Assessment of the condition of the Swan Canning Estuary in 2013, based on the Fish Community Indices of estuarine condition.

Final report

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Executive summary

This report, commissioned by the Swan River Trust, describes the monitoring and evaluation of fish communities in the Swan Canning Riverpark during 2013 and applies the Fish Community Indices that have been developed in recent years as a measure of the ecological condition of the Swan Canning Estuary. These indices, developed for the shallow, nearshore waters of the estuary and also for its deeper, offshore waters, integrate information on various biological variables (metrics), each of which quantifies an aspect of the structure and/or function of estuarine fish communities and responds to a range of stressors affecting the ecosystem.

Fish communities were sampled using different nets at six nearshore and six offshore sites in each of four zones of the estuary during summer and autumn 2013, with as many fish as possible returned to the water alive following their identification. The resulting data on the abundances of each fish species from each sample were used to calculate a fish community index score (0-100). These index scores were then compared to scoring thresholds to determine ecological condition grades (A-E) for each zone and for the estuary as a whole, based on the fish community.

Nearshore Fish Communities

Overall, the index scores derived from fish communities in the nearshore waters of the Swan Canning Estuary suggest these estuarine habitats were in generally good (B) to fair (C) ecological condition across both summer and autumn 2013, with the average nearshore index scores for most zones and for the estuary as a whole lying between 59 and 71 in each season. In comparison to historic data, the 2013 assessment for the estuary as a whole was consistent with a pattern of good-fair (B/C) condition assessments in recent years, following an apparent improvement in the condition of the estuary between 2005/06 and 2008/09, based on the nearshore fish community data.

The composition of nearshore fish communities in the Swan Canning Estuary in summer and autumn was dominated by small bodied, schooling species. Most notable of these was the tropical, estuarine/marine hardyhead C*raterocephalus mugiloides,* which was highly abundant throughout the estuary but particularly in the Middle Swan Estuary (MSE) and Canning Estuary (CE) zones. Two other hardyhead species, the Elongate hardyhead (*Atherinosoma elongate*), and Ogilby's hardyhead (*Atherinomorus vaigiensis*), dominated the nearshore catches in the Lower Swan Canning Estuary (LSCE) whilst another, Wallace's hardyhead (*Leptatherina wallacei*), was highly abundant in the Upper Swan Estuary (USE), as was the Perth herring (*Nematalosa vlaminghi*).

As is typically observed in this estuary, the number of species recorded in the nearshore waters of each zone was greatest in the lower reaches of the system (23 species) and declined upstream. However, the 20 species recorded from nearshore catches in the USE during 2013 was notably higher than the 14 species recorded from comparable catches in the USE during 2012. This was caused by greater influx of marine species to the upper reaches of the estuary during 2013 than during 2012, as a result of the generally higher salinities observed in the system during the current monitoring year.

Offshore fish communities

The ecological condition of offshore waters in the summer of 2013 was similar to the corresponding season in 2012 with good to fair (B to C) grading across all zones. Scores were, however, lower for all zones during autumn 2013. This was particularly true of the CE and USE zones and may reflect the generally greater extent and severity of low dissolved oxygen conditions during

autumn sampling this year. An overall assessment of fair (C) condition for offshore habitats in 2013 represents a slight decline from the pattern of good-fair (B/C) condition that have been recorded since 2011, albeit still an improvement on the poor condition recorded during 2009.

In general, the composition of offshore fish communities was also fairly typical for the Swan Canning Estuary in summer and autumn of 2013, being dominated by Perth herring, which comprised just over 29% of the catches from the LSCE and 78-93% of those from the CE, MSE and USE. Tailor (*Pomatomus saltatrix*) was also relatively abundant in the offshore waters of several zones, and particularly in the LSCE. However, the Southern eagle ray (*Myliobatis australis*) was caught in unusually large numbers from the offshore waters of the LSCE.

In both seasons during 2013, the CE zone had the lowest offshore scores, reflecting relatively low diversity, a relatively high proportion of species that feed on decomposing organic material and, during autumn, the generally low numbers of species observed. The presence of hypoxic conditions in this zone may have brought a shift of some members of the fish community into the more favourable conditions of the adjacent nearshore waters.

Overall

The ecological condition of both nearshore and offshore waters across the estuary as a whole, based on fish communities, was again assessed as generally good to fair during the current monitoring year.

Background

The Swan River Trust has been working closely with other government agencies, local government authorities, community groups and research institutions to reduce nutrient and organic loading to the Swan Canning river system. This is a priority issue for the waterway that has impacts on water quality, ecological health and community benefit.

Until recently the Trust's environmental monitoring program has been focused on water quality reporting in the estuary and catchment and it has long been envisaged that reporting on ecological health will be a key component of Riverpark reporting in the future. Reporting on changes in fish communities provides insight into the biotic integrity of the system and offers one measure to complement the existing water quality monitoring program

Through a collaborative project between the Trust, Murdoch University, Department of Fisheries and Department of Water, Fish Community Indices were developed for assessing the ecological condition of the Swan Canning Estuary (Hallett et al. 2012, Hallett and Valesini 2012). These indices were developed for the shallow, nearshore waters of the estuary and also for its deeper, offshore waters, as the composition of the fish communities living in these different environments tends to differ. The indices integrate information on various biological variables ('metrics'; Table 1), each of which quantifies an aspect of the structure and/or function of estuarine fish communities and responds to a wide array of stressors affecting the ecosystem. The fish-based indices therefore provide a means to assess an important component of the ecology of the system and how it responds to changes in estuarine condition.

Table 1. Summary of the fish metrics comprising the nearshore and offshore Fish Community Indices developed for the Swan Canning Estuary (Hallett et al. 2012).

Metric	**Predicted response to degradation**	***Nearshore Index***	***Offshore Index***
Number of species (No.species)	Decrease	✓	✓
Shannon-Wiener diversity (Sh-div)[a]	Decrease		✓
Proportion of trophic specialists (Prop.trop.spec.) [b]	Decrease	✓	
Number of trophic specialist species (No.trop.spec.)[b]	Decrease	✓	✓
Number of trophic generalist species (No.trop.gen.)[c]	Increase	✓	✓
Proportion of detritivores (Prop.detr.)[d]	Increase	✓	✓
Proportion of benthic-associated individuals (Prop.benthic)[e]	Decrease	✓	✓
Number of benthic-associated species (No.benthic)[e]	Decrease	✓	
Proportion of estuarine spawning individuals (Prop.est.spawn)	Decrease	✓	✓
Number of estuarine spawning species (No.est.spawn)	Decrease	✓	
Proportion of *Pseudogobius olorum* (Prop. *P. olorum*) [f]	Increase	✓	
Total number of *Pseudogobius olorum* (Tot no. *P. olorum*) [f]	Increase	✓	

[a] A measure of the biodiversity of species
[b] Species with specialist feeding requirements (e.g. those which only eat small invertebrates)
[c] Species which are omnivorous or opportunistic feeders
[d] Species which eat detritus (decomposing organic material)
[e] Species which live on, or are closely associated with, the sea/river bed
[f] The Blue-spot or Swan River goby, a tolerant, omnivorous species which often inhabits silty habitats

In response to increasing degradation of estuarine ecosystems, fish species with specific habitat, feeding or other environmental requirements will become less abundant and diverse, whilst a few species with more general requirements become more abundant, ultimately leading to an overall reduction in the diversity of fish species. So, in a degraded estuary with poor water, sediment and habitat quality, the abundance and diversity of specialist feeders (*e.g.* Garfish and Tailor), bottom-living ('benthic-associated') species (*e.g.* Cobbler and Flathead) and estuarine spawning species (*e.g.* Black bream, Perth herring and Yellow-tail grunter) will decrease, as will the overall number and diversity of species. In contrast, generalist feeders (*e.g.* Banded toadfish or Blowfish) and detritivores (*e.g.* Sea mullet), which eat particles of decomposing organic material will become more abundant and dominant (see left side of Fig. 1). The reverse will be observed in a relatively unspoiled system which is subjected to fewer human stressors (right side of Fig. 1; noting that this conceptual diagram represents either end of a continuum of ecological condition from poor to good).

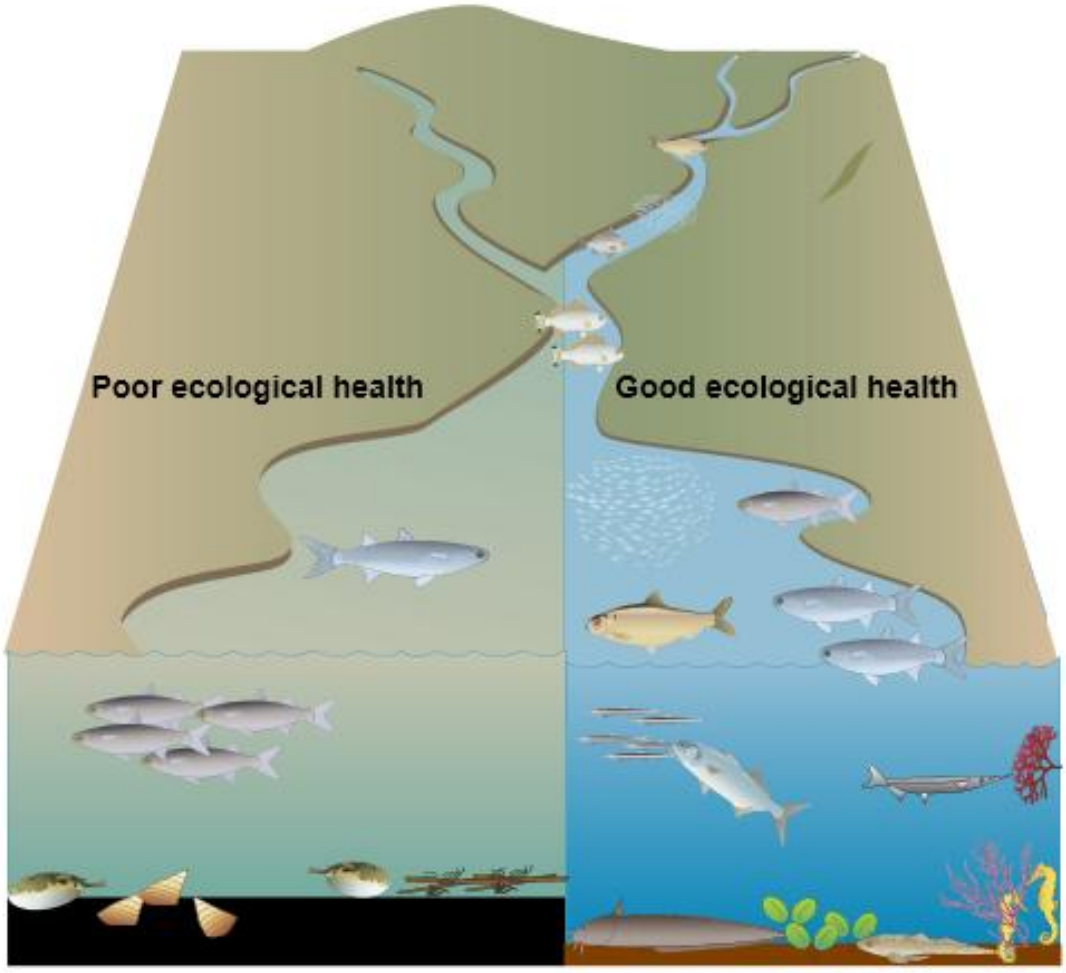

Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of poor and good ecological condition. (Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].)

Each of the metrics that make up the Fish Community Indices are scored from 0-10 according to the numbers and proportions of the various fish species present in samples collected from the estuary using either seine or gill nets. These metric scores are summed to generate an index score for the sample, which ranges from 0-100. Grades (A-E) describing the condition of the

estuary, and/or of particular zones, are then awarded based on the index scores (see methods section below for more details).

Study objectives

This report describes the monitoring and evaluation of fish communities in the Swan Canning Riverpark during 2013 for the purposes of applying the Fish Community Indices as a measure of ecological condition. The objectives of this study were to:

1. Undertake monitoring of fish communities in mid-summer and mid-autumn periods, following an established approach as detailed in Hallett and Valesini (2012), including six nearshore and six offshore sampling sites in each estuarine management zone.
2. Analyse the information collected so that the Fish Community Indices are calculated for nearshore and offshore waters in each management zone and for the estuary overall. The information shall be presented as quantitative index scores, qualitative condition grades and descriptions of the fish communities. Radar plots shall also be used to demonstrate the patterns of fish metric scores for each zone.
3. Provide a report that summarizes the approach and results and that can feed into an estuarine reporting framework.

Methods

Fish communities were sampled at six nearshore and six offshore sites in each of four zones of the Swan Canning Estuary (LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary; Fig. 2) during both summer (30 January-14 February) and autumn (15-29 April) 2013, using a 21.5 m seine net and sunken, multimesh gill nets (Fig. 3), respectively. The seine net was walked out from the beach to a maximum depth of approximately 1.5 m and deployed parallel to the shore, and then rapidly dragged towards and onto the shore. The gill nets, consisting of eight 20 m-long panels with stretched mesh sizes of 35, 51, 63, 76, 89, 102, 115 and 127 mm, were deployed (*i.e.* laid parallel to the bank at a depth of 2-8 m, depending on the site) from a boat immediately before sunset and retrieved after three hours.

Once a sample had been collected, any fish that could immediately be identified to species (e.g. those larger species which are caught in relatively lower numbers) were identified, counted and returned to the water alive. All other fish caught in the nets were placed into zip-lock polythene bags, euthanized in an ice slurry and preserved on ice in eskies in the field for subsequent identification and counting, except in cases where large catches (e.g. thousands) of small fish were obtained. In such instances, an appropriate sub-sample (e.g. one-half to one-eighth of the catch) was retained for identification and estimation of the numbers of each species, and the remaining fish were returned alive to the water to minimise the impact on fish populations. All retained fish were then frozen until their identification in the laboratory. See appendices (i and ii) for full details of the sampling locations and methods employed.

The data on the abundances of each fish species from each sample were used to derive values for each of the relevant metrics comprising the nearshore and offshore indices (see Hallett et al. 2012, Hallett and Valesini 2012). Metric scores were then calculated from these metric values, which were in turn combined to form the index scores. The detailed methodology for how this is achieved is provided in Hallett and Valesini (2012), but can be simply summarised as follows:

1. Calculate metric values for each sample, after allocating each of its component fish species to their appropriate Habitat guild, Estuarine Use guild and Feeding Mode guild (appendix iii).

2. Convert metric values to metric scores (0-10) via comparison with the relevant (zone- and season-specific) reference condition values for each metric.
3. Combine scores for the component metrics into a scaled index score (0-100) for each sample.
4. Compare the index score to the thresholds used to determine the condition grade for each sample (Table 2; Hallett, Submitted), noting that intermediate grades e.g. B/C (good-fair) or C/B (fair-good) are awarded if the index score lies within one point either side of a grade threshold.

The index scores and condition grades for nearshore and offshore samples collected during summer and autumn 2013 were then examined to assess the condition of the Swan Canning Estuary during this period and compared to previous years.

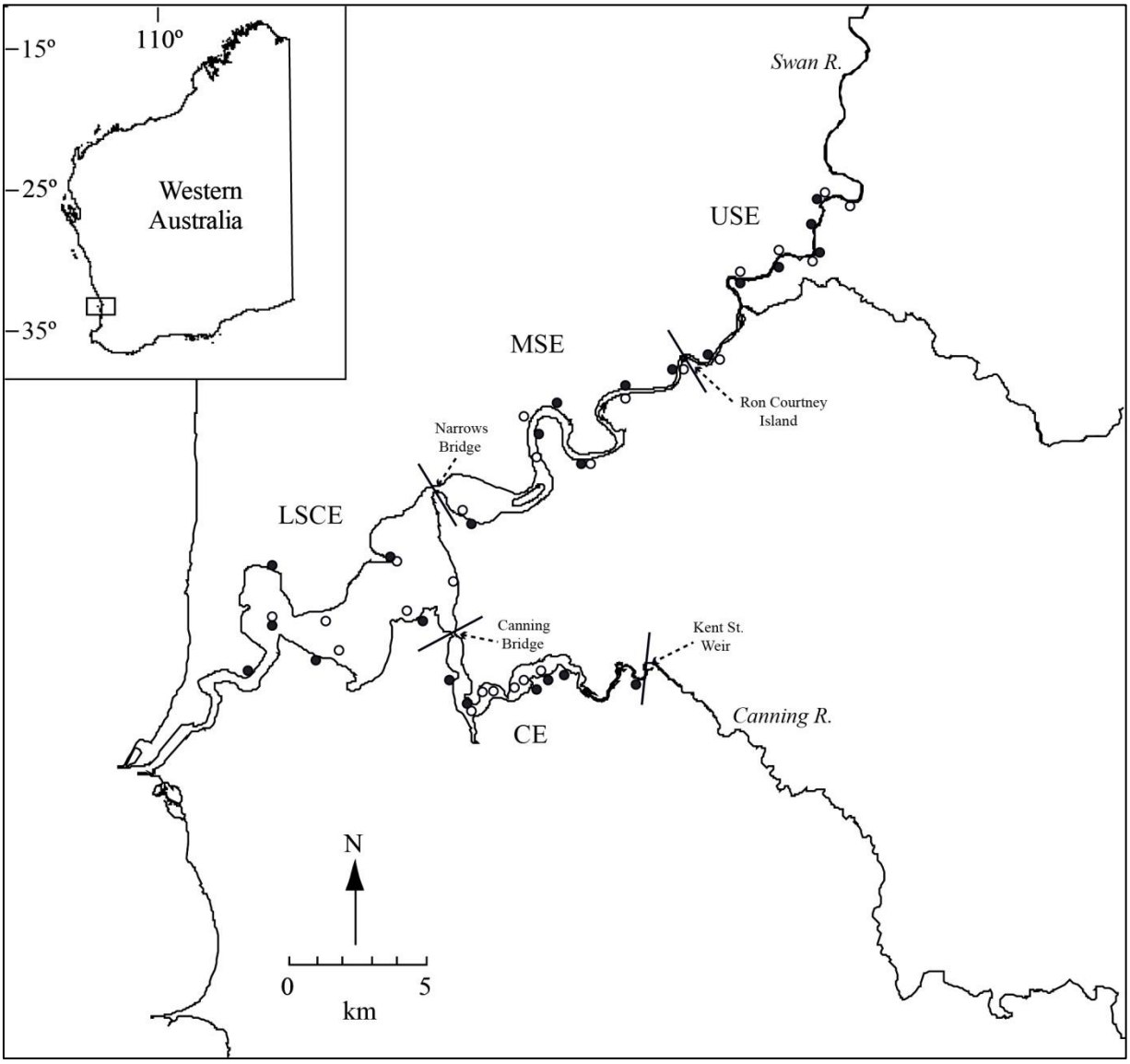

Figure 2: Locations of nearshore (black circles) and offshore (open circles) sampling sites for the Fish Community Indices of estuarine condition. LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary.

Table 2: Fish Community Index scores comprising each of the five condition grades for both nearshore and offshore waters.

Condition grade	Nearshore index scores	Offshore index scores
A (very good)	>74.5	>70.7
B (good)	64.6-74.5	58.4-70.7
C (fair)	57.1-64.6	50.6-58.4
D (poor)	45.5-57.1	36.8-50.6
E (very poor)	<45.5	<36.8

Figure 3: Images of the beach seine netting (upper row) used to sample the fish community in shallower, nearshore waters and the multimesh gill netting (lower row) used to sample fish communities in deeper, offshore waters of the Swan Canning Estuary. (Images courtesy of Steeg Hoeksema and Kerry Trayler, SRT).

Results and discussion

Description of the fish community of the Swan Canning Estuary during 2013

An estimated total of 28,662 fish, belonging to 29 species, were caught in seine net samples collected from the nearshore waters of the Swan Canning during summer and autumn 2013. The vast majority of these fish belonged to small, schooling species, most notably the hardyheads (Atherinidae). The total number of species recorded per zone was greatest in the LSCE (23 species) and declined upstream, to 20 species in the USE (Table 3). Notable differences were observed between zones in the total densities of fish, being greatest in the LSCE (730 fish/100m^2, on average) and lowest in the MSE (226 fish/100m^2), although overall fish densities typically are extremely variable and provide little information about estuarine condition.

Table 3: Compositions of the fish communities observed across the six nearshore sites sampled in each zone of the Swan Canning Estuary during summer and autumn of 2013. Data for the three most abundant species in the catches from each zone are emboldened for emphasis. LSCE = Lower Swan Canning Estuary, CE = Canning Estuary, MSE = Middle Swan Estuary, USE = Upper Swan Estuary.

Species	**Common name**	**LSCE** (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
		Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution
Craterocephalus mugiloides	Mugil's hardyhead	**85.1**	**11.6**	**374.4**	**69.9**	**114.2**	**50.6**	**99.1**	**17.5**
Atherinosoma elongata	Elongate hardyhead	**371.1**	**50.8**	6.8	1.3	1.0	0.4	9.5	1.7
Leptatherina wallacei	Wallace's hardyhead	-	-	**65.5**	**12.2**	3.6	1.6	**149.5**	**26.3**
Nematalosa vlaminghi	Perth herring	-	-	4.7	0.9	14.9	6.6	**186.7**	**32.9**
Atherinomorus vaigiensis	Ogilby's hardyhead	**111.7**	**15.3**	4.0	0.7	11.1	4.9	<0.1	<0.1
Pelates octolineatus	Western striped grunter	76.2	10.4	0.5	<0.1	2.6	1.1	0.1	<0.1
Papillogobius punctatus	Red-spot goby	2.5	0.3	**21.9**	**4.1**	**15.2**	**6.8**	39.7	7.0
Torquigener pleurogramma	Blowfish/Banded toadfish	54.0	7.4	8.0	1.5	11.3	5.0	<0.1	<0.1
Aldrichetta forsteri	Yellow-eye mullet	1.0	0.1	10.8	2.0	**24.6**	**10.9**	16.8	3.0
Pseudogobius olorum	Blue-spot goby	-	-	2.5	0.5	1.5	0.7	37.4	6.6
Amniataba caudavittata	Yellowtail grunter	1.5	0.2	17.3	3.2	5.5	2.4	3.3	0.6
Acanthopagrus butcheri	Black bream	3.3	0.5	9.1	1.7	6.5	2.9	3.6	0.6
Gerres subfasciatus	Roach	9.2	1.3	3.4	0.6	5.1	2.3	1.5	0.3
Gambusia holbrooki	Mosquito fish	-	-	2.3	0.4	-	-	12.6	2.2
Leptatherina presbyteroides	Silverfish	8.9	1.2	-	-	-	-	-	-
Mugil cephalus	Sea mullet	<0.1	<0.1	2.2	0.4	2.5	1.1	3.2	0.6
Apogon rueppelli	Gobbleguts	0.4	<0.1	-	-	4.3	1.9	<0.1	<0.1
Favonigobius lateralis	Long-finned goby	2.2	0.3	<0.1	<0.1	1.3	0.6	-	-
Engraulis australis	Southern anchovy	0.3	<0.1	-	-	-	-	3.0	0.5
Sillago burrus	Western trumpeter whiting	1.9	0.3	-	-	<0.1	<0.1	-	-
Arenigobius bifrenatus	Bridled goby	-	-	0.8	0.1	<0.1	<0.1	0.5	<0.1
Afurcagobius suppositus	Southwestern goby	<0.1	<0.1	0.8	0.1	<0.1	<0.1	0.4	<0.1

Species	Common name	**LSCE** (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
		Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution
(Cont'd)									
Pomatomus saltatrix	Tailor	0.3	<0.1	0.3	<0.1	0.1	<0.1	0.4	<0.1
Sillago schomburgkii	Yellow-fin whiting	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	-	-
Platycephalus westraliae	Yellowtail flathead	0.2	<0.1	<0.1	<0.1	-	-	-	-
Ammotretis rostratus	Longsnout flounder	0.3	<0.1	-	-	-	-	-	-
Myliobatis australis	Southern eagle ray	<0.1	<0.1	-	-	-	-	-	-
Haletta semifasciata	Blue weed whiting	<0.1	<0.1	-	-	-	-	-	-
Eocallionymus papilio	Painted stinkfish	-	-	<0.1	<0.1	-	-	-	-
		23 Species		**22 Species**		**21 Species**		**20 Species**	
		Average total fish density (fish/100m^2)	Total number of fish	Average total fish density (fish/100m^2)	Total number of fish	Average total fish density (fish/100m^2)	Total number of fish	Average total fish density (fish/100m^2)	Total number of fish
		730	**10,166**	**536**	**7,455**	**226**	**3,140**	**568**	**7,901**

Table 4: Compositions of the fish communities observed across the six offshore sites sampled in each zone of the Swan Canning Estuary during summer and autumn of 2013. Data for the three most abundant species in the catches from each zone are emboldened for emphasis. LSCE = Lower Swan Canning Estuary, CE = Canning Estuary, MSE = Middle Swan Estuary, USE = Upper Swan Estuary.

Species	**Common name**	**LSCE** (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
		Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution
Nematalosa vlaminghi	Perth herring	**8.9**	**29.4**	**45**	**78.9**	**28.9**	**93.3**	**27.1**	**77.8**
Pomatomus saltatrix	Tailor	**4.1**	**13.5**	**2.3**	**4.1**	**0.3**	**1.1**	**1.3**	**3.8**
Myliobatis australis	Southern eagle ray	**5.8**	**19.2**	0.5	0.9	0.2	0.5	-	-
Gerres subfasciatus	Roach	1.6	5.2	**3.4**	**6.0**	**0.4**	**1.3**	0.7	1.9
Sardinella lemuru	Scaly mackerel	4.0	13.2	-	-	-	-	-	-
Amniataba caudavittata	Yellowtail grunter	<0.1	0.3	0.8	1.3	<0.1	0.3	**2.7**	**7.7**
Platycephalus westraliae	Yellowtail flathead	2.6	8.5	0.6	1.0	0.3	0.8	<0.1	0.2
Mugil cephalus	Sea mullet	-	-	2.3	3.9	-	-	0.7	1.9
Pelates octolineatus	Western striped grunter	1.2	3.8	0.7	1.2	<0.1	0.3	0.4	1.2
Sillago burrus	Western trumpeter whiting	0.9	3.0	<0.1	0.1	<0.1	0.3	-	-
Elops machnata	Giant herring	<0.1	0.3	-	-	**0.3**	**1.1**	0.6	1.7
Acanthopagrus butcheri	Black bream	-	-	0.2	0.3	-	-	0.7	1.9
Torquigener pleurogramma	Blowfish/Banded toadfish	0.4	1.4	0.3	0.6	<0.1	0.3	-	-
Rhabdosargus sarba	Tarwhine	-	-	0.7	1.2	-	-	-	-
Engraulis australis	Southern anchovy	0.2	0.5	-	-	<0.1	0.3	0.3	0.7
Carcharinus leucas	Bull shark	-	-	-	-	<0.1	0.3	0.3	0.7
Sillago schomburgkii	Yellow-fin whiting	-	-	0.2	0.3	<0.1	0.3	-	-
Sphyraena obtusata	Striped barracuda	0.3	0.8	-	-	-	-	-	-
Cnidoglanis macrocephalus	Estuarine cobbler	0.2	0.5	-	-	-	-	-	-

Species	Common name	**LSCE** (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
		Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution	Average catch rate (fish/net set)	% contribution
(Cont'd)									
Argyrosomus japonicus	Mulloway	-	-	-	-	-	-	0.2	0.5
Hippocampus angustus	Western spiny seahorse	<0.1	0.3	-	-	-	-	-	-
Aldrichetta forsteri	Yelloweye mullet	-	-	<0.1	0.1	-	-	-	-
		15 Species		**14 Species**		**13 Species**		**12 Species**	
		Average total catch rate (fish/net set)	Total number of fish	Average total catch rate (fish/net set)	Total number of fish	Average total catch rate (fish/net set)	Total number of fish	Average total catch rate (fish/net set)	Total number of fish
		30	**364**	**57**	**684**	**31**	**372**	**35**	**418**

Consistent with sampling in the previous year, the small, tropical hardyhead species *Craterocephalus mugiloides* again dominated the nearshore waters of the estuary in terms of abundance, comprising as much as 50% and 70% of the catches from the MSE and CE zones respectively (Table 3). This and two other hardyhead species, the Elongate hardyhead (*Atherinosoma elongata*), and Ogilby's hardyhead (*Atherinomorus vaigiensis*), dominated the nearshore catches in the LSCE. Another atherinid species, Wallace's hardyhead (*Leptatherina wallacei*), was highly abundant in the USE, as was the Perth herring (*Nematalosa vlaminghi*).

Gill net samples collected in summer and autumn 2013 from offshore waters returned 1,838 fish comprising 22 species (Table 4). The total number of species declined in an upstream direction, from 15 species in the LSCE to 12 species in the USE. This pattern is fairly typical in south-western Australian estuaries (Loneragan et al. 1986, 1987, 1989) and is consistent with observations from the Swan estuary in 2012 (Hallett, 2012). The total catches of fishes recorded per zone were very similar for the LSCE, MSE and USE, with 30-35 fish per gill net set, whilst 57 fish were caught per gill net in the CE (Table 4). The dominant species in the gill net catches from all four zones was the Perth herring, which comprised just over 29% of the catches from the LSCE, and 78-93% of those from the CE, MSE and USE. Other relatively abundant species included Tailor (*Pomatomus saltatrix*), most notably in the LSCE, Yellowtail grunter (*Amniataba caudavittata*) in the USE, and the Southern eagle ray (*Myliobatis australis*) in the LSCE (Table 4).

The nearshore and offshore fish communities of the Swan Canning Estuary in 2013 were thus broadly similar in composition to those observed during similar monitoring conducted in 2012 (Hallett, 2012). Catches using each of the two net types exhibited comparable total fish abundances in 2012 and 2013, and were dominated by broadly similar suites of species in both years. However, the numbers of species in the offshore catches were slightly yet consistently higher per zone during 2013 than during the previous year. Similarly, the 20 species recorded from nearshore catches in the USE during 2013 (Table 3) was notably higher than the 14 species recorded from comparable catches in the USE during 2012. These findings reflect a greater influx of marine species to the estuary, and particularly into its middle to upper zones, during 2013 than during 2012, as a result of the higher salinities that were generally observed in the system during the current monitoring year (appendix iv). For example, marine species such as the Southern eagle ray and the Scaly mackerel (*Sardinella lemuru*) were unusually abundant in offshore catches from the LSCE, whilst the Bull shark (*Carcharinus leucas*) and the Giant herring (*Elops machnata*) penetrated further upstream, into the offshore waters of the USE. The higher salinities could also account for the unusually high abundances of *C. mugiloides* in the nearshore waters of the upper zones of the estuary (Table 3), and the relatively low catches of Black bream (*Acanthopagrus butcheri*) from the MSE and USE during 2013.

Ecological condition in 2013 and comparison to other periods

In general, the ecological condition (based on fish communities) of the nearshore waters of the Riverpark was consistently good (B) to fair (C) across summer and autumn 2013, with the average nearshore index scores for most zones and for the estuary as a whole lying between 59 and 71 in each season (Fig. 4). The nearshore scores and condition grades were generally very consistent between summer and autumn of 2013 for most zones, although the nearshore condition of the CE zone apparently improved from summer to autumn, likely reflecting the movement of fish into the more favourable nearshore waters from the stratified, hypoxic (dissolved oxygen [DO]<2mg/L)

deeper waters of this zone during autumn (see below). Overall, however, these results are consistent with a pattern of good-fair (B/C) condition assessments in recent years, following an apparent improvement in the condition of the estuary (based on fish communities) as a whole between 2005/06 and 2008/09 (Fig. 5). The factors underlying this improvement are not known.

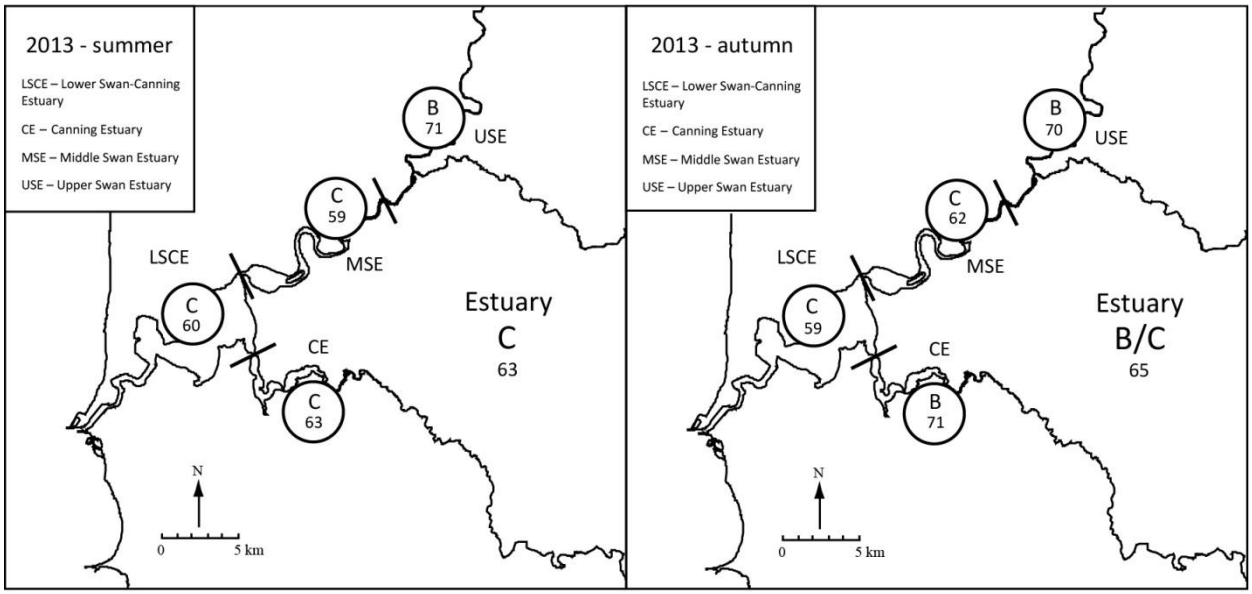

Figure 4: Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2013.

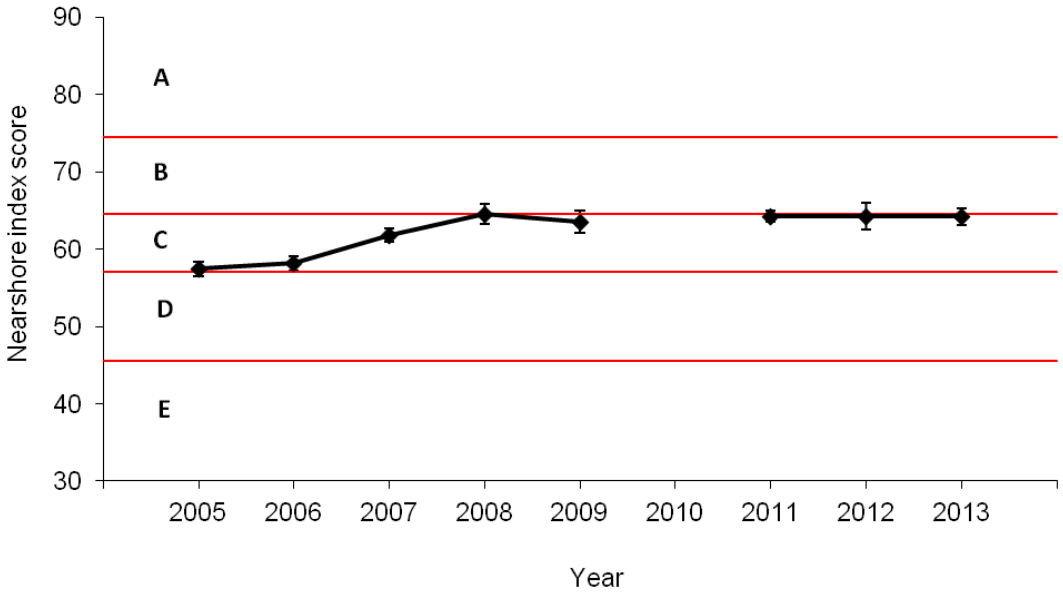

Figure 5: Trend plot of average (±SE) nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary as a whole, over recent years.

Examination of the radar plots of nearshore metric scores for each zone in each season confirms that the USE zone harboured a relatively high number of species in both summer and autumn 2013 (as shown by high scores of >8 for this positive metric; Fig. 6), likely reflecting the effects of higher salinities, as outlined above. Whilst the USE and particularly the CE zone both exhibited relatively low proportions of bottom-dwelling fishes during summer 2013 (as indicated by average scores of ≤3 for the metric for the proportion of benthic associated individuals; Fig. 6a), the relatively high scores for this metric in these zones during autumn might again reflect the movement of fish from hypoxic offshore waters into the more favourable nearshore waters (see below).

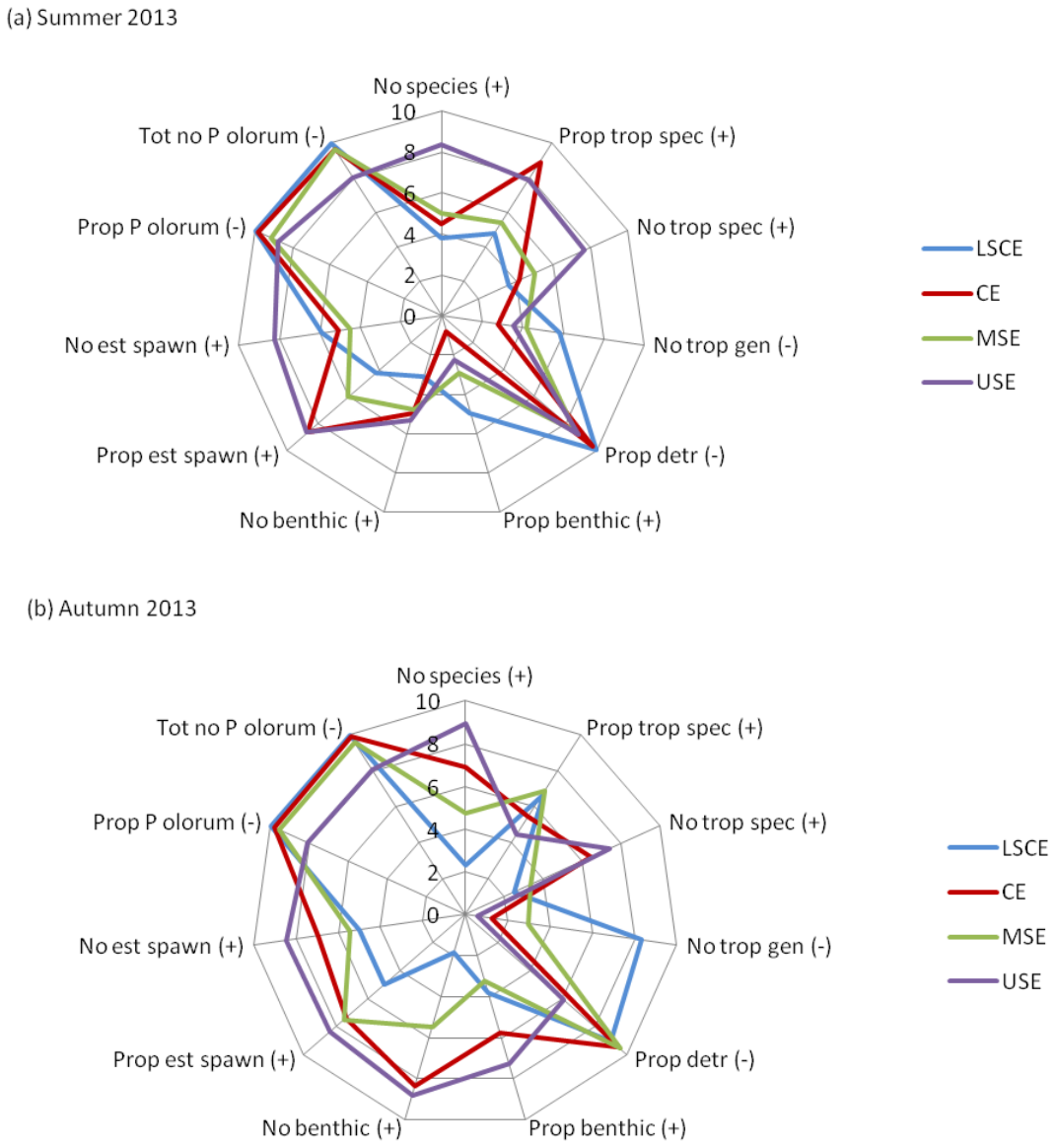

Figure 6: Average scores (0-10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2013. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names).

The ecological condition of the Riverpark's offshore waters in summer of 2013 was very similar to that observed in the corresponding season of the previous year (see Hallett 2012), being consistently good to fair (B to C) across all zones. Average offshore index scores for most zones, and for the estuary as a whole, were between about 57 and 69 points in summer 2013, with the exception of the CE zone, which scored 53 (Fig. 7). However, offshore index scores were notably three to nine points lower for all zones during autumn than during the preceding season, with the most marked declines being observed in the CE and USE. This may reflect the ecological effects of hypoxia, which affected several zones of the estuary, and particularly the CE and USE, to a greater degree during autumn than during summer in 2013 (appendix v).

Consequently, the average condition of offshore waters for the estuary during 2013 was assessed as fair (C), and represents a slight decline from the pattern of good-fair (B/C) condition assessments that have been recorded since 2011, albeit still an improvement on the poor condition recorded during 2008-09 (Fig. 8).

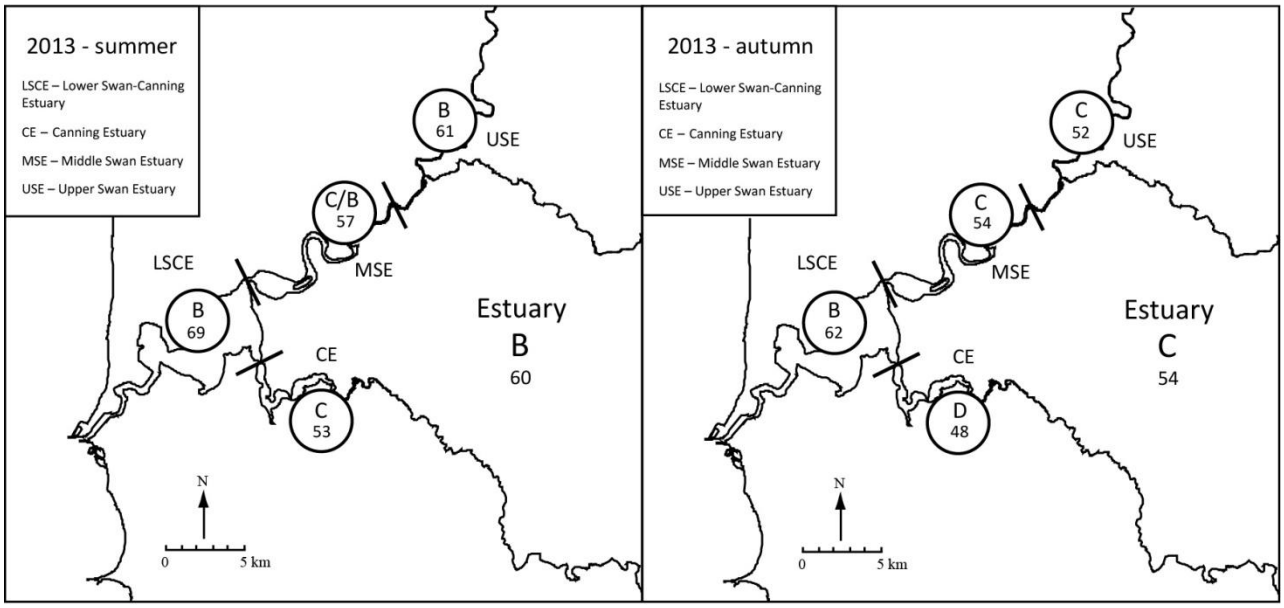

Figure 7: Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2013.

In each season during 2013, the lowest average offshore scores were observed in the CE zone (Fig. 7) (as was the case in 2012 also; Hallett 2012). This may be attributed in part to the ecological effects of hypoxia, which was comparatively severe and widespread within the CE zone around the time of sampling in autumn of 2013 (appendix v). Examination of the radar plots of offshore metric scores for each zone in each season reveal the fair ecological condition of the CE during summer 2013 to have been driven by relatively low species diversity and by a relatively high proportion of species that feed on decomposing organic material, as indicated by low average scores for Shannon-Wiener diversity (a positive metric) and the proportion of detritivores (a negative metric; Fig. 9a). Similarly, the poor ecological condition of this zone during autumn of 2013 can also

be attributed to low species diversity and a relatively high proportion of species that feed on decomposing organic material, as well as to low numbers of species in general (indicated by low average scores for the positive metric, Number of species; Fig. 9b).

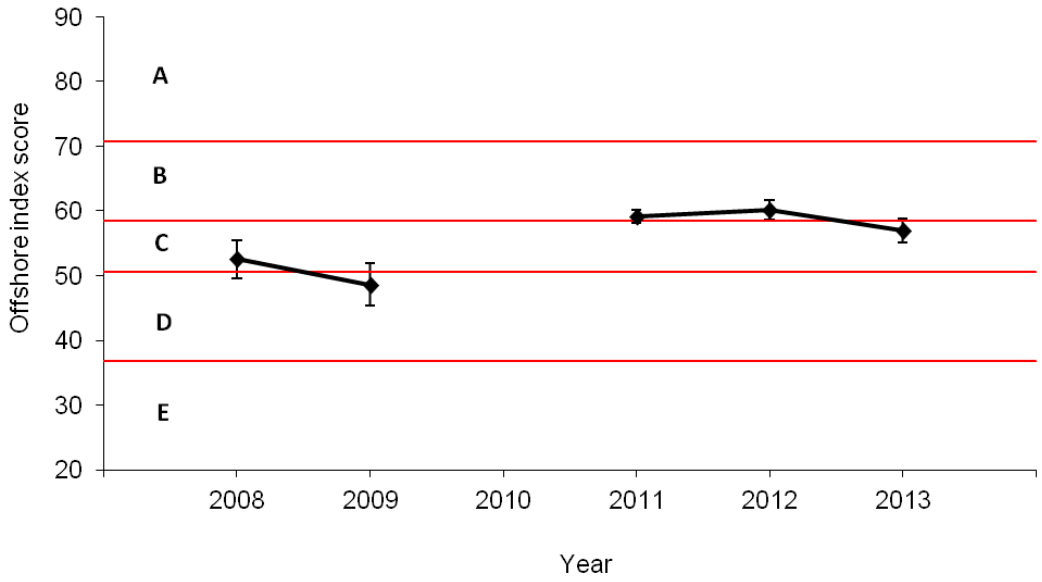

Figure 8: Trend plot of average (±SE) offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary as a whole, over recent years.

In conclusion, the presence of hypoxic conditions throughout certain offshore zones of the estuary at times during 2013, and particularly during the autumn, appears to have led to slightly lower ecological condition of offshore habitats during 2013 compared to 2012. This decline was most notable in the CE and USE zones, and brought about an apparent shift of some members of the fish community into the more favourable conditions of the adjacent nearshore waters. Nonetheless, the ecological condition of both nearshore and offshore waters across the estuary as a whole, based on fish communities, was again assessed as generally good to fair during the current monitoring year.

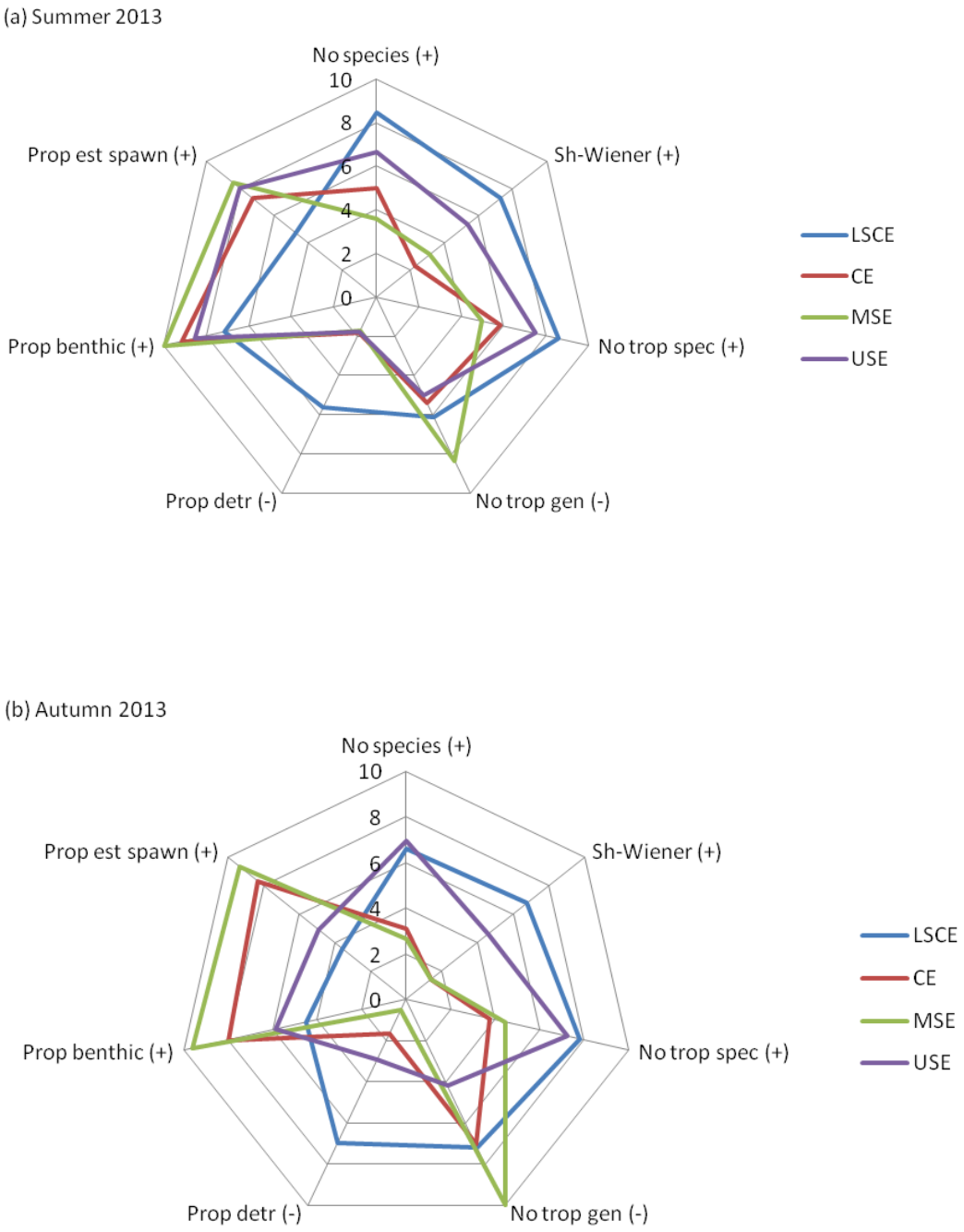

Figure 9: Average scores (0-10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2013. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names).

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Appendix: (i) Descriptions of (a) nearshore and (b) offshore sampling sites under the FCI annual monitoring regime. LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary

Zone	Site Code	Lat-Long (S, E)	Description
(a) – *Nearshore*			
LSCE	LSCE3	32°01'29'', 115°46'27''	Shoreline in front of vegetation on eastern side of Point Roe, Mosman Pk
	LSCE4	31°59'26'', 115°47'08''	Grassy shore in front of houses to east of Claremont Jetty
	LSCE5	32°00'24'', 115°46'52''	North side of Point Walter sandbar
	LSCE6	32°01'06'', 115°48'19''	Shore in front of bench on Attadale Reserve
	LSCE7	32°00'11'', 115°50'29''	Sandy bay below Point Heathcote
	LSCE8	31°59'11'', 115°49'40''	Eastern side of Pelican Point, immediately south of sailing club
CE	CE1	32°01'28'', 115°51'16''	Sandy shore to south of Deepwater Point boat ramp
	CE2	32°01'54'', 115°51'33''	Sandy beach immediately to north of Mount Henry Bridge
	CE5	32°01'40'', 115°52'58''	Bay in Shelley Beach, adjacent to jetty
	CE6	32°01'29'', 115°53'11''	Small clearing in vegetation off North Riverton Drive
	CE7	32°01'18'', 115°53'43''	Sandy bay in front of bench, east of Wadjup Point
	CE8	32°01'16'', 115°55'14''	Sandy beach immediately downstream of Kent Street Weir
MSE	MSE2	31°58'12'', 115°51'07''	Sandy beach on South Perth foreshore, west of Mends St Jetty
	MSE4	31°56'34'', 115°53'06''	Shoreline in front of Belmont racecourse, north of Windan Bridge
	MSE5	31°56'13'', 115°53'23''	Beach to west of jetty in front of Maylands Yacht Club
	MSE6	31°57'13'', 115°53'56''	Small beach upstream of Belmont Water Ski Area boat ramp
	MSE7	31°55'53'', 115°55'10''	Beach in front of scout hut, east of Garratt Road Bridge
	MSE8	31°55'37'', 115°56'18''	Vegetated shoreline, Claughton Reserve, upstream of boat ramp
USE	USE1	31°55'20'', 115°57'03''	Small beach adjacent to jetty at Sandy Beach Reserve, Bassendean
	USE3	31°53'43'', 115°57'32''	Sandy bay opposite Bennett Brook, at Fishmarket Reserve, Guildford
	USE4	31°53'28'', 115°58'32''	Shoreline in front of Guildford Grammar stables, opposite Lilac Hill Park
	USE5	31°53'13'', 115°59'29''	Small, rocky beach after bend in river at Ray Marshall Park
	USE6	31°52'41'', 115°59'31''	Small beach with iron fence, in front of Caversham house
	USE7	31°52'22'', 115°59'39''	Sandy shore on bend in river, below house on hill, upstream of powerlines
(b) – *Offshore*			
LSCE	LSCE1G	32°00'24'', 115°46'56''	In deeper water *ca* 100 m off north side of Point Walter sandbar
	LSCE2G	32°00'12'', 115°48'07''	Alongside seawall west of Armstrong Spit, Dalkeith
	LSCE3G	32°01'00'', 115°48'44''	Parallel to shoreline, running westwards from Beacon 45, Attadale
	LSCE4G	32°00'18'', 115°50'01''	In deep water of Waylen Bay, from *ca* 50 m east of Applecross jetty
	LSCE5G	31°59'37'', 115°51'09''	Perpendicular to Como Jetty, running northwards
	LSCE6G	31°59'12'', 115°49'42''	*Ca* 20 m from, and parallel to, sandy shore on east side of Pelican Point
CE	CE1G	32°01'58'', 115°51'36''	Underneath Mount Henry Bridge, parallel to northern shoreline
	CE2G	32°01'48'', 115°51'46''	Parallel to, and *ca* 20 m from, western shoreline of Aquinas Bay
	CE3G	32°01'49'', 115°52'19''	To north of navigation markers, Aquinas Bay
	CE4G	32°01'48'', 115°52'33''	Adjacent to Old Post Line (SW-ern end; Salter Point)
	CE5G	32°01'36'', 115°52'52''	Adjacent to Old Post Line (NE-ern end; Prisoner Point)
	CE6G	32°01'20'', 115°53'15''	Adjacent to Old Post Line, Shelley Water
MSE	MSE1G	31°58'03'', 115°51'03''	From jetty at Point Belches towards Mends St Jetty, Perth Water
	MSE2G	31°56'57'', 115°53'05''	Downstream of Windan Bridge, parallel to Burswood shoreline
	MSE3G	31°56'22'', 115°53'05''	Downstream from port marker, parallel to Joel Terrace, Maylands
	MSE4G	31°57'13'', 115°54'12''	Parallel to shore from former boat shed jetty, Cracknell Park, Belmont
	MSE5G	31°55'57'', 115°55'12''	Parallel to southern shoreline, upstream of Garratt Road Bridge
	MSE6G	31°55'23'', 115°56'25''	Parallel to eastern bank at Garvey Pk, from south of Ron Courtney Island
USE	USE1G	31°55'19'', 115°57'09''	Parallel to tree-lined eastern bank, upstream of Sandy Beach Reserve
	USE2G	31°53'42'', 115°57'40''	Along northern riverbank, running upstream from Bennett Brook
	USE3G	31°53'16'', 115°58'42''	Along northern bank on bend in river, to north of Lilac Hill Park
	USE4G	31°53'17'', 115°59'23''	Along southern bank, downstream from bend at Ray Marshall Pk
	USE5G	31°52'13'', 115°59'40''	Running along northern bank, upstream from Sandalford winery jetty
	USE6G	31°52'13'', 116°00'18''	Along southern shore adjacent to Midland Brickworks, from outflow pipe

Appendix: (ii) Descriptions of sampling and processing procedures

Nearshore sampling methods

- On each sampling occasion, one replicate sample of the nearshore fish community is collected from each of the fixed, nearshore sampling sites.
- Sampling is not conducted during or within 3-5 days following any significant flow event.
- Nearshore fish samples are collected using a beach seine net that is 21.5 m long, comprises two 10 m-long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m-long bunt (3 mm mesh) and fishes to a depth of 1.5 m.
- This net is walked out from the beach to a maximum depth of approximately 1.5 m and deployed parallel to the shore, and is then rapidly dragged towards and onto the shore, so that it sweeps a roughly semicircular area of approximately 116 m^2.
- If a seine net deployment returns a catch of fewer than five fish, an additional sample is performed at the site (separated from the first sample by either 15 minutes or by 10-20 m distance). In the event that more than five fish are caught in the second sample, this second replicate is then used as the sample for that site, and those fish from the first sample returned to the water alive. If, however, 0-5 fish are again caught, the original sample can be assumed to have been representative of the fish community present, and be used as the sample for that site. The fish from the latter sample are then returned alive to the water. The above procedure thus helps to identify whether a collected sample is representative of the fish community present and enables instances of false negative catches to be identified and eliminated.
- Once an appropriate sample has been collected, any fish that may be readily identified to species (*e.g.* those larger species which are caught in relatively lower numbers) are counted and returned to the water alive.
- All other fish caught in the nets are placed into zip-lock polythene bags, euthanized in an ice slurry and preserved on ice in eskies in the field, except in cases where large catches (*e.g.* thousands) of small fish are obtained. In such cases, an appropriate sub-sample (*e.g.* one half to one eighth of the entire catch) is retained and the remaining fish are returned alive to the water. All retained fish are then bagged and frozen until their identification in the laboratory.

Offshore sampling methods

- On each sampling occasion, one replicate sample of the offshore fish community is collected from each of the fixed, offshore sampling sites.
- Sampling is not conducted within 3-5 days following any significant flow event.
- Offshore fish samples are collected using a sunken, multimesh gill net that consists of eight 20 m-long panels with stretched mesh sizes of 35, 51, 63, 76, 89, 102, 115 and 127 mm. These nets are deployed (*i.e.* laid parallel to the bank) from a boat immediately before sunset and retrieved after three hours.
- Given the time and labour associated with offshore sampling and the need to monitor the set nets for safety purposes, a maximum of three replicate net deployments is performed within a single zone in any one night. The three nets are deployed sequentially, and retrieved in the same order.
- During net retrieval (and, typically, when catch rates are sufficiently low to allow fish to be removed rapidly in the course of retrieval), any fishes that may be removed easily from the net are carefully removed, identified, counted, recorded and returned to the water alive as the net is pulled into the boat.

- All other fish caught in the nets are removed once the net has been retrieved. Retained fish are placed into zip-lock polythene bags in an ice slurry, preserved on ice in eskies in the field, and subsequently frozen until their identification in the laboratory.

Following their identification to the lowest possible taxon in the field or laboratory by fish specialists trained in fish taxonomy, all assigned scientific and common names are checked and standardised by referencing the Checklist of Australian Aquatic Biota (CAAB) database (Rees *et al.* 2006), and the appropriate CAAB species code is allocated to each species. The abundance data for each species in each sample is entered into a database for record and subsequent computation of the biotic indices.

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Appendix: (iii) List of species previously caught from the Swan Canning Estuary, and their functional guilds:
D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic
MS, Marine straggler; MM, Marine migrant; SA, Semi-anadromous; ES, Estuarine species; FM, Freshwater migrant
ZB, Zoobenthivore; PV, Piscivore; ZP, Zooplanktivore; DV, Detritivore; OV, Omnivore/Opportunist; HV, Herbivore

Species name	Common name	Habitat guild	Estuarine Use guild	Feeding Mode guild
Heterodontus portusjacksoni	Port Jackson shark	D	MS	ZB
Carcharinas leucas	Bull shark	P	MS	PV
Myliobatis australis	Southern Eagle ray	D	MS	ZB
Elops machnata	Giant herring	BP	MS	PV
Hyperlophus vittatus	Whitebait / sandy sprat	SP	MM	ZP
Spratelloides robustus	Blue sprat	SP	MM	ZP
Sardinops neopilchardus	Australian pilchard	P	MS	ZP
Sardinella lemuru	Scaly mackerel	P	MS	ZP
Nematalosa vlaminghi	Perth herring	BP	SA	DV
Engraulis australis	Southern anchovy	SP	ES	ZP
Galaxias occidentalis	Western minnow	SB	FM	ZB
Carassius auratus	Goldfish	BP	FM	OV
Cnidoglanis macrocephalus	Estuarine cobbler	D	MM	ZB
Tandanus bostocki	Freshwater cobbler	D	FM	ZB
Hyporhamphus melanochir	Southern Sea Garfish	P	ES	HV
Hyporhamphus regularis	Western River Garfish	P	FM	HV
Gambusia holbrooki	Mosquito fish	SP	FM	ZB
Atherinosoma elongata	Elongate hardyhead	SP	ES	ZB
Leptatherina presbyteroides	Presbyter's hardyhead	SP	MM	ZP
Atherinomorus vaigensis	Ogilby's hardyhead	SP	MM	ZB
Craterocephalus mugiloides	Mugil's hardyhead	SP	ES	ZB
Leptatherina wallacei	Wallace's hardyhead	SP	ES	ZP
Cleidopus gloriamaris	Knightfish / Pineapplefish	D	MS	ZB
Stigmatophora nigra	Wide-bodied pipefish	D	MS	ZB
Vanacampus phillipi	Port Phillip pipefish	D	MS	ZB
Phyllopteryx taeniolatus	Common seadragon	D	MS	ZB
Hippocampus angustus	Western spiny seahorse	D	MS	ZP
Stigmatophora argus	Spotted pipefish	D	MS	ZP
Urocampus carinirostris	Hairy pipefish	D	ES	ZP
Filicampus tigris	Tiger pipefish	D	MS	ZP
Pugnaso curtirostris	Pugnose pipefish	D	MS	ZP
Gymnapistes marmoratus	Devilfish	D	MS	ZB
Chelidonichthys kumu	Red gurnard	D	MS	ZB
Platycephalus laevigatus	Rock Flathead	D	MS	PV
Platycephalus westraliae	Yellowtail flathead	D	ES	PV
Leviprora inops	Long-head Flathead	D	MS	PV
Pegasus lancifer	Sculptured Seamoth	D	MS	ZB
Amniataba caudavittata	Yellow-tail trumpeter	BP	ES	OP
Pelates octolineatus	Western striped grunter	BP	MM	OV
Pelsartia humeralis	Sea trumpeter	BP	MS	OV
Edelia vittata	Western pygmy perch	BP	FM	ZB
Apogon rueppelli	Gobbleguts	BP	ES	ZB
Siphamia cephalotes	Woods Siphonfish	BP	MS	ZB

Species name	Common name	Habitat guild	Estuarine Use guild	Feeding Mode guild
Sillago bassensis	Southern school whiting	D	MS	ZB
Sillago burrus	Western trumpeter whiting	D	MM	ZB
Sillaginodes punctata	King George whiting	D	MM	ZB
Sillago schomburgkii	Yellow-finned whiting	D	MM	ZB
Sillago vittata	Western school whiting	D	MM	ZB
Pomatomus saltatrix	Tailor	P	MM	PV
Trachurus novaezelandiae	Yellowtail scad	P	MS	ZB
Scomeroides tol	Needleskin queenfish	P	MS	PV
Pseudocaranx dentex	Silver trevally	BP	MM	ZB
Pseudocaranx wrightii	Sand trevally	BP	MM	ZB
Arripis georgianus	Australian herring	P	MM	PV
Pentapodus vitta	Western butterfish	BP	MS	ZB
Gerres subfasciatus	Roach	BP	MM	ZB
Acanthopagrus butcheri	Southern black bream	BP	ES	OP
Rhabdosargus sarba	Tarwhine	BP	MM	ZB
Argyrosomus japonicus	Mulloway	BP	MM	PV
Pampeneus spilurus	Black-saddled goatfish	D	MS	ZB
Enoplosus armatus	Old wife	D	MS	ZB
Aldrichetta forsteri	Yellow-eye mullet	P	MM	OV
Mugil cephalus	Sea mullet	P	MM	DV
Sphyraena novaehollandiae	Snook	P	MS	PV
Sphyraena obtusata	Striped barracuda	P	MS	PV
Haletta semifasciata	Blue weed whiting	D	MS	OV
Siphonognathus radiatus	Long-rayed weed whiting	D	MS	OV
Neoodax baltatus	Little weed whiting	D	MS	OV
Odax acroptilus	Rainbow cale	D	MS	OV
Parapercis haackei	Wavy grubfish	D	MS	ZB
Petroscirtes breviceps	Short-head sabre blenny	SB	MS	OV
Omobranchus germaini	Germain's blenny	SB	MS	ZB
Parablennius intermedius	Horned blenny	D	MS	ZB
Parablennius postoculomaculatus	False Tasmanian blenny	SB	MS	OV
Istiblennius meleagris	Peacock rockskipper	D	MS	HV
Cristiceps australis	Southern crested weedfish	D	MS	ZB
Pseudocalliurichthys goodladi	Longspine stinkfish	D	MS	ZB
Eocallionymus papilio	Painted stinkfish	D	MS	ZB
Nesogobius pulchellus	Sailfin goby	SB	MS	ZB
Favonigobius lateralis	Long-finned goby	SB	MM	ZB
Afurcagobius suppositus	Southwestern goby	SB	ES	ZB
Pseudogobius olorum	Blue-spot / Swan River goby	SB	ES	OV
Arenigobius bifrenatus	Bridled goby	SB	ES	ZB
Callogobius mucosus	Sculptured goby	SB	MS	ZB
Callogobius depressus	Flathead goby	SB	MS	ZB
Papillogobius punctatus	Red-spot goby	SB	ES	ZB
Tridentiger trigonocephalus	Trident goby	SB	MS	ZB
Pseudorhombus jenynsii	Small-toothed flounder	D	MM	ZB
Ammotretis rostratus	Longsnout flounder	D	MM	ZB
Ammotretis elongatus	Elongate flounder	D	MM	ZB
Cynoglossus broadhursti	Southern tongue sole	D	MS	ZB
Acanthaluteres brownii	Spiny-tailed Leatherjacket	D	MS	OV
Brachaluteres jacksonianus	Southern pygmy leatherjacket	D	MS	OV

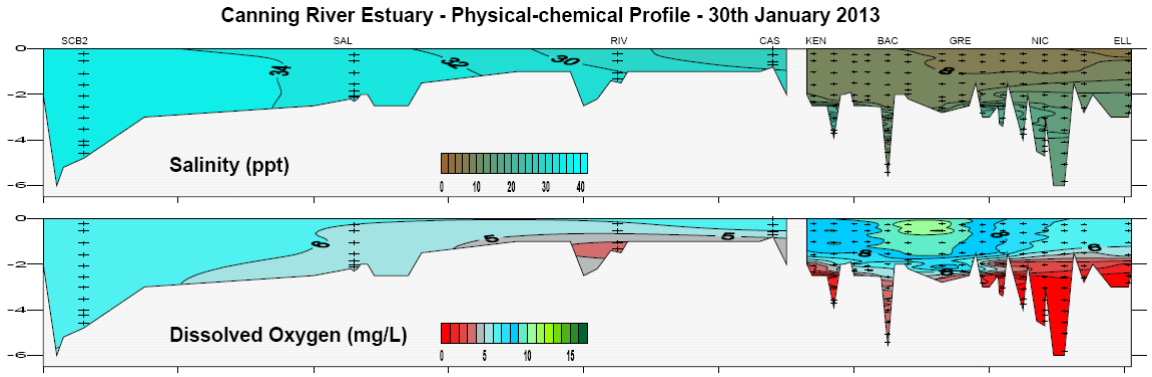
Species name	Common name	Habitat guild	Estuarine Use guild	Feeding Mode guild
Scobinichthys granulatus	Rough Leatherjacket	D	MS	OV
Chaetodermis pencilligera	Tasselled leatherjacket	D	MS	OV
Meuschenia freycineti	Sixspine leatherjacket	D	MM	OV
Monacanthus chinensis	Fanbellied Leatherjacket	D	MM	OV
Eubalichthys mosaicus	Mosaic leatherjacket	D	MS	OV
Acanthaluteres vittiger	Toothbrush Leatherjacket	D	MS	OV
Acanthaluteres spilomelanurus	Bridled Leatherjacket	D	MM	OV
Torquigener pleurogramma	Blowfish / banded toadfish	BP	MM	OP
Contusus brevicaudus	Prickly toadfish	BP	MS	OP
Polyspina piosae	Orange-barred puffer	BP	MS	OP
Diodon nicthemenus	Globefish	D	MS	ZB
Scorpis aequipinnis	Sea sweep	P	MS	ZP
Neatypus obliquus	Footballer sweep	P	MS	ZP

Appendix: (iv) Average salinities measured across all nearshore and offshore sampling sites during 2012 and 2013.

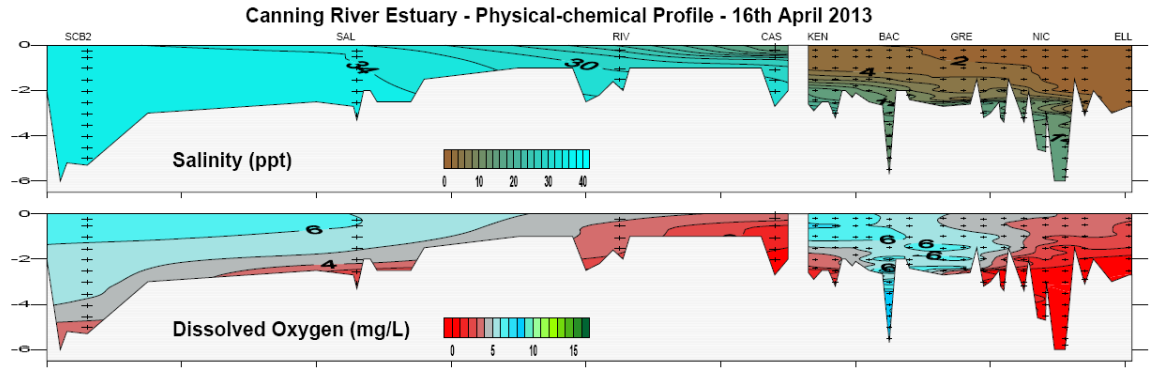
	2012		2013	
	Summer	Autumn	Summer	Autumn
Nearshore	25.3	28.9	30.6	30.6
Offshore (surface)	26.0	30.4	30.9	30.6
Offshore (bottom)	26.4	31.7	31.5	32.5

<u>Appendix:</u> (v) Vertical contour plots of salinity and dissolved oxygen concentrations (mg/L) measured at monitoring stations along the length of the Swan Canning Estuary on occasions closely corresponding to fish community sampling of:

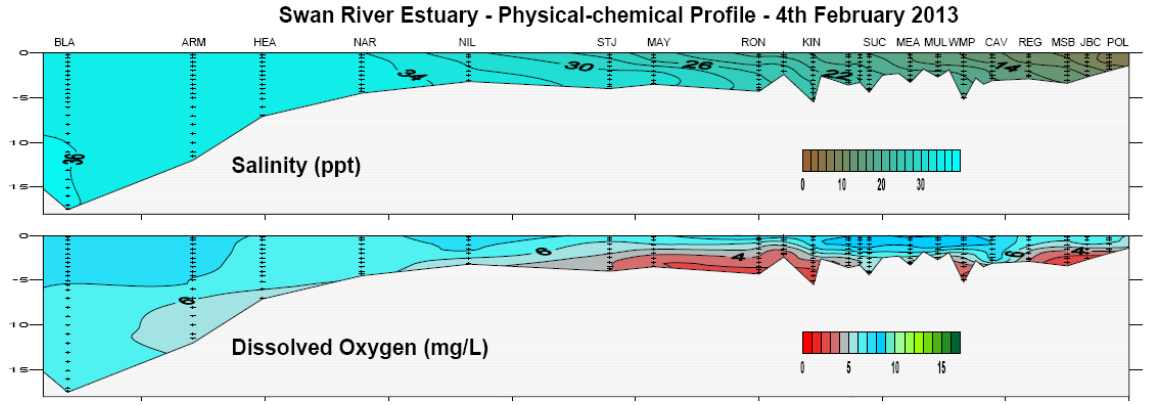
CE zone in summer 2013



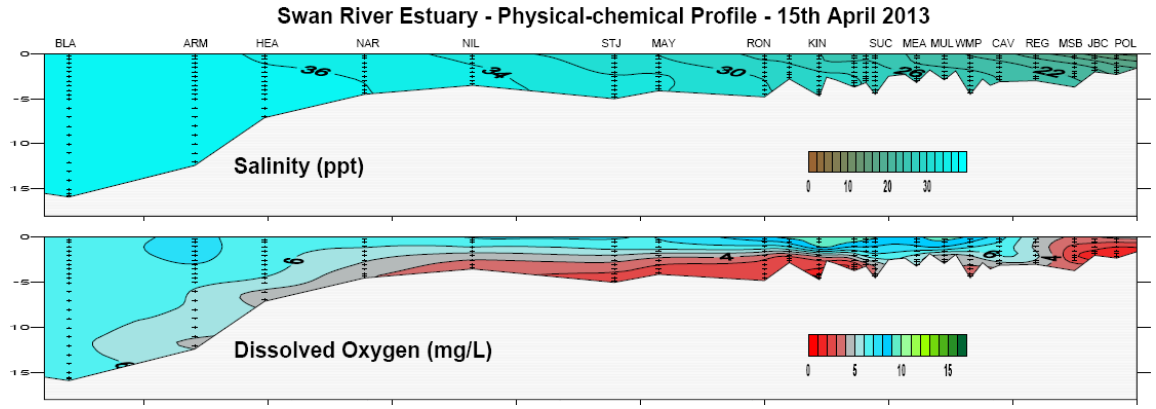
CE zone in autumn 2013



LSCE, MSE and USE zones in summer 2013



USE zone in autumn 2013



LSCE and MSE zones in autumn 2013