The current state of food resources supporting waterbird and fish populations in the Coorong

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Executive summary

The Coorong is widely regarded as the most important waterbird wetland in the Murray-Darling Basin. The current ecological condition of the Coorong, however, is deteriorated, particularly in the South Lagoon. Since the Millennium Drought, there have been further reductions in the abundances of important waterbirds, including some threatened species (e.g. fairy tern) and migratory waders. Restoration actions are required to improve the ecological health of the Coorong. Over the last nine months, a range of urgent investigations have been conducted to obtain critical data and knowledge to inform effective management of the Coorong. This study aimed to understand the current state of potential food resources for waterbird and fish populations in the Coorong during late summer 2019. Specific objectives were to: 1) assess the current abundance, biomass and diversity of macro-invertebrate and fish in the Coorong, as a potential prey resources; and 2) trial methods for assessing energy content of these resources.

Field sampling was undertaken for quantitative assessments of macro-invertebrates and fish assemblages during February–March 2019. Multiple sampling sites were selected in the Murray Mouth, North Lagoon and South Lagoon of the Coorong, allowing the collection of samples along a broad salinity gradient to investigate the influence of salinity on food abundance, diversity and quality (energy content). Further laboratory analyses were conducted on six macro-invertebrate species (representative of Crustacea, Polychaeta and Mollusca) and six key fish species (smallmouth hardyhead, yelloweye mullet, congolli, sandy sprat, Tamar goby and lagoon goby) to determine their abundance, biomass and energy content. This included trialling methods for bomb-calorimetry analyses on invertebrates and fish.

The study revealed a clear regional difference in the availability of potential food resources of waterbird and fish populations in late summer 2019. Species diversity generally declined from north to south in the Coorong. The diversity and abundance of potential macro-invertebrate prey was low in the South Lagoon, while there was a greater diversity at sites closer to the Murray Mouth and North Lagoon. Potential prey availability also varied across locations within several sites, with higher macro-invertebrate abundance in sediments of the channel and on the peninsula side than in mudflats along the mainland shore.

During 2019, the total abundance of small-bodied fish was about a third of the peak abundance in March 2014, and was slightly below the mean level since 2011. Only three salt-tolerant species (i.e. smallmouth hardyhead, yelloweye mullet and congolli) were present in the South Lagoon, where smallmouth hardyhead dominated the abundance and biomass as potential prey for piscivorous waterbirds. In the North Lagoon, fish biomass (key species combined) was the greatest, which, in addition to the greater species diversity, suggests the North Lagoon is likely an important feeding ground for piscivorous birds and fish. The Murray Mouth region was also important due to much higher diversity and slightly higher biomass density of fish compared to the South Lagoon. Nevertheless, overall fish biomass in the North Lagoon and Murray Mouth are likely underestimated in this study due to sampling targeting towards smaller fish that are known to be important prey and the selection of key species with a focus on South Lagoon restoration.

During this study, methods were trialled for assessing the energy content of macro-invertebrate and fish and the first energetic data obtained for potential prey items in the Coorong. The measured energy content ranged from ~5–19 kJ/g DM for macro-invertebrates and ~15–23 kJ/g DM for fish in the Coorong. Variation in energy contents across the regions generally appeared low for both macro-invertebrates and fish, but the data are based on a small sample size and for one season. Overall, the energy contents of macro-invertebrates and fish from the Coorong were mostly within the range of literature values for related species, and the emerging differences indicate the need for further investigations on their spatial and temporal patterns and the food web energetics. Based on the species for which energy contents were analysed and their biomass present at the time of this survey, the total energy density per site ranged from 0 (throughout the South Lagoon) to >100 kJ/m^2 (at sites in the Murray Mouth) for macro-invertebrates, and from 2095 (at Villa de Yumpa in the South Lagoon) to >12,000 kJ/1000 m^2 (at Long Point and Mark Point in the North Lagoon) for fish (key species only). For the Coorong, seasonal differences in the provision of energy could affect overwintering shorebirds that need to obtain sufficient energy over the southern summer for their return migration. This project provided insight into the quantity and quality of potential food resources for waterbirds and fish in the Coorong during late summer 2019. The findings and data collected will contribute

to the development of quantitative food web models, which will provide a tool to inform management in order to maximise food resources for key fish and waterbirds and increase resilience of the food web and ecosystem health of the Coorong, particularly for the South Lagoon.

Acknowledgments

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1 Introduction

1.1 Background

The Coorong is widely regarded to be the most important waterbird wetland in the Murray-Darling Basin (Kingsford et al. 2011). It is a unique and important wetland that provides important ecological, cultural, social and economic values at local, national and international scales. Along with Lake Alexandrina, Lake Albert and the Murray Mouth, the Coorong is listed as a Ramsar wetland of International Importance (Phillips and Muller 2006).

On top of a long-term decline in the condition of the region due to water extraction, the ecology of the Coorong was substantially degraded during the Millennium Drought. Most notably this included large reductions in the abundances of some waterbirds, particularly fairy tern and migratory shorebirds (Paton et al. 2009). Whilst the relatively recent increase in river inflows (2010–2018) to the Coorong improved the condition of some ecological values, other values have not recovered or have continued to decline, particularly those of the South Lagoon. This is associated with the prevalence of filamentous algae that is preventing aquatic plants (in particular *Ruppia tuberosa*) from completing their life-cycle and interfering with the ability of waterbirds to feed on both plants and invertebrates in mudflats and potentially on fish in water (Collier et al. 2017; Brookes et al. 2018).

Maintaining a productive and resilient food web is critical to preserving the ecological character of the Coorong. Under suitable environmental conditions in the Coorong, the trophic productivity supports a diversity of biota across multiple trophic levels, including fish and waterbirds (Brookes et al. 2009; Deegan et al. 2010; Dittmann et al. 2018). A more complex food web with multiple trophic levels, as present in the Murray Mouth and North Lagoon, is seen to be more resilient than a simple food web occurring under the hypersaline conditions of the South Lagoon (Brookes et al. 2015; Giatas and Ye 2016; Breaux et al. 2019). However, a simple and productive food web could also be important for supporting particular species and overall biodiversity. Since the Millennium Drought, conditions in the Coorong, including changes in the water level, salinity regime and potentially nutrient dynamics, have altered the community composition of key food resources in the Coorong, including macro-invertebrates and fish, which are important ecological components and potential food sources for fish and waterbirds (see Appendix A).

Ecological monitoring of key biota in the Coorong has been undertaken over the last decade and provided significant foundational knowledge and some conceptual understanding of food webs (e.g. Giatas et al. 2018), yet an integrated quantitative food web model for the Coorong, particularly the southern Coorong, is a key knowledge gap. Furthermore, links between river flow, nutrient resources and salinity levels for productivity and ecosystem energetics are unknown (Brookes et al. 2015). Uncertainties remain regarding what food items actually support the fish and birds and their relative importance in the South Lagoon, and what food resources are required to maintain viable populations of fish and waterbirds. Additionally, key knowledge gaps remain in relation to critical food resources available, harvestable and bioenergetically valuable for key species across seasonal and spatial scales within the Coorong.

An independent expert panel established by the Goyder Institute for Water Research recommended a number of actions to restore the Ecological Character of the South Lagoon (in addition to environmental water recovery) (Brookes et al. 2018). One of these actions included improving our knowledge on how to maximise nutrient turnover into productive elements such as plants, invertebrates, fish and birds and incorporating knowledge into a response strategy. This project is a first step in addressing this action and is focussed on investigating macro-invertebrates and fish as potential food resources for waterbirds and fish populations in the Coorong during 2019.

1.2 Objectives

Food availability, the nutritional value of prey items and competition with other predators are key factors influencing the density/abundance of waterbirds (Goss-Custard 1977a; Zwarts and Wanink 1993; Goss-

Custard et al. 2002; Zharikov and Skilleter 2003). In this study, we used different measures of food availability including abundance (numbers), biomass (as wet or dry mass) and energy (content and density), which is a staged approach towards the bioenergetics assessment of food webs. Energy is the fundamental and most reliable measure of 'food supply' to support consumers.

This project aimed to understand the current state of potential food resources supporting waterbird and fish populations in the Coorong. Specific objectives were:

- To assess the abundance, diversity and biomass of potential food resources in the Coorong during late summer 2019, with a focus on macro-invertebrates and fish assemblages, and
- To trial methods for assessing the energy content of potential food resources and obtain preliminary data on their energy content.

The methods developed during this project may be applied in future bioenergetics studies, and the preliminary energy content data will allow initial relationships to be developed to explore the variability of food quality between different types of resources and under different salinity conditions. These energy and assemblage data will aid the development of quantitative food web models, which build upon previous work in the Coorong (i.e. Geddes and Francis 2008; Deegan et al. 2010; Giatas and Ye 2016). These models would provide tools to inform management in order to maximise food resources for key fish and waterbirds, particularly for the South Lagoon ecosystem. The approaches used here will also provide a basis for future investigations of the major food resources and their relative contribution to the diet for key waterbird and fish species.

1.3 Approach

Macro-invertebrates are common food items for shorebirds (Viain et al. 2011; Lourenço et al. 2017) and fish for piscivorous birds (Paton et al. 2018). We determined the abundance (density), biomass and energy content of potential macro-invertebrate and fish prey items for waterbirds as previous studies have shown the relevance of all of these measures. For example, the feeding rate of shorebirds was shown to depend on the density of large polychaetes, but on the biomass of smaller worms (Goss-Custard 1977b). Eastern curlews switch to consumption of higher quality (energy rich) prey during pre-migration, but prey behaviour and prey availability also determined prey choice (Zharikov and Skilleter 2004; Dann 2014). The various measures are also used in food web and bioenergetic modelling in estuaries (Saint-Beat et al. 2013; Brigolin et al. 2014; Bueno-Pardo et al. 2018).

Field investigations were undertaken during February–March 2019 to quantitatively assess the current abundance, biomass and diversity of potential food resources in the Coorong, focussing on benthic macro-invertebrates and fish assemblages. Fish sampling was carried out through *The Living Murray* (TLM) Coorong fish condition monitoring program, whereas funding from this project was used to complement this monitoring program by collecting samples of key fish species and by-catch (i.e. shore crab) for energy content analyses and evaluating them in the context of the state of food resources for waterbirds in the Coorong. The energy content was determined for a subset of taxa/species for macro-invertebrates and fish across the Coorong.

Multiple sampling sites were selected in the Murray Mouth, North Lagoon and South Lagoon of the Coorong, as habitat heterogeneity and environmental conditions can affect prey availability and foraging patterns (Rosa et al. 2007; VanDusen et al. 2012). Salinity and accessible habitat can affect the available energy for waterbirds (Brand et al. 2014), fish diets (Lamontagne et al. 2016) and the functioning of estuarine food webs (Breaux et al. 2019). This sampling regime allowed samples to be collected along a broad salinity gradient in order to investigate the influence of salinity on abundance, diversity, biomass and energy content of potential food sources. At the time of the survey in late summer/autumn of 2019, salinities were around or below seawater level in the Murray Mouth and North Lagoon, but hypersaline south of Noonameena. Water levels were low in the Coorong lagoons, in particular in the South Lagoon (Figure 1).

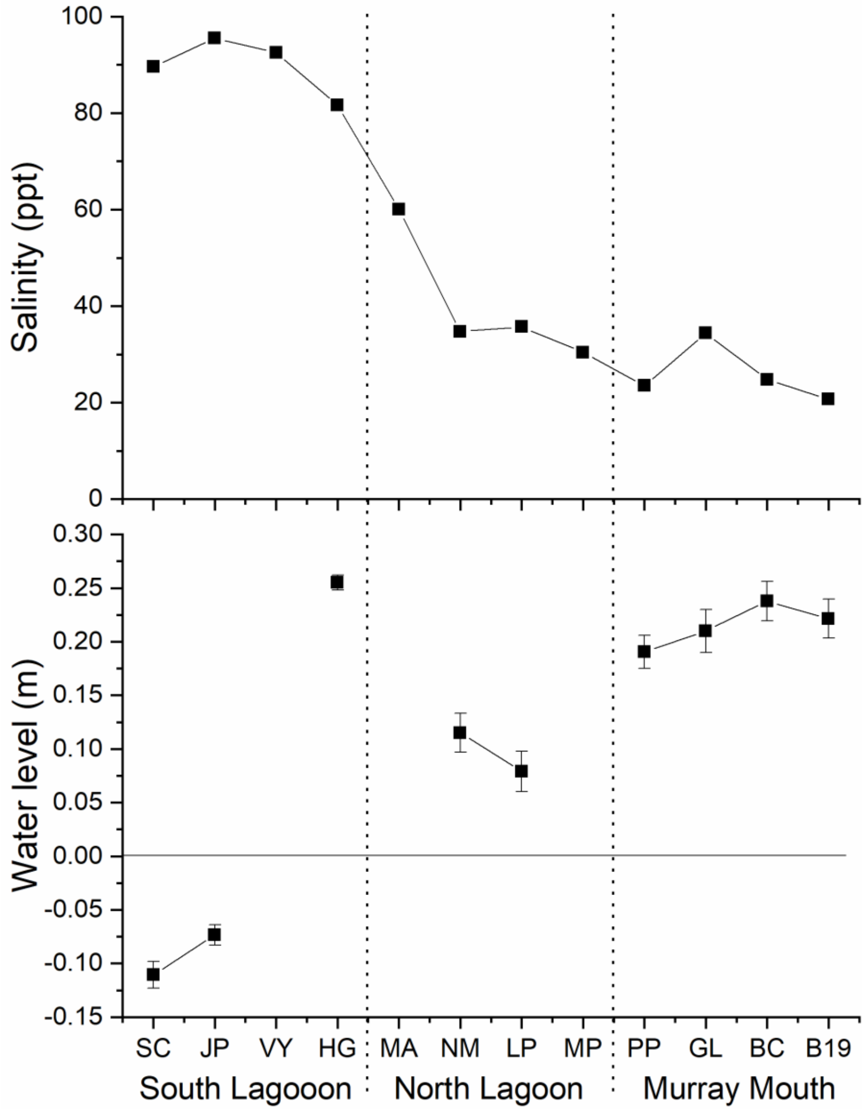

Figure 1. Salinity and water level across the Coorong from the South Lagoon to the Murray Mouth at sites sampled for macro-invertebrates and fish during the sampling period of late February to March 2019. Water level data were obtained from www.waterconnect.sa.gov.au. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19. Note: water level data for GL came from Ewe Island.

Laboratory analyses were conducted to assess the abundance, biomass and energy content of potential food resources. This included trialling methods for sample preparation, processing and bomb-calorimetry analyses on invertebrates and fish; collecting initial data on the energetic relationships with the wet and dry mass (weight) for different taxa; and exploring the effects of salinity on food energy content.

More detailed materials and methods are presented in Section 2 for field sampling of macro-invertebrates and fish, and in Section 3 for laboratory sample processing and analysis for energy content and estimating energy density based on abundance (numbers), biomass and energy content.

2 State of potential food resources in the Coorong in late summer 2019

2.1 Macro-invertebrates

2.1.1 MATERIALS AND METHODS FOR MACRO-INVERTEBRATES

Sampling for benthic macro-invertebrates occurred in February/March 2019 across seven sites from the Murray Mouth to the South Lagoon (Table 1, Figure 2). At each site, two to three locations were sampled to assess the spatial pattern of potential prey availability (diversity and abundance) from the exposed sediments on the mainland shore and Younghusband and Sir Richard peninsulas, and the submerged sediments of the main channel of the Coorong. Exposed mudflat sediments were either intertidal (in the Murray Mouth) or wetted episodically by wind seiching and the overall water level changes in the Coorong. The sampling sites were aligned as best as possible with those for fish studies of this project, and invertebrate sampling occurred prior to fish sampling. Due to extreme heat (>44˚C), sampling had to be abandoned in the afternoon of 1st March, but resumed later in March. Subtidal sediments and intertidal areas on the peninsula side of the Coorong were sampled by a small boat. Where the water level was too low to launch the boat, subtidal samples were obtained from wading into deeper water from shore (knee to hip deep). At Hells Gate, the western side of the Coorong was not sampled due to the close proximity to mudflats on the eastern side of the Coorong. For the Murray Mouth area near Beacon 19, the land-based mudflat was sampled in the Mundoo Channel near Hunters Creek.

Table 1: Sampling design and sampling dates for macro-invertebrates in the Coorong in late February and March 2019. n.s. means not sampled as water level was too low to reach the peninsula. For Hells Gate, sampling on the peninsula side was n/a (not applicable) because of the very narrow distance to the shore side. As Monument Road opposite Beacon 19 could not be accessed, intertidal shore samples were taken at a mudflat in Mundoo Channel at Hunters Creek.

REGION	SITE	DATE SAMPLED FOR EACH LOCATION		
		INTERTIDAL -SHORE	SUBTIDAL	INTERTIDAL-PENINSULA
South Lagoon	Salt Creek	27/3/2019	27/3/2019	n.s.
	Jack Point	1/3/2019	1/3/2019	n.s.
	Hells Gate	1/3/2019	1/3/2019	n/a
North Lagoon	Noonameena	28/2/2019	27/3/2019	n.s.
	Long Point	28/2/2019	28/2/2019	28/2/2019
Murray Mouth	Pelican Point	28/2/2019	28/2/2019	28/2/2019
	Beacon 19/Hunters Creek	27/2/2019	27/2/2019	27/2/2019

At each site and location, five replicate samples were taken. Macro-invertebrates were obtained from intertidal sediments on the shore by using a PVC corer (83.32 cm^2 surface area) which was pushed 15–20 cm deep into the sediment. The sample was sieved through 500 µm mesh in the field to separate macrofauna from sediment and rinsed into zip-lock bags. Previous studies in the Coorong using both a 500 µm and 250 µm mesh found similar species, abundances and distributions of macro-invertebrates based on both methods (Rolston and Dittmann 2009; Dittmann et al. 2010), which aligned with other studies (e.g. Pinna et al. 2014). The subtidal benthos and peninsula locations were sampled with an Ekman grab sampler (225 cm^2 surface area) and sediment was rinsed through a 500 µm sieve and into a zip-lock bags. All samples were frozen (-20˚C) in a portable freezer before being stored in freezers at Flinders University. Biomass was determined as wet and dry mass for each macro-invertebrate species and replicate sample from all sites. After measuring wet weight (to within 0.0001 g), samples were dried in an oven at 60 °C to constant weight (see Section 3 for further detail). For small molluscs (<10 mm in size, e.g. *Arthritica helmsi*, Hydrobiidae, *Salinator fragilis*), biomass was determined with shell, while the shell was removed for larger bivalves (*Soletellina alba, Spisula trigonella*). Abundance and biomass data were calculated as individuals or mass per m^2.

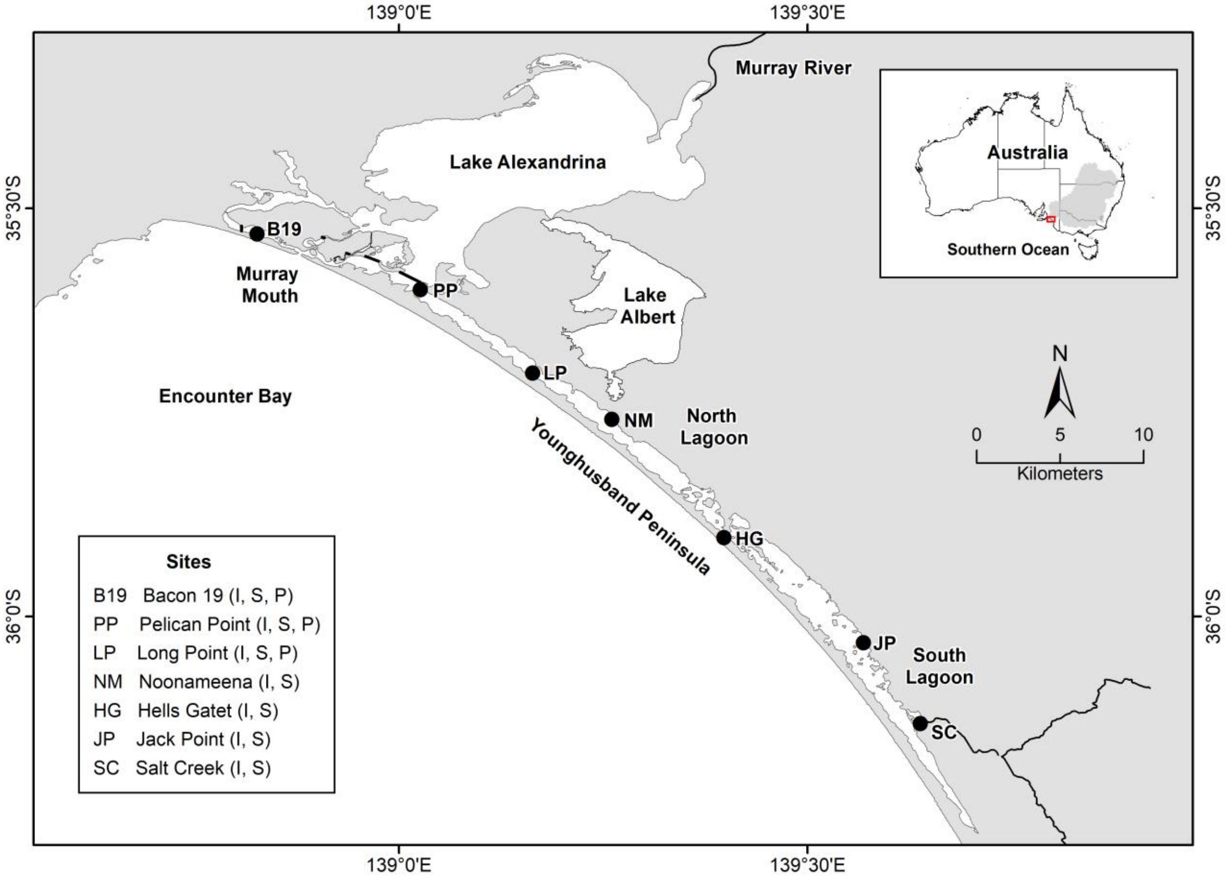

Figure 2. Maps showing the sampling sites for macro-invertebrates in the Coorong in February and March 2019. I, S, and P refer to locations sampled at the sites: intertidal, submerged or on the peninsula side respectively.

2.1.2 SPATIAL PATTERNS OF MACRO-INVERTEBRATE DIVERSITY, ABUNDANCE AND BIOMASS

The number of macro-invertebrate taxa recorded in sediments across the Coorong increased from south to north (Figure 3). A total of eight taxa were found throughout the South Lagoon, but only four macro-invertebrate taxa were found on average across the three sites (Table 1) in this region. In the North Lagoon, ten macro-invertebrate taxa were recorded and the mean number of taxa for the sites was seven taxa. The Murray Mouth had the highest number of taxa (17) with 13 on average across the sites, and all major taxa were present at each site (Figure 3). Annelids, bivalves and crustaceans accounted for most taxa and the taxonomic composition and species numbers were comparable across the locations at most sites, especially in the Murray Mouth (Figure 3). The survey detected several mollusc species which were not previously recorded in TLM monitoring program (Dittmann et al. 2017).

Overall, twenty macro-invertebrate taxa were recorded during the survey. Seven of these taxa were rare and represented by one individual only, while six taxa accounted for >1% of all individuals and were present in >50% of all samples. Of these more common taxa, the micro-mollusc *A. helmsi* was most abundant, accounting for 51% of all individuals found, followed by amphipods which accounted for nearly 26% of all individuals. Additional key macro-invertebrate taxa, based on their abundances and occurrence, included the polychaetes *Simplisetia aequisetis*, and *Capitella* sp., chironomid larvae and hydrobiid snails.

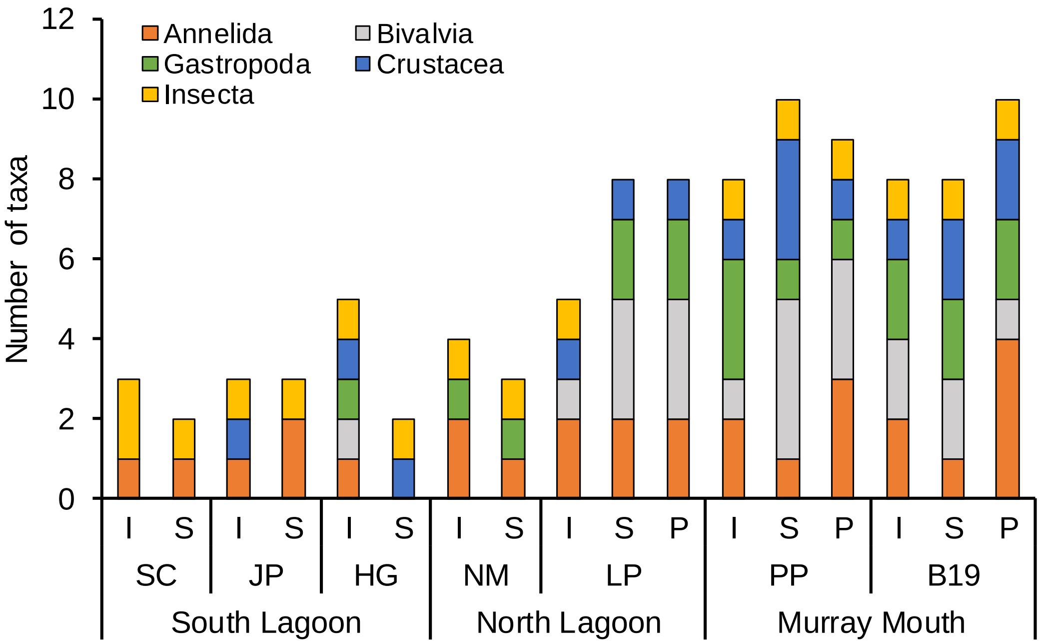

Figure 3. Number of macro-invertebrate taxa, and high-level taxonomic composition, recorded in samples at the study sites in the Coorong in February/March 2019. Insecta comprised mostly Diptera (Chironomid larvae). SC=Salt Creek, JP=Jack Point, HG=Hells Gate, NM=Noonameena, LP=Long Point, PP=Pelican Point, B19=Beacon 19. The locations sampled at each site were at the shore based intertidal (I), submerged sediments of the channel (S), and mudflats on the peninsula side (P).

Macro-invertebrate abundance showed a clear gradient across the Coorong and was several orders of magnitude higher in the Murray Mouth than in the South Lagoon (Figure 4a, Table 2). The South Coorong sites and locations sampled were characterised by very low individual densities of macro-invertebrates, apart from the submerged sediments at Salt Creek where chironomid larvae and capitellid polychaetes were present (Figure 4b and f). For shorebirds, abundance of macro-invertebrates was high in the Murray Mouth on mudflats of both the peninsula and the landward shore side. Abundances were also high at Long Point in the North Lagoon. The higher abundances were composed of bivalves (mostly *A. helmsi*), crustaceans (amphipods), polychaetes (mostly *S. aequisetis*) and gastropods (hydrobiid snails and *Salinator* sp.) (Figure 4c to e). For fish, abundance of macro-invertebrates in submerged sediments of the Coorong channel was also higher in the North Lagoon and Murray Mouth, due to the same taxa (Figure 4). The highest individual density in subtidal sediments was found at Beacon 19. Differences in abundances between locations were site specific and also varied with macro-invertebrate taxa (Table 2).

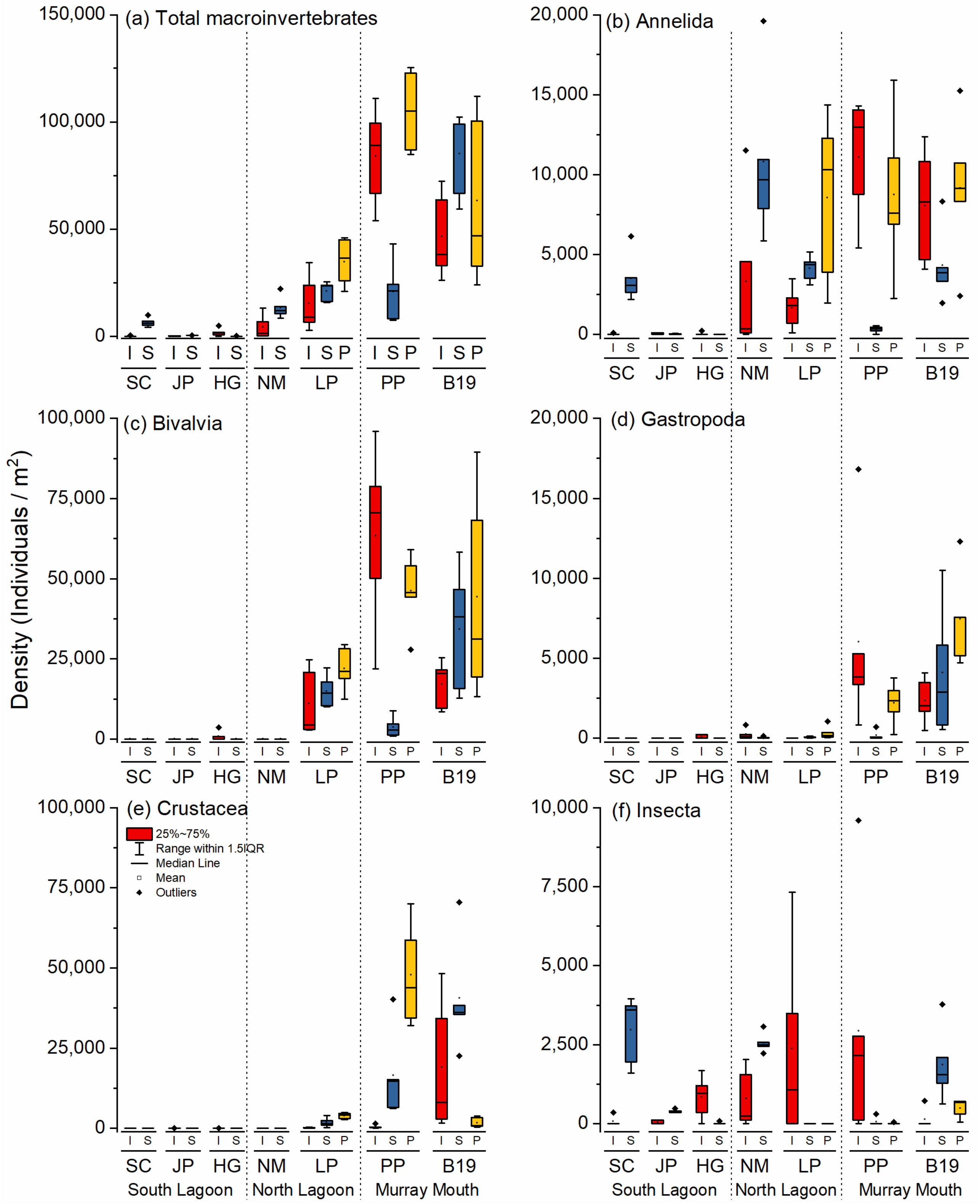

Figure 4. Boxplots of macro-invertebrate individual densities for all taxa (a) and the main taxa (b to f) represented in samples from the survey in the Coorong in February/March 2019. Insecta comprised mostly chironomid larvae. SC=Salt Creek, JP=Jack Point, HG=Hells Gate, NM=Noonameena, LP=Long Point, PP=Pelican Point, B19=Beacon 19. The locations sampled at each site were at the shore based intertidal (I, red colour), submerged sediments of the channel (S, blue colour), and mudflats on the peninsula side (P, yellow colour). Note the different y-axes scales.

Table 2: Test results from permutational ANOVA on differences in abundances for all (total) macro-invertebrates and those of several higher taxa across the regions, sites within regions and locations in the Coorong in February/March 2019. Pairwise test results for location differences are shown for each site, with I=shore based intertidal, S=submerged sediments of the channel, and P=mudflats on the peninsula side. Sites were: SC=Salt Creek, JP=Jack Point, HG=Hells Gate, NM=Noonameena, LP=Long Point, PP=Pelican Point, B19=Beacon 19.

		TOTAL	ANNELIDA	BIVALVIA	GASTROPODA	CRUSTACEA	INSECTA
MAIN TEST	df	$P_{(PERM)}$	$P_{(PERM)}$	$P_{(PERM)}$	$P_{(PERM)}$	$P_{(PERM)}$	$P_{(PERM)}$
Region (Re)	2	0.0097	ns	ns	0.0001	ns	ns
Location (Lo)	2	ns	ns	ns	ns	ns	ns
Site: Si(Re)	4	ns	0.0001	0.0001	0.0051	0.0001	0.0007
(Re) x (Lo)	3	ns	ns	ns	ns	ns	ns
(Si(Re)) x (Lo)	5	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001
Res	68						
PAIRWISE TESTS							
SITE	LOCATION						
B19	P, S	ns	ns	ns	ns	0.0081	0.032
	P, I	ns	ns	ns	0.0084	0.0469	0.0466
	S, I	0.0419	ns	0.0493	ns	ns	0.0158
PP	P, S	0.007	0.0076	0.0078	0.0153	0.0251	ns
	P, I	ns	ns	ns	ns	0.0083	0.047
	S, I	0.0078	0.0084	0.0066	0.007	0.0081	ns
LP	P, S	ns	ns	ns	ns	0.0303	
	P, I	0.0443	0.0328	ns	0.0076	0.0074	ns
	S, I	ns	0.0161	ns	0.0444	0.018	ns
NM	S, I	0.0407	ns		ns		0.0061
HG	S, I	ns	ns	ns	ns	ns	0.0467
JP	S, I	0.0074	ns			ns	0.007
SC	S, I	0.0079	0.01				0.0078

The biomass of macro-invertebrates (Figure 5) showed a similar pattern to the individual densities (Figure 4a), with a gradient of decreasing biomass towards the South Lagoon, where wet and dry mass weights of the insect larvae and capitellid worms found were almost negligible (Figure 5). Biomass varied at a site-specific level and subject to the location within sites (Table 3). The biomass of macro-invertebrates was highest in submerged sediments of the channel at Long Point in the North Lagoon, where a higher density of the larger bivalve *S. trigonella* was found, and larger specimens of the polychaete *S. simplisetia*. Biomass of macro-invertebrates was also high in the channel of the Murray Mouth. For mudflats, abundances and biomass of macro-invertebrates were higher at peninsula locations than on the landward shore between Long Point and Beacon 19.

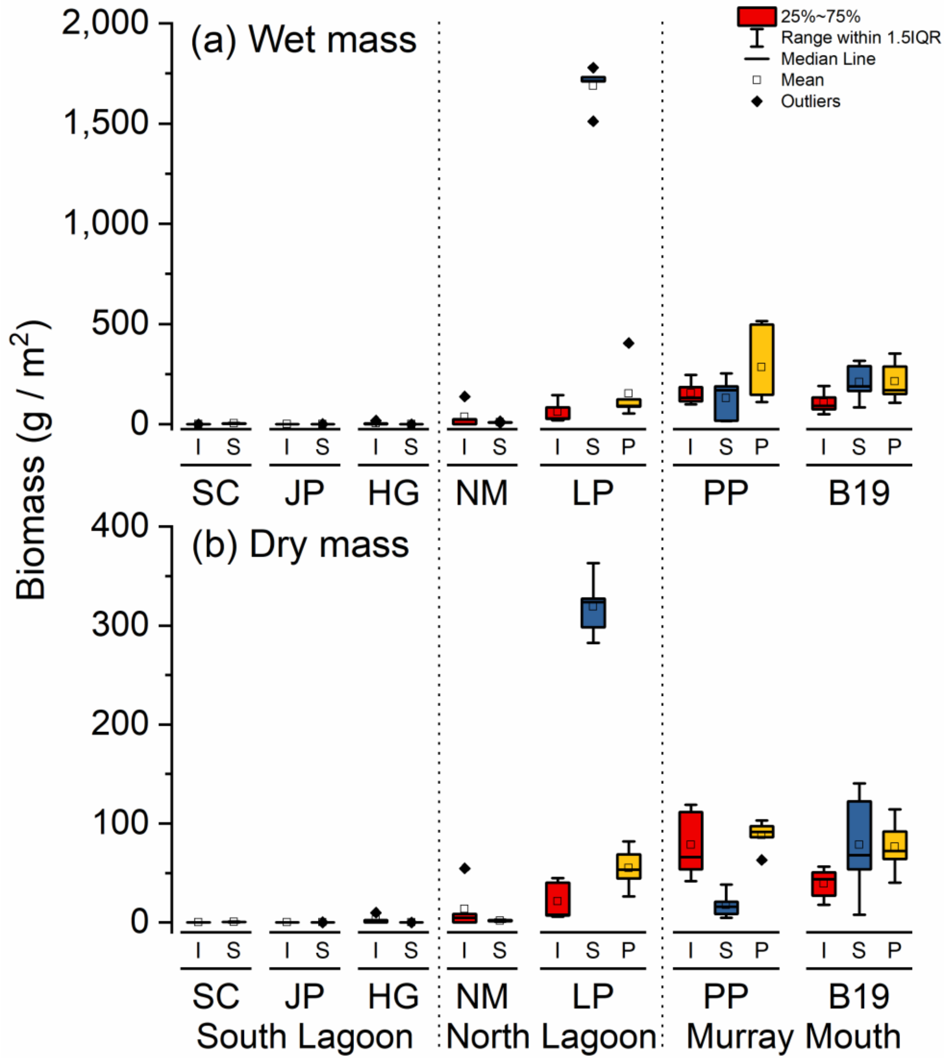

Figure 5. Boxplots of macro-invertebrate biomass as (a) wet mass (WM) and (b) dry mass (DM) for all taxa from the survey in the Coorong in February/March 2019. SC=Salt Creek, JP=Jack Point, HG=Hells Gate, NM=Noonameena, LP=Long Point, PP=Pelican Point, B19=Beacon 19. The locations sampled at each site were at the shore based intertidal (I, red colour), submerged sediments of the channel (S, blue colour), and mudflats on the peninsula side (P, yellow colour). Note the different y-axes scales.

Table 3: Test results from permutational ANOVA on differences in biomass (as wet or dry mass) for macro-invertebrates across the regions, sites within regions and locations in the Coorong in February/March 2019.

MAIN TEST	df	WET MASS $P_{(PERM)}$	DRY MASS $P_{(PERM)}$
Region (Re)	2	ns	ns
Location (Lo)	2	ns	ns
Site: Si(Re)	4	0.0001	0.0001
(Re) x (Lo)	3	ns	ns
(Si(Re)) x (Lo)	5	0.0001	0.0001
Res	68		

2.2 Fish

2.2.1 MATERIALS AND METHODS FOR FISH

Fish data and sample collection was conducted during March 2019 by TLM fish condition monitoring at twelve sites in the Coorong, with four sites in each region (Murray Mouth, North Lagoon and South Lagoon) (Figure 6; Appendix B1). As part of this, shore crabs (*Paragrapsus gaimardii*) were also collected as by-catch for energy content analysis given they are a key food resource of macro-invertebrate for fish (Giatas and Ye 2015). At each site, sampling was conducted during the day using a standard seine net (61 m net length, 29 m wing length, 22 mm mesh, 3 m bund length (8 mm mesh); *n* = 3 hauls). The seine net was deployed in a semi-circle, which sampled to a maximum depth of 2 m and swept an area of ~592 m^2. All fish collected in each haul were identified to species, and the total number of individuals of each species recorded. In addition, the number of shore crabs caught in seine nets were recorded. A random subsample of 'key species', i.e. those likely to occur in the South Lagoon and are known to be important food resource for higher level predators in other regions of the Coorong (Appendix A), were retained from each site, except for Godfrey's Landing (Table 4). These key species were smallmouth hardyhead (*Atherinosoma microstoma*), yelloweye mullet (*Aldrichetta forsteri*), congolli (*Pseudaphritis urvillii*), sandy sprat (*Hyperlophus vittatus*), Tamar goby (*Afurcagobius tamarensis*), lagoon goby (*Tasmanogobius lasti*) and shore crab. Samples were kept frozen for future laboratory processing and analysis of nutritional values (energy content) for key species. Biomass (wet weight) of key fish species was calculated using Catch Per Unit Effort (CPUE) data and mean fish weights during sampling, and dry biomass was calculated following oven drying (see Section 3). Biomass density (per 1000 m^2) was calculated for key species using the area of water sampled via seine net.

Table 4: Fish and shore crab subsample retained from the Murray Mouth (MM), North Lagoon (NL) and South Lagoon (SL) of the Coorong during the field trip in March 2019. Shore crab = *Paragrapsus gaimardii*. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19.

	NUMBER OF SUBSAMPLE										
	MM			NL				SL			
SPECIES	B19	BC	PP	MP	LP	NM	MA	HG	VY	JP	SC
Smallmouth hardyhead	33	17	25	32	47	32	15	30	32	30	20
Congolli	7	5	3	1	5	12	12				1
Yelloweye mullet	19	13	5	5	9	11	8	12			6
Tamar goby	10	4	12		20						
Lagoon goby		3			10						
Sandy sprat	10	30	5	21	32	30	30				
Shore crab	5		5	8	3	2					

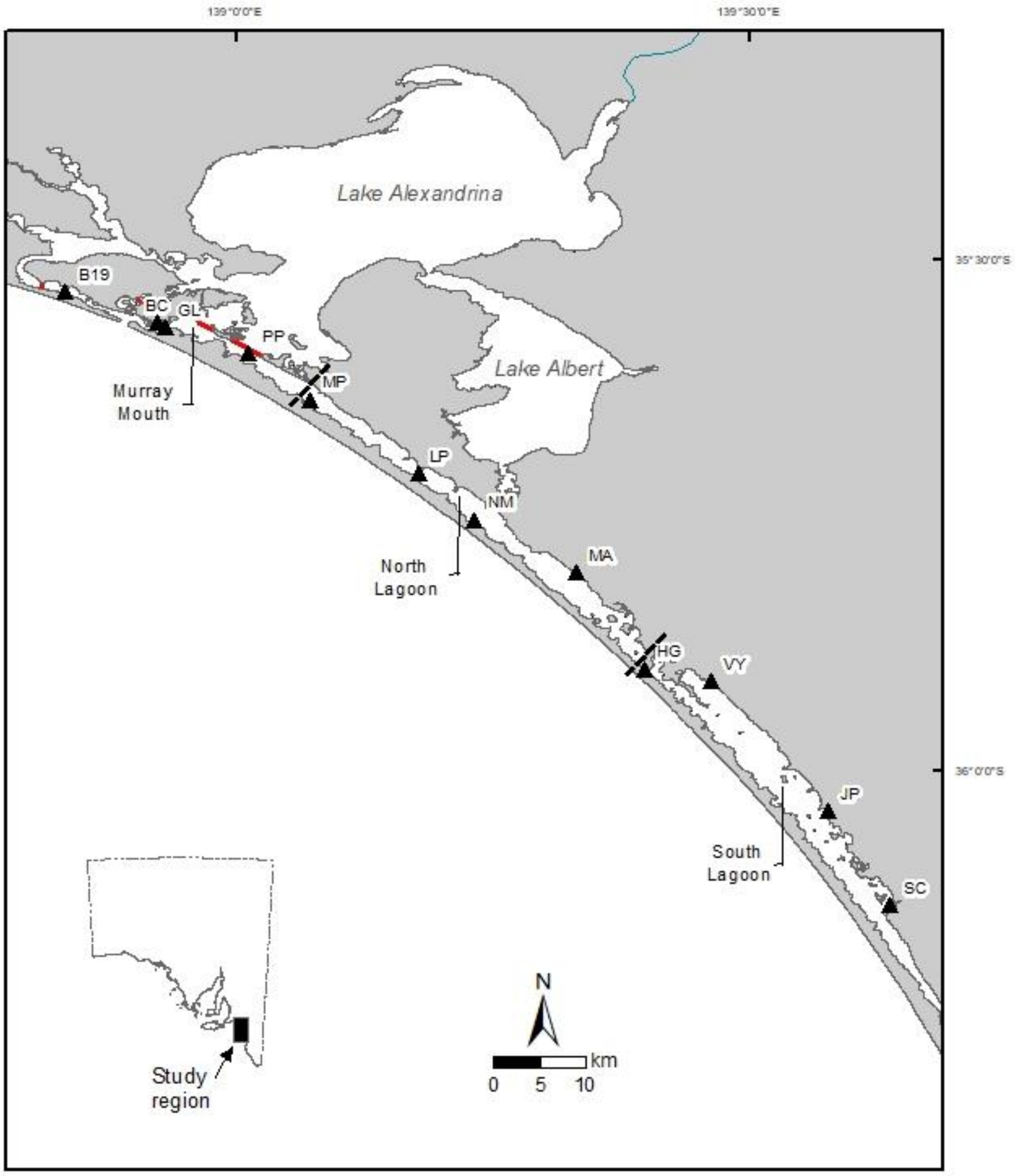

Figure 6. Fish sampling sites in the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19.

2.2.2 SPATIAL PATTERNS OF FISH DIVERSITY, ABUNDANCE AND BIOMASS

The number of fish species recorded across the Coorong increased from south to north (Figure 7). A total of three species were found in the South Lagoon, but only two on average per site across the four sites in this region. In the North Lagoon, 14 fish species were recorded and the mean number of species across four sites was eight species. The Murray Mouth had the highest species number (19) with 12 species on average across the four sites, and all species found were present in this region except for prickly toadfish (Appendix B3). Overall, 20 fish species were recorded during the survey in March 2019, with nine small bodied-fish species and 11 mid to large-bodied fish species. All species were previously found in the Coorong through TLM fish survey.

A total of 39,746 fish were sampled during March 2019, with 98% being small-bodied fish. Smallmouth hardyhead was the most abundant species across all regions and accounted for 81% of the overall catch (by number) (Figures 7 and 8). This was followed by sandy sprat (15%), although they were not present in the

South Lagoon (Appendix B3). The total abundance of fish (CPUE, number/seine net) showed a general trend of increase from the north to south along the Coorong, mainly driven by the numbers of smallmouth hardyhead, a species with a strong tolerance to high salinities (Figures 7 and 8). Yelloweye mullet and congolli were the only two other species (mid to large-bodied) than smallmouth hardy present in the South Lagoon. The abundance of yelloweye mullet was higher in the Murray Mouth than in the North and South lagoons, whereas congolli was most abundant in the North Lagoon compared to the other two regions (Figure 8). For two other small-bodied species, the Tamar goby was more abundant in the Murray Mouth, particularly at Beacon 19, whereas the lagoon goby was only sampled at Long Point in the North Lagoon in high numbers (Figure 8). The total abundance of fish and abundances of each key species differed significantly between regions (*P*=0.001) and sites (*P*<0.01) except for the lagoon goby (Table 5).

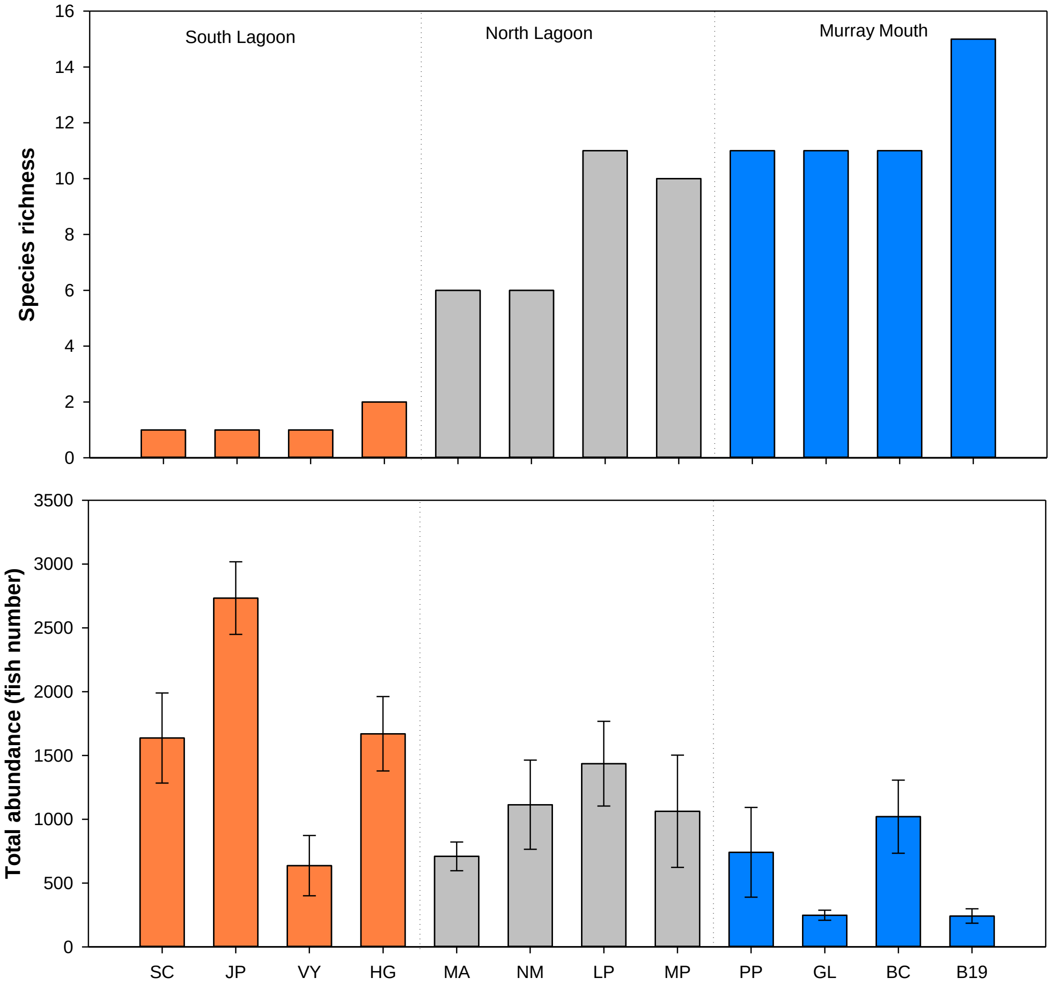

Figure 7. Species richness (number of fish species) (top) and total abundance (fish number) (bottom) recorded at each site sampled in the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19.

Table 5: Test results from permutational ANOVA on differences in abundances for all fish (all species combined) and each of key species across the regions, sites nested within regions, in the Coorong during March 2019.

		TOTAL ABUNDANCE	SMALLMOUTH HARDYHEAD	SANDY SPRAT	YELLOWEYE MULLET	CONGOLLI	TAMAR GOBY	LAGOON GOBY
MAIN TEST	df	*P(PERM)*	*P(PERM)*	*P(PERM)*	*P(PERM)*	*P(PERM)*	*P(PERM)*	*P(PERM)*
Region (Re)	2	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	0.584
Site: Si(Re)	9	**0.009**	**0.009**	**0.001**	**0.001**	**0.001**	**0.001**	0.14
Res	24							

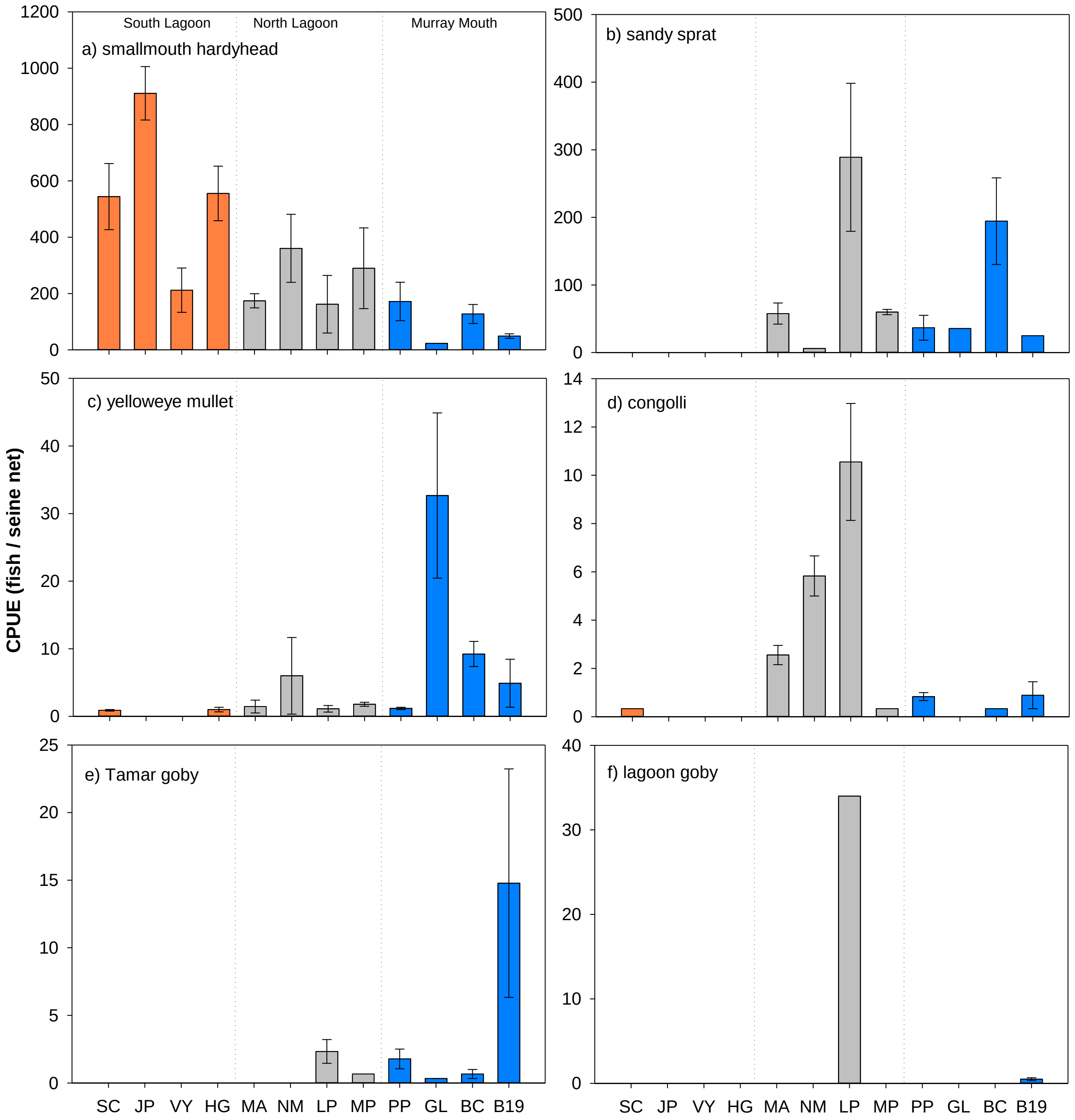

Figure 8. Relative abundance (CPUE) of key fish species (a–f) collected by standard seine net at different sites across three regions of the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19. Note the different y-axes scales.

The size of prey items is an important determining factor in diet selection of piscivorous birds. For example, fairy tern are known to feed on small-bodied fish (e.g. smallmouth hardyhead) (O'Connor and Rogers 2013) and juveniles of larger species such as mullet (Hitchcock 1937). Therefore, further analysis was undertaken on catch and length data of the six key species collected in March 2019 to explore the proportion of small-sized prey fish using an arbitrary size of <60 mm total length (TL) (Table 6). The majority of the four small-bodied species collected across the regions were <60 mm TL. In contrast, less than 50% of the two larger species collected were <60 mm TL in each region.

Table 6: Proportion of key fish species with total length <60 mm collected across Murray Mouth (MM), North Lagoon (NL) and South Lagoon (SL) of the Coorong during March 2019.

SPECIES	PERCENT OF FISH WITH TOTAL LENGTH <60 MM		
	MM	NL	SL
Small-bodied species			
Smallmouth hardyhead	87%	97%	99%
Sandy sprat	100%	100%	
Tamar goby	92%	74%	
Lagoon goby	100%	100%	
Medium-bodied species			
Yelloweye mullet	38%	48%	0%
Congolli	39%	44%	0%

The biomass for each key fish species (Figures 9 and 10) showed a similar spatial pattern to the abundance (CPUE) (Figure 8). The pattern of the wet (Figure 9) and dry (Figure 10) mass were identical, with dry mass values being about 25% of the wet values. Smallmouth hardyhead generally had the highest biomass in the South Lagoon, although density varied among sites (Villa de Yumpa biomass was among the lowest). In the North Lagoon, the overall fish biomass of key species appeared to be the highest among three regions due to the abundance of mid- to large-bodied species (yelloweye mullet and congolli), along with moderately high numbers of small-bodied species (smallmouth hardyhead and sandy sprat) (Figures 9 to 11). The overall biomass of key species in the North Lagoon was about twice that in the South Lagoon (Figure 11). In the Murray Mouth, the biomass of key fish species was similar to that in the South Lagoon, primarily attributed to yelloweye mullet, smallmouth hardyhead and sandy sprat, although fish diversity was the highest in this region. Nevertheless, as key species in this project were selected because of their likeliness to occur in the South Lagoon, fish biomasses presented in this report could be underestimated in the Murray Mouth and North Lagoon. Furthermore, biomass of larger-bodied species (e.g. mulloway and bony herring) are underestimated because sampling targeted small-bodied species and juveniles of larger-bodied fish species. The biomass (wet or dry mass) of sandy sprat, yelloweye mullet and congolli varied significantly between regions (*P*=0.001) and sites (*P*<0.02) and the biomass of Tamar goby differed significantly between regions (*P*=0.001), but not sites (*P>0.5*) (Table 7). However, no significant spatial differences were detected in biomass for smallmouth hardyhead and lagoon goby.

Table 7: Test results from permutational ANOVA on differences in fish biomass (wet and dry mass) for key species across the regions, sites nested within regions, in the Coorong during March 2019.

MAIN TEST	df	SMALLMOUTH HARDYHEAD $P_{(PERM)}$	SANDY SPRAT $P_{(PERM)}$	YELLOWEYE MULLET $P_{(PERM)}$	CONGOLLI $P_{(PERM)}$	TAMAR GOBY $P_{(PERM)}$	LAGOON GOBY $P_{(PERM)}$
Wet mass							
Region (Re)	2	0.167	**0.001**	**0.001**	**0.001**	**0.001**	0.691
Site: Si(Re)	8	0.148	**0.001**	**0.001**	**0.014**	0.829	0.107
Res	22						
Dry mass							
Region (Re)	2	0.075	**0.001**	**0.001**	**0.001**	**0.001**	0.721
Site: Si(Re)	8	0.171	**0.003**	**0.001**	**0.012**	0.568	0.104
Res	22						

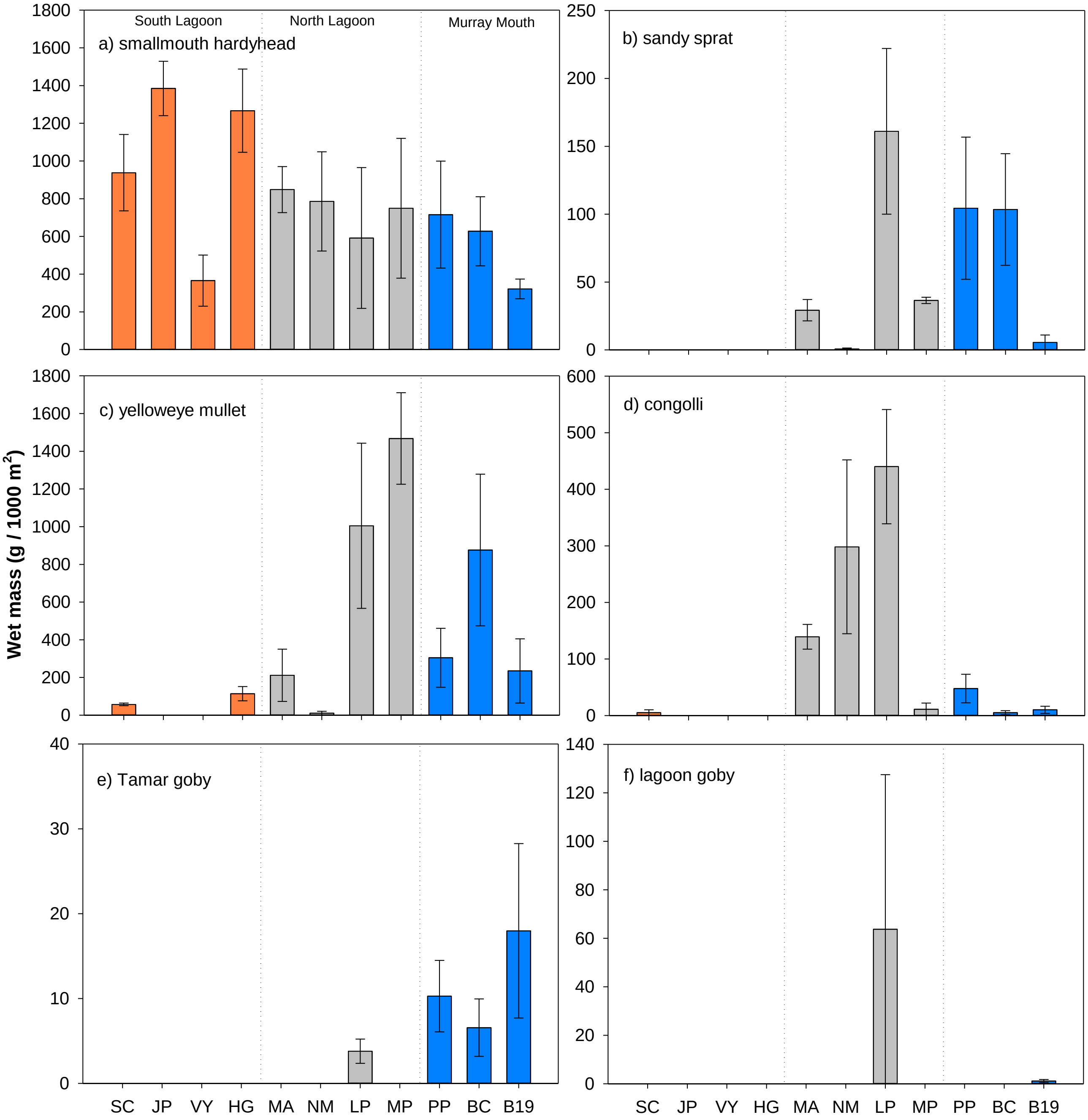

Figure 9. Biomass (as grams wet mass) per 1000 m^2 for key fish species (a–f) collected by standard seine net at different sites across three regions of the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19. Note the different y-axes scales.

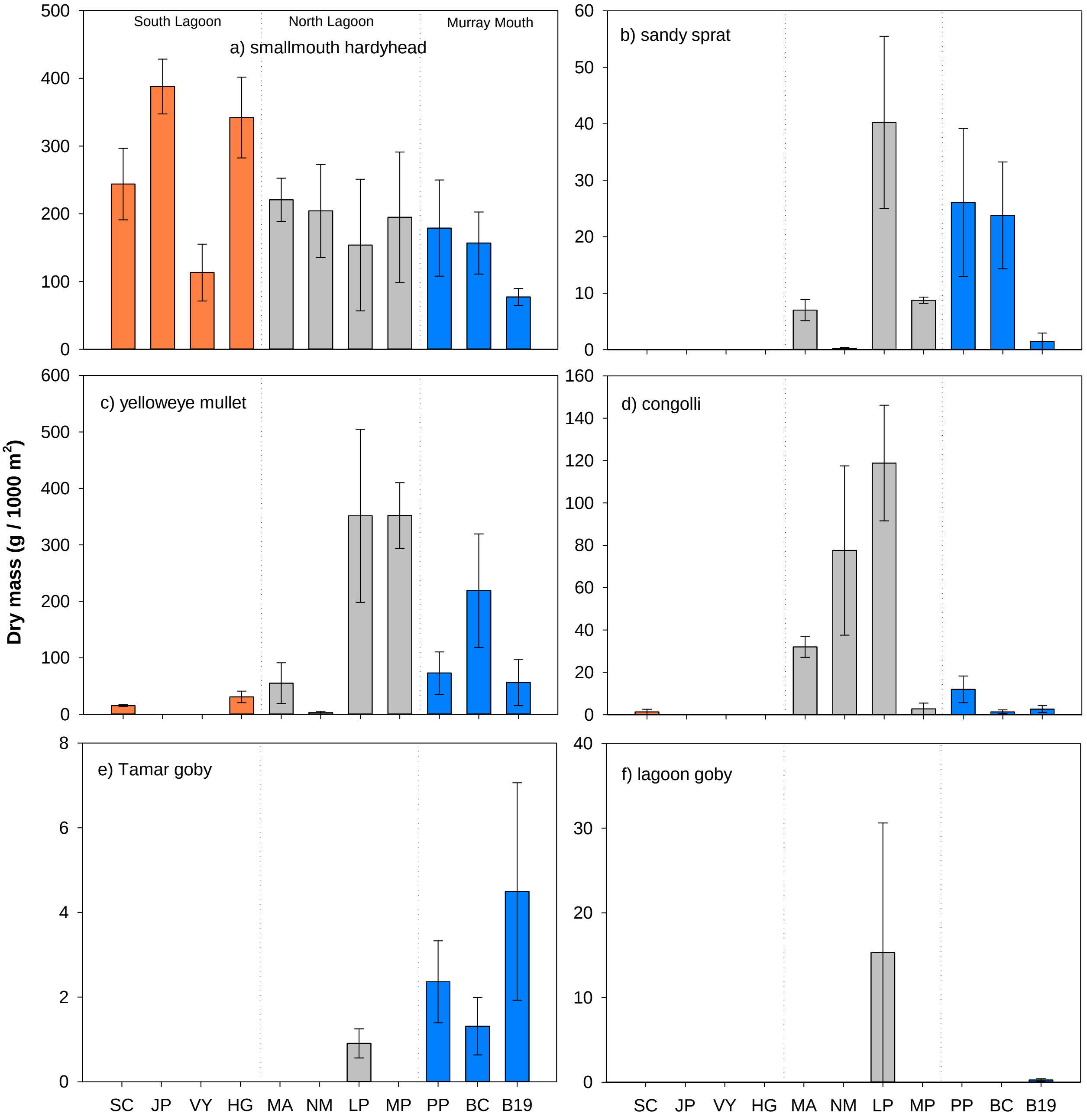

Figure 10. Biomass (as grams dry mass) per 1000 m^2 for key fish species (a–f) collected by standard seine net at different sites across three regions of the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19. Note the different y-axes scales.

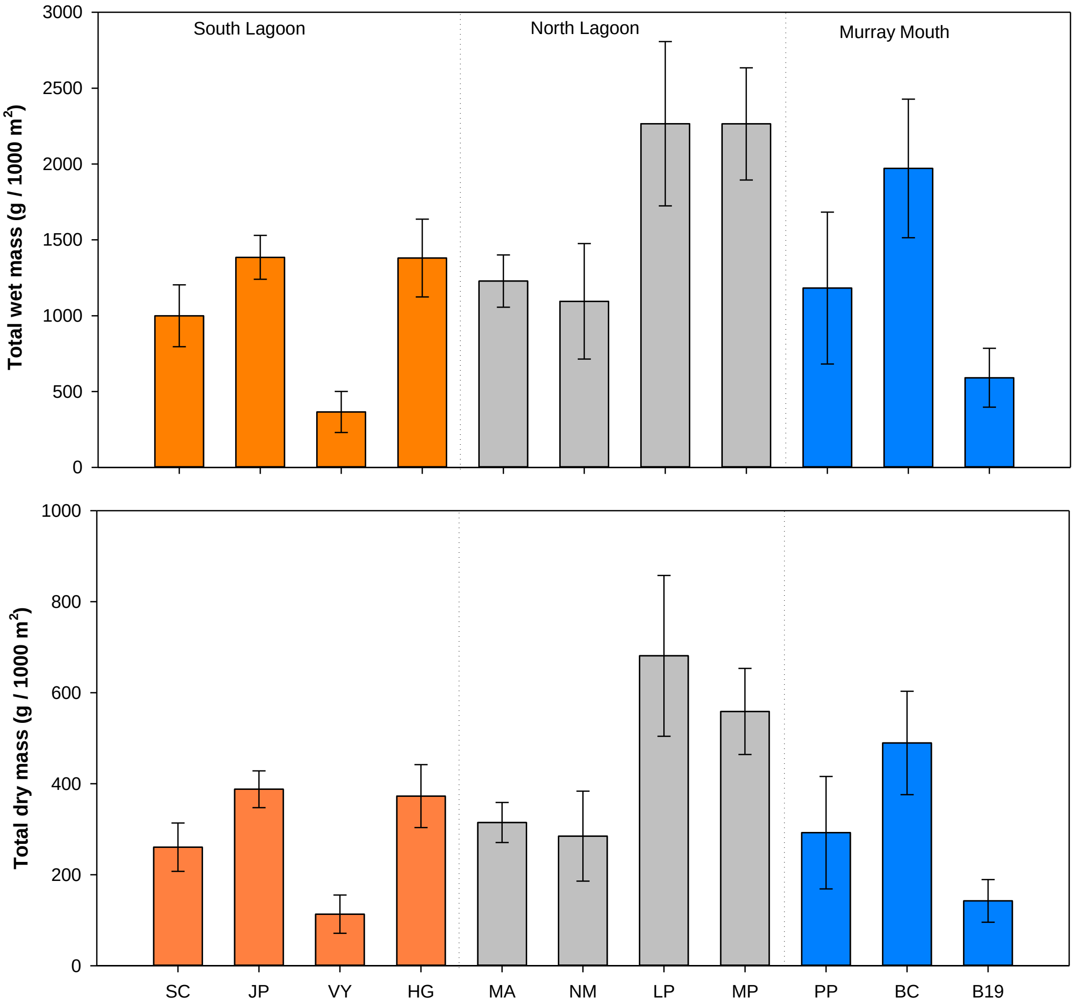

Figure 11. Mean total wet and dry biomass (as grams) (six key fish species combined) per 1000 m^2 by standard seine net at different sites across three regions of the Coorong during March 2019. SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mt Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, GL=Godfrey's Landing, BC=Boundary Creek, B19=Beacon 19. Note the different y-axes scales.

3 Energy content of potential food resources – trial assessments

3.1 Material and methods for bioenergetic studies

The calorific value of macro-invertebrates and fish was determined to obtain energy content (kJ/g mass per species) and energy density (kJ/m^2 or kJ/1000 m^2) values for samples collected in the Coorong. Calorimetry is a standard process for determining the energy content of organic matter, based on the heat production of samples burned in a bomb-calorimeter (Glover et al. 2010; van der Meer et al. 2013). Samples for calorimetric analyses were acquired from the surveys for macro-invertebrates and fish (see Section 2), and frozen in the field and stored frozen until further processing. Freezing samples for calorimetry reduces the risk of underestimating energy density from dissolving of lipids in ethanol (Bertoli et al. 2018).

Frozen samples for macro-invertebrates were thawed just before sorting. All specimens were identified to species level and their individual abundance recorded. Specimens of each species per replicate sample were weighed for wet mass (e.g. to within 0.0001 g) after blotting dry for one minute to remove excess moisture (Bertoli et al. 2018). Shore crabs were thawed and measured for carapace width (to within 1 mm) and weighed (to within 0.01 g). Carapace muscle tissue was removed from each individual and pooled within sites.

Frozen fish samples were thawed in the laboratory and each individual was measured for TL (to within 1 mm) and wet mass (to within 0.01 g). A representative set of each key species of fish were further processed for calorimetry. Sample preparation occurred using both traditional and subsample methods (Glover et al. 2010). Dorsal muscle tissue was removed from larger individuals (>~150 mm), whilst body (head and alimentary tract removed) or fillets were removed for analysis for smaller (<~150 mm) individuals. For very small-bodied fish, the whole fish was used. Tissue was pooled within sites to produce a collective wet mass sample of ~5.5 g where possible. Preliminary analyses showed no difference in calorific values for fish with skin and bone compared to fish flesh only, thus skin and bones were not separated for small and medium sized fish.

All samples were dried in an oven at 60˚C for up to 136 h, or until constant weight was recorded, and then stored in a desiccator. Dry mass was weighed on a micro balance (to 0.0001 g). In preparation for calorimetric analyses, each sample of dried material (fish or macro-invertebrate) was ground to a powder consistency using mortar and pestle and then sealed in a plastic vial until processing in a bomb-calorimeter.

The calorimeter required a minimum of 0.5 g dry mass per sample in a homogenous layer for efficient burn. This could not be achieved for all species, as not enough dry mass could be obtained from the organisms found in the survey in February and March 2019. Where possible, replicate samples per species and site or region were analysed for energy content. In cases were too little dry mass material was available, the dry mass per species was pooled across replicates per site or region to obtain one sample for calorimetry from the region or entire Coorong.

The calorimeter used was a ballistic bomb-calorimeter (Gallenkamp CBB-330-010L). Benzoic acid standard was used for every 10 to 20 samples (Wacasey and Atkinson 1987; McPhee et al 2015). Equation 1 was used for estimating energy content Q as kilo Joules per gram dry mass (kJ/g DM) of invertebrates and fish, based on: the known energy constant for Benzoic acid as a standard (2.6433×10^4 kJ/kg), calorimetric temperature range during the organic sample burn process and, the organic sample dry mass.

$$Q\ (\mathrm{kJ/g}) = K * V/M \qquad [1]$$

whereby:

K = (known energy of Benzoic acid standard * mass of Benzoic acid reference) / calorimetric burn temperature change for the reference standard;
V = calorimetric burn temperature change of sample; and
M = Dry mass of organic sample (g).

Problems were encountered with compacting small bivalves (*A. helmsi*) and gastropods (hydrobiid snails), leading to failures in the burn. Energy content determinations could thus not be accomplished for all species. Samples of dry mass were kept, and analyses can be carried out once the new model of calorimeter with a semi-micro oxygen combustion vessel capable of analysing samples in a range from 25 to 200 mg is operational.

For macro-invertebrates, energy contents are mostly presented as Joule (kJ) per dry mass (DM), shell-free dry mass or ash-free dry mass (Brey et al. 1988; van der Meer et al. 2013). For fish, energy content is converted from kJ/g DM to a wet mass (WM) base by multiplying the energy content with the proportion of dry to wet mass from the sample (Glover et al. 2010). This step is taken for bioenergetic models as piscivorous predators are feeding on fish in a wet form (Johnson et al. 2017).

We were able to determine the energy content for six taxa of macro-invertebrate and fish each, and across several regions, with a total of 93 calorimetric analyses run (Table 8). To obtain estimates of the energy density per region at the time of the surveys in February/March 2019, the energy content (kJ/DM) was multiplied with the mean dry mass per m^2 for macro-invertebrates. For fish, the energy density was estimated by multiplying the energy content (kJ/WM) with the mean WM of the species per 1000 m^2 by standard seine net for each region.

Table 8: Overview of the number of taxa/species for macro-invertebrates and fish for which calorimetric analyses were carried out in this study, the Coorong regions from which enough material for energy contents were obtained and the total number of samples analysed by calorimetry during 2019. MM= Murray Mouth, NL=North Lagoon, SL=South Lagoon. In some cases material from several sites per region was used.

	NUMBER OF TAXA ANALYSED	REGIONS COVERED	SAMPLES ANALYSED FOR CALORIMETRY
Macro-invertebrates	6	MM, NL	16
Fish	6	MM, NL, SL	77

3.2 Energy content of potential food resources

3.2.1 MACRO-INVERTEBRATE ENERGY CONTENT

For macro-invertebrates, the energy content measured ranged from about 5 to 19 kJ/g DM (Table 9). The energy content could be determined for several taxa and species across the main representative taxonomic groups of macro-invertebrates in estuarine sediments. Variation in energy contents across some of the regions appeared low, but the data are currently based on a small sample size and for one season. Comparisons within and across regions cannot yet be made as not enough dry material could be obtained for the calorimetric analyses with replicates for each region. For the South Lagoon, the low individual density of macro-invertebrates did not yield enough material for calorimetric analyses.

The energy density for macro-invertebrates across the three regions revealed that the availability of energy for higher trophic levels decreases from the Murray Mouth and North Lagoon into the South Lagoon (Figure 12). It also emerged that the energy density can be very patchy, between and within sites, especially for the highly mobile crabs (*P. gaimardii*), and the larger bivalves dwelling in the sediments (*S. trigonella*, *S. alba*).

Shore crabs (*P. gaimardii*) were also caught in seine netting for fish from sites in the Murray Mouth and North Lagoon, and based on the dry mass from those catches, the energy density for this crab was estimated as 22.26 kJ/1000 m^2 for the North Lagoon, and 7.88 kJ/1000 m^2 for the Murray Mouth.

Table 9: Calorimetric energy content (kilo Joule (kJ) per gram dry mass (DM)) for macro-invertebrates in the Coorong in February/March 2019. Values are presented for species for whom enough dry mass material could be obtained for calorimetry, and where replicates could be analysed as mean with standard error (SE). Values in italics are single measurements. Not enough material was available from macro-invertebrates in the South Lagoon.

TAXA		ENERGY CONTENT (kJ/g DM)								
		NORTH LAGOON			MURRAY MOUTH			ALL REGIONS		
		MEAN	±	SE	MEAN	±	SE	MEAN	±	SE
Amphipoda	Crustacea							18.00	±	0.14
Simplisetia aequisetis	Polychaeta	17.48	±	0.23	19.27	±	4.08	18.55	±	2.28
Paragrapsus gaimardii	Crustacea	*15.67*			*10.95*			13.33	±	1.37
Spisula trigonella	Bivalvia	14.83	±	1.63				14.83	±	1.63
Soletellina alba	Bivalvia							*11.46*		
Salinator fragilis	Gastropoda	*4.97*			*4.96*			4.96	±	0.004

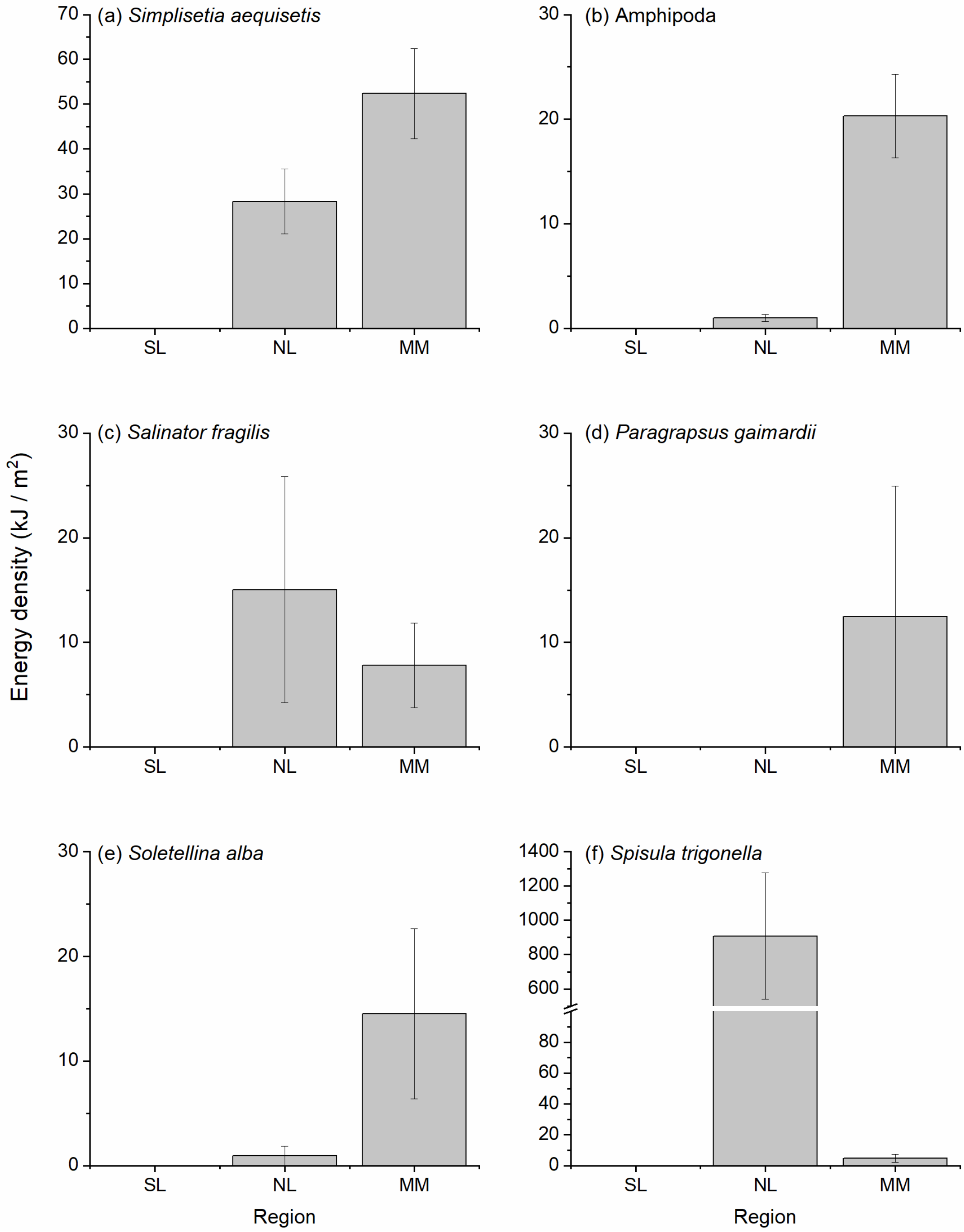

Figure 12. Energy density (mean ± SE) in kilo Joule (kJ) per m^2 of several macro-invertebrate species in the three regions of the Coorong (SL=South Lagoon, NL=North Lagoon, MM=Murray Mouth) in February/March 2019. Calorimetric analyses and dry mass data were from all samples in each region.

3.2.2 FISH ENERGY CONTENT

For fish, the mean energy content measured per region ranged from about 15 to 23 kJ/g DM, which equated to an estimated range of 3.60 to 5.99 kJ/g WM, although most samples had an energy content of 4.5 to 6 kJ/g WM (Table 10; Appendix C1). For individual species, variation in energy contents within and across regions appeared low. Similarly, energy content was generally similar across species, but results need to be viewed with caution as not enough dry material could be obtained for the calorimetric analyses with replicates of some species (e.g. sandy sprat, Tamar goby and Lagoon goby) for each region.

Table 10: Regional values for calorimetric energy content (kilo Joule (kJ) per gram wet mass (WM)) for fish in the Coorong, where sample material was available from several sites per region during March 2019. The mean ± standard error (SE) are presented per region. Values without SE are based on single measurements from the region. *insufficient biomass for analysis. Refer to Appendix C for site-specific values.

SPECIES	ENERGY CONTENT (kJ/g WM)								
	SOUTH LAGOON			NORTH LAGOON			MURRAY MOUTH		
	MEAN	±	SE	MEAN	±	SE	MEAN	±	SE
Smallmouth hardyhead	5.73	±	0.22	5.21	±	0.16	4.87	±	0.18
Yelloweye mullet	5.99	±	0.25	5.64	±	0.55	5.53	±	0.14
Congolli	4.78			5.23	±	0.32	5.68	±	0.08
Sandy Sprat				4.90	±	0.004	4.50		
Tamar goby				3.60			4.47	±	0.26
Lagoon goby				4.34			*		

The energy density for fish across the three regions reveals that higher trophic levels can obtain energy from fish throughout the Coorong. Based on the energy density of the six investigated key species in each region, the total energy density was highest in the North Lagoon (>9100 kJ/1000 m^2) compared to ca 6400 kJ/1000 m^2 in the Murray Mouth and nearly 6000 kJ/1000 m^2 in the South Lagoon. All key fish species were available to higher trophic levels in the Murray Mouth and North Lagoon and contributed to the energy density in these regions (Figure 13). In the South Lagoon, energy was only available for piscivorous predators through three species (smallmouth hardyhead, yelloweye mullet and congolli) and the energy density here was almost exclusively accounted for by smallmouth hardyhead (Figure 13). Non-key species that were caught during fish sampling have not been presented in these graphs. These species are usually most abundant in the Murray Mouth and North Lagoon regions (Appendix B3).

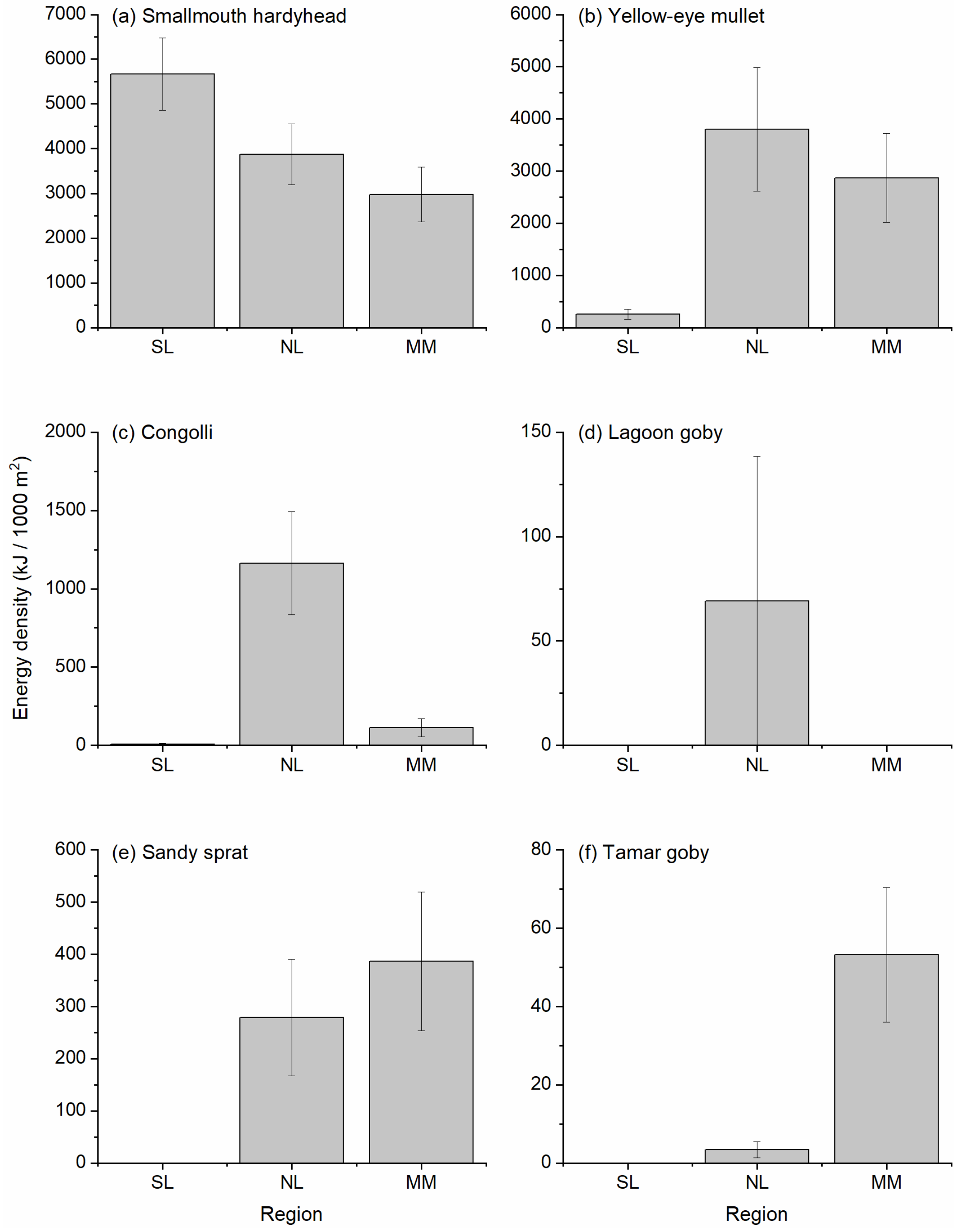

Figure 13. Energy density (mean ± SE) in kilo Joule (kJ) per 1000 m^2 of key fish species in the three regions of the Coorong (SL=South Lagoon, NL=North Lagoon, MM=Murray Mouth) in March 2019. Calorimetric analyses and wet mass data were from all sites of seine net catches in each region. Lagoon goby was present in the MM but had insufficient biomass for energetic analysis.

4 Discussion

4.1 State of potential food resources in late summer 2019

The assessment of abundance and diversity of potential food resources for waterbird and fish in the Coorong in late summer 2019 (Objective 1) revealed clear regional differences. The species diversity generally declined from the north to south in the Coorong. This pattern was consistent with the findings from previous studies in this region, which showed that in the South Lagoon, the food web was simple and consisted of very few species per trophic level. In the North Lagoon and Murray Mouth, the food web was more complex with multiple species per trophic level and representatives of several trophic levels present (Deegan et al. 2010; Brookes et al. 2015; Giatas and Ye 2016). The more complex food webs in the northern reaches of the Coorong are deemed to be more resilient than the South Lagoon, where no ‘fall-back’ options exist. However, abundant saline communities could also be important for supporting individual species (Paton et al. 2018). To inform South Lagoon restoration, this study was conducted along a broad salinity gradient of the Coorong so that relationships between salinity and food resources could be explored. Given the potential for inflows from the South East, the southern part of the South Lagoon may experience fresher conditions in the future (similar salinities as in the estuary near Murray Mouth and North Lagoon).

Shorebirds feed mostly on benthic macro-invertebrates in tidal flats, but are not very selective in their prey choice, taking prey items which are available and harvestable for them (Dann 2000; Rogers et al. 2007; Spruzen et al. 2008). Yet, Spruzen et al. (2008) found a positive correlation between macro-invertebrate diversity and biomass and shorebird feeding density. Most of the common fish in the Coorong also have a diverse range of prey items in their diet (Giatas et al. 2018), which can be more restrictive during drought (Lamontagne et al. 2016). During this study, the diversity of macro-invertebrate prey available to shorebirds and fish predators was low in the South Lagoon, compared to the Murray Mouth. Shorebirds could access a higher biomass of macro-invertebrates in mudflats on both the shore and peninsula sides of the channel at Long Point and in the Murray Mouth. We found that the diversity, abundance and biomass of potential prey also varied across the locations at several sites, with higher macro-invertebrate abundance in sediments of the channel and on the peninsula side than in mudflats along the mainland shore, where TLM monitoring was carried out (DEWNR 2017; Dittmann et al. 2017). The spatial sampling design applied in this investigation thus gave a higher resolution for the assessment of food availability throughout the Coorong.

The pattern of macro-invertebrate abundance, distribution and biomass indicated a spatial gradient along the lengths of the Coorong, with a change near Noonameena. At the time of the survey after a very hot and dry summer 2019, the South Lagoon offered very few macro-invertebrates as potential food for shorebirds and fish. The biomass of macro-invertebrates found during this survey ranged from 0 to 363 g DM per m^2, which was a comparable range of biomass as found by Rogers et al. (2007) for mudflats in Port Phillip Bay (range 0.6 to 248, with one outlier of 1138 g DM per m^2), but in the South Lagoon, the mean biomass was only 0.5 g DM per m^2. The decline in macro-invertebrate diversity, abundance and biomass along this gradient can be explained by a salinity threshold of 64 ppt (Dittmann et al. 2015). Above this threshold, which is exceeded from the southern end of the North Lagoon and throughout the South Lagoon, very few macro-invertebrates exist who can tolerate the extreme hypersalinity. The hypersalinity in the South Lagoon is thus affecting the prey availability, similar to other hypersaline systems (Breaux et al. 2019; Tweedley et al. 2019). Chironomid larvae are some of the few macro-invertebrates tolerant to higher salinities and can vary in abundance with seasons and along salinity gradients (Geddes and Butler 1984; Geddes 2005; Dimitriadis and Cranston 2007). Chironomid larvae are prey for shorebirds (Sanchez et al. 2006; Pedro and Ramos 2009), but as their abundance was lower in early summer (TLM macro-invertebrate monitoring, Dittmann et al. 2019) than in late summer/early autumn (this study), prey depletion by migratory shorebirds was unlikely.

Fish diversity generally declined from Murray Mouth toward South Lagoon, with only three species in the South Lagoon (i.e. smallmouth hardyhead, yelloweye mullet and congolli). These three species are capable of tolerating high salinities, with 50% lethal concentrations of ~80–106 ppt (McNeil et al. 2013). Smallmouth hardyhead was the most abundant species and represented the major biomass of potential food resources for piscivorous waterbirds in the South Lagoon. The high biomass of smallmouth hardyhead could be supported by a range of prey items including ostracods, copepods and insect larvae (e.g. chironomid larvae) (Hossain et al. 2017) although zooplankton were not quantitatively assessed in this study. In the North Lagoon, fish biomass (key species combined) was the greatest, which, in addition to the greater species diversity, suggesting greater food availability in the North Lagoon for piscivorous birds and fish. The Murray Mouth region was also potentially an important foraging ground due to much higher prey diversity and slightly higher biomass density compared to the South Lagoon. Furthermore, the majority of the four small-bodied species collected across the regions were <60 mm TL and, therefore, provided potential prey for small piscivorous birds in the Coorong (e.g. fairy tern, O'Connor and Rogers 2013). As previously noted, the biomass for North Lagoon and Murray Mouth in this study are probably underestimated due to sampling bias toward small-bodied fish and small individuals of mid- to large-bodied fish, and the selection of key species based on their likely occurrence in the South Lagoon. This reflects the overarching aim of the urgent ecological investigations with a focus on gaining knowledge to inform the restoration of the South Lagoon and a productive, resilient and functioning food web in the Coorong.

Comparing the fish catch during March 2019 with previous years in the Coorong (Appendix B3), the total abundance of small-bodied fish in this year was about a third of the peak abundance in March 2014 and slightly below the mean over the last nine years, suggesting the regional abundance of potential prey was currently below average level for the period of 2011–2019. Overall, the presence and abundance of fish species has been highly variable along the salinity gradient of the Coorong and between years since 2007, with the River Murray flow and salinity being a strong influencing factor (Zampatti et al. 2010; Ye et al. 2016). Freshwater inflows into estuaries facilitate a variety of processes, but most importantly for fishes, flow influences salinity regime, habitat connectivity and productivity (Ye et al. 2016). Salinity is a primary environmental driver of biotic patterns and processes in estuaries (Geddes and Butler 1984; Kennish 1990); it influences fish distribution, with fish inhabiting areas that have salinities within species-specific preference or tolerance ranges (Potter and Hyndes 1994; McNeil et al. 2013). Estuarine salinity regimes may also influence fish abundance through their effect on reproduction. For example, sperm, eggs and larvae often have specific salinity tolerances (e.g. for black bream, *Acanthopagrus butcheri*, see Newton 1996; Haddy and Pankhurst 2000). In addition, connectivity is critical for the recruitment of diadromous species (e.g. congolli) given their critical life-history attributes (i.e. migration between freshwater, estuarine and marine environments). River inflows also enhance productivity in estuaries, providing additional food resources to fish populations (Bice et al. 2016). Studies in the Coorong show that fish species richness and abundance generally decrease during drought (e.g. 2001–2010) (Noell et al. 2009; Zampatti et al. 2010) but increase following high flows (e.g. 1983/84, 2010/11, 2011/12) (Geddes 1987; Ye et al. 2012). Over the past years, smallmouth hardyhead has been the most abundant fish species except for 2007, when no fish were caught in the South Lagoon due to extremely high salinities >150 PSU after a protracted drought period (Ye et al. 2015a). Sandy sprat was generally the second most abundant fish species, although their distribution was usually restricted to the Murray Mouth and North Lagoon except during years post flood/high flows (e.g. 2012, 2013), when substantial numbers entered the South Lagoon. These two small-bodied fish species are important prey for piscivorous fish and waterbirds in the Coorong.

4.2 Energy contents of potential prey items

For shorebirds, the harvestable prey is not only affected by prey availability, but also the profitability, which considers energy intake per unit handling time (Zwarts and Wanink 1993; Dann 2000). Energy contents of prey items are integral to bioenergetic models (Bertoli et al 2018), informing on food profitability (Tableau et al. 2015, 2016) and assessments of favourable foraging areas (Grond et al. 2015). By comparing the available energy in wetlands with the energy requirements of shorebirds and waterbirds, Brand et al. (2014) could demonstrate that wetland restoration, in particular through lowering of salinity levels, increased the carrying capacity for the birds. Their study also revealed seasonal variation in energy requirements and as the energy density of macro-invertebrate prey can also vary with season (Zwarts and Wanink 1993), shorebirds have been found to switch to high-energy diet during their pre-migration period (Zharikov and Skilleter 2004). Assessing the total available energy that a wetland like the Coorong could supply to support waterbird and migratory shorebird populations is thus possible, following the example of Brand et al. (2014).

To inform future investigations, we trialled assessing the energy content of potential prey items (i.e. macro-invertebrate and fish) (Objective 2). The trial not only tested the method, but yielded data which showed that the energy contents of macro-invertebrates and fish from the Coorong were mostly comparable to literature values for related species.

For macro-invertebrates, the energy contents measured fell within the range of caloric values found in the literature, which are mostly derived from northern Europe (Appendix C2). The energy content we determined for amphipods (mean 18.00 kJ/g DM) was higher than for amphipod species reported in the literature (~15–16 kJ/g DM; Appendix C2). For bivalves and gastropods, our mean values (11.46–14.83 and 4.96 kJ/g DM, respectively) were generally lower than for related species elsewhere (Appendix C2). Energy values can vary with the size and sex of macro-invertebrates and across seasons (Rumohr et al. 1987; Bertoli et al. 2018). For chironomid larvae, Bertoli et al. (2018) detected significant seasonal differences in energy content over consecutive years, although the range of values was low (14.86-15.98 kJ/g DM, Appendix C2). We were not yet able to determine the energy content of several potential prey items, such as chironomid larvae or the bivalve *A. helmsi*. The energy content we determined for the snail *S. fragilis* was lower than literature values for related species (Appendix C2), which could possibly arise from their food availability. The diet of pulmonate snails includes organic matter, detritus and microphytbenthos (Saintilan and Mazumder 2010; Giatas and Ye 2015; Peng et al. 2017). Variation in energy content of potential prey over space and time thus needs to be further determined for the Coorong, where changes in environmental conditions can be extreme across the year.

The measured energy contents for fish in this study fell within the range of energy content for the same or related species in the literature (Appendix C3), where values usually are between 4 and 7 kJ/g WM (Lawson et al. 2018; McCluskey et al. 2016). For yelloweye mullet, our measurements (mean 5.77 kJ/g WM) were slightly higher than a published value from Western Australia (4.58 kJ/g WM; Appendix C3). Site and seasonal differences could contribute to such differences, as found for energy contents of estuarine fish in Western Australia (McCluskey et al. 2016). Furthermore, the energy density of total fish at their estuarine study site was found to be between 20,000 to >40,000 kJ per seine net. These higher values were not comparable to what we obtained in this study for the Coorong given our focus was on selected small and medium sized fish, and biomass and energy of other species and large-bodied fish were not included in our estimates.

For estuarine fish, Schloesser and Fabrizio (2015) found that calculated values for energy content from proximate components, such as proteins or lipid contents, can overestimate the measured energy content than from bomb-calorimetry. Using values of energy content from published literature from the same or related species can also result in over- or underestimation of consumption in bioenergetic models, compared to actual measurements from bomb-calorimetry (Johnson et al. 2017). It is therefore necessary for us to continue measurements of key fish species over space and time for developing a quantitative bioenergetic model of the Coorong.

In this study, for macro-invertebrates, energy contents appeared to vary among different taxa/species tested, although no distinct differences were observed across regions except for *P. gaimardii*. For fish, variation in energy contents appeared low across regions for each species and across all species tested. However, results need to be viewed with caution as not enough dry material could be obtained for the calorimetric analyses of some taxa. Furthermore, energy contents of prey items could vary spatially and temporally, likely influenced by environmental and species/individual conditions (Rumohr et al. 1987; McCluskey et al. 2016; Bertoli et al. 2018). Therefore, further study will be required in the Coorong.

As both macro-invertebrates and fish distributions are affected by salinity, the energy density determined so far for a subset of species (see Section 3) indicates that the North Lagoon has a higher energy density than adjacent regions (Figure 14). For fish, the greater energy density in the North Lagoon compared to South Lagoon was mainly attributed to the greater abundance and diversity of mid- to large-bodied fish given most of the estuarine species are euryhaline and able to tolerate the wide range of salinity in the North Lagoon (30–60 ppt) observed during this study, whereas most of the South Lagoon had salinities >92 ppt which were not favourable for most species. The energy density of fish in the Murray Mouth region is probably underestimated due to the focus of this study, with the energy density of larger bodied fish present in the Murray Mouth and North Lagoon not included. For macro-invertebrates, the energy density presented is based on a subset of key species for which energy content could be determined (*S. aequisetis*, amphipods, *S.*

fragilis, *P. gaimardii, S. alba* and *S. trigonella*) but the spatial trend will reflect the gradient of their overall abundance and biomass distribution with salinity, restricting macro-invertebrate prey availability and energy density to regions of the Coorong with salinities <64 ppt. Patchiness in the distribution further effects the pattern, as apparent from the high biomass and energy density at Long Point from the bivalve *S. trigonella*. However, this study provides a preliminary assessment only based on a subset of species for which the caloric content was determined.

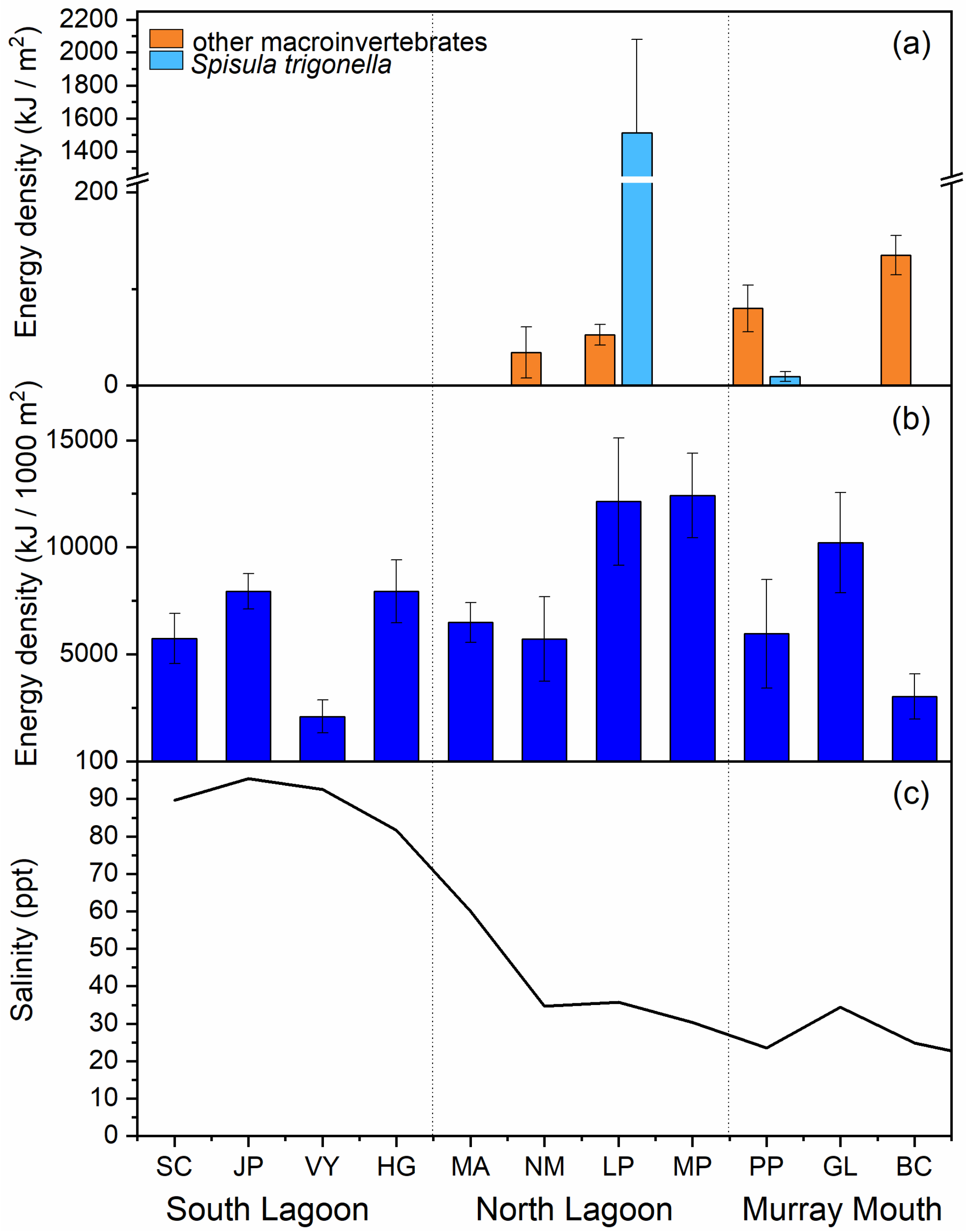

Figure 14. Energy density from the macro-invertebrates (a) and fish (key species) (b) analysed in this study from the three regions of the Coorong, and the salinity gradient (c) across the regions from summer/late autumn 2019. For macro-invertebrates, the high energy density from the bivalve *Spisula trigonella* is presented separately to 'other macro-invertebrates'. Fish include only small and medium sized bodied fish. See text for further detail.

4.3 Conclusion and outlook

This study assessed the current state of potential food resources (macro-invertebrates and fish) for waterbird and fish populations during late summer 2019 in the Coorong. It has taken an important step forward in Coorong studies by using biomass and energy, as the measure of food abundance and quality. The study also provided the first data on the energy content of key prey items in the Coorong, which is essential to inform future bioenergetic models. Although caloric values obtained were generally comparable to the literature values for related species, the emerging differences indicate the need for further investigation including understanding how the energy content and density available in the food web varies across the length of the Coorong and over time. Seasonal patterns of abundance and energy content in fish prey are not necessarily aligned, for example, McCluskey et al. (2016) found higher prey abundance in summer, but higher energy rich prey in winter. Seasonal patterns in energy consumption by waterbirds and interannual variation in predation by piscivorous birds were reported in estuaries of South Africa (Cowley et al. 2017; Hean et al. 2017). For the Coorong, seasonal variability in provision of energy could affect overwintering shorebirds who need to obtain sufficient energy over the southern summer for their return migration. Additionally, energy content of further food items need to be determined for shorebirds and piscivorous fish, as well as for some prey fish, such as ostracods and planktonic prey for smallmouth hardyhead (Geddes and Frances 2008; Silvester 2011; Hossain et al. 2017). Further investigations will also need to consider effects of the macroalgal mats in the Coorong on prey availability, foraging behaviour and trophic structure (Green et al 2015; Green and Fong 2016; Le Luherne et al. 2016).

Ensuring a sampling regime that can accurately estimate total biomass within the system, as well as turnover and energy, is critical to understand bioenergetics and inform quantitative food web modelling. For this, additional studies are required to determine intake and consumption rates of Coorong biota (e.g. waterbirds) to link the energy demand with the energy provision of the ecosystem (Brand et al. 2014; Lawson et al. 2018). Most predators in estuarine systems can switch between prey items (McPhee et al. 2015), and many of the fish and waterbirds in the Coorong have a more generalised diet (Appendix A; Brookes et al. 2015; Giatas et al. 2018). Together with information on changing presence and abundance of prey items subject to environmental conditions, such information will allow the development of quantitative food web and bioenergetic models which can test effects of various river flow, nutrient and salinity scenarios to inform adaptive management of the Coorong ecosystem and the restoration of ecological character of the South Lagoon.

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Appendix A - Literature review of the key food sources for waterbirds and fish

Previous food web investigations of the Coorong have provided a preliminary and/or qualitative understanding of the Coorong food web and the relationships between hydrology, key food sources and some fish and waterbird species (e.g. Lamontagne et al. 2007; Geddes and Francis 2008; Deegan et al. 2010; Giatas and Ye 2016). Investigations have often focused on the food resources for specific biota (e.g. fish) and have generally been limited in the spatial (e.g. Murray Mouth and North Lagoon) and temporal scale (i.e. warmer months). Most diet investigations in the South Lagoon have focussed on feeding behaviour of birds (e.g. Rogers and Paton 2009).

A summary of the diet literature available from the Coorong is provided in Appendix A1. Smallmouth hardyhead is the only fish species that has been assessed for diet in the South Lagoon of the Coorong (Hossain et al. 2017), although yelloweye mullet diet was reported (Giatas 2012) for two individuals at Hells Gate, at the northern end of the South Lagoon. From November 2013 to March 2014, the diet of smallmouth hardyhead was investigated at two sites (Jack Point and Salt Creek) in the South Lagoon (Hossain et al. 2017). Ostracods were the most numerically abundant prey consumed, followed by harpacticoid copepods and chironomid larvae and pupae. However, the result was probably reflective of prey items of this species in 2013-14 under the environmental conditions following several high flow years (2010–2013). A number of other fish species (e.g. congolli, yelloweye mullet, black bream) occur in the South Lagoon (Ye et al. 2015b), particularly seasonally during lower salinities, and influence the food web. The diets and food preferences of these species in this region are unknown.

Bird feeding behaviour has been observed in the South Lagoon by D. Paton and colleagues (Paton et al. 2018). From March 1965 to January 1966, the diets of grey teal (*Anas gracilis*), chestnut teal (*Anas castanea*) and Australian shelduck (*Tadorna tadornoides*) from the South Lagoon were quantitatively assessed through gut-content analysis (Delroy 1974). Wigeongrass (*Ruppia spiralis*), muskgrass tubers (*Lamprothamnium papulosum*) and seed contributed to most (>90 %) of the diet of each species. Whilst sampled in the South Lagoon, it is important to note that these individuals may have foraged in other locations.

Appendix A1. Quantitative gut-content or scat analyses conducted for abundant species of fish, mammals and birds in the Coorong by region. Note: bird diet has mostly been inferred from feeding observations (Paton et al. 2018). Species have been allocated into feeding mode functional groups (FM) based on all available dietary literature (for juveniles and adults): ZP = zooplanktivore, DV = detritivore, HV-o = obligate herbivore, HV-f = facultative herbivore, OV = omnivore, PV = piscivore, IV-o = obligate invertivore, IV-f = facultative invertivore (adapted from Elliott et al. 2007). LL=Lower Lakes, MM=Murray Mouth, NL= North Lagoon, SL=South Lagoon. Literature in reference list of this report.

SPECIES	FM	MAIM DIET ITEMS	SOURCE	REGION			
				LL	MM	NL	SL
FISH							
Marine							
Mulloway (*Argyrosomus japonicus*)	PV	Atherinids, gobies, mugilids, sandy sprat, bony herring, congolli, crabs, mysid shrimp, palaemonid shrimp, amphipods.	Hall 1986			X	
			Geddes and Francis 2008			X	
			Deegan et al. 2010		X		
			Giatas and Ye 2015		X	X	
Yelloweye mullet (*Aldrichetta forsteri*)	OV	Polychaetes, amphipods, copepods, mysid shrimp, palaemonid shrimp, crabs, bivalves, detritus, filamentous algae.	Geddes and Francis 2008			X	
			Deegan et al. 2010		X	X	
			Giatas 2012		X	X	X
Greenback flounder (*Rhombosolea tapirina*)	IV-f	Amphipods, polychaetes, copepods, mysid shrimp, bivalve siphons, insect larvae.	Deegan et al. 2010		X		
			Earl 2014		X	X	
Australian salmon (*Arripis trutta* and *A. truttaceus*)	PV	Sandy sprat, smallmouth hardyhead, gobies, copepods, amphipods, mysid shrimp.	Giatas and Ye 2015		X		
Sandy sprat (*Hyperlophus vittatus*)	ZP	Copepods and nauplii, cladocerans, amphipods, ostracods, crab zoea, mysid shrimp, rotifers.	Bice et al. 2016		X		
			Hossain et al. 2017		X	X	
Estuarine							
Black bream (*Acanthopagrus butcheri*)	OV	Crabs, gobies, bivalves, polychaetes, filamentous algae.	Weng 1970				
			Deegan et al. 2010				
Smallmouthed hardyhead (*Atherinosoma microstoma*)	IV-o	Amphipods, polychaetes, copepods, insect larvae, mysid shrimp, ostracods.	Geddes and Francis 2008			X	
			Deegan et al. 2010		X	X	
			Silvester 2011	X	X		
			Hossain et al. 2017		X	X	X
Tamar goby (*Afurcagobius tamarensis*)	IV-f	Amphipods, polychaetes, copepods, ostracods, mysid shrimp, teleosts.	Geddes and Francis 2008			X	
			Silvester 2011	X	X		
			Hossain et al. 2017		X	X	
Catadromous							
Congolli (*Pseudaphritis urvillii*)	IV-f	Amphipods, polychaetes, mysid shrimp.	Deegan et al. 2010				
			Johnson 2014/Giatas and Ye 2015	X	X	X	
Freshwater							
Bony herring (*Nematolosa erebi*)	HV-f/DV	Detritus, filamentous algae, copepods, cladocerans and ostracods.	Atkins 1984	X			
Common carp (*Cyprinus carpio*)	DV/OV	Filamentous algae, amphipods, chironomid larvae, gastropods, cladocerans and copepods.	Hall 1981	X			
MAMMALS							
Long-nosed fur seal (*Arctocephalus forsteri*)	PV	Common carp, bony herring, gobies, mulloway and golden perch.	Goldsworthy et al. 2019		*N/A		
BIRDS							
Grey teal (*Anas gracilis*)	HV-f	*Ruppia* and *Lamprothamnium* tubers and seeds.	Delroy 1974				X
Chestnut teal (*Anas castanea*)	HV-f	*Ruppia* and *Lamprothamnium* tubers and seeds.	Delroy 1974				X
Australian shelduck (*Tadorna tadornoides*)	HV-f	*Ruppia* and *Lamprothamnium* tubers and seeds.	Delroy 1974				X

* scats and regurgitates collected from barrages separating MM and LL.

Appendix B - Additional information for sampling in the Coorong during 2019

Appendix B1. Fish sampling sites in the Coorong during March 2019.

SITE	LATITUDE (°S)	LONGITUDE (°E)	DISTANCE FROM MOUTH (KM)
Murray Mouth			
Beacon 19	35.534	138.832	6.5
Boundary Creek	35.564	138.923	3.5
Godfrey's Landing	35.568	138.932	4.4
Pelican Point	35.595	139.014	12.8
North Lagoon			
Mark Point	35.638	139.076	20.3
Long Point	35.693	139.166	31.5
Noonameena	35.757	139.232	40.2
Mt Anderson	35.811	139.293	48.1
South Lagoon			
Hells Gate	35.903	139.398	62.9
Villa de Yumpa	35.914	139.463	70.2
Jack Point	36.042	139.576	85.8
Salt Creek	36.132	139.638	98.4

Appendix B2. Plankton sampling in the Coorong during February/March 2019 and processing trials.

Further samples were taken in February and March 2019 to trial the processing of plankton and meiofauna for bioenergetic analyses.

Plankton sampling occurred together with the macro-invertebrate sampling, in the centre of the channel. Plankton samples were taken with plankton nets of two different mesh sizes (63 µm and 125 µm mesh cod ends; *n* = 4 per mesh size, per site) across 1-minute tows through the water column. At Beacon 19 (first site sampled), tows were made for 10 minutes, but the nets clogged up, leading to a reduction in the lengths of the tows. Boat speed for plankton tows was 1–2 knots, and where the subtidal was accessed by walking into deeper water, plankton tows were done at walking pace. All plankton samples were frozen (-20˚C) in a portable freezer and stored in freezers at Flinders University. Preliminary analyses of these samples at the University of Adelaide showed that no plankton could be identified from the frozen samples. An alternative to freezing has to be found for further processing of plankton samples for bioenergetic studies.

Meiofauna samples were taken at all sites as for macro-invertebrates with a cut-off syringe (10 mL with covering 1.54 cm^2 sediment surface area). In the deeper channel, subsamples for meiofauna were taken out of each of the Ekman grab samples. These samples were frozen as well as was recommended for calorimetry, but separation of meiofauna from sediment is thus difficult and soft-bodied meiofauna lost through freezing.

Appendix B3. Catch summary and species richness of fish collected by seine net from the three regions of the Coorong from March 2007 to March 2019. Regions are Murray Mouth (MM), North Lagoon (NL) and South Lagoon (SL). Total catches for key species during March 2019 are highlighted in red.

				Mar-07				Mar-11				Mar-12				Mar-13				Mar-14
	MM	NL	SL	T	MM	NL	SL	T	MM	NL	SL	T	MM	NL	SL	T	MM	NL	SL	T
Small-bodied species																				
Australian anchovy																	3			3
Australian pilchard																				
Australian smelt					700	321		1,021	146	8		154	47	36		83	5			5
Blue sprat																				
Bluespot goby														1		1		31		31
Bridled goby					8			8	3	2		5	4	18	7	29	201	141		342
Common galaxias					7			7	3			3								
Dwarf flat-headed gudgeon																				
Flat-headed gudgeon					107			107	5			5	5	1		6	1			1
Little weed whiting																	1			1
Red-spotted shore crab																				
Sandy sprat	273	8		75	75			75	4,376	1,926	1,940	8,242	1,435	3,020	580	5,035	72,952	425		73,377
Lagoon goby	2	1		3		4		4	4	29		33	5	69		74	57	221		278
Smallmouth hardyhead	80	1,686		1,766	423	15,560	17,290	33,273	27	1,177	8,954	10,158	370	2,848	14,435	17,653	861	13,975	21,070	35,906
Tamar goby	13	32		45	68			68	10	1		11	22	96		118	176	190		366
Total	**368**	**1,727**	**0**	**2,095**	**1,388**	**15,885**	**17,290**	**34,563**	**4,574**	**3,143**	**10,894**	**18,611**	**1,888**	**6,089**	**15,022**	**22,999**	**74,257**	**14,983**	**21,070**	**110,310**
Mid to large-bodied species																				
Australian herring																				
Barred toadfish																				
Black bream	3			3													1			1
Bony herring					1,589	75		1,664	1,444	41	1	1,486	21	7	1	29	14	2		16
Carp					96			96	7			7								
Congolli		3		3	18	6		24	2	24		26	17	115	29	161	5	328	2	335
Golden perch					9			9												
Goldspot mullet													1			1				
Greenback flounder	6	7		13		3		3	15	14		29	5	49		54	12	8		20
King George whiting																				
Longsnout flounder									6	6				12		12	3			3
Prickly toadfish										1		1	45	1		46				
Redfin perch					191	1		192	8			8								
River garfish	23	13		36	58	1		59	3	29	1	33	34	9		43	62	36		98
Sea mullet																				
Smooth toadfish	52	1		53						3		3	13	17		30	15	3		18
Soldier fish																	3			3
Southern crested weedfish																				
Southern garfish	1																			
Western Australian salmon	165			165					4	2		6	21			21	19			19
Yelloweye mullet	96			96	28	78		106	63	23	3	89	458	40	25	523	666	27	3	696
Total	**346**	**24**	**0**	**369**	**1,989**	**164**	**0**	**2,153**	**1,552**	**143**	**5**	**1,700**	**615**	**250**	**55**	**920**	**800**	**404**	**5**	**1,209**
Grand Total	**714**	**1,751**	**0**	**2,465**	**3,377**	**16,049**	**17,290**	**36,716**	**7,137**	**3,286**	**11,503**	**20,311**	**2,503**	**6,339**	**15,077**	**23,919**	**75,057**	**15,387**	**21,075**	**111,519**
Total number of species	**11**	**8**	**0**		**14**	**9**	**1**		**17**	**15**	**5**		**16**	**16**	**6**		**19**	**12**	**3**	

Appendix B3. Continued

	Mar-15				Mar-16				Mar-17				Mar-18				Mar-19			
	MM	NL	SL	**T**	MM	NL	SL	**T**	MM	NL	SL	**T**	MM	NL	SL	**T**	MM	NL	SL	**T**
Small-bodied species																				
Australian anchovy					24			**24**												
Australian pilchard					1			**1**												
Australian smelt	16			**16**	55			**55**	98			**98**								
Blue sprat					2			**2**					7			**7**	461	1		**462**
Bluespot goby	1	4		**5**	15			**15**	3	20		**23**		53		**54**	2	14		**16**
Bridled goby	94	7		**101**	30	1		**31**					1	18		**19**	2	3		**5**
Common galaxias	12			**12**					21			**21**	4			**4**				
Dwarf flat-headed gudgeon					1			**1**												
Flat-headed gudgeon	7			**7**					61			**61**	3			**3**	2			**2**
Little weed whiting																				
Red-spotted shore crab																	12	9		**21**
Sandy sprat	152	354		**506**	16,183	949		**17,132**	2,698	90		**2,788**	4,237	47		**4,284**	2,263	3,678		**5,941**
Lagoon goby		5		**5**	1			**1**	5			**5**	2			**2**	3	102		**105**
Smallmouth hardyhead	663	2,186	9,135	**11,984**	2,601	7,350	24,735	**34,686**	8,130	16,180	12,890	**37,200**	4,823	2,056	9,950	**18,539**	3,283	8,885	20,010	**32,178**
Tamar goby	688	62		**750**	365	1,226		**1,591**	1,375	152		**1,527**	133	127		**277**	154	23		**177**
Total	**1,633**	**2,618**	**9,135**	**13,386**	**19,278**	**9,526**	**24,735**	**53,539**	**12,391**	**16,442**	**12,890**	**41,723**	**9,210**	**2,301**	**9,950**	**23,189**	**6,182**	**12,715**	**20,010**	**38,907**
Mid to large-bodied species																				
Australian herring																				
Barred toadfish	25			**25**													9			**9**
Black bream	1			**1**									10	7		**17**	56			**56**
Bony herring	253	87	2	**342**	51	39		**90**	1,728	61		**1,789**		1		**1**	17			**17**
Carp																				
Congolli	48	43	2	**93**	29	7	1	**37**	6	168		**174**	16	69	18	**107**	14	154	1	**169**
Golden perch																				
Goldspot mullet					2			**2**												
Greenback flounder	18	19		**37**	5	5		**10**					8	20		**28**	13	12		**25**
King George whiting													10			**10**	2			**2**
Longsnout flounder	7			**7**									1			**1**				
Prickly toadfish	27			**27**	4			**4**	4	2		**6**	15			**15**		2		**2**
Redfin perch																				
River garfish	1	19	1	**21**	12	1		**13**	30	145		**175**	7	2		**13**	12	2		**14**
Sea mullet															1	**1**				
Smooth toadfish	34	4		**38**					3			**3**					20	4		**24**
Soldier fish	1			**1**									1			**1**	1			**1**
Southern crested weedfish	1			**1**																
Southern garfish																				
Western Australian salmon	3			**3**										3		**3**				
Yelloweye mullet	177	37	13	**227**	179	6		**185**	1,871	122		**1,993**	73	47	59	**179**	428	75	17	**520**
Total	**596**	**209**	**18**	**823**	**282**	**58**	**1**	**341**	**3,642**	**498**	**-**	**4,140**	**141**	**149**	**78**	**376**	**572**	**249**	**18**	**839**
Grand Total	**2,229**	**2,827**	**9,153**	**14,209**	**19,560**	**9,584**	**24,736**	**53,880**	**16,033**	**16,940**	**12,890**	**45,863**	**9,351**	**2,450**	**10,028**	**21,829**	**6,754**	**12,964**	**20,028**	**39,746**
Total number of species	**21**	**12**	**5**		**18**	**9**	**2**		**14**	**9**	**1**		**17**	**12**	**4**		**19**	**14**	**3**	

Appendix C - Energy content values for macro-invertebrates and fish from this study and literature

Appendix C1: Calorimetric energy content (kilo Joule (kJ) per gram wet mass (WM)) for fish collected in the Coorong during March 2019. Values are presented for species for whom enough dry mass material could be obtained for calorimetry. Where material was combined from two adjacent sites, the cells are encircled by a dotted line. Values in italics are single measurements. Site codes are: SC=Salt Creek, JP=Jack Point, VY=Villa de Yumpa, HG=Hells Gate, MA=Mount Anderson, NM=Noonameena, LP=Long Point, MP=Mark Point, PP=Pelican Point, BC=Boundary Creek, B19=Beacon 19.

SPECIES	ENERGY CONTENT (kJ/g WM)										
	SOUTH LAGOON				NORTH LAGOON				MURRAY MOUTH		
	SC	JP	VY	HG	MA	NM	LP	MP	PP	BC	B19
Smallmouth hardyhead		5.43	6.15	5.61	5.44	4.94	4.92	5.54	5.14	4.95	4.52
Yelloweye mullet	5.48			6.24	5.29	4.97	7.27	5.04	5.50	5.79	5.31
Congolli	4.78				4.48	5.55	5.58	6.08	5.81	5.68	5.54
Lagoon goby							*4.34*				
Sandy Sprat					4.90		4.89		4.50		
Tamar goby							3.6		4.21	4.72	

Appendix C2: Energy content values (dry mass, DM) for macro-invertebrates from marine and estuarine sediments based on data from this study (set in bold), and literature.

TAXA	ENERGY CONTENT (kJ/g DM)		REGION	SOURCE
	(MEAN ± SE OR MEDIAN)	MIN-MAX RANGE, 95% CONFIDENCE INTERVAL LOWER, UPPER LIMIT)		
Crustacea	15.31	14.63, 16.55	Europe	Brey et al. 1988
Amphipoda	**18.00 ± 0.14**		**South Australia**	**this study**
Corophium volutator	15.41	13.27 - 16.85	Europe	Rumohr et al. 1987
***Gammarus* spp.**	16.11	10.23 - 19.66	Europe	Rumohr et al. 1987
***Idothea* spp. (Isopoda)**		6.7 - 24.87	Europe	Rumohr et al. 1987
Mysidacea		13.54 - 30.47	Europe	Rumohr et al. 1987
Australian ghost shrimp	12.72 ± 0.25		Victoria	Dann 2014
Paragrapsus gaimardii	**13.33 ± 1.37**	**10.95 - 15.67**	**South Australia**	**this study**
Brachynotus spinosus	12.97 ± 0.13		Victoria	Dann 2014
Bivalvia	18.85	18.35, 19.33	Europe	Brey et al. 1988
Spisula trigonella	**14.83 ± 1.63**	**13.07 - 18.09**	**South Australia**	**this study**
Soletellina alba	**11.46**		**South Australia**	**this study**
Abra alba	18.8	17.02 - 20.26	Europe	Rumohr et al. 1987
Macoma balthica	17.79	16.12 - 19.05	Europe	Rumohr et al. 1987
Tellina deltoidalis	7.58		Europe	Dann 2014
Gastropoda	18.24	17.01, 19.06	Europe	Brey et al. 1988
Salinator fragilis	**4.96 ± 0.01**		**South Australia**	**this study**
Littorina littorea	19.76	18.70 - 21.41	Europe	Rumohr et al. 1987
***Hydrobia* spp.**	24.61		Europe	Rumohr et al. 1987
Polychaeta	16.79	15.29, 17.5	Europe	Brey et al. 1988
Polychaeta errantia	17.5	16.67, 20.34	Europe	Brey et al. 1988
Polychaeta sedentaria	14.19	11.14, 17.2	Europe	Brey et al. 1988
Simplisetia aequisetis	**18.55 ± 2.28**	**13.80 - 27.26**	**South Australia**	**this study**
***Nephtys* spp.**	17.52	15.50 - 19.75	Europe	Rumohr et al. 1987
Nereis diversicolor	18.04	16.48 - 19.70	Europe	Rumohr et al. 1987
***Lumbrinereis* sp.**	13.39 ± 0.08		Victoria	Dann 2014
Oligochaeta	22.36	21.51, 22.79	Europe	Brey et al. 1988
Insect larvae	22.44	21.99, 22.88	Europe	Brey et al. 1988
Chironomid larvae	22.3		Europe	Rumohr et al. 1987
Chironomid larvae	15.37	14.86 - 15.98	Europe	Bertoli et al. 2018

Appendix C3: Energy content values (wet mass, WM) for estuarine fish based on data from this study (set in bold), and literature.

TAXA	COMMON NAME	ENERGY CONTENT (kJ/g WM)		REGION	SOURCE
		MEAN ± SE	VARIATION (MIN-MAX RANGE)		
Atherinidae					
Atherinosoma microstoma	**Smallmouth hardyhead**	**5.25 ± 0.11**	**4.41 - 6.27**	**South Australia**	**this study**
Leptatherina presbyteroides	Elongate hardyhead	4.23		Western Australia	McCluskey et al. 2016
Bovichtidae					
Pseudaphritis urvilii	**Congolli**	**5.47 ± 0.14**	**4.36 - 6.52**	**South Australia**	**this study**
Clupeidae					
Hyperlophus vittatus	**Sandy Sprat**	**4.77 ± 0.13**	**4.5 - 4.9**	**South Australia**	**this study**
Hyperlophus vittatus	Sandy Sprat	6.59		Western Australia	McCluskey et al. 2016
Hyperlophus vittatus	Sandy Sprat	4.24		New South Wales	Lawson et al. 2018
Gobiidae		4.26		Scotland	Healy 1972, cited in Lawson et al. 2018
Afurcagobius tamarensis	**Tamar goby**	**4.18 ± 0.32**	**3.6 - 4.72**	**South Australia**	**this study**
Tasmanigobius lasti	**Lagoon goby**	**4.34**		**South Australia**	**this study**
Mugiligae					
Aldrichetta fosteri	**Yelloweye mullet**	**5.77 ± 0.14**	**4.82 - 8.35**	**South Australia**	**this study**
Aldrichetta fosteri	Yelloweye mullet	4.58		Western Australia	McCluskey et al. 2016

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