood from the same catchments, with a very similar (rotifer-dominated) zooplankton assemblage – there is no unequivocal answer. There *is* a suggestion of a recovery of microcrustacean populations with flow reduction in Lake Alexandrina to a assemblage as described by Geddes (1984), but a rotifer-dominated riverine plankton also occurs. Lake Albert appeared to maintain more of it's 'plankton integrity' than other CLLMM regions…it appears to be buffered against extremes, it's zooplankton egg bank is likely heterogeneous and responsive to whichever water is available…freshwater species hatch when the lake is fresh(er), halophile species hatch during periods of salinization.

The prediction that "Zooplankton assemblages will increase in diversity and/or biomass over time in response to increased flows and inundation of previously dry margins" was not supported by the 2012-13 sampling regime.

2. Will species be able to maintain any range increases observed in 2011-2012?

The suite of freshwater rotifers released into the Coorong Nth Lagoon in 2011-12 would only be able to persist and reproduce in fresh water. Salinity increases via the Murray Mouth, or movement longitudinally into more saline water masses, would be lethal. Similarly, estuarine taxa, if not eurytolerant, would not survive in incursing freshwater in the MurrayMouth/Coorong Nth Lagoon for protracted periods. All the species recorded in 2012-13 were recorded in previous years. Those that weren't may have been in habitats that weren't sampled (littoral), been missed by the extended sampling interval (rotifers have a 4-6 day life cycle), or in the case of the freshwater taxa washed into the Coorong/Murray Mouth, succumbed to increasing salinity. 90% of the zooplankton assemblage recorded during 2012-13 below the barrages also occurred above them (Appendix 1).

3. Will continued flows be dominated by River Murray or Darling River communities and do they persist in the Lakes?

If Jockwar Rd can be taken as a fair indicator of contributions to the L. Alexandrina zooplankton, yes, this is a rotifer-dominated riverine assemblage, and it was the most diverse of all sites on the three dates sampled. However...why the evident diversity does not persist 'downstream' into L. Alexandrina is interesting…only a proportion of the incoming assemblage was recorded from mid-lake. Zooplankton is known to avoid currents, move towards the shore if mobile, although this is more likely for microcrustaceans than smaller and more passive rotifers. Predation (by other zooplankton, macroinvertebrates and fish) may be significant, albeit unstudied in this project. Whatever the cause, on the basis of the 2012-13 samples, no, the entire assemblage does not persist in the Lakes.

4. a Are there any similarities and/or differences in community structure over differing flow scenarios

As summarized in previous CLLMM reports (Lock 2011, Shiel & Aldridge 2011, Shiel & Tan 3013) source waters will provide characteristic communities to the Lower Lakes…the 2011-12 plankton was very similar to that of 2010-11 largely because the floods derived from the same northern basin catchments at the same time of the year. High flows from a more heavily impounded system, such as the Murray/Goulburn, would provide a significantly different plankton assemblage.

Overbank floods from different river systems which scour billabongs or other standing waters on the floodplain will return significant diversity and biomass to the river system. The nature of this contribution will differ with each system.

Similarities in zooplankton community structure are broadly imposed by flow: flowing waters support a protist/rotifer zooplankton, standing waters provide a stable habitat, whether artificial (reservoir, impoundment) or natural (lake, billabong) in which microcrustaceans can complete life cycles and reproduce. Waters released or flushed from such storages are more likely to provide a microcrustacean-dominated community. The prediction "Changes in the zooplankton communities will be observed in relation to differing flows (i.e. drought and higher flow periods)" is supported, and perhaps qualified by "and sources".

b How do 2012-2013 zooplankton communities compare to previous monitoring?

Significantly reduced, from 50-75% of the assemblages recorded previously. Intuitively, this is as likely to be due to reduced sampling frequency and site changes as to any reduction in flows. However, for the prediction "Zooplankton communities in the Murray Mouth and Coorong will be dominated by halophiles and communities will change along the salinity gradient" there is some support. Although barrage releases continued to export freshwater microfauna into the immediate environs of the barrages, there was a clear preponderance of halophiles along the length of the Coorong, in protists (tintinnids), rotifers (*Synchaeta/Testudinella*) copepods (*Acartia/*harpacticoids) and a suite of small estuarine macroinvertebrates. There is also support for the prediction:" Zooplankton communities in the Goolwa Channel and Lake Albert will be dominated by estuarine/halotolerant species whilst Lake Alexandrina will have a more lacustrine and freshwater community." Even with the reduced sampling intensity, it is apparent that the Goolwa Channel and L. Albert are localized repositories of discrete and adapted species, possibly because they provide a more heterogeneous environment than does the open L. Alexandrina with it's more 'predictable' source of freshwater and riverine inocula.

5. Relationship between zooplankton, microalgae, nutrients and water quality.

See Oliver *et al*. 2013. The only recommendations we would make pursuant to that report is that *all* sites be included in future analyses – information is lost when, for example, Goolwa Channel sites, which are spatially heterogeneous, are omitted – and that analyses are performed to species–level resolution. Information is again lost when the taxonomic resolution is coarse. Analysing by genera or families is fraught when there are multiple representatives of those taxa with specific ecological requirements in different parts of the system, e.g. multiple species of *Synchaeta* in the CLLMM region, some halophile, some not. We appreciate that there were time constraints in the reporting time frame for inclusion of the complete zooplankton data set.

6. Sampling comparison (open water v shore-based).

Sampling in open water collects true plankton, generally rotiferan if flowing, microcrustacean if not. As shown in Table 2, the components significantly absent in the 2012-13 samples are protists and rotifers, i.e. the littoral suite of testates and epiphytic/epibenthic rotifers which were abundant in the 2011-12 series. Missing from the 2012-13 cladocerans are the epibenthic macrothricids/ilyocryptids. Least change was apparent in the copepods, which in this system are primarily pelagic calanoids. That both diversity and density were lower for most sites in the 2012-13 sample series suggests that the open water may be less productive *or* subject to higher predator pressure than is the littoral region.

Conclusions

Reduced diversity and density of zooplankton assemblages in most of the CLLMM sites between Sept 2012 and Mar 2013 with respect to previous sampling are more likely to have resulted from site/method differences than to reduction in flows. The protracted interval between sampling no doubt missed taxa with a short generation time, e.g. protists and rotifers. Sampling of open water sites selected for a true plankton, which is less diverse than the littoral or heleoplankton sampled in the 2011-12 series, and in the Lower Lakes sites of the 2010-11 series. Notably missing from all regions of the CLLMM in the 2012-13 series were the suite of testate amoebae and littoral Rotifera documented in the earlier sampling. Only 50-54% of the previously-recorded species from L. Alexandrina, the Goolwa Channel and Coorong sites were encountered again. 75% of the L. Albert species were retrieved, suggesting site-specific buffering. As in previous monitoring, the Murray Mouth had a mixed freshwater/estuarine plankton, the latter increasing along the salinity gradient of the North Lagoon to Long Point, with a sparse halophile assemblage at Villa De Yumpa in the Sth Lagoon.

Recommendations

•The protracted sampling interval made difficult recognition of drivers of community change separate from or independent of natural successional events. A shorter sampling time frame would alleviate this impediment. We recognize budgetary constraints, but some compromises in sampling intensity may be possible.

•Similarly, change of sampling sites to open water, with no comparative sampling from littoral/riparian habitats limited the interpretation of observed differences in assemblages from those of previously sampled sites. It would be useful, again within the limits of budget(s), to have a pairwise comparison of open water/littoral sites within one or more of the CLLMM regions.

•Questions arise regarding the persistence of only a fraction of the R. Murray zooplankton at the outfall (Jockwar Rd) into L. Alexandrina proper. Longitudinal samples along a transect may provide some clarification.

•Food web interactions in general at this level are still unstudied for the Coorong/Lower Lakes. Again in 2012-13 distinct and dense pulses of bacteriovores (ciliates) were apparent, but what they were responding to is not known, although senescent algae or decomposition products from riparian margins are likely.

•Zooplankton/juvenile fish interactions remain poorly researched.

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APPENDIX 1: Cumulative zooplankton species list, 2010-13, CLLMM region

Appendix 2: Zooplankton sampling sites 2012-2013 (2011-2012 ID)

Location	Site Name	Easting	Northing
Lake Alexandrina	Lake Alex Middle*	344300	6062650
Lake Alexandrina	Point McLeay (ZOO01)	323334	6067399
Lake Alexandrina	Loveday Bay (ZOO04)	326364	6061874
Lake Alex/R Murray inlet	Jockwar Rd (ZOO03)†		
Narrung Narrows	Narrung Narrows (ZOO07)	335447	6068555
Lake Albert	Lake Albert Opening (ZOO08)	333095	6077956
Lake Albert	Meningie (ZOO09)	348605	6052257
Tributaries	Finniss River (GCW03)	306744	6076329
Tributaries	Currency Creek (GCW10)	298426	6073856
Goolwa Channel	Goolwa Barrage (GCW06)	300556	6067724
Murray Mouth Estuary	Mundoo Channel (C7)	308180	6065224
Murray Mouth Estuary	Tauwitcherie Barrage (C10)	319060	6060458
Coorong	Mark Point (C11)	325762	6054914
Coorong	Long Point (C12)	333756	6048257
Coorong	Villa De Yumpa*	359175	6022894

*= new site in 2012-2013

† = added 2nd field trip, 11/13 Dec 2012