# Assessment of the condition of the Swan-Canning Estuary in 2015, based on the Fish Community Indices of estuarine condition. Final report to the Department of Parks and Wildlife

Hallett, C.S.; Tweedley, J.R.

# Assessment of the condition of the Swan Canning Estuary in 2015, based on the Fish Community Indices of estuarine condition.

**Final report**

**July 2015**


Chris Hallett and James Tweedley

*Centre for Fish and Fisheries Research, Murdoch University*


Prepared for the Department of Parks and Wildlife

**Disclaimer**

The authors have prepared this report in accordance with the usual care and thoroughness of the Centre for Fish and Fisheries Research (CFFR), for use by the Department of Parks and Wildlife and only those third parties who have been authorised in writing by the CFFR to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose required by the Department of Parks and Wildlife. The methodology adopted and sources of information used by the authors are outlined in this report. The authors have made no independent verification of this information beyond the agreed scope of works, and they assume no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to the authors was false. This report was prepared during May-June 2015 and is based on the information reviewed at the time of preparation. The authors disclaim any responsibility for changes that may have occurred after this time. This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

**Acknowledgements**

Gratitude is expressed to our colleagues in the Centre for Fish and Fisheries Research at Murdoch University who assisted with sampling of the fish community, especially Dan Yeoh. We also thank the Department of Parks and Wildlife for supplying water quality plots and unpublished algal and water quality data for the Swan Canning Estuary.

**Recommended citation:**

Hallett, C.S. and Tweedley, J.R. (2015). Assessment of the condition of the Swan Canning Estuary in 2015, based on the Fish Community Indices of estuarine condition. Final report to the Department of Parks and Wildlife, Murdoch University, 37 pp.

*Cover image acknowledgements: Matt Hourston, Dave Morgan, Mark Allen, Gavin Sarre (Murdoch University)*

## Executive summary

This report, commissioned by the Department of Parks and Wildlife, describes the monitoring and evaluation of fish communities in the Swan Canning Riverpark during 2015 and applies the Fish Community Indices (FCI) 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 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 2015. 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*

Overall, the index scores for the nearshore waters of the Swan Canning Estuary show that these estuarine habitats were in generally good (B) to fair (C) ecological condition across both summer and autumn 2015, with the average nearshore index scores for most zones and for the estuary as a whole lying between 61 and 71 in each season. The assessment for the estuary as a whole in 2015 was consistent with the pattern of good-fair (B/C) condition assessments observed in recent years.

The composition of nearshore fish communities in the Swan Canning Estuary in summer and autumn was similar to those observed in 2012-2014, and was again dominated by small bodied, schooling species of hardyheads and gobies. For the first time since annual monitoring began in 2012, Wallace's hardyhead (*Leptatherina wallacei*) was the most abundant fish species overall, comprising 56% and 33% of the total catches from the CE and USE, respectively. The prevalence of this species (which is abundant in rivers across the southwest of WA and generally prefers to inhabit less saline waters in estuaries) can be attributed to the fresher conditions that were observed throughout much of the estuary during autumn of 2015, compared to previous monitoring years.

The tropical hardyhead *Craterocephalus mugiloides* was once again among the most common species in catches from the nearshore waters of all four zones, comprising 16-61% of the total catch. Other abundant species included the Elongate hardyhead (*Atherinosoma elongata*), Blowfish (*Torquigener pleurogramma*) and Gobbleguts (*Ostorhinchus rueppellii*) in the LSCE, Southern anchovy (*Engraulis australis*) in the CE, and Perth herring (*Nematalosa vlaminghi*) in the MSE and USE.

The introduced Pearl cichlid (*Geophagus brasiliensis*) was again encountered during monitoring for the FCI in 2015. Sixty immature individuals were caught from nearshore waters immediately downstream of Kent Street Weir in the CE during February 2015. This is the first time this species has been recorded from the CE (*i.e.* the brackish, estuarine portion of the Canning River), providing further evidence of its expanding distribution within this system.

As is typical for this estuary, the total number of species recorded per zone declined in an upstream direction, from 19 species in the LSCE, CE and MSE to 14 species in the USE. The total number of species caught in nearshore waters during 2015 (25) was considerably less than the 35 species caught during 2014 and can be attributed to salinity changes.

High and stable salinities were present throughout much of the estuary during 2014, and would have led more marine species to enter the estuary and a wider range of species to penetrate further up into the system. In contrast, average salinities throughout the system during autumn of 2015 were the lowest observed since annual monitoring commenced in 2012. These conditions are likely to have prohibited many of the marine species that had entered the estuary during 2013 and 2014 from doing so during 2015, thus explaining the lower number of species recorded during the current monitoring year.

*Offshore fish communities*

The ecological condition of the Riverpark's offshore waters in summer and autumn of 2015 was broadly similar to that observed in the corresponding seasons of the previous year, being generally good (B) to fair (C). This is consistent with the pattern of good-fair (B/C) or fair-good (C/B) condition assessments that have been recorded for offshore waters since 2011.

However, the condition of the CE zone was once again rated as poor (D) during summer of 2015. The low scoring was driven by relatively low numbers and diversity of fish species and by a relatively high proportion of fish species that feed on decomposing organic material (*e.g.* Perth herring). This was probably caused in part by hypoxic (*i.e.* low dissolved oxygen) conditions that developed following stratification of the water column in late January/early February. However, given that the CE has exhibited the poorest offshore condition of any zone in each of the last four years, it may also reflect that other factors are influencing the diversity and richness of fish communities in this zone.

In general, the composition of offshore fish communities in summer and autumn of 2015 was fairly typical for the Swan Canning Estuary, being dominated by Perth herring, which comprised 30% of the catches from the LSCE and 61–95% of those from the CE, MSE and USE. Other relatively abundant species included the Southern eagle ray (*Myliobatis australis*) and Western trumpeter whiting (*Sillago burrus*) in the LSCE, Scaly mackerel (*Sardinella lemuru*) and Tailor (*Pomatomus saltatrix*) in the CE, and Yellowtail grunter (*Amniataba caudavittata*) in the MSE and USE.

*Overall*

Across the estuary as a whole, the ecological condition of both nearshore and offshore waters was again assessed as generally good (B) to fair (C) during the current monitoring year. This is consistent with the pattern of good-fair (B/C) or fair-good (C/B) condition assessments that have been recorded for offshore waters since 2011 and for nearshore waters since 2008.

# Assessment of the condition of the Swan Canning Estuary in 2015, based on the Fish Community Indices of estuarine condition

## Contents

## 1. Background

Government agencies, local government authorities, community groups and research institutions continue to work collaboratively 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.

Until recently, the government's environmental monitoring program on the Swan and Canning Rivers (now managed through the Department of Parks and Wildlife (DPaW)) 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 Swan River Trust, Murdoch University, Department of Fisheries and Department of Water, Fish Community Indices (FCI) were developed for assessing the ecological condition of the Swan Canning Estuary (Valesini et al. 2011, Hallett et al. 2012, Hallett and Valesini 2012, Hallett 2014). These indices, which have been subjected to extensive testing and validation over a period of several years (*e.g.* Hallett and Valesini 2012), have 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. This is demonstrated by the ability of the indices to track the changes in estuarine condition that were associated with harmful algal blooms during 2004 (Hallett et al. 2015), 2011 (Hallett et al. 2012) and 2012 (Hallett 2012b). Moreover, recent refinements of the grading system for the FCI have increased its ability to communicate, simply and reliably, the degree of ecological perturbation impacting on the Swan Canning Estuary and its individual management zones (Hallett 2014).

## 2. Rationale

The Fish Community 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, as do the methods used to sample them. 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 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 FCI is a community based index and summarizes the response of the entire fish assemblage. It does not focus on individual species or measure biological performance of any one species in terms of age, growth or biomass production.

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, ultimately leading 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 which 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 poor to 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 2015 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 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.

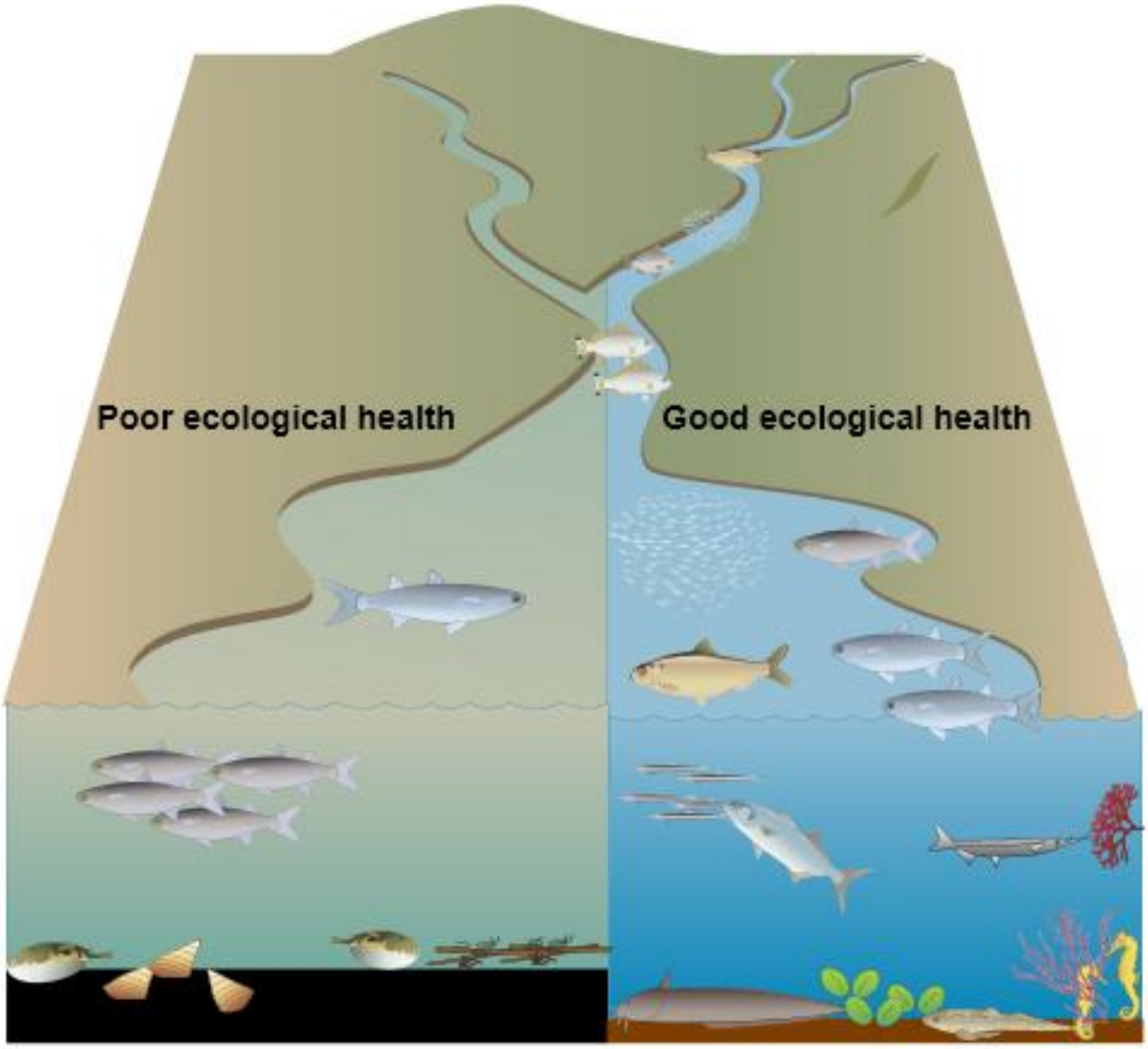



**Figure 1.** Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of poor and good ecological condition. (Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].)

## 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 (19 January – 3 February) and autumn (20 April – 1 May) 2015, using a 21.5 m seine net and 160 m 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, euthanised 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 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 2015 were then examined to assess the condition of the Swan Canning Estuary during this period and compared to previous years.

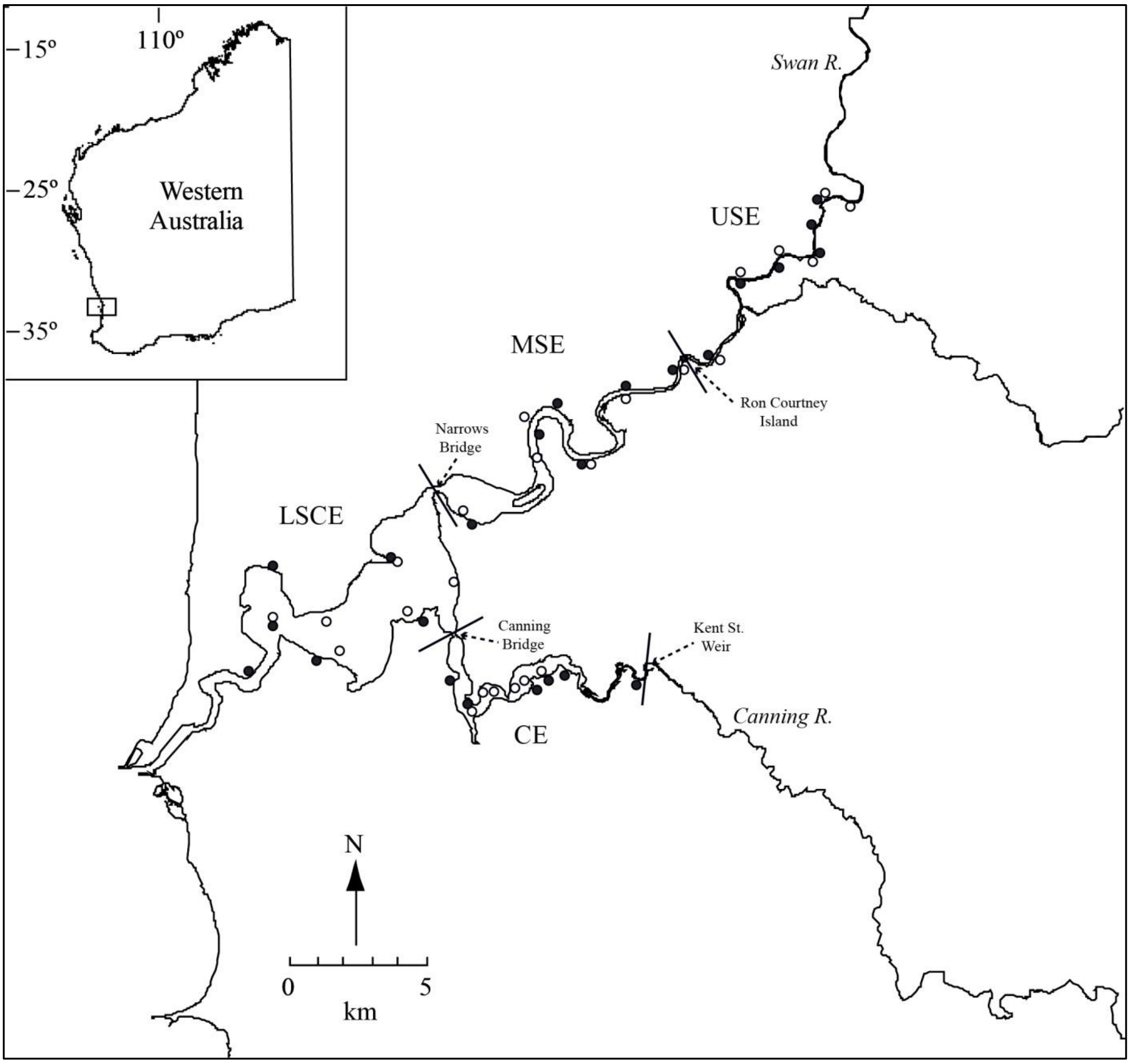



**Figure 2:** Locations of nearshore (black circles) and offshore (open circles) sampling sites for the Fish Community Indices of estuarine condition. LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary.

**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, Jen Eliot and Kerry Trayler, DPaW).

## 5. Results and discussion

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

In general, average salinities measured at the time of sampling during summer of 2015 were comparable to those recorded in summer of the previous year (~28). This suggests that conditions were, on the whole, slightly more saline than during the summer of 2012 (~26) but fresher than the equivalent period in 2013 (~31; Appendix iv). Salinities during the autumn of 2015 (~29) were, on average, lower than those observed during autumn of the previous three years, and notably lower than those recorded in 2014 (~33). As in previous monitoring years, average dissolved oxygen concentrations measured at the time of sampling during 2015 indicated generally well oxygenated conditions (>4 mg/L) across the estuary as a whole.

Vertical contour plots (Appendix v), of interpolated salinity and dissolved oxygen (DO) concentrations measured at WA Department of Water (DoW) monitoring stations along the length of the Swan Canning Estuary, provide more detail of the environmental conditions present throughout the system during the monitoring period. Summer conditions throughout the Swan Estuary were similar to those of the previous year, with quite brackish conditions in the USE zone, yet relatively good levels of oxygenation and little stratification throughout. During autumn, rainfall in early to mid-April caused some stratification of the water column of the USE, with some hypoxia (DO <2 mg/L) across parts of the MSE and USE.

In the CE zone, conditions were relatively well-mixed and adequately oxygenated in mid- to late January. Subsequently, 40 mm of rainfall in the week prior to February 3rd led to significant stratification of the water column, with freshwater flows overlying brackish bottom waters. As a result, hypoxic conditions had developed across parts of the CE by early February, most notably at Riverton and from Castledare to Kent Street Weir. Significant hypoxia was also present by February 5th at Rossmoyne, between WA DoW water quality monitoring stations (Tweedley, unpublished data). During autumn of 2015, considerable stratification of the water column of the CE was evident following 53 mm of rain in the week prior to April 13th. The degree of stratification eased over the following weeks as freshwater flows declined, leading to a largely saline water column by the end of April. Further rain then led to the reestablishment of stratification, which became severe by the 13th May (Appendix v). Hypoxic conditions were recorded in bottom waters between Kent St and Castledare and were associated with a fish kill (>1,000 black bream; Kerry Trayler, SRT, personal communication). However, this event occurred following the completion of FCI sampling in the CE zone on May 1st, and so would not have affected the monitoring results for the CE zone.

### *5.2 Description of the fish community of the Swan Canning Estuary during 2015*

An estimated total of 19,543 fish, belonging to 25 species, were caught in seine net samples collected from the nearshore waters of the Swan Canning Estuary during summer and autumn 2015. 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 19 species in the LSCE, CE and MSE to 14 species in the USE (Table 3). The total number of species caught in nearshore waters during 2015 was considerably less than the 35 species caught during 2014. Similarly, the total number of fish caught in 2015 was 7,500 to 9,000 fewer than in 2012–2013, and >11,000 fewer than in 2014. However, total fish densities show a great degree of variability over space and time and generally provide little information about estuarine condition. Reasons for the observed patterns in these results, and particularly in terms of the number of species, are discussed below.

The hardyheads (Atherinidae) dominated catches from the nearshore waters of the estuary in 2015, consistent with the results from previous years. For the first time since annual monitoring began in 2012, Wallace's hardyhead (*Leptatherina wallacei*) was the most abundant fish species overall, and comprised 56% and 33% of all fish recorded from the CE and USE, respectively (Table 3). The tropical hardyhead *Craterocephalus mugiloides* was once again among the most common species in catches from the nearshore waters of all four zones, comprising 16-61% of the total catch, and the Elongate hardyhead (*Atherinosoma elongata*) was also highly abundant, but only in the LSCE zone, where it comprised 55% of the overall catch. Other abundant species included Blowfish (*Torquigener pleurogramma*) and Gobbleguts (*Ostorhinchus rueppellii*) in the LSCE, Southern anchovy (*Engraulis australis*) in the CE, and Perth herring (*Nematalosa vlaminghi*) in the MSE and USE (12% and 18%, respectively). These findings may largely be explained by the 'fresher' conditions that were observed throughout much of the estuary during autumn of 2015. Higher than expected catches of *L. wallacei* – a species which is abundant in rivers across the southwest of WA and which, in estuaries, generally prefers to inhabit less saline waters (Potter et al. 2015) – were thus observed in the CE, MSE and USE zones during 2015. In contrast, *A. elongata*, a species that can tolerate highly elevated salinities (Veale et al. 2014) and prefers to inhabit saltier regions of estuaries, was largely restricted to the zone closest to the ocean.

**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 2015. 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 |
| *Leptatherina wallacei* | Wallace's hardyhead | 0.2 | <0.1 | **294.3** | **56.3** | **24.4** | **11.5** | **81.8** | **32.5** |
| *Craterocephalus mugiloides* | Mugil's hardyhead | **66.8** | **16.0** | **87.6** | **16.8** | **128.4** | **60.6** | **49.7** | **19.8** |
| *Atherinosoma elongata* | Elongate hardyhead | **229.5** | **54.9** | 32.6 | 6.2 | 4.0 | 1.9 | 0.1 | <0.1 |
| *Nematalosa vlaminghi* | Perth herring | - | - | 12.0 | 2.3 | **11.6** | **5.5** | **44.2** | **17.6** |
| *Gambusia holbrooki* | Mosquito fish | - | - | 26.6 | 5.1 | <0.1 | <0.1 | 18.0 | 7.2 |
| *Engraulis australis* | Southern anchovy | - | - | **33.6** | **6.4** | 2.2 | 1.0 | 3.6 | 1.4 |
| *Torquigener pleurogramma* | Blowfish/Banded toadfish | **29.7** | **7.1** | 3.2 | 0.6 | 3.7 | 1.7 | - | - |
| *Acanthopagrus butcheri* | Black bream | 2.5 | 0.6 | 11.7 | 2.2 | 10.4 | 4.9 | 9.6 | 3.8 |
| *Ostorhinchus rueppellii* | Gobbleguts | **29.7** | **7.1** | - | - | 1.8 | 0.8 | - | - |
| *Pelates octolineatus* | Western striped grunter | 25.9 | 6.2 | 0.4 | <0.1 | 0.5 | 0.2 | - | - |
| *Atherinomorus vaigensis* | Ogilby's hardyhead | 19.7 | 4.7 | 5.6 | 1.1 | 1.2 | 0.6 | - | - |
| *Amniataba caudavittata* | Yellowtail grunter | 2.2 | 0.5 | 2.7 | 0.5 | 9.3 | 4.4 | 10.4 | 4.1 |
| *Favonigobius punctatus* | Yellowspotted sand goby | 0.1 | <0.1 | 2.3 | 0.4 | 5.6 | 2.6 | 15.5 | 6.2 |
| *Pseudogobius olorum* | Blue-spot goby | - | - | 2.9 | 0.5 | 0.6 | 0.3 | 16.6 | 6.6 |
| *Leptatherina presbyteroides* | Presbyter's hardyhead/ silverfish | 6.5 | 1.5 | - | - | - | - | - | - |
| *Gerres subfasciatus* | Roach | <0.1 | <0.1 | 1.4 | 0.3 | 2.8 | 1.3 | 0.5 | 0.2 |
| *Geophagus brasiliensis* | Pearl cichlid | - | - | 4.3 | 0.8 | - | - | - | - |
| *Mugil cephalus* | Sea mullet | 2.6 | 0.6 | 0.3 | <0.1 | 0.3 | 0.1 | 0.6 | 0.3 |
| *Aldrichetta forsteri* | Yellow-eye mullet | 0.1 | <0.1 | 0.6 | 0.1 | 2.9 | 1.4 | - | - |
| *Sillago burrus* | Western trumpeter whiting | 0.4 | 0.1 | 0.6 | 0.1 | 1.5 | 0.7 | - | - |
| *Amoya bifrenatus* | Bridled goby | - | - | 0.1 | <0.1 | 0.8 | 0.4 | 0.7 | 0.3 |

| 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 |
| *Spratelloides robustus* | Blue sprat | 1.4 | 0.3 | - | - | - | - | - | - |
| *Hyperlophus vittatus* | Sandy sprat | <0.1 | <0.1 | - | - | - | - | <0.1 | <0.1 |
| *Rhabdosargus sarba* | Tarwhine | 0.1 | <0.1 | - | - | - | - | - | - |
| *Sphyraena obtusata* | Striped barracuda | <0.1 | <0.1 | - | - | - | - | - | - |
| | | **19 Species** | | **19 Species** | | **19 Species** | | **14 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 |
| | | **485** | **5,816** | **606** | **7,275** | **246** | **2,952** | **292** | **3,500** |

**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 2015. 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.

| | | **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 | **5.8** | **30.0** | **55.7** | **84.2** | **49.7** | **94.5** | **28.9** | **60.6** |
| *Amniataba caudavittata* | Yellowtail grunter | - | - | 0.2 | 0.3 | **0.6** | **1.1** | **14.5** | **30.4** |
| *Sardinella lemuru* | Scaly mackerel | 0.8 | 3.9 | **4.1** | **6.2** | - | - | - | - |
| *Platycephalus westraliae* | Yellowtail flathead | 2.3 | 11.7 | 0.3 | 0.5 | **0.9** | **1.7** | 0.2 | 0.4 |
| *Myliobatis australis* | Southern eagle ray | **3.3** | **17.4** | <0.1 | 0.1 | <0.1 | 0.2 | - | - |
| *Sillago burrus* | Western trumpeter whiting | **3.0** | **15.7** | - | - | <0.1 | 0.2 | - | - |
| *Pomatomus saltatrix* | Tailor | 0.6 | 3.0 | **1.8** | **2.8** | 0.3 | 0.6 | 0.3 | 0.5 |
| *Pelates octolineatus* | Western striped grunter | 1.3 | 7.0 | 1.0 | 1.5 | <0.1 | 0.2 | - | - |
| *Engraulis australis* | Southern anchovy | 0.2 | 0.9 | 0.6 | 0.9 | <0.1 | 0.2 | 1.3 | 2.8 |
| *Rhabdosargus sarba* | Tarwhine | <0.1 | 0.4 | 1.4 | 2.1 | - | - | - | - |
| *Argyrosomus japonicus* | Mulloway | - | - | - | - | <0.1 | 0.2 | **1.4** | **3.0** |
| *Elops machnata* | Giant herring | 0.8 | 4.4 | - | - | 0.3 | 0.6 | <0.1 | 0.2 |
| *Gerres subfasciatus* | Roach | 0.5 | 2.6 | 0.3 | 0.5 | 0.2 | 0.3 | 0.3 | 0.5 |
| *Acanthopagrus butcheri* | Black bream | - | - | 0.4 | 0.6 | - | - | 0.8 | 1.6 |
| *Cnidoglanis macrocephalus* | Estuarine cobbler | 0.2 | 0.9 | 0.2 | 0.3 | - | - | - | - |
| *Heterodontus portusjacksoni* | Port Jackson shark | 0.2 | 0.9 | - | - | - | - | - | - |
| *Carcharinas leucas* | Bull shark | - | - | - | - | 0.2 | 0.3 | - | - |
| *Pseudocaranx wrightii* | Sand trevally | 0.2 | 0.9 | - | - | - | - | - | - |
| *Mugil cephalus* | Sea mullet | - | - | - | - | - | - | <0.1 | 0.2 |
| *Pseudorhombus jenynsii* | Small-toothed flounder | <0.1 | 0.4 | - | - | - | - | - | - |
| | | **15 Species** | | **12 Species** | | **12 Species** | | **10 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 |
| | | **19** | **230** | **66** | **793** | **53** | **631** | **48** | **573** |

Gill net samples collected in summer and autumn 2015 from offshore waters returned 2,227 fish, comprising 20 species (Table 4). The total catch of fish from 2015 was the highest total recorded for offshore waters since annual monitoring began in 2012, and was considerably higher than the 1,600 fish (21 species) caught in 2014. As in the nearshore waters, the total number of species declined in an upstream direction, from 15 species in the LSCE to 10 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 Canning Estuary in 2012, 2013 and 2014 (Hallett 2012a, 2013, Hallett and Tweedley 2014).

As in the three previous years, the dominant species among gill net catches from all four zones was the Perth herring, which comprised 30% of the catches from the LSCE and 61–95% of those from the CE, MSE and USE. Other relatively abundant species included the Southern eagle ray (*Myliobatis australis*) and Western trumpeter whiting (*Sillago burrus*) in the LSCE, Scaly mackerel (*Sardinella lemuru*) and Tailor (*Pomatomus saltatrix*) in the CE, and Yellowtail grunter (*Amniataba caudavittata*) in the MSE and USE (Table 4).

Overall, the nearshore and offshore fish communities of the Swan Canning Estuary in 2015 were thus broadly similar in species composition to those observed during equivalent monitoring conducted annually since 2012, and were dominated by similar suites of species in each year. (Hallett 2012a, 2013, Hallett and Tweedley 2014). However, it is notable that 10 fewer species were recorded from nearshore waters in 2015 than in 2014. Elevated salinities were observed throughout the autumn monitoring period in both 2013 and 2014 (Appendix iv) and resulted in a greater influx and penetration of marine species into the estuary during these years (Hallett and Tweedley 2014). In contrast, salinities throughout the system during autumn of 2015 were the lowest recorded since annual monitoring commenced in 2012 (Appendix iv). The lower salinities observed during 2015 would not have been conducive to many of the marine straggler species, which had entered the estuary during 2013 and 2014, doing so during 2015.

### *5.3 Detection of Pearl cichlid during FCI monitoring*

It is also important to note that the Pearl cichlid (*Geophagus brasiliensis*; Fig. 4) was again encountered in 2015 during monitoring for the FCI. Sixty individuals of this invasive introduced species were captured from the nearshore waters of site CE8 (Kent Street Weir) during February 2015. The Pearl cichlid was first reported from the Swan River catchment in 2006 (Beatty et al. 2013), and was caught at three sites in the USE zone during FCI monitoring in 2014 (Hallett and Tweedley 2014). Although Pearl cichlids have been widely detected throughout the freshwater reaches of the Canning River previously (Steve Beatty, Murdoch University, personal communication), this species has not been captured previously from the estuarine waters downstream of Kent St. Weir (Fig. 5). Its presence in the CE zone thus represents a concerning new expansion in the distribution of this species within this system.

Given the small size of the captured individuals (Total Length; range = 30–69 mm, mean = 40.8 mm), it is possible that these fish were carried downstream from the Kent St. Weir pool and into the estuary in the flows that followed rainfall in late January/early February of 2015. The ability of this species to tolerate direct exposure to high salinities (18-27) and to acclimate to full strength seawater (36) is well documented (De Graaf and Coutts 2010), and it is therefore very likely that this species is capable of spreading throughout large parts of the Canning Estuary, downstream of its current distribution, in addition to further expanding its established distribution in the Swan Estuary and the Swan and Canning Rivers.

**Figure 4:** Pearl cichlid, *Geophagus brasiliensis* (Image courtesy of David Morgan, Freshwater Fish Group & Fish Health Unit, Murdoch University).

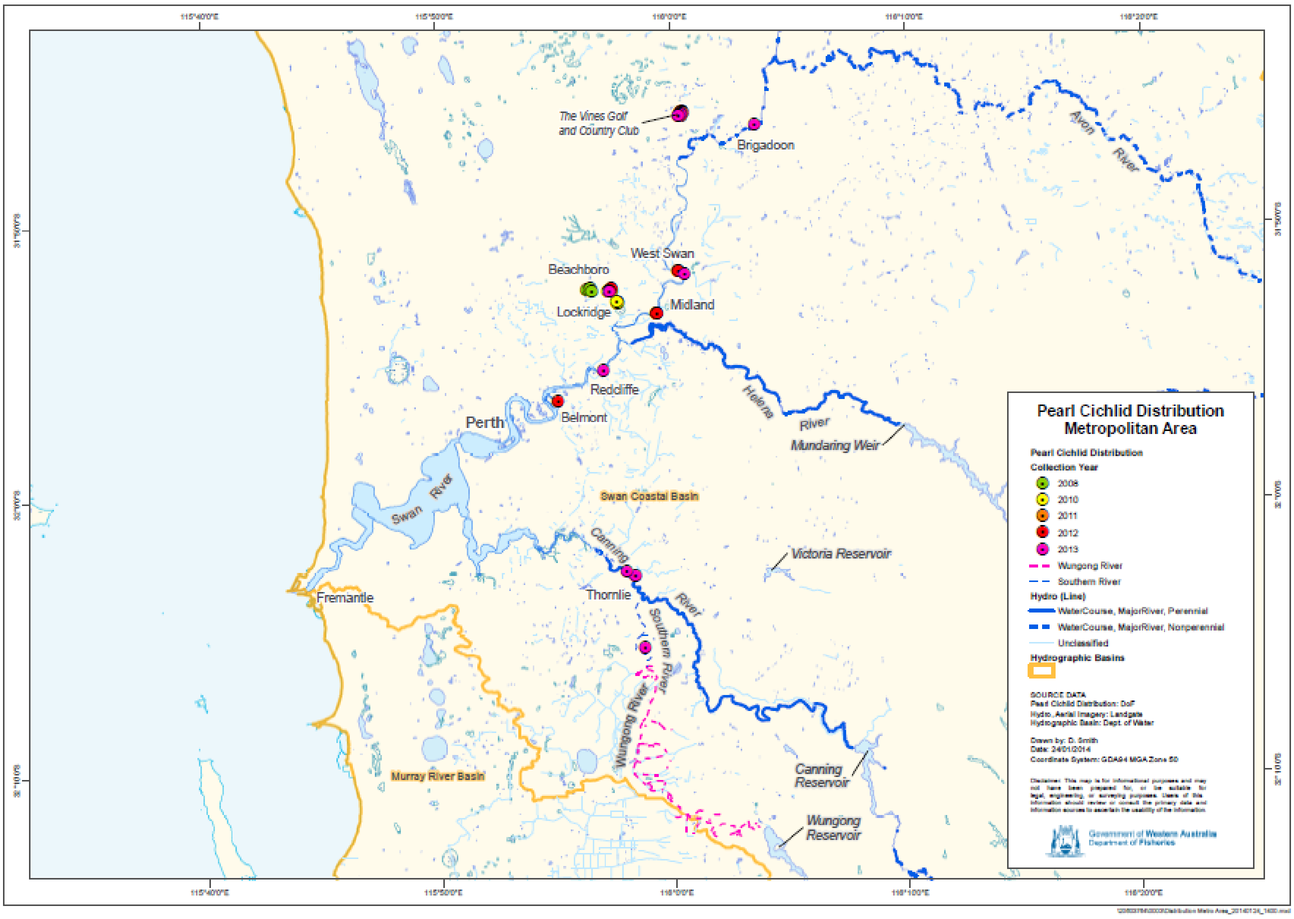



**Figure 5:** Distribution of the Pearl cichlid, *Geophagus brasiliensis*, in the Perth metropolitan area. (Map courtesy of the Department of Fisheries, Western Australia).

### *5.4 Ecological condition in 2015 and comparison to other periods*

*Nearshore waters*

The ecological condition (based on fish communities) of the nearshore waters of the Riverpark was consistently good (B) to fair (C) during the 2015 monitoring period, with the average nearshore FCI scores for all zones and for the estuary as a whole lying between 61 and 71 in each season (Fig. 6). The nearshore FCI scores and condition grades exhibited little change from summer to autumn, with the average FCI score for any particular zone differing by just 4 points between seasons.

The nearshore condition in 2015 represents a decrease from that observed during the previous year (Fig. 7), although it should be emphasised that 2014 was somewhat unusual. The higher FCI scores recorded in 2014 were attributed to increases in the total numbers of fish species recorded within the estuary, as high and stable salinities and a relatively low prevalence of hypoxic conditions throughout much of the system encouraged more marine species to enter the estuary and a wider range of species to penetrate further up into the system (Hallett and Tweedley 2014). Overall, the results from nearshore waters in 2015 are consistent with a pattern of good to fair (B/C) condition assessments in recent years, following an apparent improvement (based on fish communities) in the nearshore condition of the estuary as a whole between 2005/06 and 2008/09 (Fig. 7). The factors underlying this improvement are not known, but are currently under investigation (Valesini et al. in prep.).

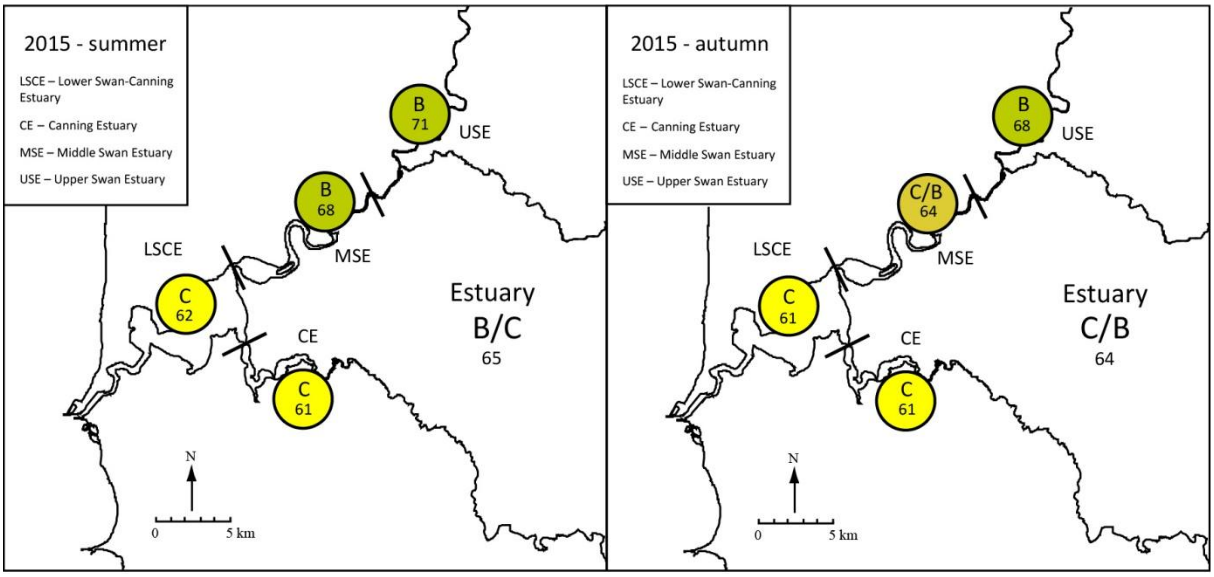



**Figure 6:** Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2015.

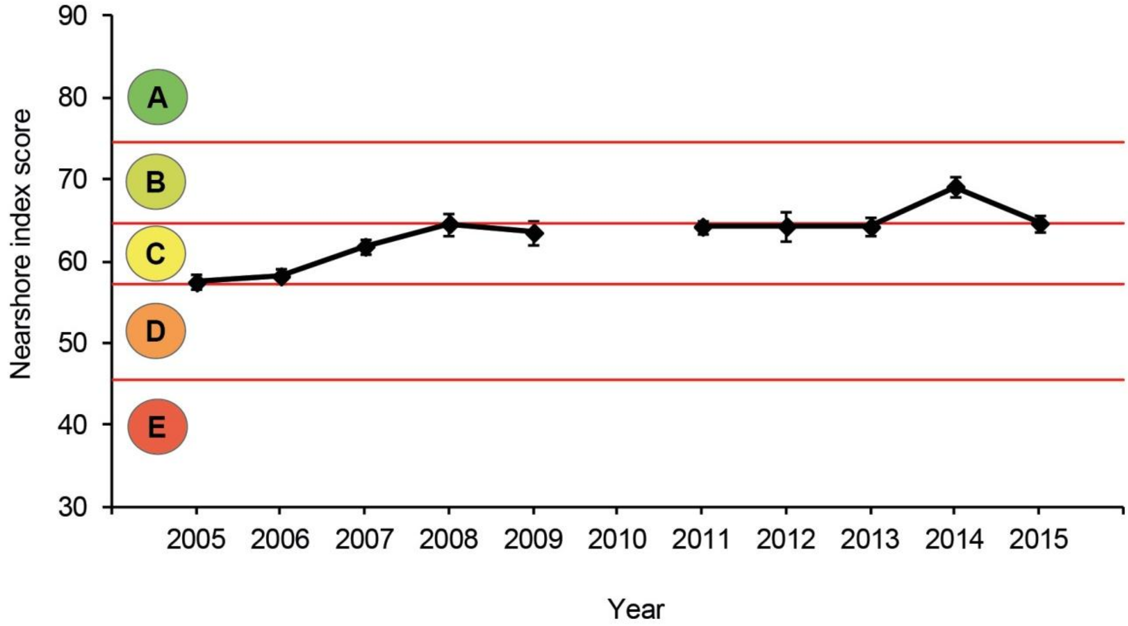



**Figure 7:** Trend plot of average (±SE) nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary as a whole, over recent years. Red lines denote boundaries between condition grades.

Examination of the radar plots of nearshore metric scores for each zone in each season confirms that the CE and LSCE zones both harboured relatively low numbers of species in both summer and autumn of 2015 (as shown by scores of approximately 4 or less for this positive metric; Fig. 8). Also noticeable are the low scores for numbers and/or proportions of benthic (bottom-dwelling) species that were present in the CE and LSCE zones during 2015. The lower numbers of species in these zones likely reflects the effects of slightly 'fresher' salinities during 2015 (see section 5.2) and, in the case of the CE, the effects of stratification-induced hypoxia across parts of this zone at certain times. In contrast, the number of species was relatively high in the USE during summer of 2015, as shown by a score of 8 for this metric.

*Offshore waters*

The ecological condition of the Riverpark's offshore waters in summer and autumn of 2015 was broadly similar to that observed in the corresponding seasons of the previous year (see Hallett and Tweedley 2014). Offshore ecological condition was again assessed as being generally good (B) to fair (C), with the average FCI score for most zones in a given season differing by just 4 points or less between 2014 and 2015 (Fig. 9). Notably, the condition of the CE zone was again rated as poor (D) during summer of 2015, meaning that it once again exhibited the poorest ecological condition (based on fish communities) of the four zones. The fact that the CE has exhibited the poorest offshore condition in each of the last four years suggests other factors may be influencing the fish communities of the deeper waters of this zone, and warrants further investigation.

The reason for the poor condition of the CE zone during summer of 2015 is unclear. Sampling of this zone occurred on January 21st and February 2nd, and water quality data collected concurrently did not indicate the presence of hypoxia at CE sampling sites (Appendix iv). However, it is possible that hypoxia had developed between January 28th and February 3rd, and particularly at night, due to the stratification of the water column that was established across much of the CE around this time (see section 5.1 and Appendix v). It is also possible that one or more other, currently unknown, factors were influencing the fish communities at this time. Appendix vi provides comment on some of the issues that make difficult the interpretation of causal factors underlying changes in FCI scores.

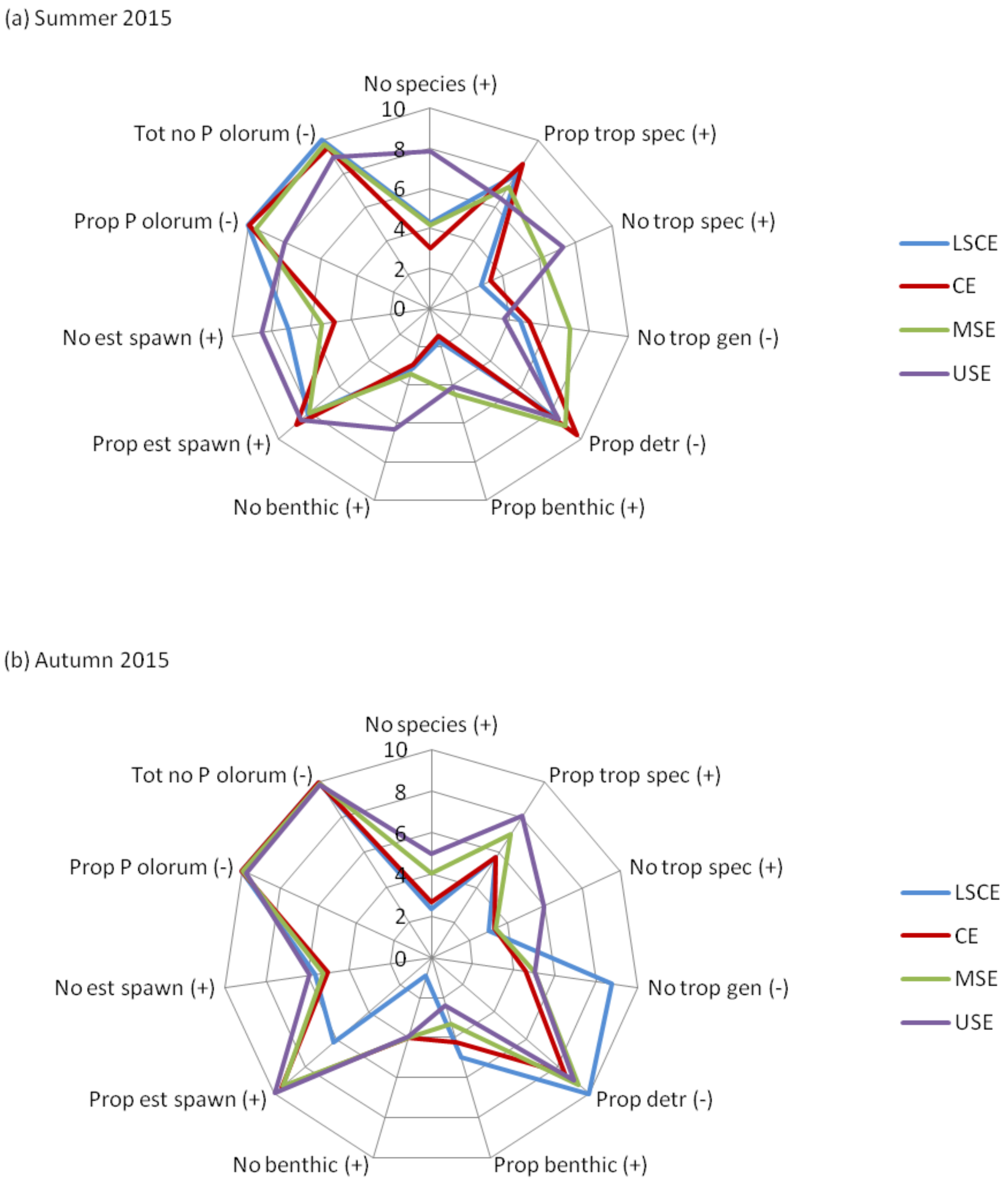



**Figure 8:** Average scores (0-10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2015. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names).

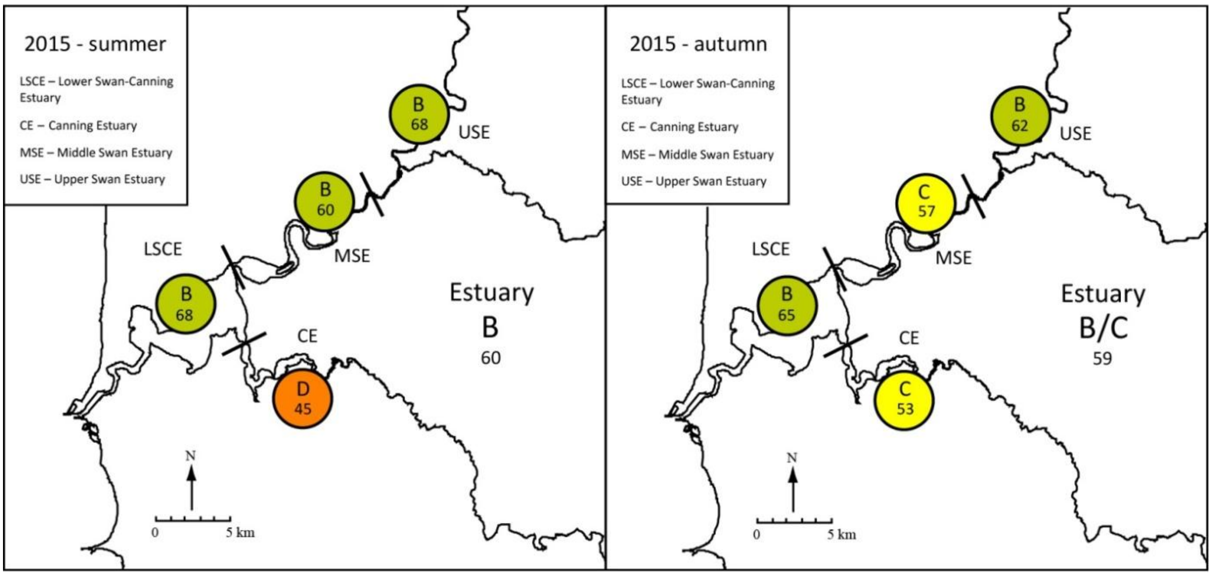



**Figure 9:** Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Riverpark, and for the estuary as a whole, in summer and autumn of 2015.

Despite the relatively poor ecological condition of the CE zone during summer of 2015, the average FCI scores for offshore waters across the estuary as a whole, *i.e.* 60 (B) in summer and 59 (B/C) in autumn (Fig. 9) were very similar to those recorded in previous years. This is consistent with 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).

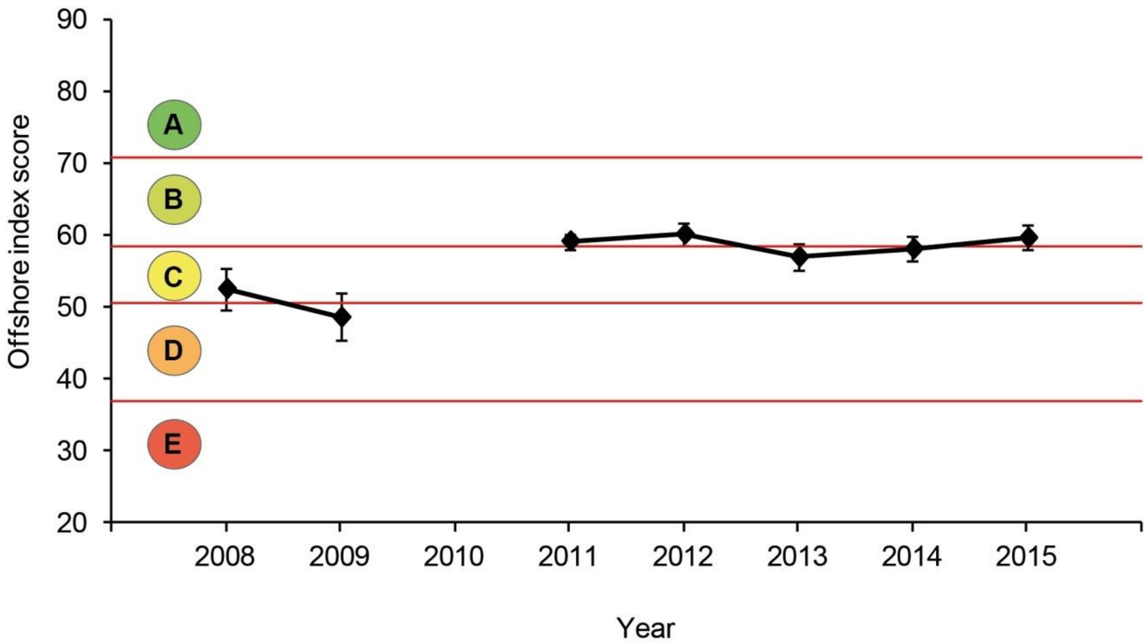



**Figure 10:** Trend plot of average (±SE) offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary as a whole, over recent years. Red lines denote boundaries between condition grades.

Radar plots of offshore metric scores for each zone in each season show the poor ecological condition of the CE during summer of 2015 to have been driven by relatively low scores for the numbers and diversity of fish species (both positive metrics) and by a relatively high proportion of fish species that feed on decomposing organic material (a negative metric; Fig. 11). These results mirror the findings from previous years for the CE zone (Hallett 2013, Hallett and Tweedley 2014).

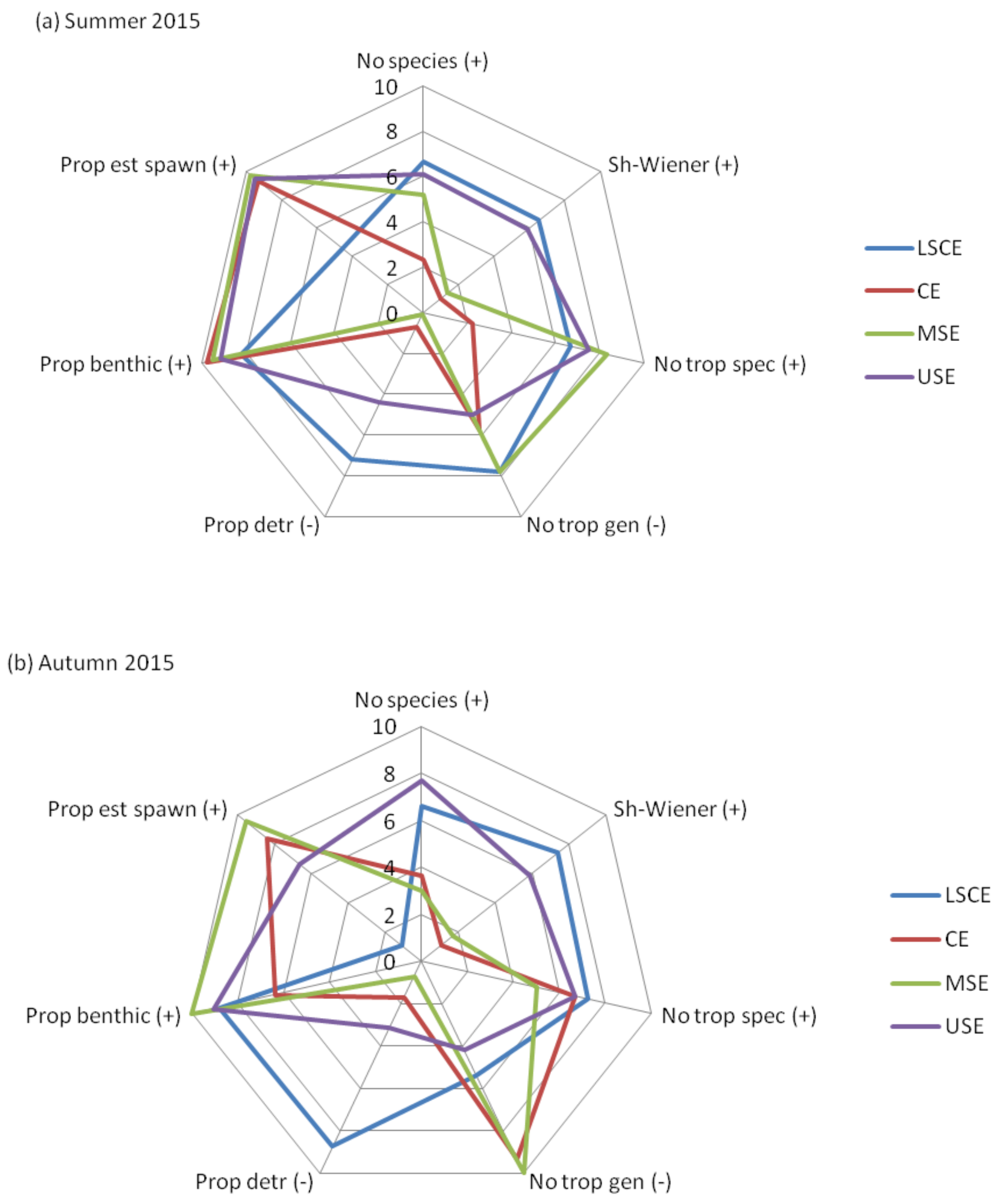



**Figure 11:** Average scores (0-10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2015. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable (see Table 1 for metric names).

*Summary*

The Fish Community Index looks at 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. The indices do not provide information on species specific population dynamics or health.

In summary, and across the estuary as a whole, the ecological condition of both nearshore and offshore waters was again assessed as generally good (B) to fair (C) during the current monitoring year (based on fish communities). This is consistent with the pattern of good-fair (B/C) or fair-good (C/B) condition assessments that have been recorded for offshore waters since 2011 and for nearshore waters since 2008. Notably, the CE zone again proved the exception to this rule, with the offshore waters of this zone exhibiting poor ecological condition (based on fish communities) during summer of 2015. It is unclear whether hypoxic conditions, which may have become established in the bottom waters of much of this zone around the time of sampling, were responsible for its poor condition. However, given that the CE has exhibited the poorest offshore condition in each of the last four years, other factors may also be exerting pressure on fish species diversity and richness in the deeper waters of this zone. Further investigation of this zone may be warranted.

## 6. References

Beatty, S.J., Morgan, D.L., Keleher, J., Allen, M.G., Sarre, G.A. (2013). The tropical South-American cichlid, *Geopphagus brasiliensis* in Mediterranean climatic south-western Australia. *Aquatic Invasions* 8: 21-36.

De Graaf, M., Coutts, T. (2010). Invasive potential of a South-American fish species, *Geophagus brasiliensis*, in the Swan River, Western Australia: based tolerance to instantaneous and gradual changes in salinity. *Journal of the Royal Society of Western Australia* 93: 147–151.

Fonseca, V.F., Vasconcelos, R.P., Gamito, R., Pasquaud, S., Gonçalves, C.I., Costa, J.L., Costa, M.J., Cabral, H.N. (2013). Fish community-based measures of estuarine ecological quality and pressure–impact relationships. *Estuarine, Coastal and Shelf Science* 134: 128–137.

Gibson, G.R., Bowman, M.L., Gerritsen, J., Snyder, B.D. (2000). Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance. EPA 822-B-00-024. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Hallett, C.S. (2014). Quantile-based grading improves the effectiveness of a multimetric index as a tool for communicating estuarine condition. *Ecological Indicators* 39: 84-87.

Hallett, C.S. (2013). Assessment of the condition of the Swan Canning Estuary in 2013, based on the Fish Community Indices of estuarine condition. Final report to the Swan River Trust. Murdoch University.

Hallett, C.S. (2012a). Assessment of the condition of the Swan Canning Estuary in 2012, based on the Fish Community Indices of estuarine condition. Final report to the Swan River Trust. Murdoch University.

Hallett, C.S. (2012b). Brief report on fish community responses to the *Karlodinium veneficum* bloom of May 2012, including the response of the Fish Community Index of Estuarine Condition. Final report to the Swan River Trust. Murdoch University.

Hallett, C.S., Tweedley, J.R. (2014). Assessment of the condition of the Swan Canning Estuary in 2014, based on the Fish Community Indices of estuarine condition. Final report to the Swan River Trust. Murdoch University.

Hallett, C.S., Valesini, F.J. (2012). Validation of the Fish Community Index of Estuarine Condition and development of a monitoring regime for the Swan Canning Riverpark. Final Report to the Swan River Trust. Murdoch University.

Hallett, C.S., Valesini, F.J., Clarke, K.R., Hesp, S.A., Hoeksema, S.D. (2012). Development and validation of a fish-based, multimetric index for assessing the ecological health of Western Australian estuaries. *Estuarine, Coastal and Shelf Science* 104-105: 102-113.

Hallett, C.S., Valesini, F.J., Clarke, K.R., Hoeksema, S.D. (2015). Effects of a harmful algal bloom on the community ecology, movements and spatial distributions of fishes in a microtidal estuary. *Hydrobiologia,* In press, DOI: 10.1007/s10750-015-2383-1.

Loneragan, N.R., Potter, I.C., Lenanton, R.C.J. (1989). Influence of site, season and year on contributions made by marine, estuarine, diadromous and freshwater species to the fish fauna of a temperate Australian estuary. *Marine Biology* 103: 461-479.

Loneragan, N.R., Potter, I.C., Lenanton, R.C.J., Caputi, N. (1987). Influence of environmental variables on the fish fauna of the deeper waters of a large Australian estuary. *Marine Biology* 94: 631-641.

Loneragan, N.R., Potter, I.C., Lenanton, R.C.J., Caputi, N. (1986). Spatial and seasonal differences in the fish fauna in the shallows of a large Australian estuary. *Marine Biology* 92: 575-586.

Potter, I.C., Tweedley, J.R., Elliott, M., Whitfield, A.K. (2015). The guilds representing the different ways fish use estuaries: a refinement and expansion. *Fish and Fisheries* 16 (2): 230-239.

Tyler, R.M., Brady, D.C., Targett, T.E. (2009). Temporal and spatial dynamics of diel-cycling hypoxia in estuarine tributaries. *Estuaries and Coasts* 32: 123–145.

Valesini, F.J., Hallett, C.S., Cottingham, A. (In prep.). Multi-decadal changes in the fish fauna of an extensively modified estuary.

Valesini, F.J., Hallett, C.S., Cottingham, A., Hesp, S.A., Hoeksema, S.D., Hall, N.G., Linke, T.E., Buckland, A.J. (2011). Development of biotic indices for establishing and monitoring ecosystem health of the Swan Canning Estuary. Final Report to the Swan River Trust, Department of Water, Department of Fisheries. Murdoch University.

Veale, L., Tweedley, J.R., Clarke, K.R., Hallett, C.S., Potter, I.C. (2014). Characteristics of the ichthyofauna of a temperate microtidal estuary with a reverse salinity gradient, including inter-decadal comparisons. *Journal of Fish Biology* 85 (5): 1320-1354.

Villéger, S., Ramos Miranda, J., Flores Hernández, D., Mouillot, D. (2010). Contrasting changes in taxonomic vs. functional diversity of tropical fish communities after habitat degradation. *Ecological Applications* 20: 1512–1522.

Whitfield, A.K., Elliott, M. (2002). Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology* 61: 229-250.

**Appendix (i):** 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.* 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.

Rees, A.J.J., Yearsley, G.K., Gowlett-Holmes, K. and Pogonoski, J. (2006). 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 5th June 2015.

**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 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 |
| *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 |
| *Sillago schomburgkii* | Yellow-finned whiting | D | MM | ZB |

| Species name | Common name | Habitat guild | Estuarine Use guild | Feeding Mode guild |
|---|---|---|---|---|
| *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* | Yellowspotted sand 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 |
| *Chaetodermis pencilligera* | Tasselled leatherjacket | D | MS | OV |

| Species name | Common name | Habitat guild | Estuarine Use guild | Feeding Mode guild |
|---|---|---|---|---|
| *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):

**(a)** Average salinities, measured at the time of sampling, across all nearshore and offshore sampling sites during 2012–2015.

| | 2012 | | 2013 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | Summer | Autumn | Summer | Autumn | Summer | Autumn | Summer | Autumn |
| Nearshore | 25.3 | 28.9 | 30.6 | 30.6 | 27.4 | 33.2 | 27.8 | 28.0 |
| Offshore (surface) | 26.0 | 30.4 | 30.9 | 30.6 | 27.6 | 33.5 | 28.0 | 28.5 |
| Offshore (bottom) | 26.4 | 31.7 | 31.5 | 32.5 | 28.7 | 33.9 | 28.6 | 30.0 |

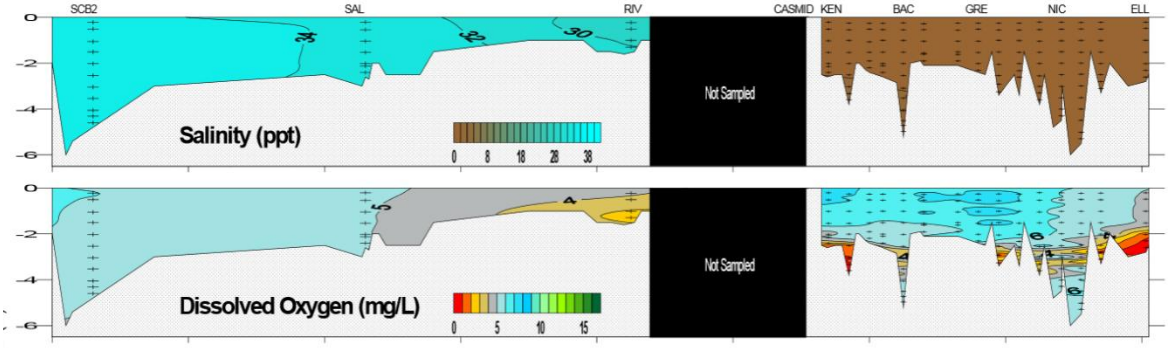
**(b)** Average dissolved oxygen concentrations (mg/L), measured at the time of sampling, across all nearshore and offshore sampling sites during 2012–2015.

| | 2012 | | 2013 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | Summer | Autumn | Summer | Autumn | Summer | Autumn | Summer | Autumn |
| Nearshore | 6.3 | 8.3 | 7.5 | 7.1 | 6.6 | 7.5 | 6.6 | 8.4 |
| Offshore (surface) | 6.0 | 6.2 | 6.9 | 6.7 | 6.4 | 6.6 | 7.1 | 7.6 |
| Offshore (bottom) | 5.3 | 4.1 | 7.4 | 4.6 | 4.9 | 6.1 | 5.2 | 6.7 |

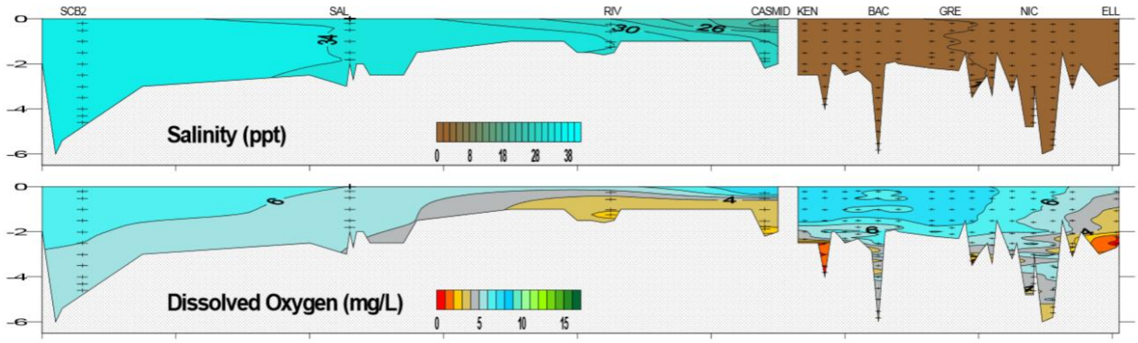
**Appendix (v):** Vertical contour plots of salinity and dissolved oxygen concentrations (mg/L) measured at monitoring stations along the length of the Swan Canning Estuary on occasions closely corresponding to fish community sampling. Obtained from SRT website (http://www.swanrivertrust.wa.gov.au/swan-river-trust/publications/monitoring-and-evaluation).

**Canning Estuary zone in summer 2015.**

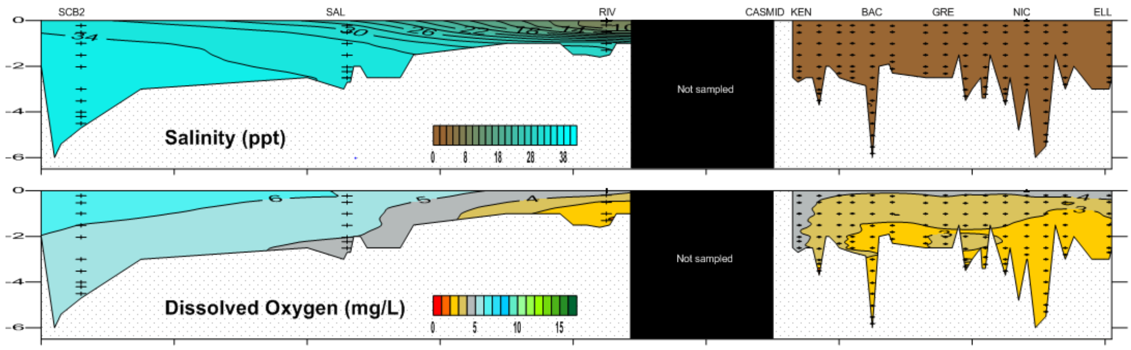
Canning River Estuary - Physical-chemical Profile - 20th January 2015



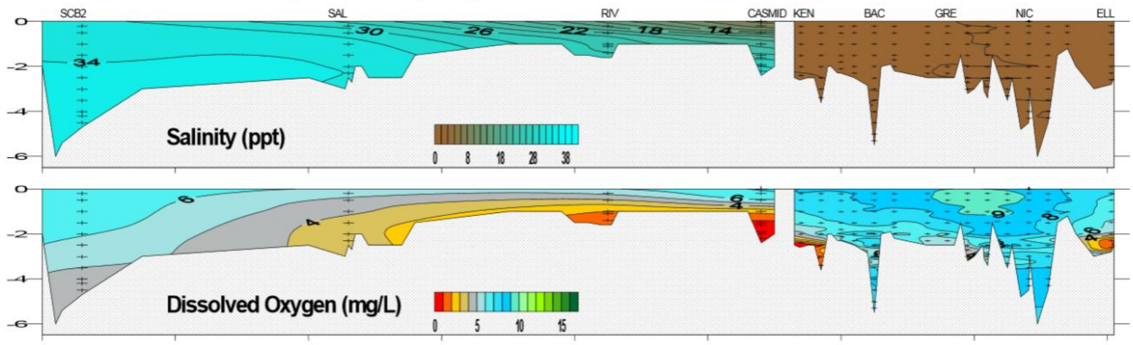

Canning River Estuary - Physical-chemical Profile - 28th January 2015



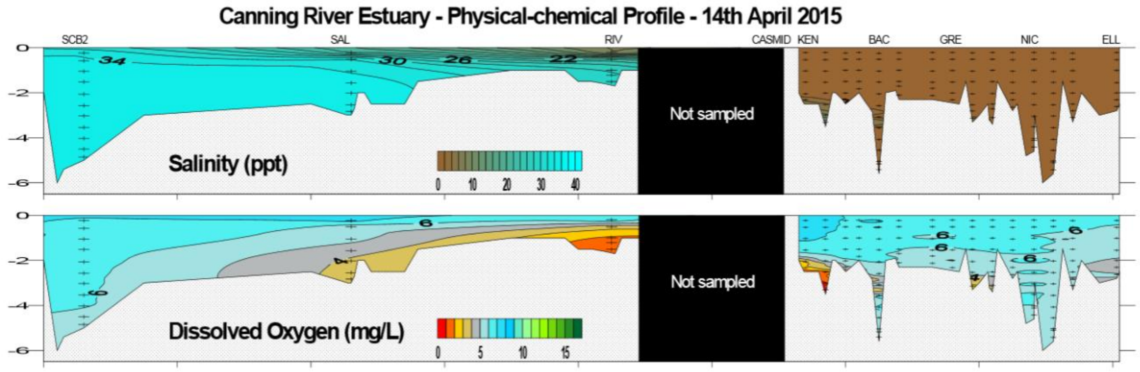

Canning River Estuary - Physical-chemical Profile - 3rd February 2015

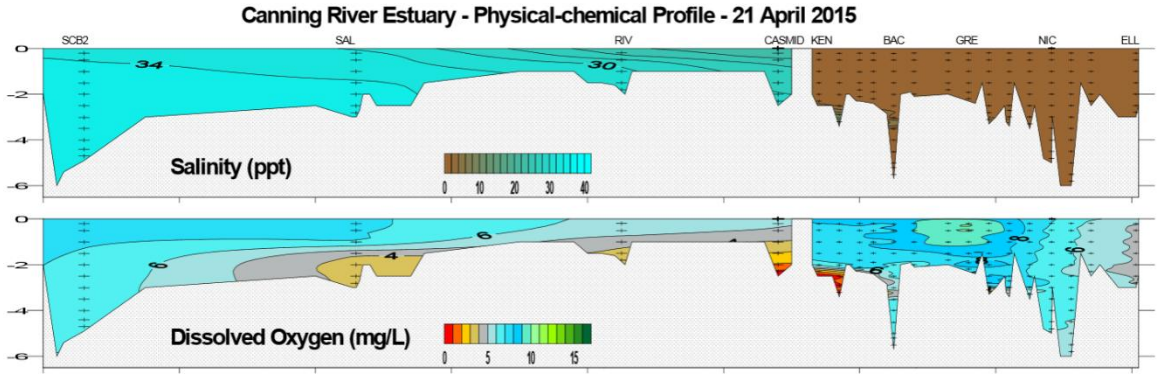


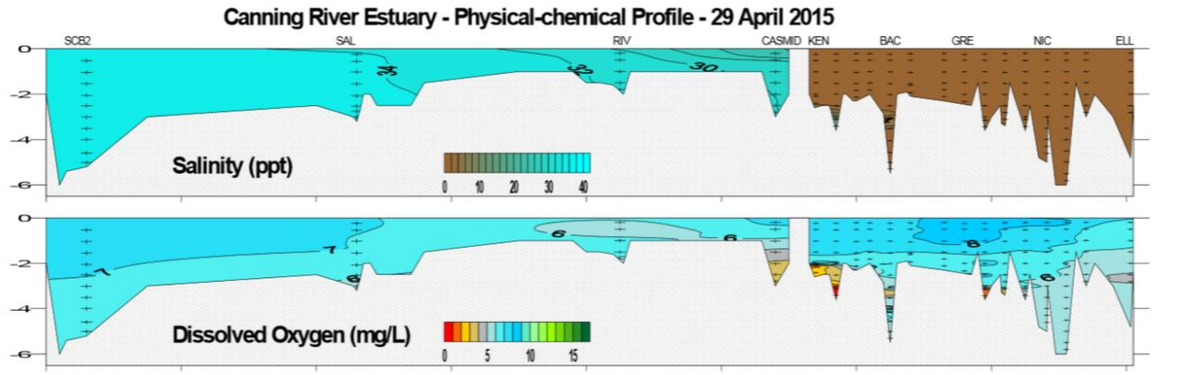

Canning River Estuary - Physical-chemical Profile - 10th February 2015

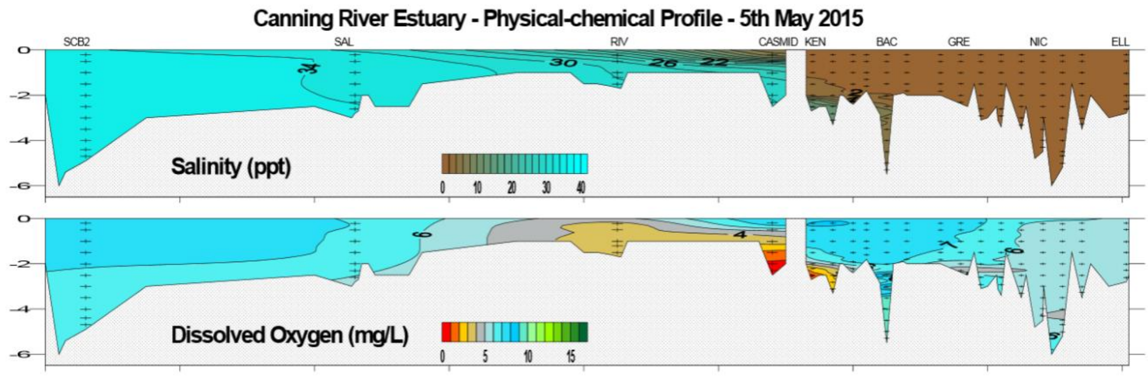


**Canning Estuary zone in autumn 2015.**

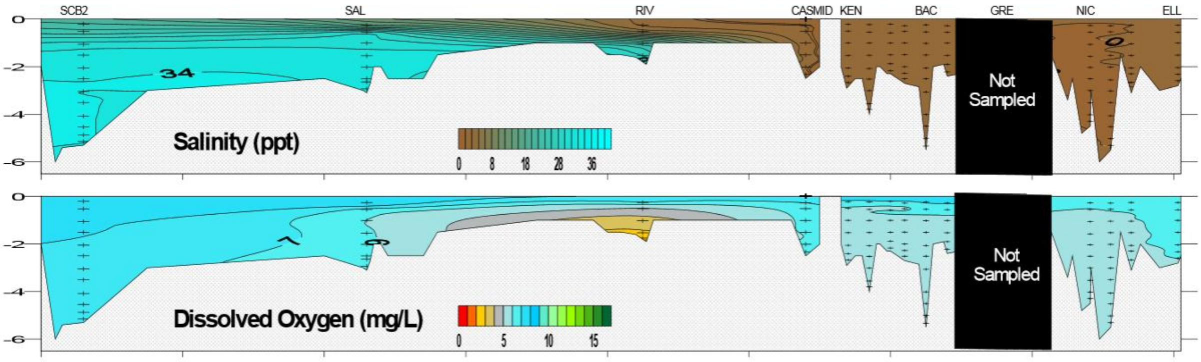


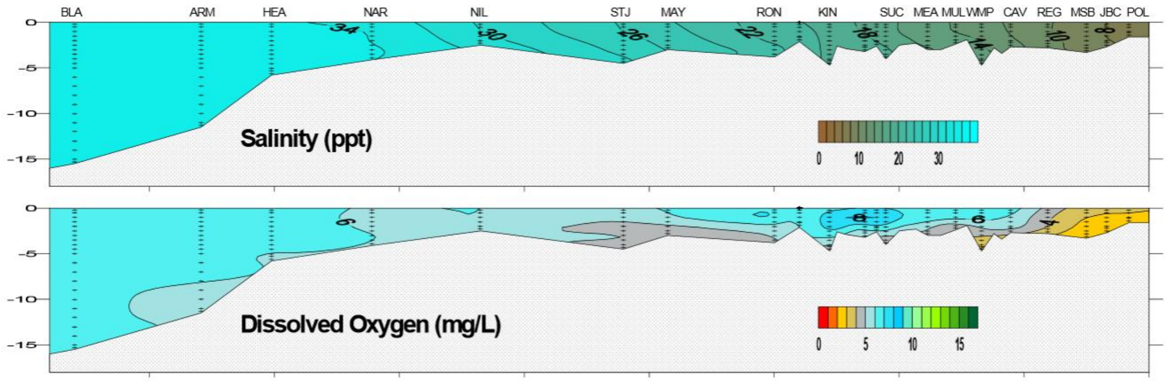



Canning River Estuary - Physical-chemical Profile - 19 May 2015

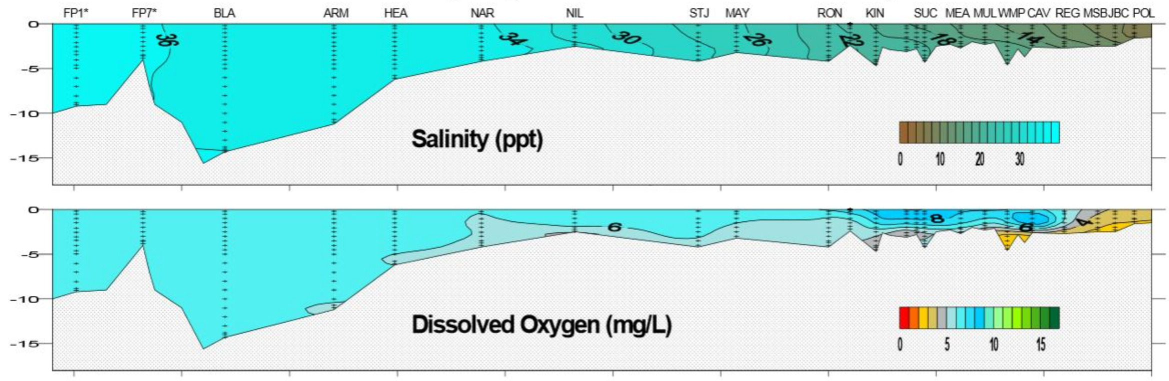



**Lower Swan Canning Estuary, Middle and Upper Swan Estuary zones in summer 2015.**

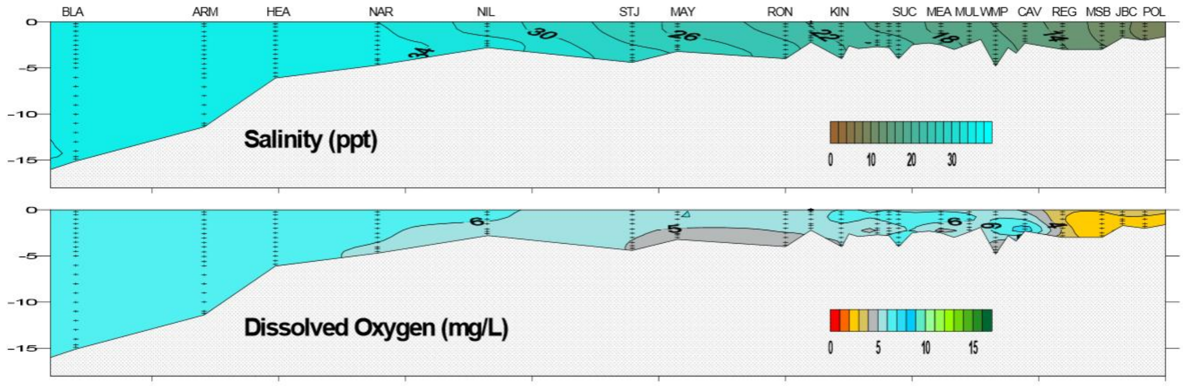
Swan River Estuary - Physical-chemical Profile - 19th January 2015




Swan River Estuary - Physical-chemical Profile - 27th January 2015

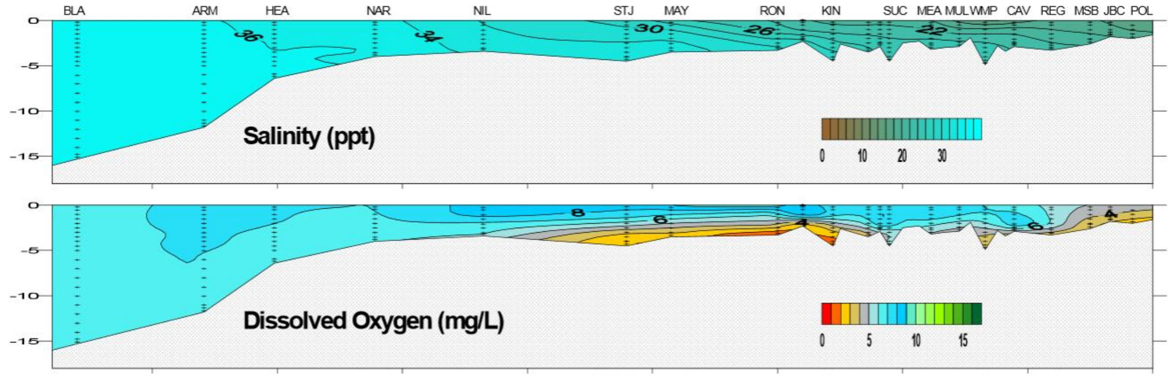



Swan River Estuary - Physical-chemical Profile - 2nd February 2015

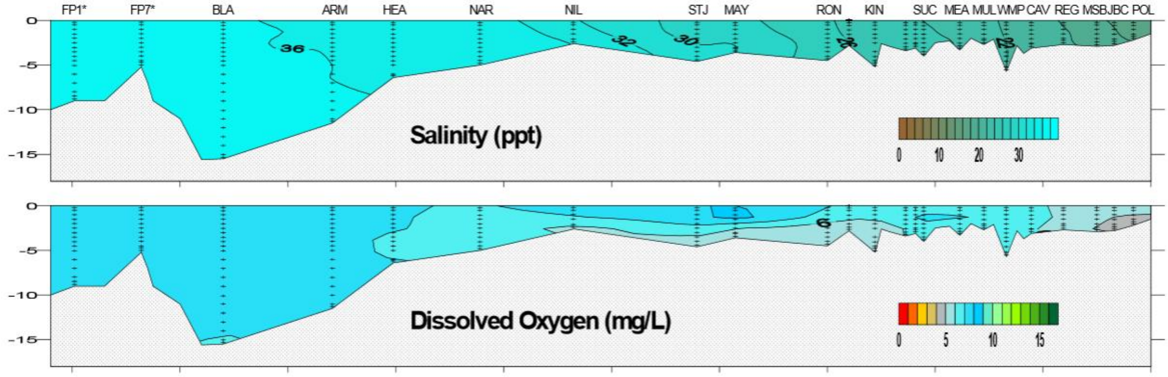


**Lower Swan Canning Estuary, Middle and Upper Swan Estuary zones in autumn 2015.**

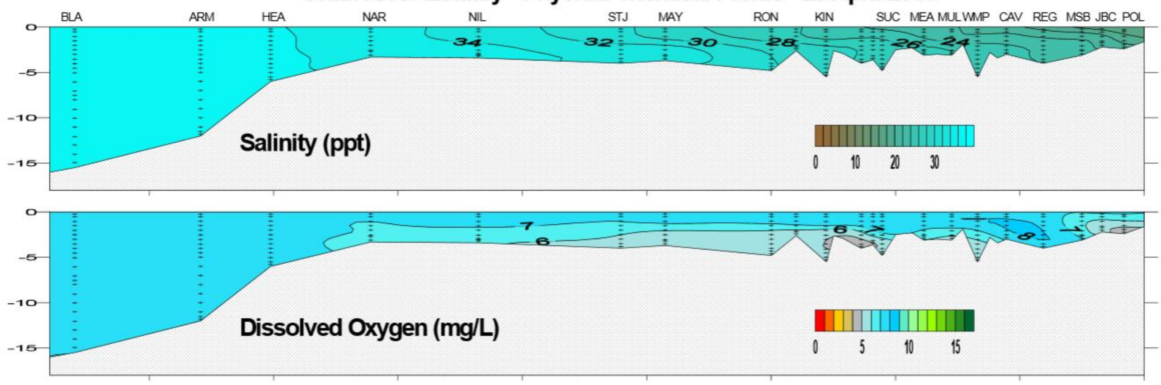
Swan River Estuary - Physical-chemical Profile - 13th April 2015



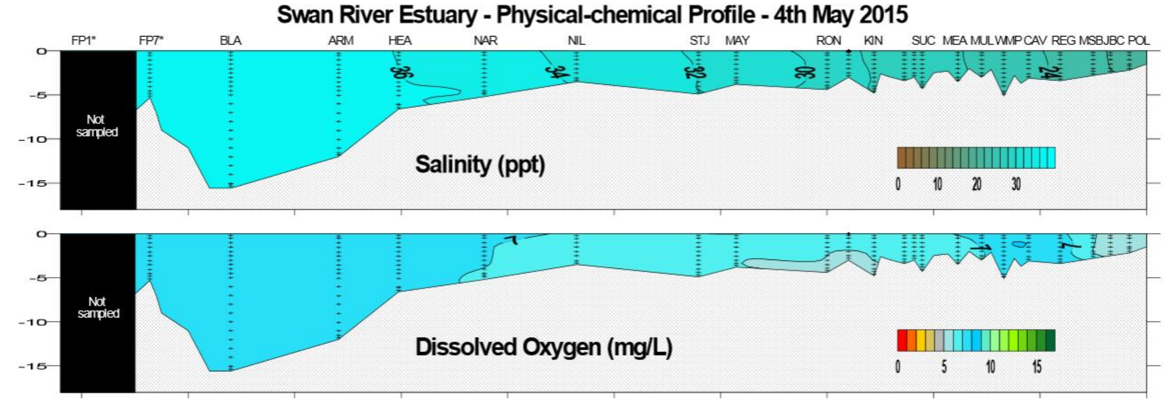

Swan River Estuary - Physical-chemical Profile - 20 April 2015




Swan River Estuary - Physical-chemical Profile - 28 April 2015




Swan River Estuary - Physical-chemical Profile - 4th May 2015



**Appendix (vi):** Comment: Monitoring of water quality and the challenges of identifying factors driving changes in FCI scores

Water quality measurements taken concurrently with fish community samples during summer of 2015 indicated that conditions in the CE zone were generally well oxygenated at this time (Appendix iv). Those collected by the DoW show that the water column of this zone was heavily stratified by February 3rd, yet give no indication of notable hypoxia at this time (Appendix v). Nonetheless, the poor condition of the offshore waters of the CE suggests that one or more factors had a negative impact on the fish communities during summer. As discussed below, our current monitoring of water quality does not always allow us to adequately describe the spatial and temporal dynamics of DO and other potentially influential factors, particularly at night and/or in certain parts of the system. This prevents us from fully understanding the spatial and temporal scales of changes in key variables during certain events (*e.g.* periods of high river flow, algal blooms or stratification-induced hypoxia), and so hinders the interpretation of the factors influencing the fauna and broader ecological condition of the system. Two issues are particularly relevant.

Measurements of water quality throughout the estuary currently provide only a snapshot in time and are made during the day and/or soon after sunset. Measurements made on a single occasion are assumed to be fairly representative of those that would be observed over a longer period (*e.g.* the week); an assumption that is likely to be violated in many instances within the dynamic estuarine environment. For example, such monitoring is likely to miss the short-term declines in DO concentrations that will affect the estuary at certain times (Tyler et al. 2009). This includes the hypoxia that can develop following stratification of the water column, and the nocturnal declines in DO that are frequently associated with algal blooms. In the latter case, algal respiration in the absence of photosynthesis and oxidative decomposition of settling organic matter tend to generate DO minima at night or around sunrise (Tyler et al. 2009; Hallett et al. 2015). Except in localized monitoring zones around the oxygenation plants, these declines in environmental condition would not be detected by the current water monitoring regime in the Swan Canning Estuary, yet are likely to exert a strong influence on the distribution and behaviour of fishes and thus impact on FCI scores.

Also, existing water quality monitoring sites are relatively widely spaced, with several kilometres between some adjacent sites. It is implicitly assumed that this spatial arrangement of sites (and the accompanying data interpolation) provides a reliable estimate of water quality conditions between sites. However, water quality data collected concurrently with fish community samples at FCI monitoring sites indicate that this may not be the case in certain areas of the estuary. In several instances in previous years, severe hypoxia has been detected at FCI sites located between DoW monitoring stations, whilst the corresponding vertical contour plots indicated DO concentrations of >4mg/L (*e.g.* in the CE, between the Riverton Bridge and Salter Point stations, and also downstream of the Salter Point station, around Rossmoyne and Mount Henry; Hallett, unpublished data). Similarly, recent unpublished data from sampling for Western school prawns indicated that DO concentrations in the bottom waters at Rossmoyne were 0.13 mg/L on February 5th 2015 and 0.09 mg/L on May 19th, highlighting a severity and spatial extent of hypoxia that is not captured in the vertical contour plots for the corresponding periods. Furthermore, as the interpolation of water quality data is based on mid-channel measurements, there is some question over the degree to which observed patterns in water quality variables reflect conditions in adjacent nearshore waters.

Together, the above issues limit our ability to interpret changes in FCI scores and determine the causes of observed changes in ecological condition. There is a need to better quantify and understand the day-night dynamics of water quality during periods of high river flows, algal blooms etc. in the Swan Canning Estuary, and particularly how these dynamics differ at various spatial scales and between estuary zones. We suggest that this need could be addressed by supplementing existing water quality monitoring with event-based investigations that employ continuous monitoring techniques.