Assessment of the condition of the Swan Canning Estuary in 2017, based on the Fish Community Index of estuarine condition

Final report

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Executive summary

This report, commissioned by the Department of Biodiversity, Conservation and Attractions, Parks and Wildlife Service, describes the monitoring and evaluation of fish communities in the Swan Canning Riverpark during 2017 and applies the Fish Community Index (FCI) that has been developed as a measure of the ecological condition of the Swan Canning Estuary. This index, versions of which were developed for both the shallow, nearshore waters of the estuary and also for its deeper, offshore waters, integrates 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 management zones of the estuary (Lower Swan Canning Estuary, LSCE; Canning Estuary, CE; Middle Swan Estuary, MSE; Upper Swan Estuary, USE) during summer and autumn of 2017. As many fish as possible were returned to the water alive after they had been identified and counted. 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 established scoring thresholds to determine ecological condition grades (A–E) for each zone and for the estuary as a whole, based on the composition of the fish community.

Nearshore Fish Communities

The nearshore waters of the estuary as a whole were in fair-good condition (C/B) during 2017, consistent with a trend of good to fair (B/C) condition assessments in recent years. The nearshore condition in 2017 represents a decrease from that observed during the previous year, which is attributable to the unusually high summer flows that occurred following significant rainfall in February.

The average nearshore FCI scores for each of the zones of the Swan Canning Estuary show that all were in fair (C) condition in summer 2017. During autumn, the condition of the CE remained fair, whilst that of the LSCE, MSE and USE zones increased by 4–8 points from summer. These increases may in part reflect the movement of fish into nearshore waters from deeper offshore waters, which were experiencing prolonged hypoxic (low oxygen) conditions during autumn (see below).

Small-bodied, schooling species of hardyheads (Atherinidae) and gobies (Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2017, with seven of the nine most abundant nearshore species overall belonging to these families. In contrast to recent years, during which species with more marine affinities tended to dominate the catches, the most abundant fish in nearshore waters during 2017 was Wallace's hardyhead (*Leptatherina wallacei*). This atherinid, which was the dominant species in all zones except the LSCE, exhibits a preference for less saline waters and so benefitted from the marked freshwater flows that characterised the 2017 monitoring period. Other abundant species belonging to the Gobiidae and Atherinidae included the Elongate hardyhead (*Atherinosoma elongata*) in the LSCE, the Bluespot goby (*Pseudogobius olorum*) in the USE, the Red-spot goby (*Favonigobius punctatus*) in the LSCE and MSE, and the tropical hardyhead *Craterocephalus mugiloides* in the CE and MSE.

As is typical for this and similar estuaries in south-western Australia, the total number of species recorded in each zone declined in an upstream direction, from 25 species in the LSCE to just 13 species

in the USE. Fewer species were recorded from the nearshore waters of the USE in 2017 than during comparable monitoring in previous years. This reflects the significant freshwater flows and thus lower salinities that occurred in this part of the estuary during the 2017 monitoring period; conditions that are less favourable for a large number of the marine-associated and estuarine species that inhabit this system.

Offshore fish communities

The ecological condition of the estuary's offshore waters during summer of 2017 was good (B) in the LSCE and MSE, reflecting the sampling of these zones before the onset of significant river flows. In contrast, the summer condition of the USE, which was sampled after the disruption of the major flow event, was fair-poor (C/D). This is attributable to the fresher conditions that were present throughout this zone at this time, causing many of the marine and estuarine species that had been present in the USE to move downstream into more favourable salinities. The major flows, and their subsequent impacts on salinities and oxygen levels throughout the estuary, also had a marked impact on the condition of the estuary's offshore habitats into autumn. With the exception of the LSCE, the ecological condition of all zones (and the estuary as a whole) became poor (D) during autumn. In particular, the stratified conditions and severe and extensive hypoxia (low dissolved oxygen) that persisted throughout the MSE during April and May caused the offshore condition of that zone to decline by almost 20 points, from good (B) in summer to poor (D) in autumn.

The effects of the flow-induced hypoxic event in the Swan Estuary during 2017 caused the mean offshore FCI score for the estuary as a whole to decline to below 52. Overall, the ecological condition of the Swan Canning Estuary was therefore assessed as fair (C) during 2017, representing a continuing decrease from the pattern of good-fair (B/C) or fair-good (C/B) condition assessments that have been recorded for the offshore waters since 2011.

As in the five previous years of monitoring, Perth herring (*Nematalosa vlaminghi*) was among the dominant species in gill net catches from all four zones, comprising 31–35% of the catches from the LSCE and USE, and 56–58% of those from the CE and MSE. However, the lower parts of the system were also characterised by marine-associated species (Silver trevally and Southern eagle ray in the LSCE and Tailor and Tarwhine in the CE), whilst the upper zones (MSE and USE) were characterised by the estuarine species, Yellowtail grunter and Black bream, and by Sea mullet, a marine migrant species whose juveniles in particular show an affinity for lower salinity conditions.

Overall

In summary, and across the estuary as a whole, the ecological condition of nearshore waters in 2017 was assessed as fair-good (C/B), while that of the offshore waters of the system was assessed as fair (C), based on fish communities. These results indicate slightly poorer ecological condition of the system during 2017 compared to 2016, reflecting the impact of atypical summer river flows on the estuary during the current monitoring period. The resulting effects on estuarine environmental conditions included marked declines in salinities throughout much of the system, followed by the development of highly stratified and low oxygen conditions that moved upstream during autumn. The ecological consequences of these changes were most evident in the offshore waters of the MSE, whose condition decreased by almost 20 points, from good (B) in summer to poor (D) in autumn.

Assessment of the condition of the Swan Canning Estuary in 2017, based on the Fish Community Index of estuarine condition

Contents

1. Background

The Department of Biodiversity, Conservation and Attractions works with other government organizations, local government authorities, community groups and research institutions to reduce nutrient and organic loading to the Swan Canning Estuary and river system. This is a priority issue for the waterway that has impacts on water quality, ecological health and community benefit.

Environmental monitoring for the waterway includes water quality reporting in the estuary and catchment and reporting on ecological health. Reporting on changes in fish communities provides insight into the biotic integrity of the system and complements water quality reporting.

The Fish Community Index (FCI) was developed by Murdoch University, through a collaborative project (2007–2012) between the Swan River Trust, Department of Fisheries and Department of Water (Valesini et al. 2011, Hallett et al. 2012, Hallett and Valesini 2012, Hallett 2014), for assessing the ecological condition of the Swan Canning Estuary. The FCI has been subjected to extensive testing and validation over a period of several years (e.g. Hallett and Valesini 2012, Hallett 2014), and has been shown to be a sensitive and robust tool for quantifying ecological health responses to local-scale environmental perturbations and the subsequent recovery of the system following their removal (Hallett 2012, Hallett et al. 2012, 2016).

2. Rationale

Versions of the Fish Community Index 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, as do the methods used to sample them. These 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 FCI therefore provides a means to assess an important component of the ecology of the system and how it responds to, and thus reflects, changes in estuarine condition.

The responses of estuarine fish communities to increasing ecosystem stress and degradation (*i.e.* declining ecosystem health or condition) may be summarised in a conceptual model (Fig. 1). In response to increasing degradation of estuarine ecosystems, fish species with specific habitat, feeding or other environmental requirements will tend to become less abundant and diverse, whilst a few species with more general requirements become more abundant. This leads ultimately to an overall reduction in the number and diversity of fish species (Gibson et al. 2000; Whitfield and Elliott 2002; Villéger et al. 2010; Fonseca et al. 2013). 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 tend to 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 that is subjected to fewer human stressors (see right side of Fig. 1; noting that this conceptual diagram represents either end of a continuum of ecological condition from very poor to very good).

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

Each of the metrics that make up the FCI 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 a FCI 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 FCI scores (see section 4 for more details).

3. Study objectives

This report describes the monitoring and evaluation of fish communities in the Swan Canning Riverpark during 2017 for the purposes of applying the Fish Community Index 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 Index is calculated for nearshore and offshore waters in each management zone and for the estuary overall. The information shall be presented as quantitative FCI scores (0–100), qualitative condition grades

(A–E) 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 could feed into a broader estuarine reporting framework.

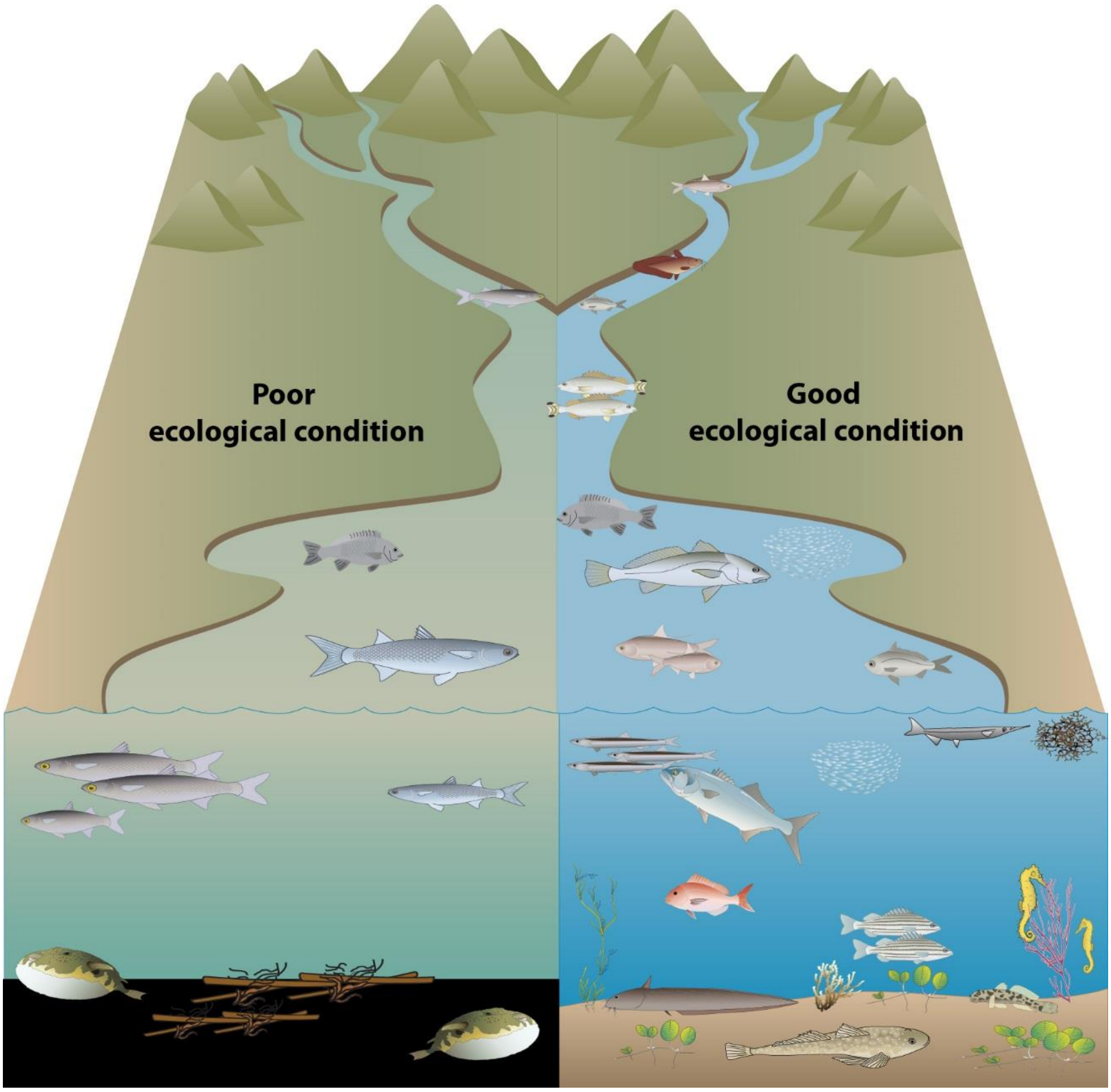


Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of poor and good ecological condition. (Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].)

4. Methods

Fish communities were sampled at six nearshore and six offshore sites in each of four management 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 (16 January–15 March) and autumn (3–24 May) 2017. Note that a significant freshwater flow event occurred during the summer sampling season, associated with marked rainfall in late January and midto early February. The resulting high river flows meant that no sampling of the fish community could be undertaken during February (as per the sampling protocol detailed in appendix ii), and summer sampling was therefore completed in early March.

Nearshore waters were sampled using a 21.5 m seine net that 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 (Fig. 3). Offshore waters were sampled using 160 m-long, sunken, multimesh gill nets, each consisting of eight 20 m-long panels with stretched mesh sizes of 35, 51, 63, 76, 89, 102, 115 and 127 mm (Fig. 3). These 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 be identified immediately to species (*e.g.* larger species that 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, euthanised in 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 abundances of each fish species in 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, and the metric scores in turn combined to form the FCI scores. The detailed methodology for how this is achieved is provided in Hallett and Valesini (2012), but can be summarised simply 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 FCI score (0–100) for each sample.
4. Compare the FCI score to the thresholds used to determine the condition grade for each sample (Table 2; Hallett, 2014), 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 FCI scores and condition grades for nearshore and offshore samples collected during summer and autumn 2017 were then examined to assess the condition of the Swan Canning Estuary during this period and compared to previous years.

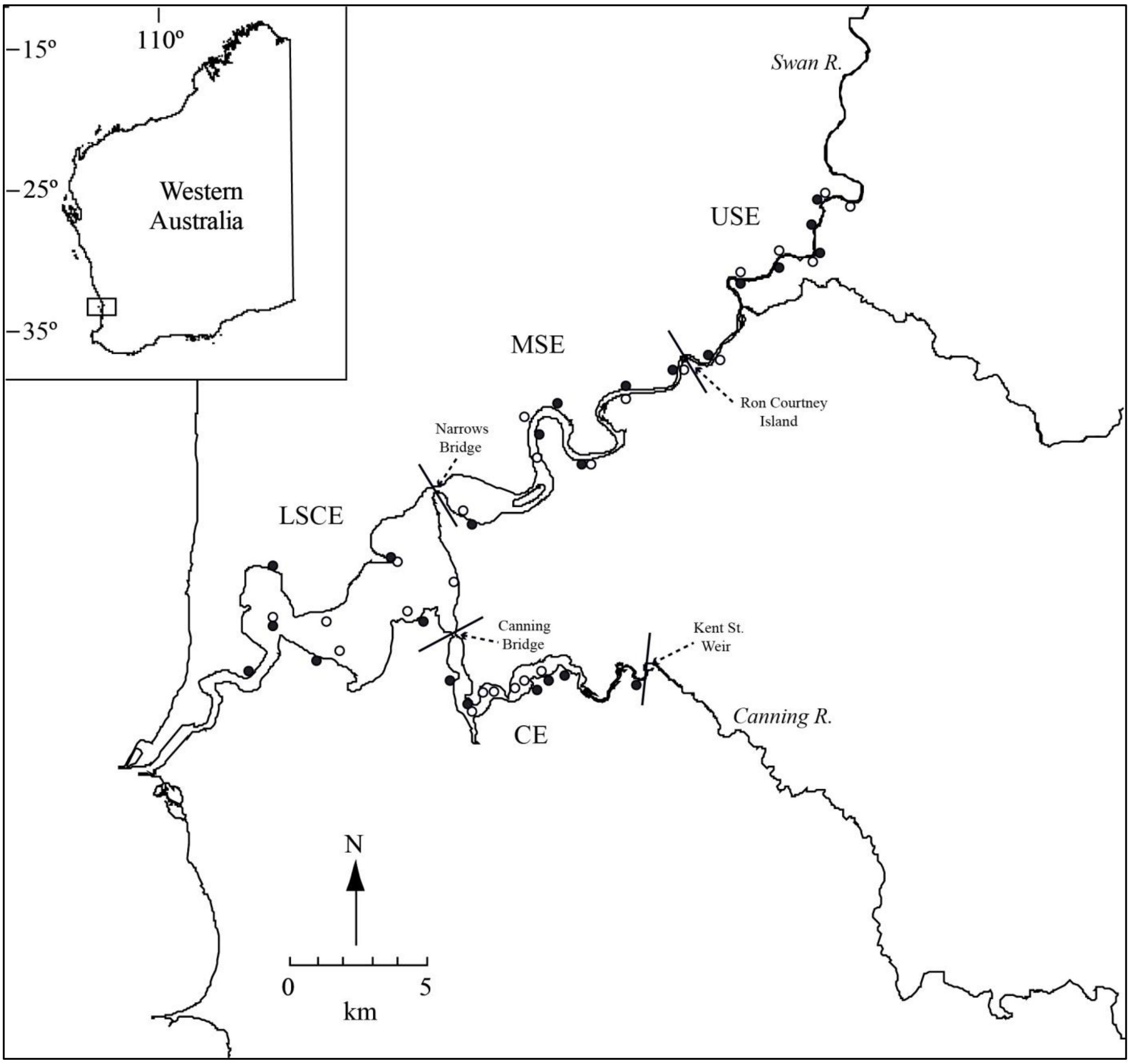


Figure 2. Locations of nearshore (black circles) and offshore (open circles) sampling sites for the Fish Community Index of estuarine condition. LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary.

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

Condition grade	Nearshore FCI scores	Offshore FCI 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, Jen Eliot and Kerry Trayler, DBCA).

5. Results and discussion

5.1 Context: water quality and environmental conditions during the 2017 monitoring period

Environmental conditions throughout the Swan Canning Estuary during the 2017 monitoring period were highly atypical in comparison to those recorded in recent years. This reflected the marked freshwater flows that were delivered to the system following heavy rainfall in late January/early February of this year. As a result, average salinities measured throughout the estuary during sampling in 2017 were lower than those recorded during each of the five preceding years (Appendix iv).

Vertical contour plots (Appendix v), of interpolated salinities and dissolved oxygen (DO) concentrations measured at regular water quality monitoring sites along the length of the Swan Canning Estuary, provide more detail of the environmental conditions present throughout the system during the monitoring period. Conditions throughout the Swan Estuary in January 2017 were similar to those of the previous year, with brackish conditions in the USE zone, yet relatively good levels of oxygenation and little stratification throughout. However, significant flows during early to mid-February resulted in almost fresh conditions throughout the USE and MSE and the development of highly stratified conditions throughout much of the LSCE. These patterns persisted until mid-March, by which time hypoxic conditions (<2 mg/L dissolved oxygen) had become established in the bottom waters of the LSCE between the Narrows and Armstrong Spit. The predicted spatial extent of hypoxia across this zone is illustrated in Fig. 4. From mid-March to mid-May, this extensive area of hypoxic bottom-water shifted upstream into the MSE and USE as river flows decreased and the salt wedge penetrated further up the system (Appendix v). Further rainfall in mid-May resulted in flows that exacerbated the stratification and re-established hypoxic conditions in the MSE and USE.

Conditions in the CE zone were well-mixed, saline and adequately oxygenated during January of 2017 (Appendix v). By mid-February, however, the significant freshwater flows had led to a highly stratified water column, with hypoxic bottom waters evident throughout deeper parts of the CE. This hypoxia extended across much of the CE during March, after which time conditions gradually improved as flows subsided and saline conditions became re-established further upstream.

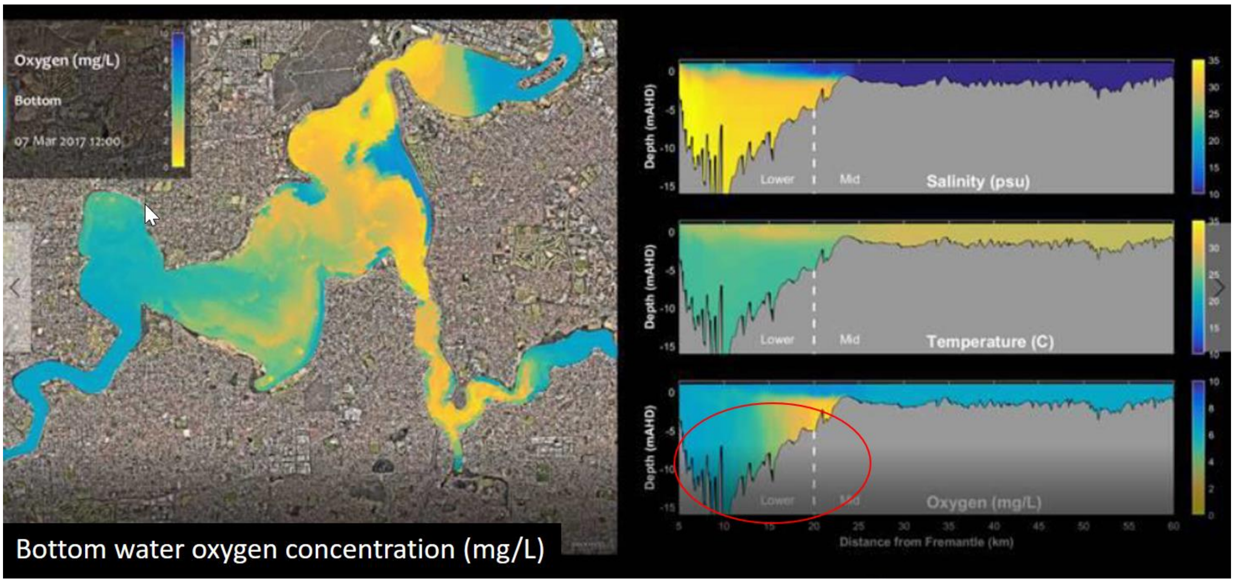


Figure 4. Modelled data showing the predicted areal extent of subsurface hypoxia (left) in the Lower Swan Canning Estuary, associated with stratified physical conditions (right). Circle on right profile delineates zone shown in left. Acknowledgment: Aquatic Ecodynamics Research Group, University of Western Australia.

5.2 Description of the fish community of the Swan Canning Estuary during 2017

An estimated 19,038 fish, belonging to 33 species, were caught in seine net samples collected from the nearshore waters of the Swan Canning Estuary during summer and autumn 2017. As is typical for this and similar estuaries in south-western Australia, the total number of species recorded in each zone declined in an upstream direction, from 25 species in the LSCE to just 13 species in the USE (Table 3). Fewer species were recorded from the nearshore waters of the USE in 2017 than during comparable monitoring in previous years. This reflects the significant freshwater flows and thus lower salinities that occurred in this part of the estuary during the 2017 monitoring period; conditions that are less favourable for a large number of the marine-associated and estuarine species that inhabit this system.

The hardyheads (Atherinidae) and gobies (Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2017, with seven of the nine most abundant nearshore species overall belonging to these families. Atherinids and gobies typically dominate the nearshore fish communities of estuaries across southwestern Australia, with different species partitioned throughout an estuary according to their environmental preferences (Prince and Potter 1983; Gill and Potter 1993). In contrast to recent years, in which species with affinities for more saline waters tended to dominate the catches (e.g. *Craterocephalus mugiloides*, *Leptatherina presbyteroides*), the most abundant fish in nearshore waters during 2017 was Wallace's hardyhead (*Leptatherina wallacei*). This atherinid, which was the dominant species in all zones except the LSCE (comprising 25.8–65.8% of all fish in the CE, MSE and USE; Table 3), exhibits a preference for less saline waters (Potter et al. 2015), and so benefitted from the marked freshwater flows that characterised the 2017 monitoring period. In contrast, *A. elongata*, which prefers more saline waters and can tolerate highly elevated salinities (Veale et al. 2014), was found predominantly in the LSCE. Other abundant species belonging to the Gobiidae and Atherinidae included the Bluespot goby (*Pseudogobius olorum*) in the USE, the Red-spot goby (*Favonigobius punctatus*) in the LSCE and MSE, and the tropical hardyhead *Craterocephalus mugiloides* in the CE and MSE (Table 3). In addition, the Western striped grunter (*Pelates octolineatus*) was abundant in the LSCE (43% of the catch), as was the introduced Mosquitofish (*Gambusia holbrooki*) in the CE and USE (18% and 4%, respectively).

Samples collected from offshore waters in summer and autumn 2017 using gill nets returned 1,125 fish, comprising 19 species (Table 4). The total number of species recorded from each zone was relatively consistent (9–11 species), yet the species comprising these totals differed markedly between the lower and upper extents of the estuary. As in the five previous years of monitoring, Perth herring (*Nematalosa vlaminghi*) was among the dominant species in offshore waters from all four zones, comprising 31–35% of the catches from the LSCE and USE, and 56–58% of those from the CE and MSE (Table 4). However, the lower parts of the system were also characterised by marine-associated species (Silver trevally and Southern eagle ray in the LSCE and Tailor and Tarwhine in the CE), whilst the upper zones (MSE and USE) were characterised by the estuarine species, Yellowtail grunter and Black bream, and by Sea mullet, a marine migrant species whose juveniles in particular show an affinity for lower salinity conditions (Whitfield et al. 2012).

Overall, the nearshore and offshore fish communities of the Swan Canning Estuary in 2017 were again broadly similar in species composition to those observed during equivalent monitoring conducted annually since 2012. Yet, the increased prevalence of estuarine and freshwater-associated species during 2017 reflected the influence of the freshwater flows that dominated the system during February and dramatically altered environmental conditions throughout the estuary. The following sections briefly describe the effects of this event on the distribution of introduced freshwater species in the estuary, before turning to a consideration of its impacts on the broader ecological condition of the Swan Canning Estuary.

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 2017. 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. * denotes introduced species

		LSCE (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
Species	**Common name**	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution	Average density (fish/100m^2)	% contribution
Leptatherina wallacei	Wallace's hardyhead	0.1	<0.1	**316.9**	**56.0**	**31.0**	**25.8**	**263.9**	**65.8**
Pseudogobius olorum	Blue-spot goby	0.1	<0.1	25.8	4.6	11.1	9.2	**98.4**	**24.5**
Pelates octolineatus	Western striped grunter	**119.6**	**42.6**	-	-	4.9	4.1	0.1	<0.1
Gambusia holbrooki	Mosquito fish *	**-**	**-**	**102.4**	**18.1**	0.2	0.2	**14.7**	**3.7**
Craterocephalus mugiloides	Mugil's hardyhead	6.6	2.4	**82.5**	**14.6**	**24.2**	**20.2**	1.9	0.5
Atherinosoma elongata	Elongate hardyhead	**82.1**	**29.3**	4.3	0.8	0.4	0.3	0.6	0.1
Favonigobius punctatus	Red-spot goby	**25.5**	**9.1**	6.4	1.1	**32.2**	**26.8**	5.0	1.3
Leptatherina presbyteroides	Presbyter's hardyhead/ silverfish	17.1	6.1	0.4	<0.1	<0.1	<0.1	-	-
Arenigobius bifrenatus	Bridled goby	<0.1	<0.1	10.7	1.9	0.5	0.4	2.9	0.7
Acanthopagrus butcheri	Black bream	1.4	0.5	6.0	1.1	3.6	3.0	2.4	0.6
Ostorhinchus rueppelli	Gobbleguts	10.2	3.6	0.9	0.2	1.2	1.0	-	-
Aldrichetta forsteri	Yellow-eye mullet	0.5	0.2	2.2	0.4	5.2	4.4	-	-
Afurcagobius suppositus	Southwestern goby	-	-	0.4	<0.1	0.4	0.3	7.2	1.8
Favonigobius lateralis	Long-finned goby	7.3	2.6	0.2	<0.1	-	-	-	-
Amniataba caudavittata	Yellowtail grunter	0.3	0.1	3.8	0.7	1.8	1.5	-	-
Nematalosa vlaminghi	Perth herring	-	-	<0.1	<0.1	1.9	1.6	3.0	0.7
Torquigener pleurogramma	Blowfish/Banded toadfish	3.8	1.4	0.4	<0.1	<0.1	<0.1	-	-
Atherinomorus vaigensis	Ogilby's hardyhead	1.4	0.5	0.1	<0.1	0.2	0.2	-	-
Sillago burrus	Western trumpeter whiting	1.2	0.4	<0.1	<0.1	0.4	0.4	-	-
Mugil cephalus	Sea mullet	<0.1	<0.1	0.6	0.1	0.4	0.4	0.3	<0.1
Geophagus brasiliensis	Pearl cichlid *	-	-	1.3	0.2	<0.1	<0.1	-	-
Hyperlophus vittatus	Sandy sprat	1.2	0.4	-	-	-	-	-	-

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
(continued)									
Stigmatopora argus	Spotted pipefish	0.8	0.3	-	-	-	-	-	-
Neoodax baltatus	Little weed whiting	0.7	0.3	-	-	-	-	-	-
Gerres subfasciatus	Roach	-	-	0.1	<0.1	<0.1	<0.1	0.5	0.1
Rhabdosargus sarba	Tarwhine	0.4	0.2	-	-	-	-	-	-
Gymnapistes marmoratus	Devilfish	0.3	0.1	-	-	-	-	-	-
Platycephalus westraliae	Yellowtail flathead	<0.1	<0.1	0.1	<0.1	-	-	-	-
Sillago bassensis	Southern school whiting	-	-	-	-	0.1	0.1	-	-
Sillaginodes punctata	King George whiting	<0.1	<0.1	-	-	-	-	-	-
Monacanthus chinensis	Fan-bellied leatherjacket	<0.1	<0.1	-	-	-	-	-	-
Galaxias occidentalis	Western minnow	-	-	<0.1	<0.1	-	-	-	-
Myliobatis tenuicaudatus	Southern eagle ray	-	-	-	-	<0.1	<0.1	-	-
		25 Species		**23 Species**		**23 Species**		**13 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
		281	**3,908**	**566**	**7,878**	**120**	**1,672**	**401**	**5,580**

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 2017. 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. * denotes introduced species

		LSCE (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
Species	**Common name**	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	**5.5**	**35.7**	**8.5**	**56.0**	**18.1**	**58.2**	**10.0**	**31.2**
Amniataba caudavittata	Yellowtail grunter	-	-	0.7	4.4	**7.2**	**23.1**	**11.5**	**35.8**
Acanthopagrus butcheri	Black bream	-	-	-	-	0.3	1.1	**6.3**	**19.7**
Mugil cephalus	Sea mullet	-	-	0.3	2.2	**2.3**	**7.2**	3.3	10.1
Pomatomus saltatrix	Tailor	2.0	13.0	**2.3**	**14.8**	1.0	3.2	-	-
Pseudocaranx dentex	Silver trevally	**2.4**	**15.7**	-	-	-	-	-	-
Myliobatis tenuicaudatus	Southern eagle ray	**2.3**	**15.1**	-	-	-	-	-	-
Platycephalus westraliae	Yellowtail flathead	1.4	9.2	<0.1	0.6	0.3	0.8	0.5	1.6
Gerres subfasciatus	Roach	0.3	1.6	0.8	5.5	1.1	3.5	-	-
Rhabdosargus sarba	Tarwhine	-	-	**1.7**	**11.0**	-	-	-	-
Engraulis australis	Southern anchovy	0.3	2.2	-	-	0.6	1.9	<0.1	0.3
Pelates octolineatus	Western striped grunter	-	-	0.8	5.0	0.2	0.5	-	-
Elops machnata	Giant herring	0.7	4.3	-	-	<0.1	0.3	<0.1	0.3
Sillago burrus	Western trumpeter whiting	0.4	2.7	-	-	-	-	-	-
Argyrosomus japonicus	Mulloway	-	-	-	-	-	-	0.3	0.8
Platycephalus laevigatus	Rock flathead	<0.1	0.5	-	-	-	-	-	-
Bidyanus bidyanus	Silver perch *	-	-	-	-	-	-	<0.1	0.3
Ostorhinchus rueppelli	Gobbleguts	-	-	<0.1	0.6	-	-	-	-
Pseudorhombus jenynsii	Small-toothed flounder	-	-	-	-	<0.1	0.3	-	-
		10 Species		**9 Species**		**11 Species**		**9 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
		15	**185**	**16**	**182**	**31**	**373**	**32**	**385**

5.3 Incidence of introduced species in the Swan Canning Estuary during 2017

Three species of introduced freshwater fish were encountered in the Swan Canning Estuary during monitoring in 2017 (Fig. 5). More than 1,600 individuals of the Mosquitofish (*Gambusia holbrooki*) were obtained from catches in the nearshore waters of the CE, MSE and USE zones. This North American poecilliid species, which was introduced to Australia in the first half of the twentieth century (Beatty and Morgan 2013), is now widespread among the estuaries of southwestern Australia and is commonly caught in the fresh to brackish waters of the upper Swan Canning Estuary (e.g. Hoeksema and Potter 2006). The Pearl cichlid (*Geophagus brasiliensis*), a tropical South American species, was also encountered again during monitoring for the FCI. Nineteen individuals of this invasive species, which was first recorded in the Swan Canning system in 2006 (Beatty and Morgan 2013), were captured from the nearshore waters of the CE and MSE. Finally, a single individual of Silver perch (*Bidyanus bidyanus*) was caught in a gill net at a site in the USE zone during May 2017. This terapontid, introduced to Western Australia from the eastern States of Australia in the late nineteenth century, has previously been reported, albeit infrequently, from the Swan River (Beatty and Morgan 2013). In the present case, the captured individual was probably flushed downstream by floodwaters from a farm dam into which it had been stocked (Stephen Beatty, Murdoch University, personal communication).

Figure 5. Introduced freshwater species recorded from the Swan Canning Estuary during Fish Community Index monitoring in 2017. From left to right; Pearl cichlid, *Geophagus brasiliensis* (image courtesy of David Morgan, Freshwater Fish Group & Fish Health Unit, Murdoch University); Mosquitofish, *Gambusia holbrooki* (image courtesy of Fishbase); Silver perch, *Bidyanus bidyanus* (author's own image).

5.4 Ecological condition in 2017 and comparison to other periods

Nearshore waters

The ecological condition (based on fish communities) of the nearshore waters of the Riverpark was generally fair (C) to good (B) during the 2017 monitoring period (Fig. 6). The condition of all zones was fair during summer 2017 (mean FCI scores 60–62), as was the average nearshore condition of the estuary overall, indicated by a mean FCI score of 61. During autumn, the condition of the CE remained fair, whilst that of the LSCE, MSE and USE zones increased by 4–8 points from summer. These increases may in part reflect the movement of fish into nearshore waters from deeper offshore waters that were experiencing hypoxic conditions in autumn (see below).

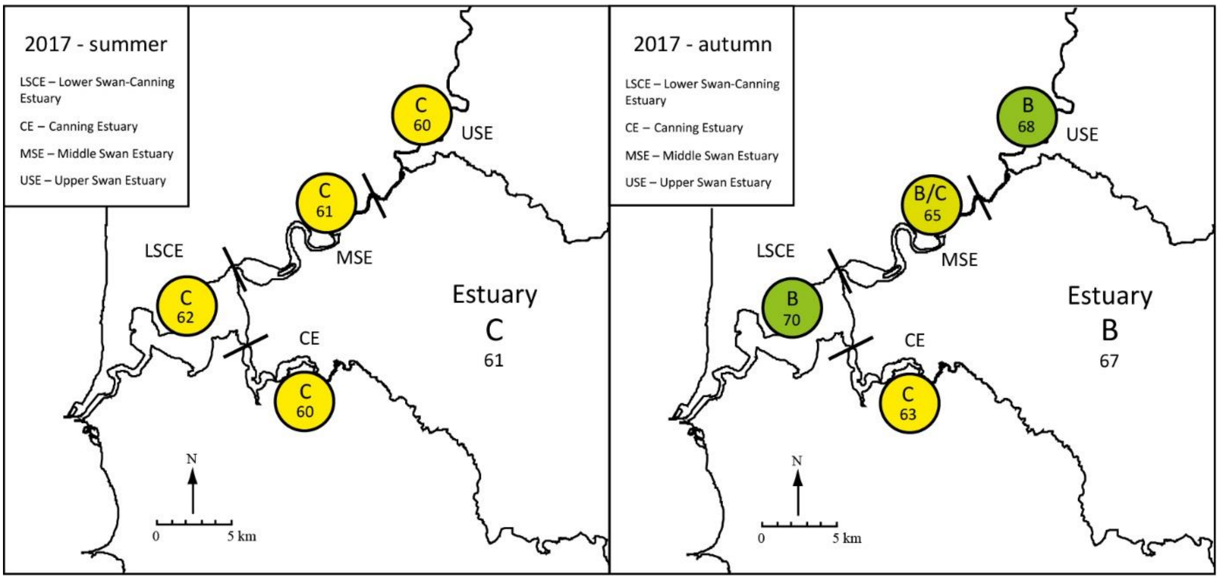


Figure 6. Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2017.

Results indicated that the nearshore waters of the estuary as a whole were in fair-good condition (C/B) during 2017, consistent with a trend of good to fair (B/C) condition assessments in recent years (Fig. 7). The nearshore condition in 2017 represents a decrease from that observed during the previous year, which is attributable to the marked differences in hydrological conditions between the two years. The 2016 monitoring period, and particularly summer of that year, saw low freshwater flows that resulted in relatively high salinities and well oxygenated conditions throughout much of the estuary. These conditions encouraged a greater number and diversity of marine species to enter the estuary and penetrate further upstream during 2016, leading to higher FCI scores (Hallett 2016). In contrast, the 2017 monitoring period was characterised by anomalously high freshwater flows during summer. These flows created unusually fresh conditions throughout the water column of the upper estuary during February, after which the water column became highly stratified as river flows subsided (Appendix v). Stratification resulted in a large area of bottom water in the LSCE, CE and lower parts of the MSE (i.e. Perth Water) becoming hypoxic (i.e. low dissolved oxygen conditions in deeper waters) by early March, and this hypoxic area extended and moved upstream in late March and April, remaining in place through much of May. These stratification-induced hypoxic events have well-documented effects on fish communities and FCI scores, including reduced species richness and declines in the proportions of bottom-dwelling species and those with specialist feeding requirements (e.g. Hallett 2016).

Radar plots of the nearshore metric scores for each zone in each season confirm that a small suite of metrics drove the poorer condition of the nearshore waters of the estuary during 2017. During summer, the FCI scores indicated relatively low numbers of species (particularly of those that spawn in the estuary) and higher proportions of *Pseudogobius olorum*, a tolerant species of goby that is associated with fresher conditions and siltier sediments. In autumn, FCI scores also reflected low numbers of species (and particularly of bottom-dwelling species and those with specialist feeding requirements) in the CE, MSE and USE zones (Fig. 8).

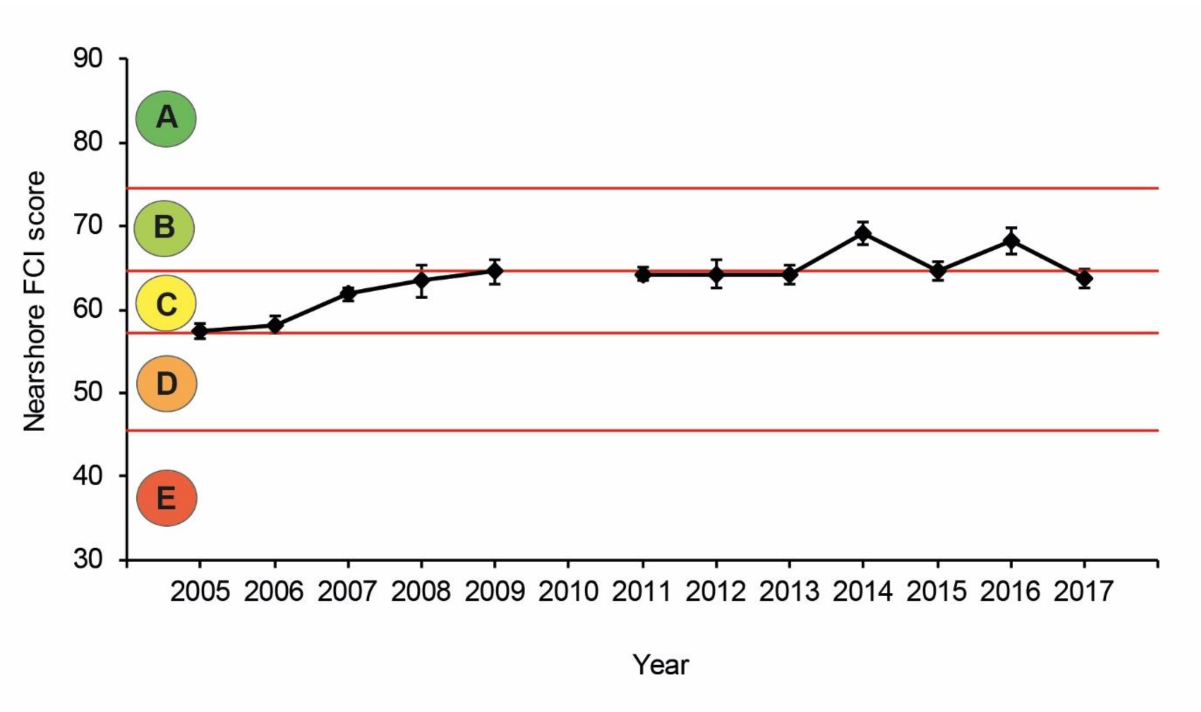
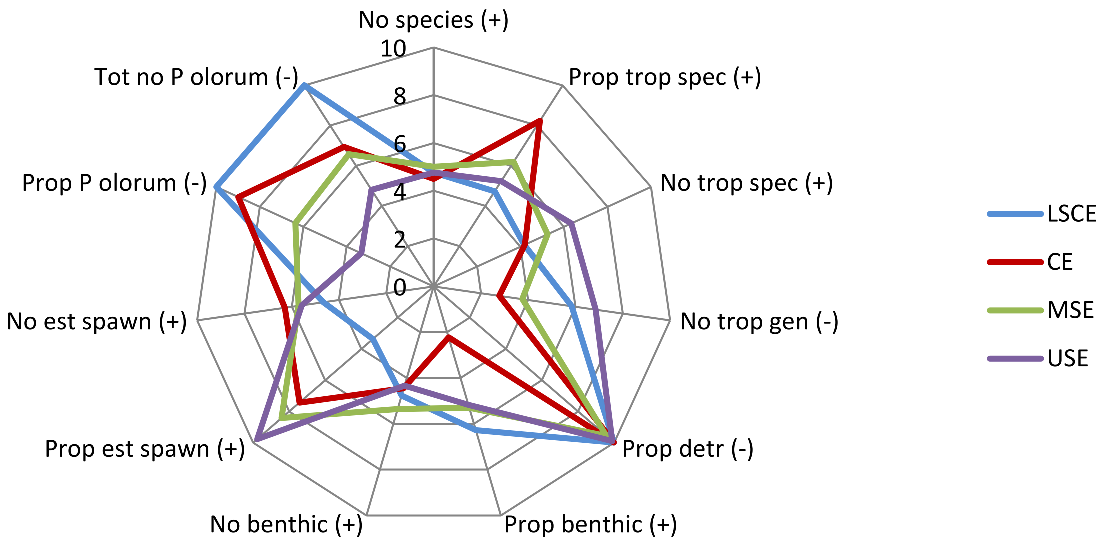


Figure 7. Trend plot of average (±SE) nearshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary as a whole, over recent years. Red lines denote boundaries between condition grades.

Offshore waters

The ecological condition of the Riverpark's offshore waters during summer of 2017 was good (B) in the LSCE and MSE (Fig. 9), reflecting the sampling of these zones before the onset of significant river flows. In contrast, the summer condition of the USE, which was sampled after the disruption of the major flow event, was fair-poor (C/D; mean FCI score of 51). This is attributable to the fresher conditions that were present throughout this zone at this time (appendix v), which would have caused many of the marine and estuarine species that had been present in the USE to move downstream into more favourable salinities, and/or into adjacent shallow waters. The major flows, and their subsequent impacts on salinities and oxygen levels throughout the estuary, also had a marked impact on the condition of the estuary into autumn. With the exception of the LSCE, the ecological condition of each zone (and the estuary as a whole) became poor (D) during autumn. In particular, the severe and extensive hypoxia that persisted throughout the MSE during April and May (see section 5.1 and appendix v) caused the condition of that zone to decline by almost 20 points, from good (B) in summer to poor (D) in autumn (Fig. 9). Similar responses of the ecological condition of the estuary to stratification-induced hypoxic events have been documented periodically since the commencement of annual FCI monitoring in 2012 (e.g. Hallett 2016).

(a) Summer 2017



(b) Autumn 2017

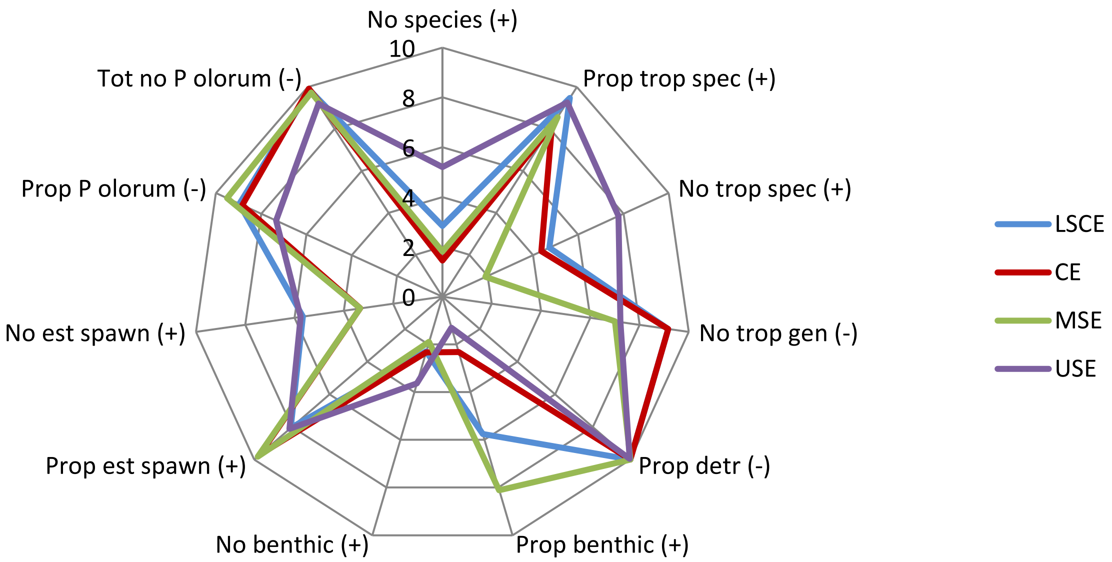


Figure 8. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2017. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names and explanations).

The FCI results from 2017 also parallel two other, previously observed patterns in the ecological condition of this system. Firstly, as typically observed in recent years, the offshore waters of the CE were in poor condition (D), perhaps reflecting the effects of hypoxia and/or algal blooms or other stressors on the fish communities of this zone. The poor condition of the CE in summer 2017 may also partly have been affected by localized high densities of *Chaetoceros minimus* (>100,000–200,000 cells/mL at Riverton Bridge, 17–24 January; unpublished data, Department of Biodiversity, Conservation and Attractions). Although no fish kills were recorded over this period, it is possible that at these densities the spines of these diatoms might irritate or damage fish gills and may therefore influence fish distribution. Secondly, the ecological condition of the estuary's offshore waters was once again generally poorer than that of its shallower, nearshore habitats, reflecting the greater susceptibility of the deeper parts of the system to a range of environmental stressors, including hypoxic events and algal blooms (Hallett et al. 2016).

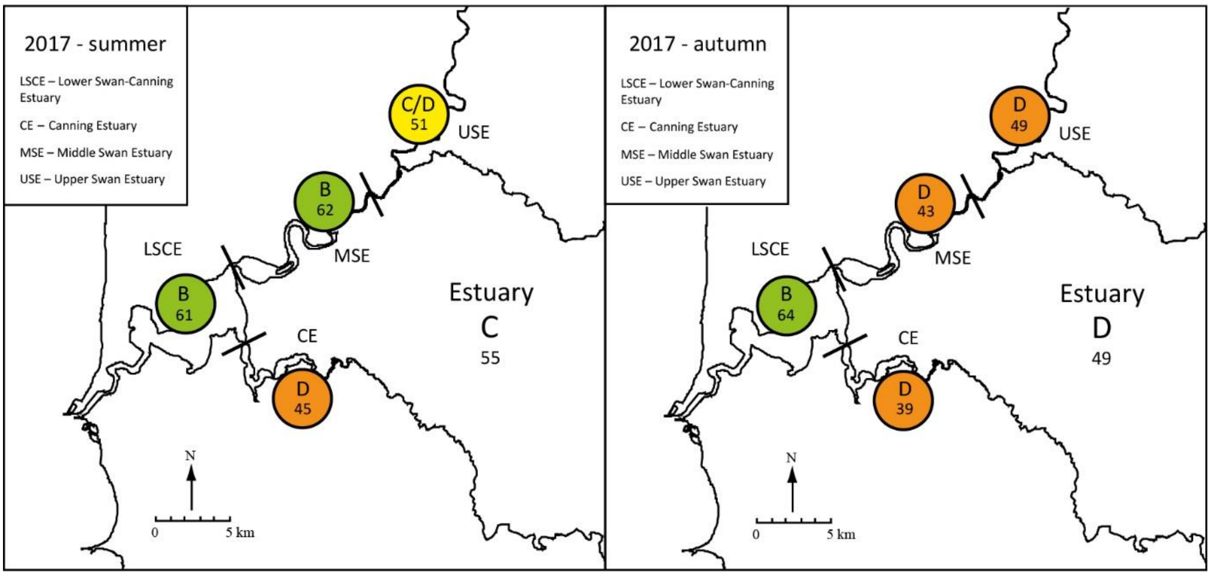


Figure 9. Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2017.

The effects of the flow-induced hypoxic event in the Swan Canning Estuary during 2017 caused the mean offshore FCI score for the estuary as a whole to decline to below 52. Overall, the ecological condition of the Swan Canning Estuary was therefore assessed as fair (C) during 2017, representing a continuing decrease from the pattern of good-fair (B/C) or fair-good (C/B) condition assessments that have been recorded for offshore waters since 2011 (Fig. 10). Work is currently underway to determine the environmental drivers of these longer-term trends, and particularly to establish the relationships between the timing and magnitude of river flows, the extent and severity of stratification-induced hypoxia, and the ecological condition of the estuary as quantified by the FCI.

Radar plots of offshore metric scores for each zone in each season shed further light on the responses of the fish community to the environmental conditions throughout the Swan Estuary during 2017. In particular, the marked decline in offshore FCI scores in the MSE during autumn was driven by decreases in the number of species and the diversity of fishes, and an increase in the proportion of species that feed on decomposing organic material (*e.g.* Sea mullet, Perth herring). This is indicated by lower average scores for *Number of species* and *Shannon-Wiener diversity* (both positive metrics) and for the *Proportion of detritivores* (a negative metric) during autumn (Fig. 11).

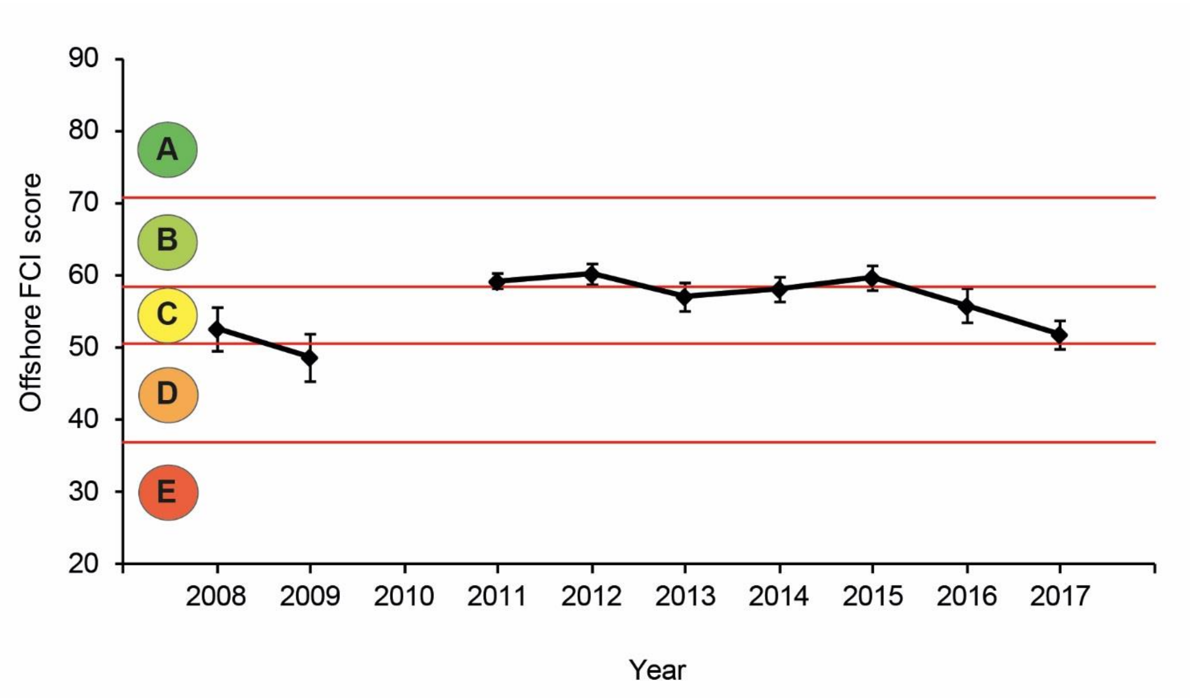


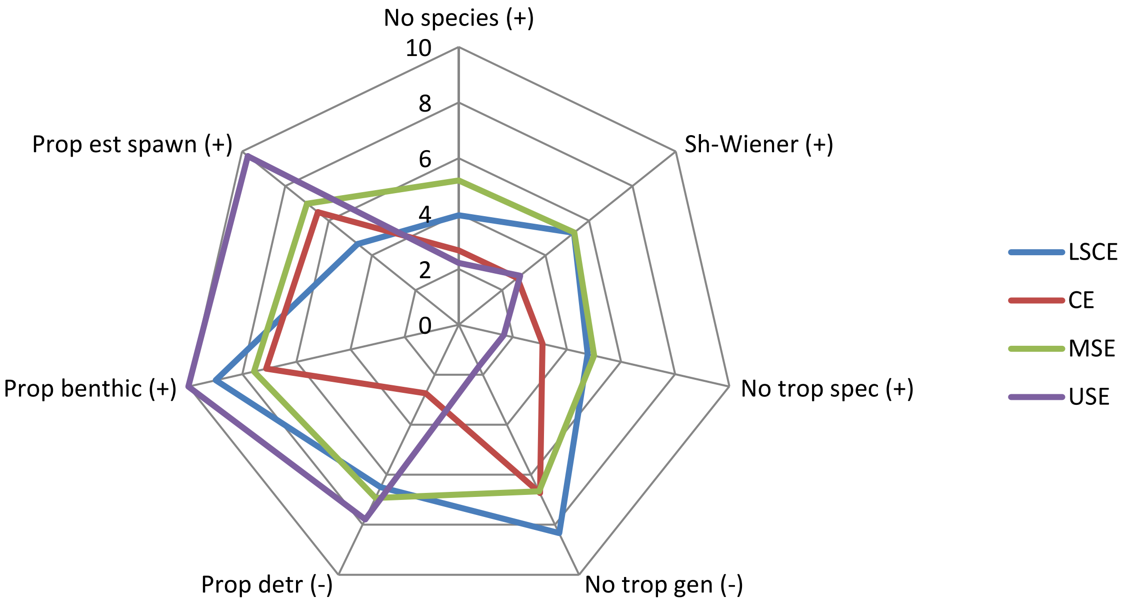
Figure 10. Trend plot of average (±SE) offshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary as a whole, over recent years. Red lines denote boundaries between condition grades.

Summary

The Fish Community Index considers the fish community as a whole and provides a means to assess how the structure and function of these communities in shallow nearshore and deeper offshore waters respond to a wide array of stressors affecting the ecosystem. Note that the FCI does not provide information on the population dynamics or health of particular species (*cf.* Cottingham et al. 2014), nor does it provide information on the size or status of the fish stocks in the estuary.

In summary, and across the estuary as a whole, the ecological condition of nearshore waters in 2017 was assessed as fair-good (C/B), while that of the offshore waters of the system was assessed as fair (C), based on fish communities. These results indicate slightly poorer ecological condition of both nearshore and offshore waters during 2017 compared to 2016, a finding that reflects the impact of atypical summer river flows on the estuary during the current monitoring period. The resulting effects on estuarine environmental conditions included marked declines in salinities throughout much of the system, followed by the development of highly stratified and low oxygen conditions that moved upstream during autumn. The ecological consequences of these changes were most evident in the offshore waters of the MSE, whose condition decreased by almost 20 points, from good (B) in summer to poor (D) in autumn.

(a) Summer 2017



(b) Autumn 2017

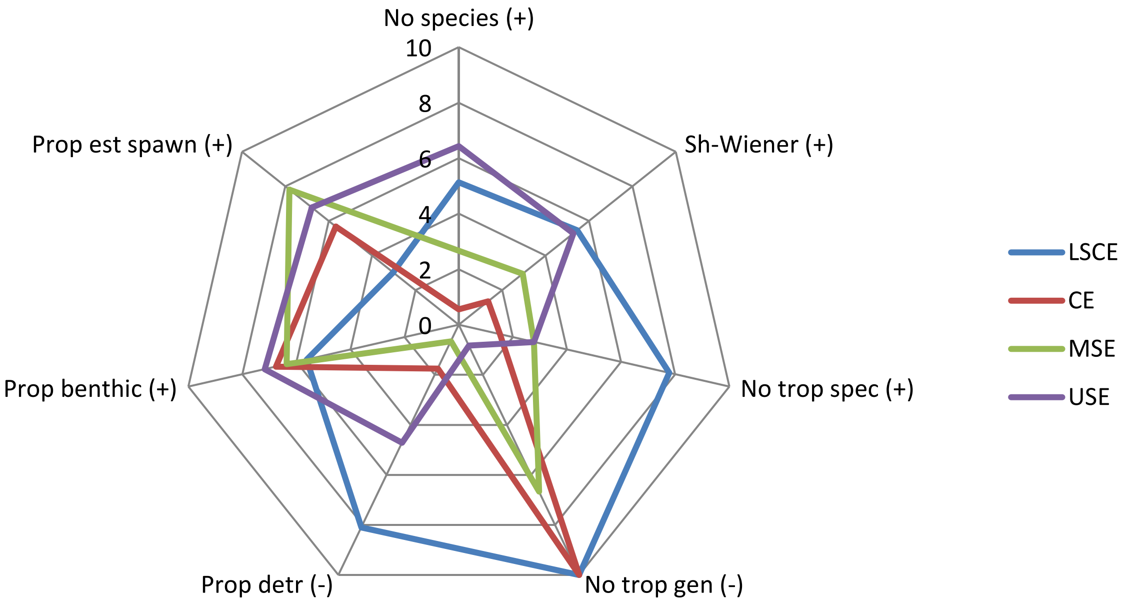


Figure 11. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2017. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names and explanations).

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<u>Appendix (i).</u> Descriptions of (a) nearshore and (b) offshore Fish Community Index monitoring sites. 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, euthanised 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.* on-line version), 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.

Rees, A.J.J., Yearsley, G.K., Gowlett-Holmes, K. and Pogonoski, J. Codes for Australian Aquatic Biota (on-line version). CSIRO Marine and Atmospheric Research, World Wide Web electronic publication, 1999 onwards. Available at: http://www.cmar.csiro.au/caab/. Last accessed 21st June 2017.

Appendix (iii). List of species 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 tenuicaudatus	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
Stigmatopora 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
Bidyanus bidyanus	Silver perch	BP	FM	OV
Pelsartia humeralis	Sea trumpeter	BP	MS	OV
Edelia vittata	Western pygmy perch	BP	FM	ZB
Ostorhinchus rueppellii	Gobbleguts	BP	ES	ZB
Siphamia cephalotes	Woods Siphonfish	BP	MS	ZB
Sillago bassensis	Southern school whiting	D	MS	ZB
Sillago burrus	Western trumpeter whiting	D	MM	ZB
Sillaginodes punctata	King George whiting	D	MM	ZB

Species name	Common name	Habitat guild	Estuarine Use guild	Feeding Mode guild
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
Geophagus brasiliensis	Pearl cichlid	BP	FM	OV
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
Lesueurina platycephala	Flathead sandfish	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
Favonigobius 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
Scobinichthys granulatus	Rough Leatherjacket	D	MS	OV

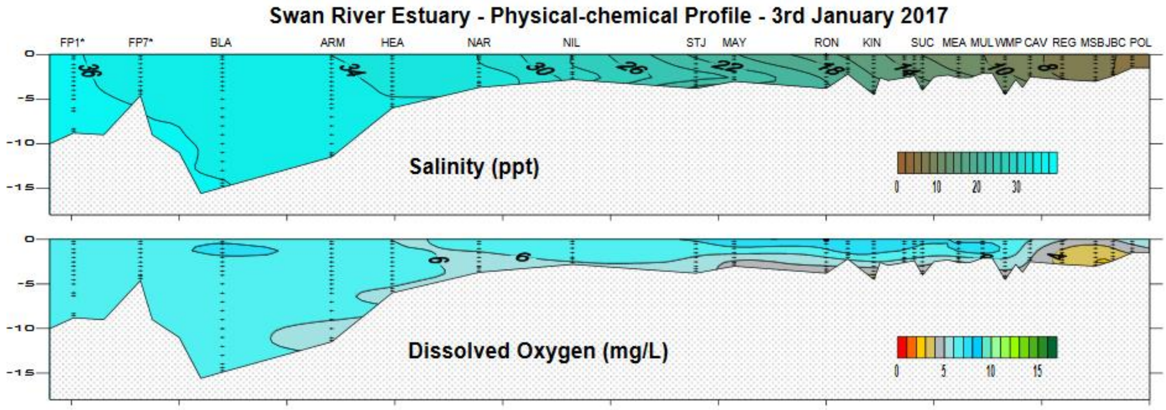
Species name	**Common name**	**Habitat guild**	**Estuarine Use guild**	**Feeding Mode guild**
Chaetodermis pencilligera	Tasselled leatherjacket	D	MS	OV
Meuschenia freycineti	Sixspine leatherjacket	D	MM	OV
Monacanthus chinensis	Fanbellied Leatherjacket	D	MM	OV
Eubalichthys mosaicus	Mosaic leatherjacket	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

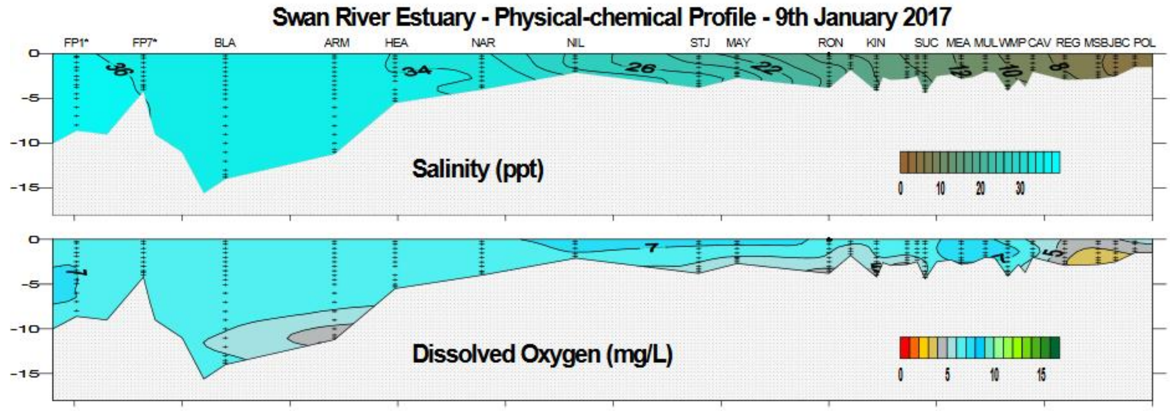
Appendix (iv). Average salinities, measured at the time of sampling, across all nearshore and offshore sampling sites during 2012–2017.

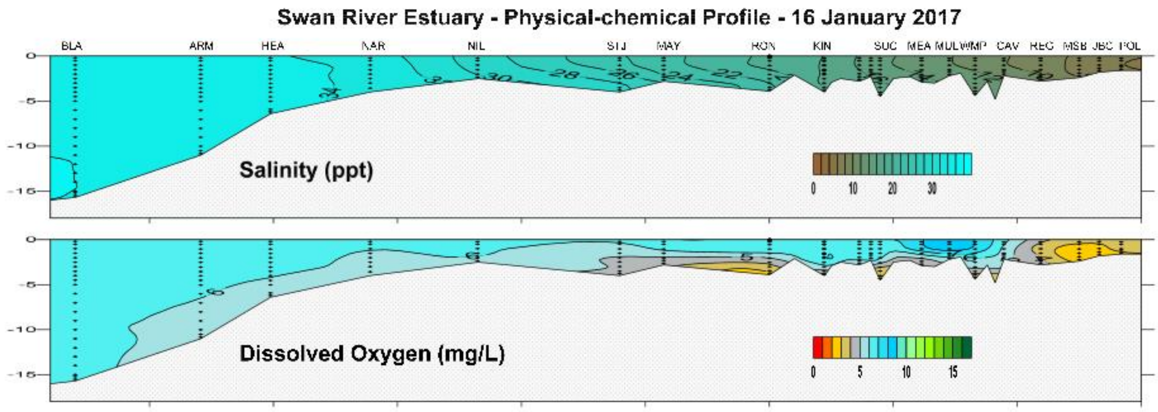
	2012		**2013**		**2014**		**2015**		**2016**		**2017**	
	SU	**AU**	**SU**	**AU**	**SU**	**AU**	**SU**	**AU**	**SU**	**AU**	**SU**	**AU**
Nearshore	25.3	28.9	30.6	30.6	27.4	33.2	27.8	28.0	29.3	27.0	21.8	24.0
Offshore (surface)	26.0	30.4	30.9	30.6	27.6	33.5	28.0	28.5	29.8	28.6	23.0	23.5
Offshore (bottom)	26.4	31.7	31.5	32.5	28.7	33.9	28.6	30.0	30.3	30.4	24.9	28.2

Appendix (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 throughout the summer to autumn period of fish community sampling. Prepared by the Department of Water and Environmental Regulation for the Department of Biodiversity, Conservation and Attractions (https://www.dpaw.wa.gov.au/management/swan-canning-riverpark/ecosystem-health-and-management/452-swan-river-vertical-plots/ and https://www.dpaw.wa.gov.au/management/swan-canning-riverpark/ecosystem-health-and-management/453-canning-river-vertical-plots/).

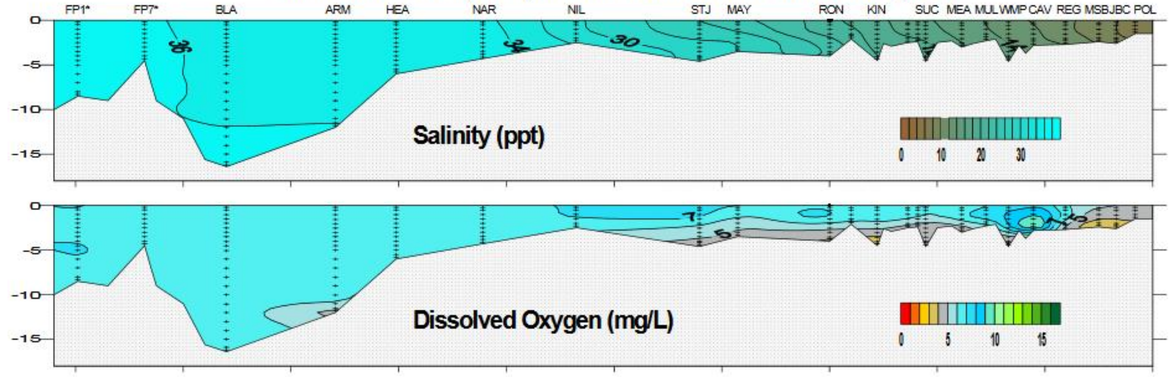
LSCE, MSE and USE zones in summer through autumn 2017.



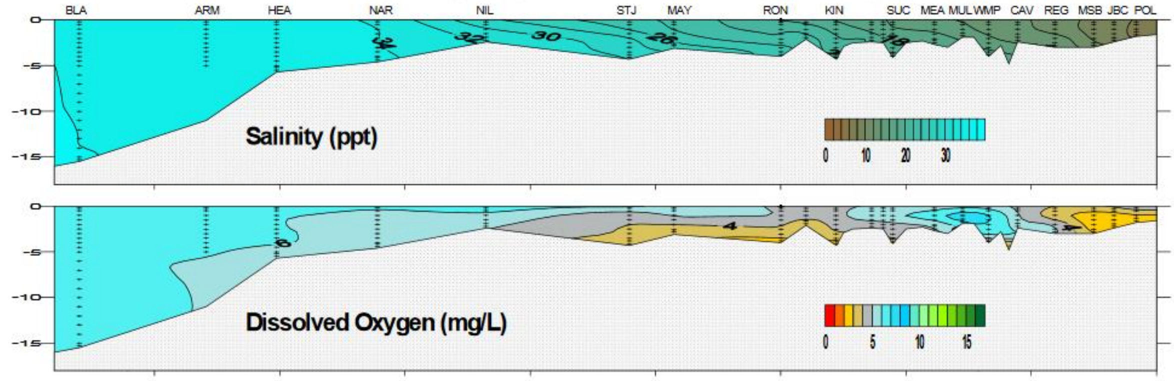




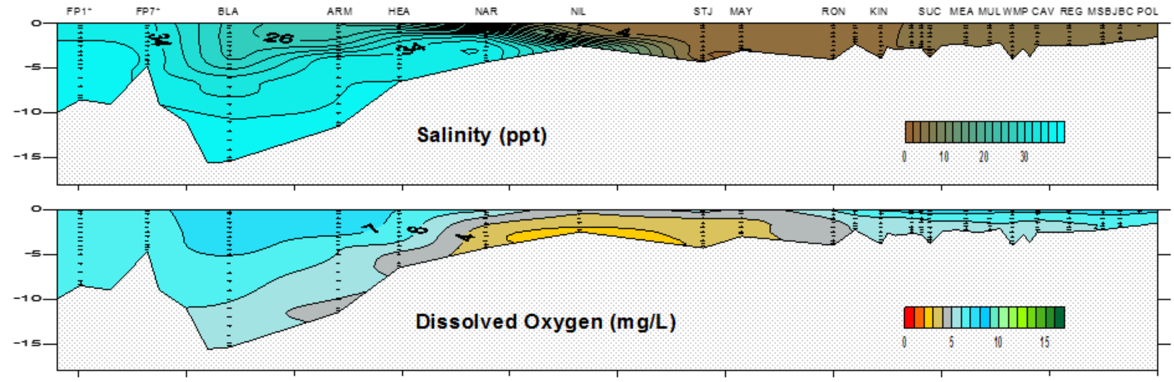
Swan River Estuary - Physical-chemical Profile - 23rd January 2017



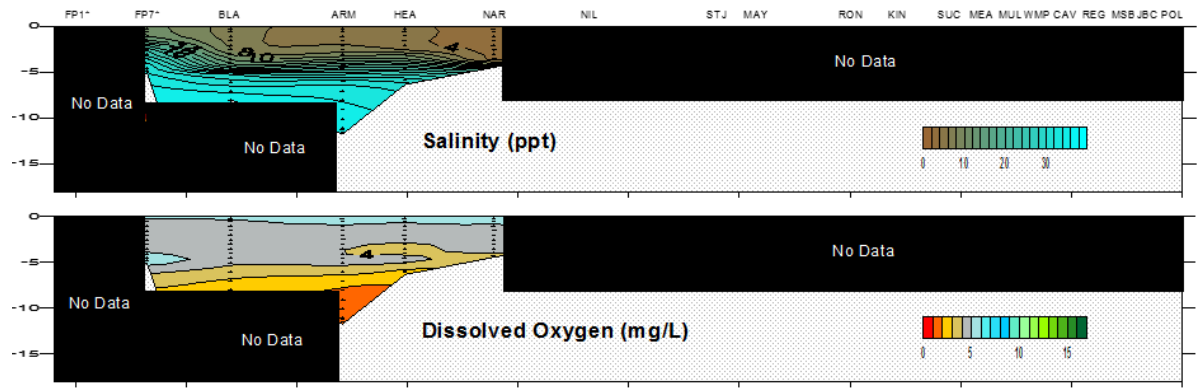
Swan River Estuary - Physical-chemical Profile - 30 January 2017



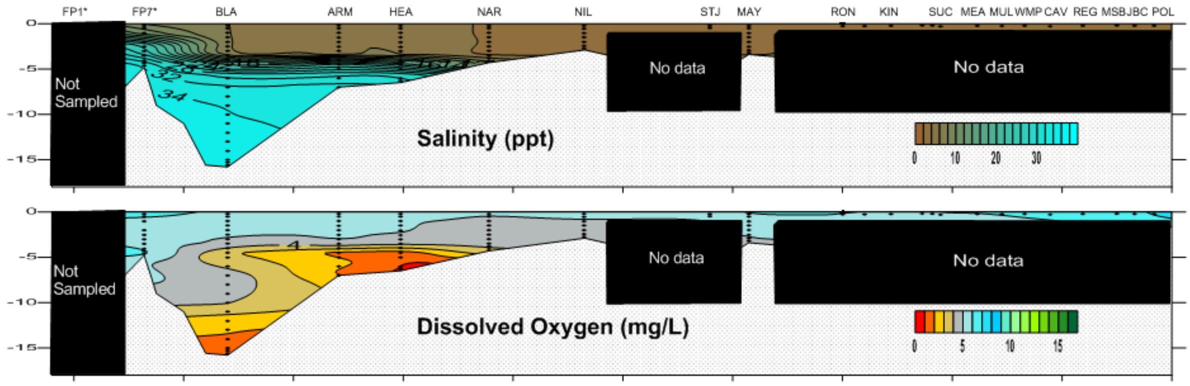
Swan River Estuary - Physical-chemical Profile - 6th February 2017



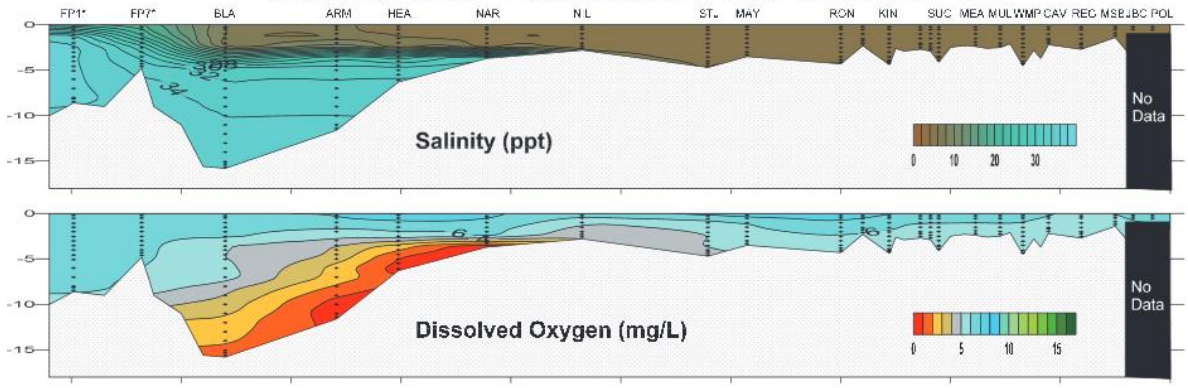
Swan River Estuary - Physical-chemical Profile - 15th February 2017



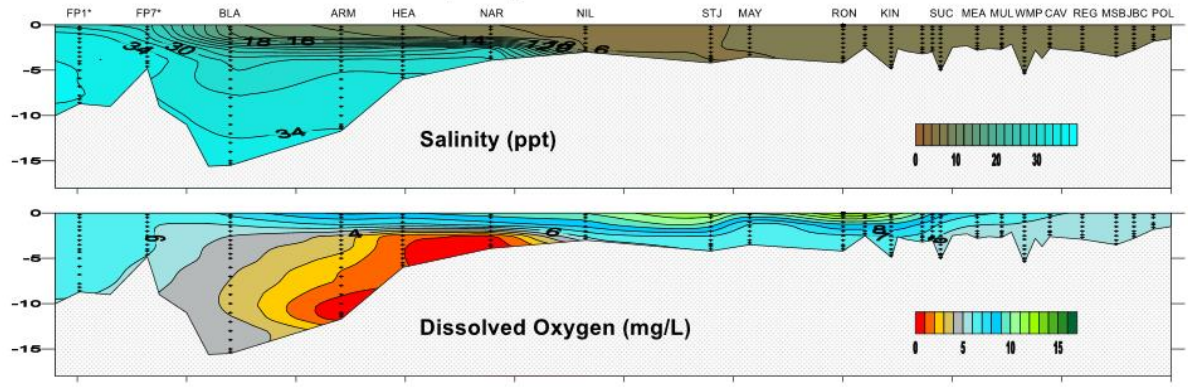
Swan River Estuary - Physical-chemical Profile - 20th February 2017



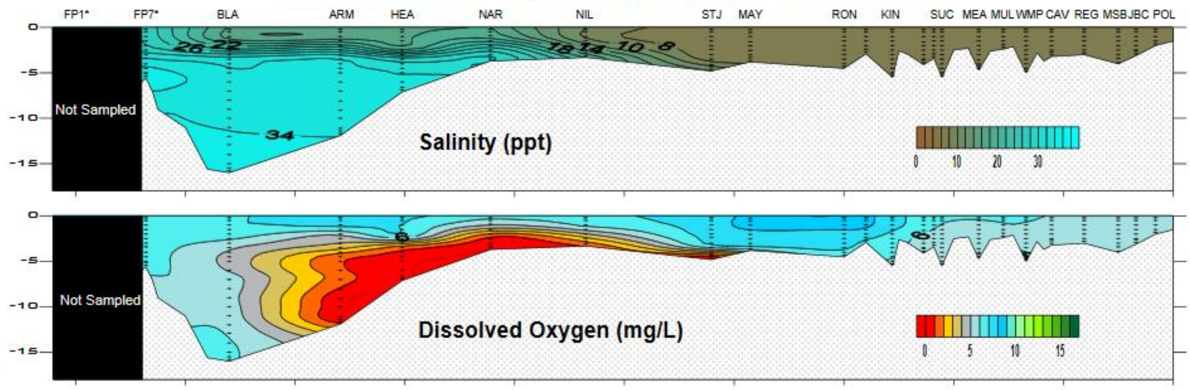
Swan River Estuary - Physical-chemical Profile - 27th February 2017



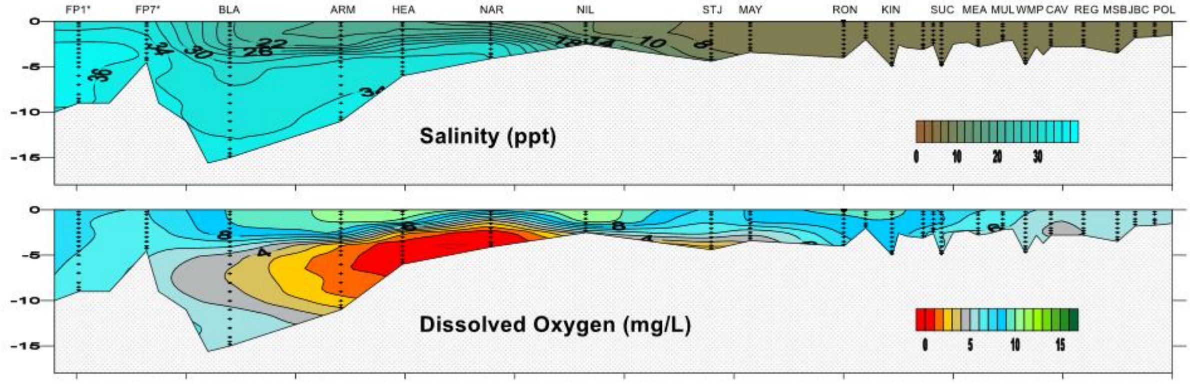
Swan River Estuary - Physical-chemical Profile - 7th March 2017



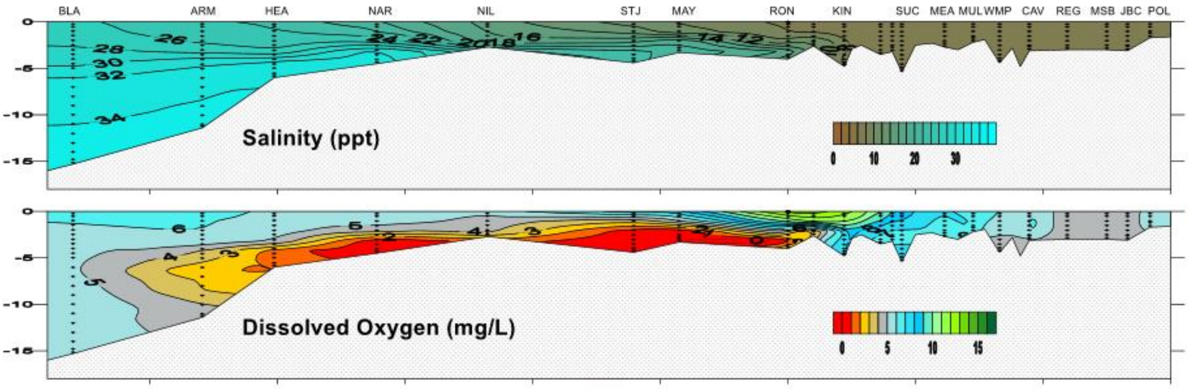
Swan River Estuary - Physical-chemical Profile - 13th March 2017



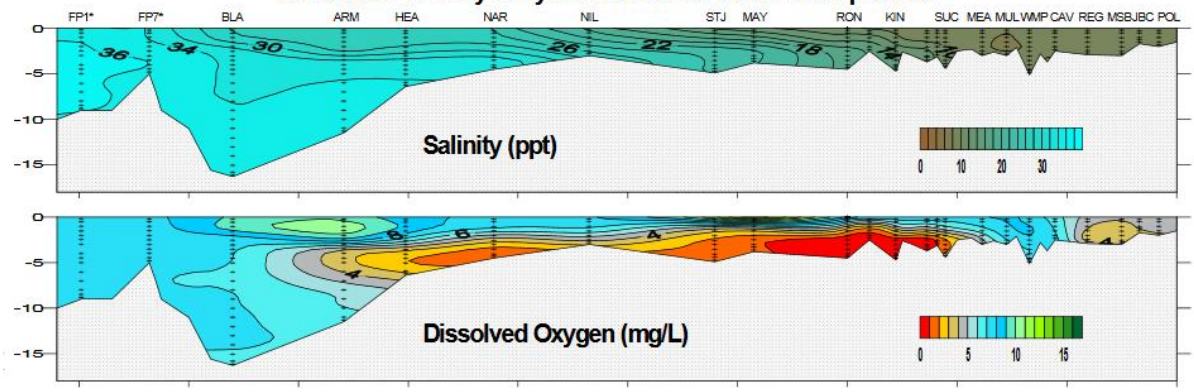
Swan River Estuary - Physical-chemical Profile - 20th March 2017



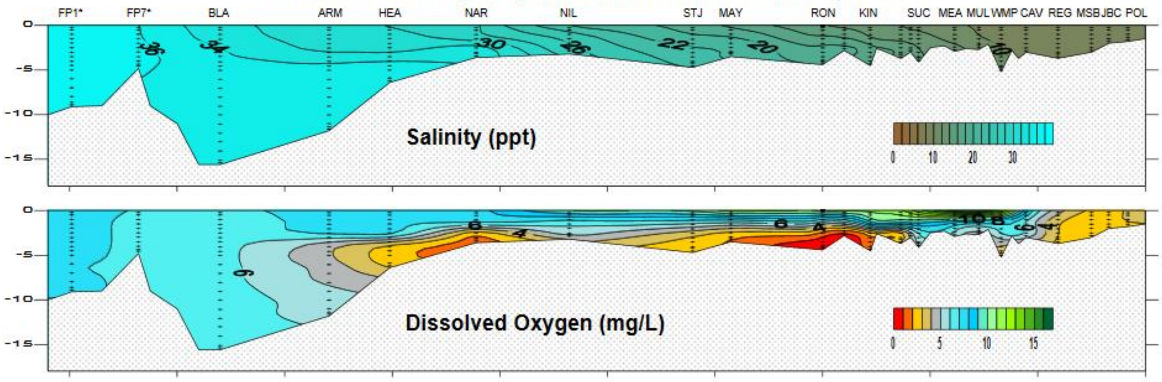
Swan River Estuary - Physical-chemical Profile - 27th March 2017

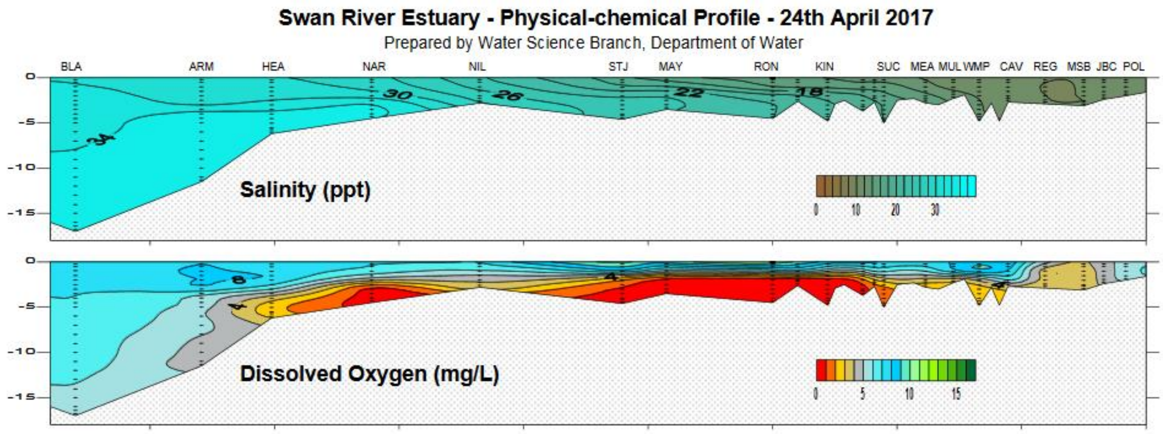


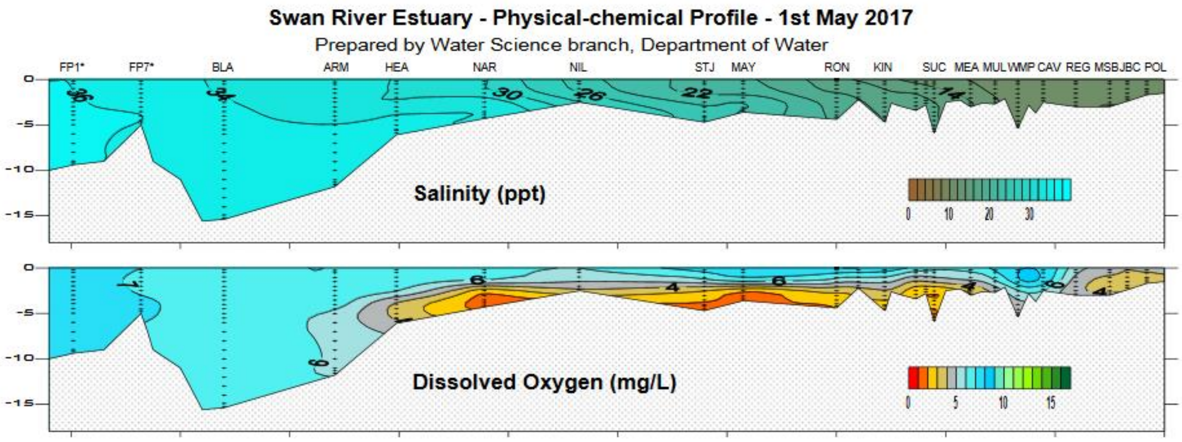
Swan River Estuary - Physical-chemical Profile - 3rd April 2017



Swan River Estuary - Physical-chemical Profile - 18th April 2017




Swan River Estuary - Physical-chemical Profile - 24th April 2017
Prepared by Water Science Branch, Department of Water
BLA ARM HEA NAR NIL STJ MAY RON KIN SUC MEA MUL WMP CAV REG MSB JBC POL
Salinity (ppt)
Dissolved Oxygen (mg/L)


Swan River Estuary - Physical-chemical Profile - 1st May 2017
Prepared by Water Science branch, Department of Water
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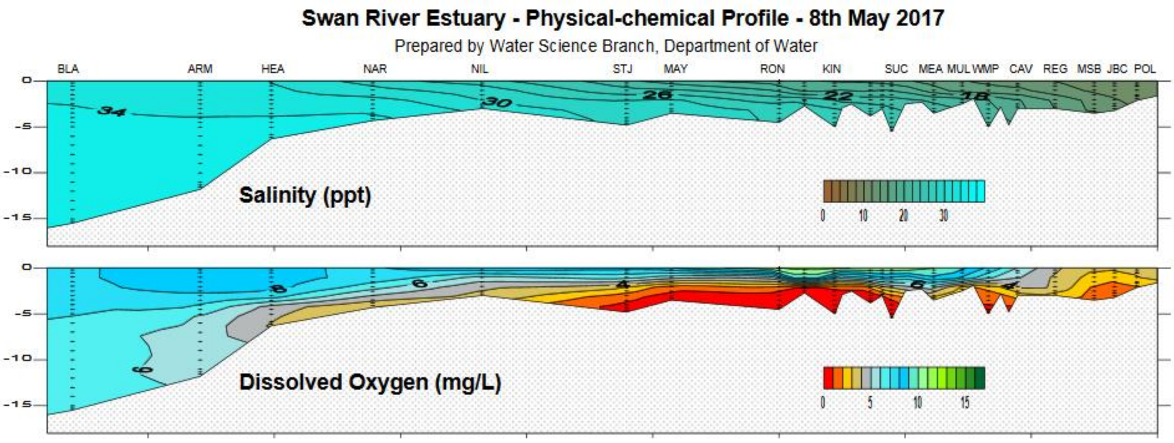
Salinity (ppt)
Dissolved Oxygen (mg/L)


Swan River Estuary - Physical-chemical Profile - 8th May 2017
Prepared by Water Science Branch, Department of Water
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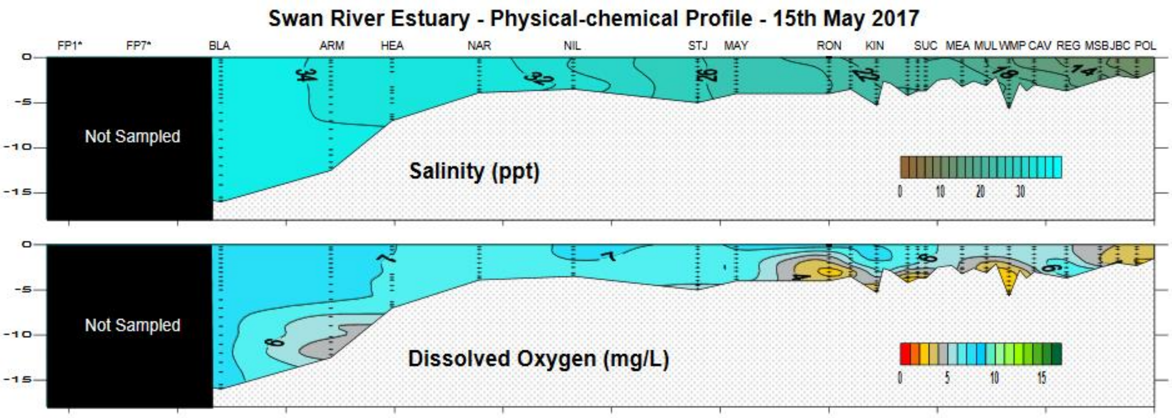
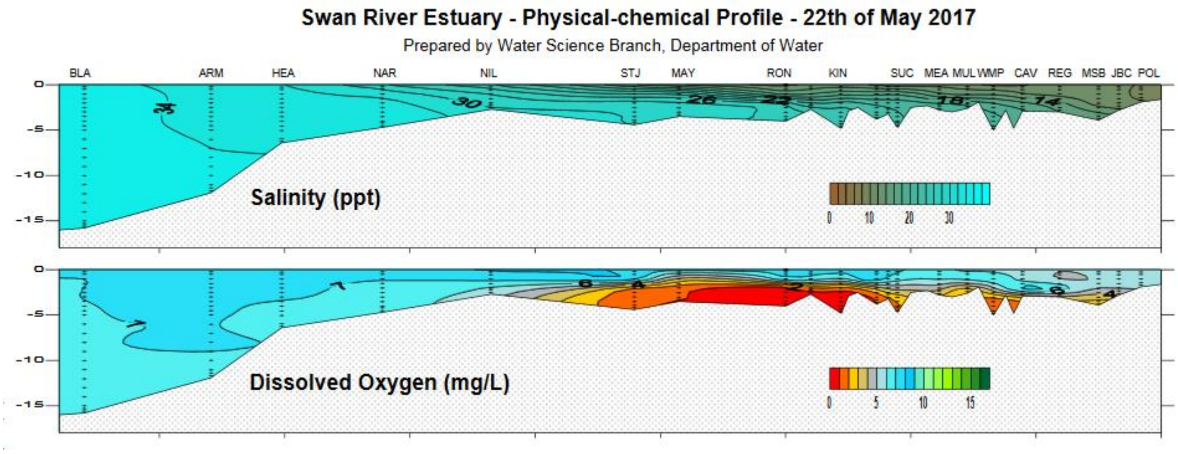
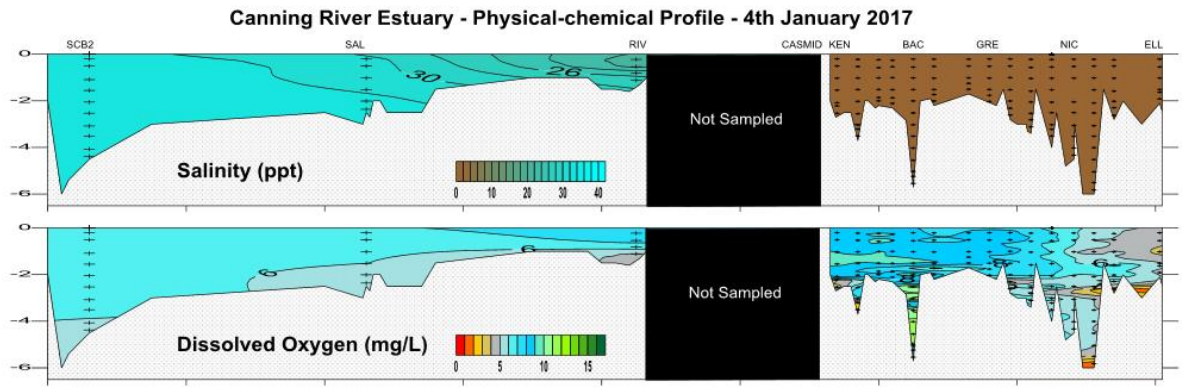
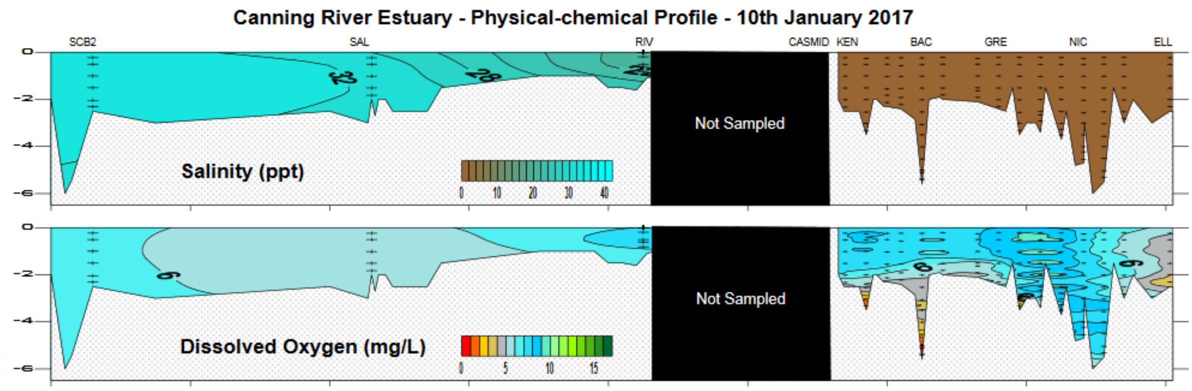
Salinity (ppt)
Dissolved Oxygen (mg/L)


Swan River Estuary - Physical-chemical Profile - 15th May 2017
FP1* FP7* BLA ARM HEA NAR NIL STJ MAY RON KIN SUC MEA MUL WMP CAV REG MSB JBC POL
Not Sampled
Salinity (ppt)
Not Sampled
Dissolved Oxygen (mg/L)

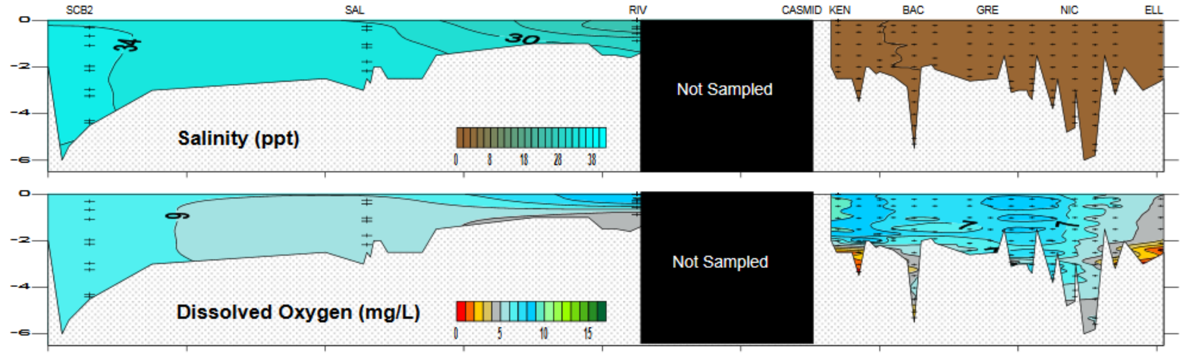


CE zone in summer through autumn 2017.

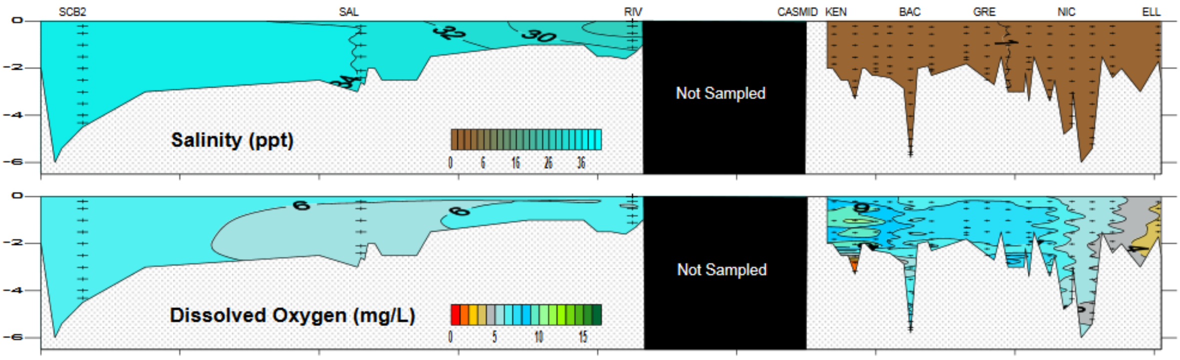




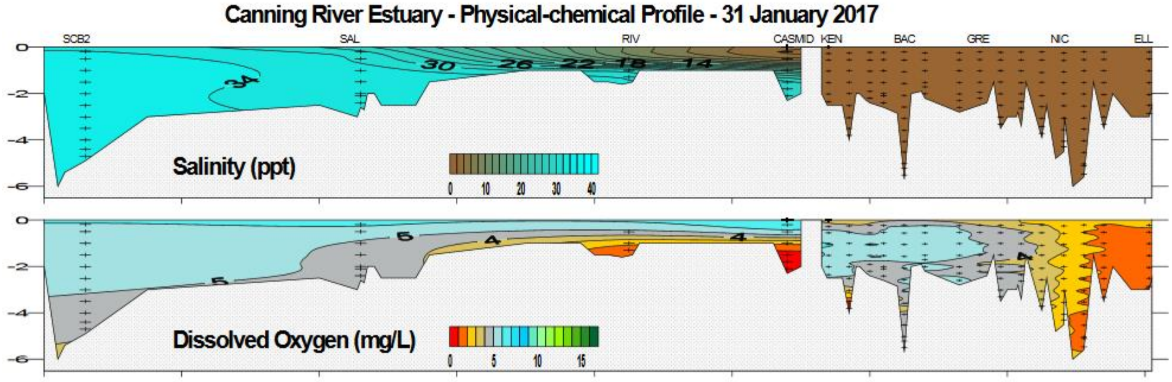
Canning River Estuary - Physical-chemical Profile - 17th January 2017



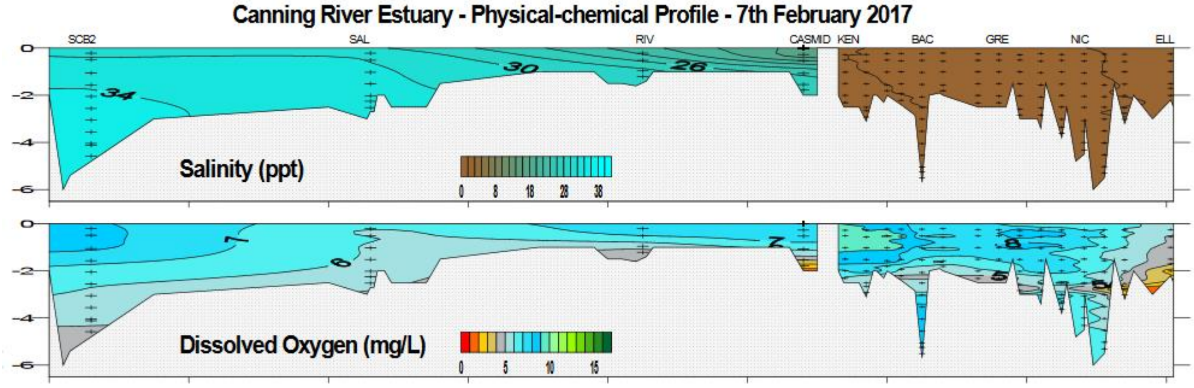
Canning River Estuary - Physical-chemical Profile - 24th January 2017



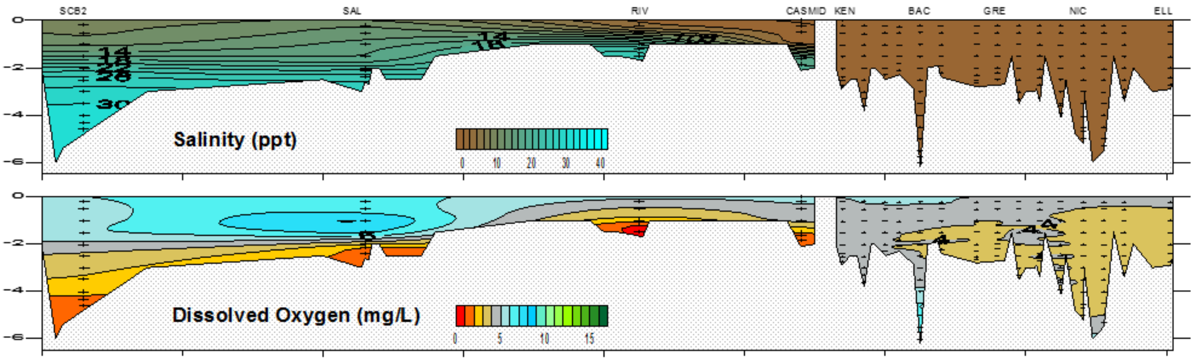
Canning River Estuary - Physical-chemical Profile - 31 January 2017



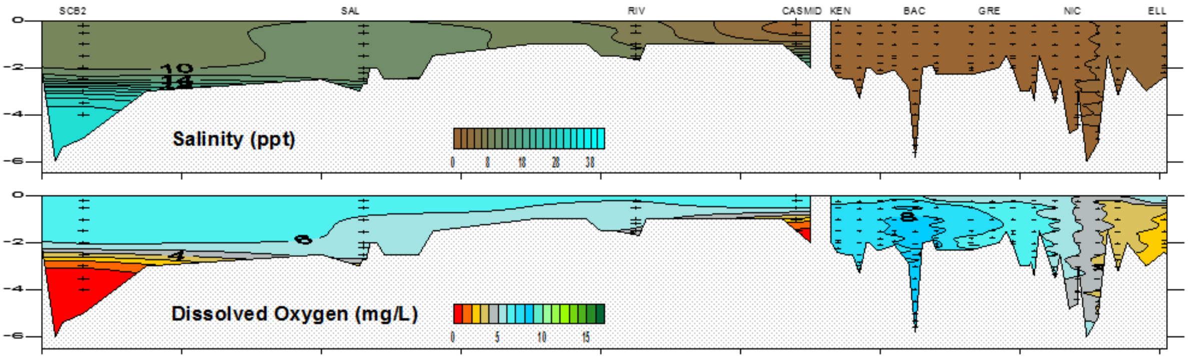
Canning River Estuary - Physical-chemical Profile - 7th February 2017



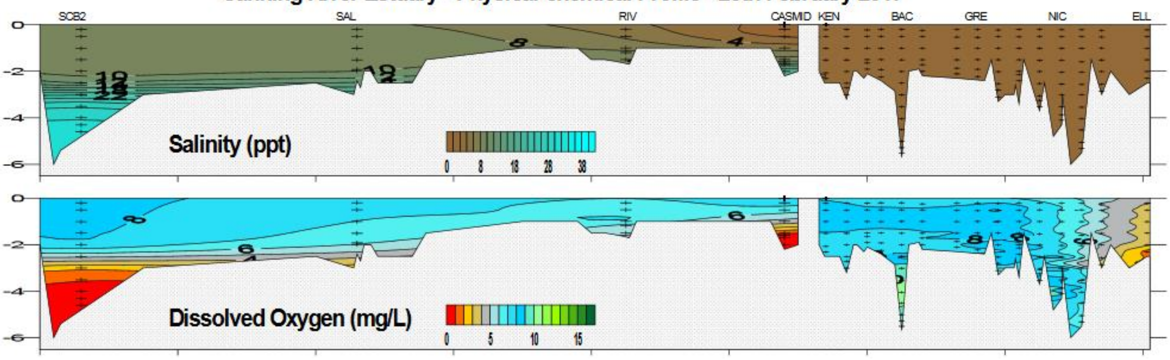
Canning River Estuary - Physical-chemical Profile - 14 February 2017



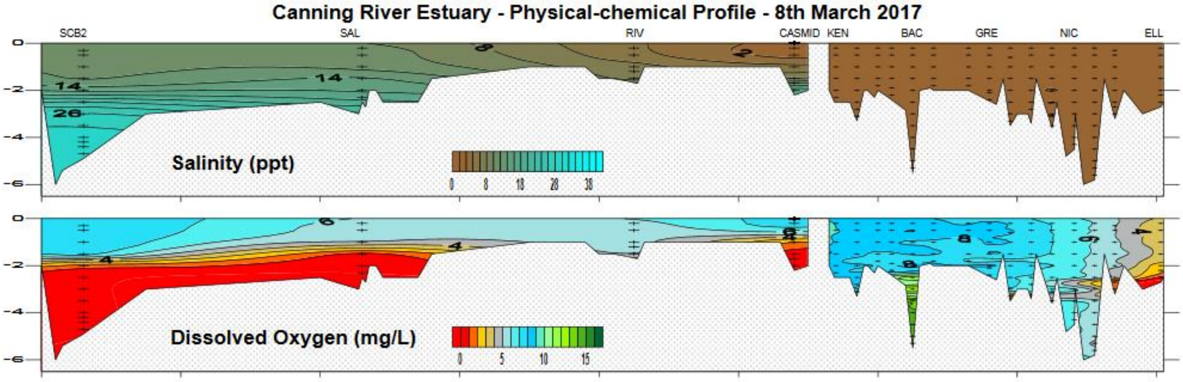
Canning River Estuary - Physical-chemical Profile - 21st February 2017



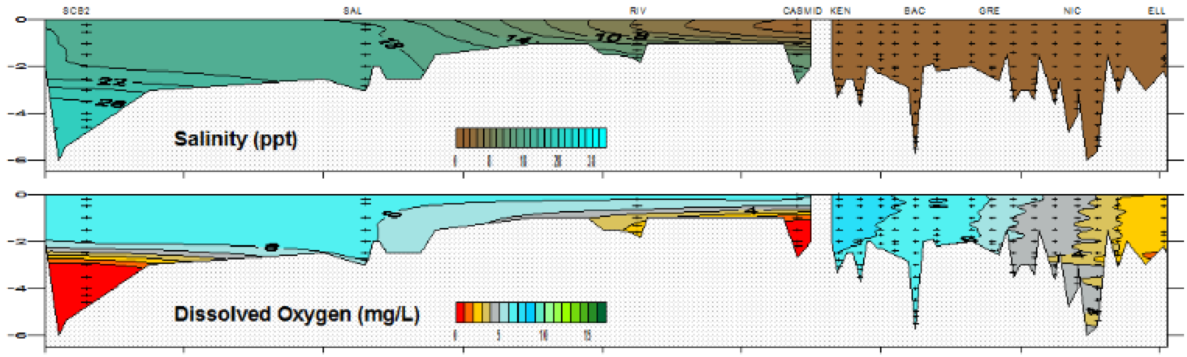
Canning River Estuary - Physical-chemical Profile - 28th February 2017



Canning River Estuary - Physical-chemical Profile - 8th March 2017



Canning River Estuary - Physical-chemical Profile - 14th March 2017



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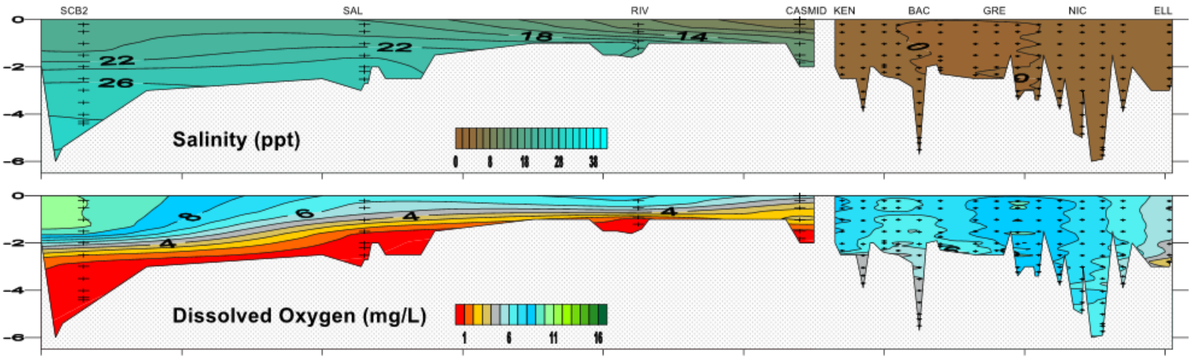
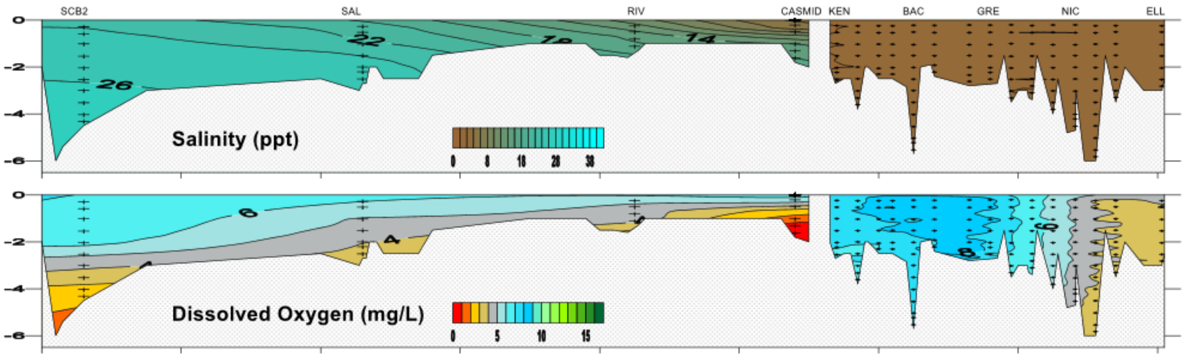
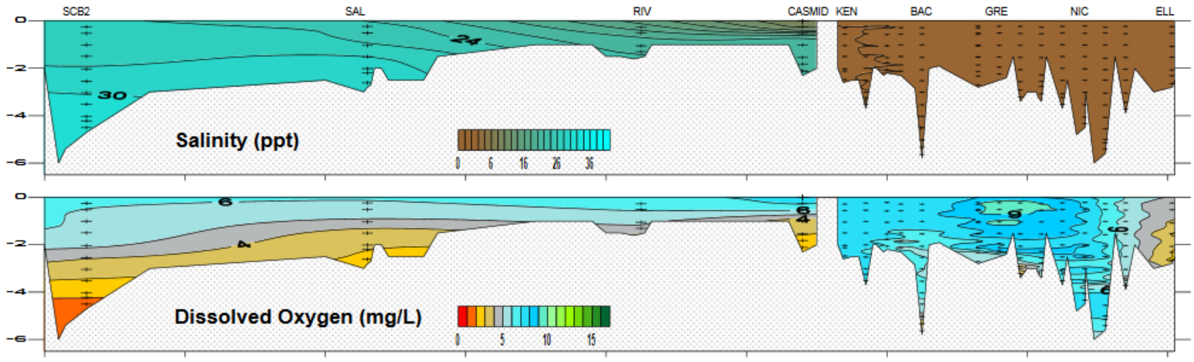
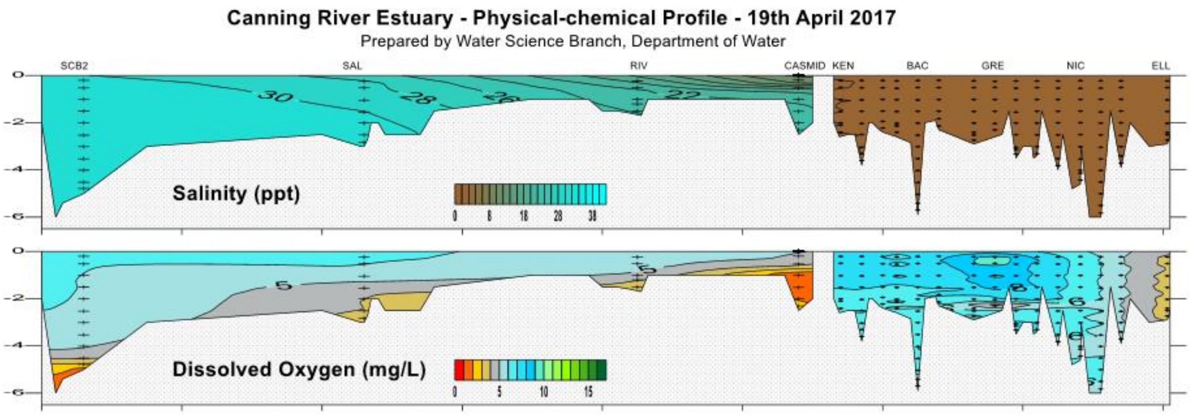


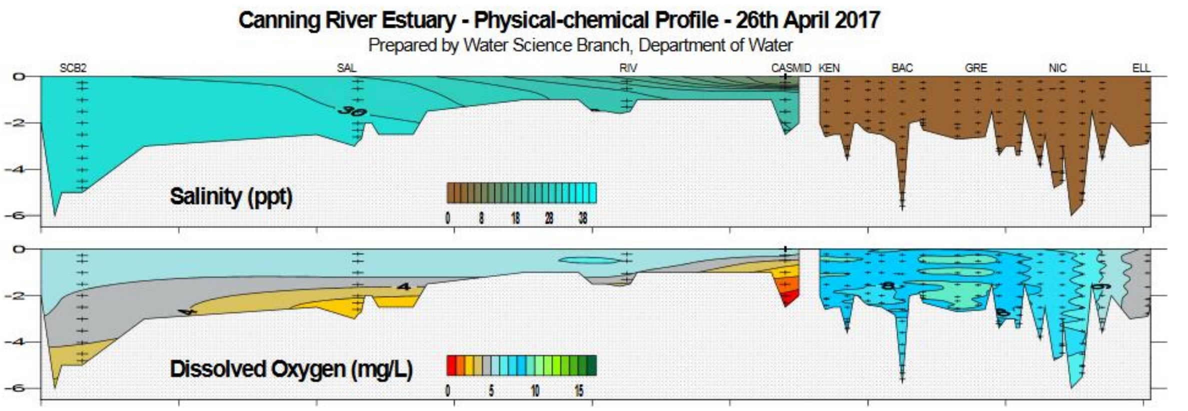
Canning River Estuary - Physical-chemical Profile - 28th March 2017

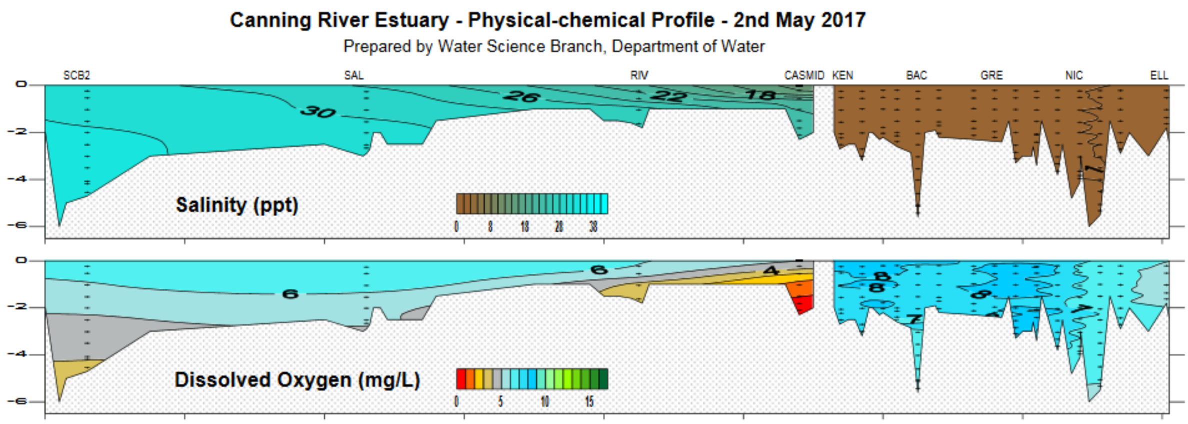


Canning River Estuary - Physical-chemical Profile - 4th April 2017




Canning River Estuary - Physical-chemical Profile - 19th April 2017
Prepared by Water Science Branch, Department of Water
SCB2
SAL
RIV
CASMID
KEN
BAC
GRE
NIC
ELL
Salinity (ppt)
Dissolved Oxygen (mg/L)


Canning River Estuary - Physical-chemical Profile - 26th April 2017
Prepared by Water Science Branch, Department of Water
SCB2
SAL
RIV
CASMID
KEN
BAC
GRE
NIC
ELL
Salinity (ppt)
Dissolved Oxygen (mg/L)


Canning River Estuary - Physical-chemical Profile - 2nd May 2017
Prepared by Water Science Branch, Department of Water
SCB2
SAL
RIV
CASMID
KEN
BAC
GRE
NIC
ELL
Salinity (ppt)
Dissolved Oxygen (mg/L)