Swan Canning Estuary condition assessment based on fish communities - 2023

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Executive summary

This report, commissioned by the Department of Biodiversity, Conservation and Attractions (DBCA), describes the monitoring and evaluation of fish communities in the Swan Canning Estuary during 2023 and applies the Fish Community Index (FCI) that was developed as a measure of the ecological condition of the estuary. This index, separate versions of which were developed for both the shallow (< 1.5 m), nearshore waters of the estuary and also for its deeper (> 1.5 m), offshore waters, integrates information on various biological variables (metrics). Each of these metrics quantifies an aspect of the structure and/or function of the fish community, and together they respond to a range of stressors affecting the ecosystem.

Fish communities were sampled using different types of net at six nearshore and six offshore sites in each of four management zones of the estuary (LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary) during summer and autumn of 2023. 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 Swan Canning 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 good/fair condition (B/C) during summer and autumn 2023, respectively, which is consistent with the overall trend in condition since both 2011. The average nearshore FCI scores for each zone of the estuary varied during summer, being best, i.e. good, in the LSCE, MSE, good/fair in the USE and lowest in the CE resulting in a fair (C) score. Although present, potentially harmful algal species were not sufficiently abundant to have impacted conditions at times of sampling. By autumn, the scores in the USE decreased to fair and those in the LSCE to fair/good, while those in the CE increased to good/fair. While the mean score for the MSE increased by 1 point, the grade remained the same, i.e. good. A storm event in late March resulted in pronounced stratification and hypoxia in parts of the USE and MSE during autumn sampling.

Small-bodied, schooling species of hardyheads (Atherinidae) and gobies (Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2023, representing 82% of all fish recorded and constituting six of the eight most abundant nearshore species. Wallace's Hardyhead was the most abundant species overall and also in the CE and USE, reflecting the preference of this species for the fresh to brackish conditions that were present in these zones during the 2023 monitoring period. Other abundant species of small, schooling fish included the Spotted Hardyhead, Common Hardyhead and Elongate Hardyhead, each of which prefers more saline waters than Wallace's Hardyhead. The Red-spot Goby and Perth Herring were abundant in the MSE, with the former species also in high densities in the USE together with the Blue-spot Goby. Larger abundances of juveniles of several marine-spawning species, including the Western Trumpeter Whiting, Yellow-eye Mullet and Sea Mullet were recorded, potentially due to the "better than average" riverine flows in winter 2021 and 2022, which are known to increase productivity and fish populations.

Offshore fish communities

The offshore waters of the Swan Canning Estuary were in good (B) condition in summer and good/fair (B/C) during autumn 2023. The overall score of good was similar to 2022 and an increase on the fair (C) grade it received in 2021, and represents only the fifth time in 15 years that good condition was achieved. Scores in the LSCE, MSE and USE in summer were good likely driven by relatively saline and oxic conditions and the absence of toxic algal blooms. Scores did decline to good/fair in the USE and MSE in autumn due to stratification-associated hypoxia as the result of a storm event in March. Once again, the offshore waters of the CE exhibited by far the lowest scores of any zone, i.e. poor (D) in summer and fair/poor (C/D) in autumn.

The persistent poor (D) scores in the CE relative to the other zones were further investigated using the long-term FCI dataset (2012-2023) to help understand which metric(s) were responsible for the low scores. Among the seven metrics used to calculate the offshore FCI, scores for the *Number of species, Shannon-Wiener diversity*, the *Number of trophic specialist species* and the *Proportion of detritivores* were all significantly lower in the CE than for the other zones. The fish fauna in the offshore waters of the CE comprises mainly the detritivorous Perth Herring (median percentage composition = 77%). The overwhelming dominance of this species and the relative absence of other species, particularly those that are trophic specialists, drive the low scores. The reasons for this are uncertain but thought to be related to a combination of water quality (e.g. salinity and night-time hypoxia), a lack of complex habitat and/or reduced food resources.

As in most previous years of monitoring, Perth Herring was among the dominant species in offshore waters from all four zones comprising 23–75% of the total catches. Other abundant species included the Southern Eagle Ray and Tailor in the LSCE (19 and 60%, respectively, of the catch), the Yellowtail Grunter in the MSE (38%) and USE (44%), and Sea Mullet in the USE (17%). The numbers of species and individuals recorded from the offshore waters in 2023 were amongst the greatest in any monitoring year. Catches of several species were relatively high in 2023, including the Hawaiian Giant Herring, Yellowtail Grunter and Sea Mullet.

Overall

Across the entire estuary, the ecological condition of both nearshore and offshore waters in 2023 was assessed as good/fair (B/C) and good (B) based on their fish communities, a slight reduction from 2022. Combined, the nearshore and offshore index scores for 2023 are the third highest ever recorded since annual monitoring began in 2012. As in 2022, the good scores for zones along the Swan axis of the estuary (LSCE, MSE and USE) were likely influenced by the strong freshwater flows in the previous winter, which would increase productivity in both the estuary and nearby coastal waters and facilitate the recruitment of fish species. The slight decrease in scores between 2022 and 2023 reflects the occurrence of a storm event in late March 2023, which resulted in stratification-induced hypoxia in parts of the USE and MSE in autumn.

Swan Canning Estuary condition assessment based on fish communities - 2023

Contents

1. Background

The Department of Biodiversity, Conservation and Attractions (DBCA) 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, in collaboration with the Western Australian government between 2007 and 2012 (Valesini et al., 2011; Hallett and Valesini, 2012; Hallett et al., 2012), and provides an assessment of the condition of the Swan Canning Estuary based on fish communities. The FCI has been subjected to extensive testing and validation over 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). The development and rationale of the FCI, along with its implementation and outcomes to date, are summarized in Hallett et al. (2019).

2. Rationale

Separate versions of the FCI were developed for the shallow, nearshore waters (< 1.5 m deep) of the estuary and also for its deeper, offshore waters (> 1.5 m deep), as the composition of the fish communities living in these different environments tends to differ, as do the methods used to sample them (Chuwen, 2009; Hoeksema et al., 2009; Potter et al., 2016). 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. Together, the metrics respond 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 (Hallett et al., 2019; Tweedley et al., 2021).

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; Tweedley et al., 2017). 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 Yellowtail 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 (Krispyn et al., 2021; right side of Fig. 1). The reverse will be observed in a relatively unspoiled system that is subjected to fewer human stressors (see left side of Fig. 1; noting that this conceptual diagram represents either end of a continuum of ecological condition from very poor to very good).

Each of the metrics that make up the FCI is scored from 0–10 according to the numbers and proportions of the various fish species present in samples collected from the estuary using either seine or gill nets. These metric scores are summed to generate an 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).

Table 1. List of the metrics used to calculate the nearshore and offshore Fish Community Indices developed for the Swan Canning Estuary. The predicted response of each metric to degradation in the estuary is also provided.

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 biodiversity

[b] Species with specialist feeding requirements (e.g. those that only eat small invertebrates)

[c] Species that are omnivorous or opportunistic feeders

[d] Species that eat detritus (decomposing organic material)

[e] Species that live on, or are closely associated with the substrate

[f] The Blue-spot or Swan River Goby, a tolerant, omnivorous species that often inhabits silty habitats (Gill and Potter, 1993)

3. Study objectives

This report describes the monitoring and evaluation of fish communities in the Swan Canning Estuary during 2023 to apply the FCI 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 FCI 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 metric scores for each zone.
3. Provide a report that summarizes the approach and results and that could feed into the broader estuarine reporting framework of the Department of Biodiversity, Conservation and Attractions.

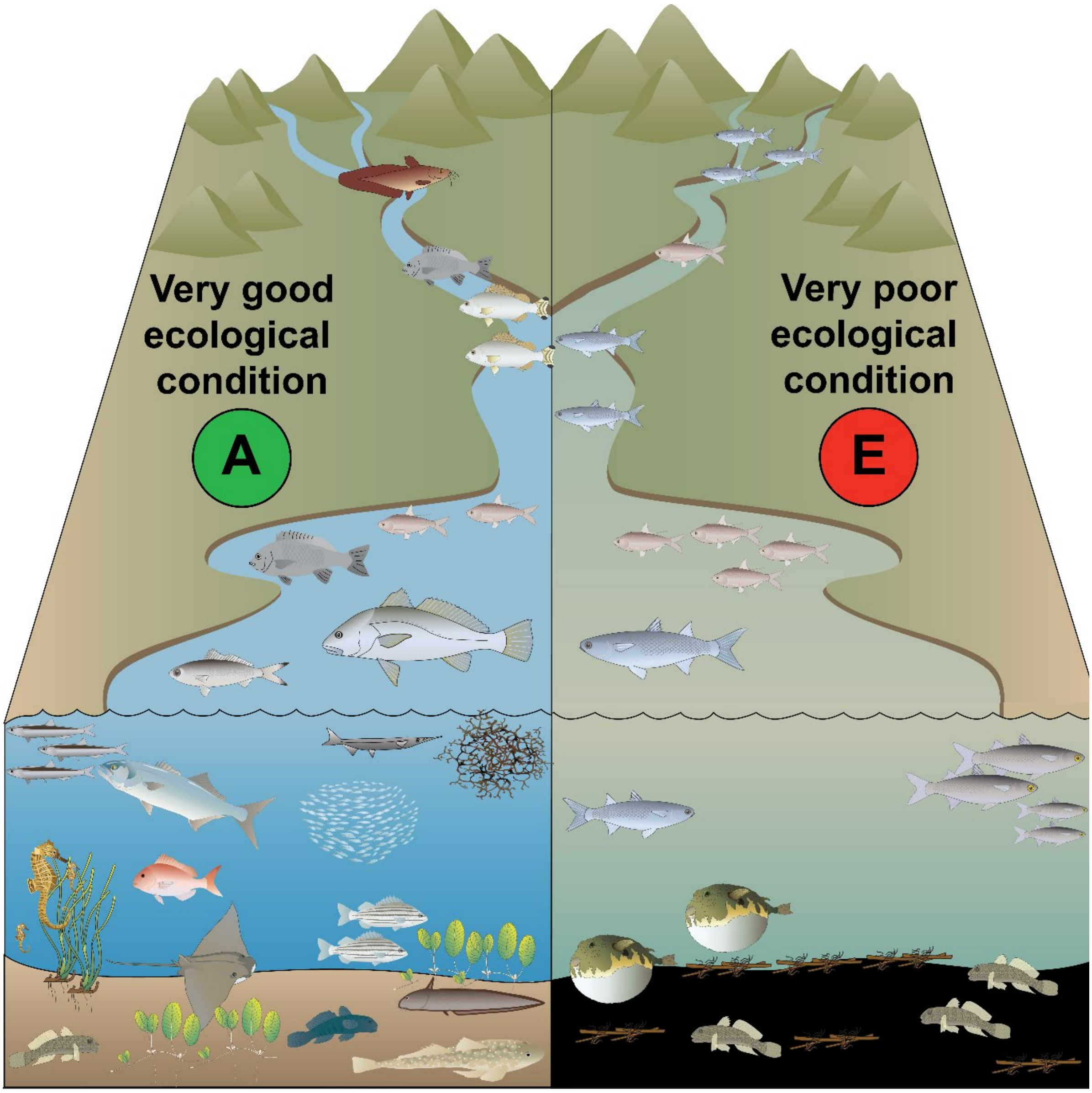


Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of very good (A) and very poor (E) ecological condition. Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].

4. Methods

Fish communities were sampled at six nearshore and six offshore sites in each of the 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 (2 - 22 February) and autumn (11 April – 3 May) of 2023. All sampling was conducted under permits approved by Murdoch University's Animal Ethics Committee (permit number RW3286/20), the Department of Primary Industries and Regional Development, Fisheries Division (exemption number 251070223) and the Department of Biodiversity, Conservation and Attractions (permit number FO25000254-4).

Nearshore waters were sampled using a 21.5 m seine net that was walked out from the beach to a maximum depth of ~ 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 depth of water at each 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 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, depending on the total size 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 by experienced fish biologists, using available keys and identification guides where required. 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 (Hallett and Valesini, 2012; Hallett et al., 2012) using bespoke code developed for the R software package. Metric scores were then calculated from these metric values, and the metric scores in turn combined to form the FCI scores. The method for calculating these scores is detailed in Hallett and Valesini (2012), but can be summarised simply as follows:

1. Allocate each fish species in a particular sample to its appropriate Habitat guild, Estuarine Use guild and Feeding Mode guild (Appendix iii), then calculate the values for each fish metric from the abundance of each fish species in the sample.
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 2023 were then examined to assess the condition of the Swan Canning Estuary during this period and were compared to previous years through a qualitative examination of the patterns and trends in scores.

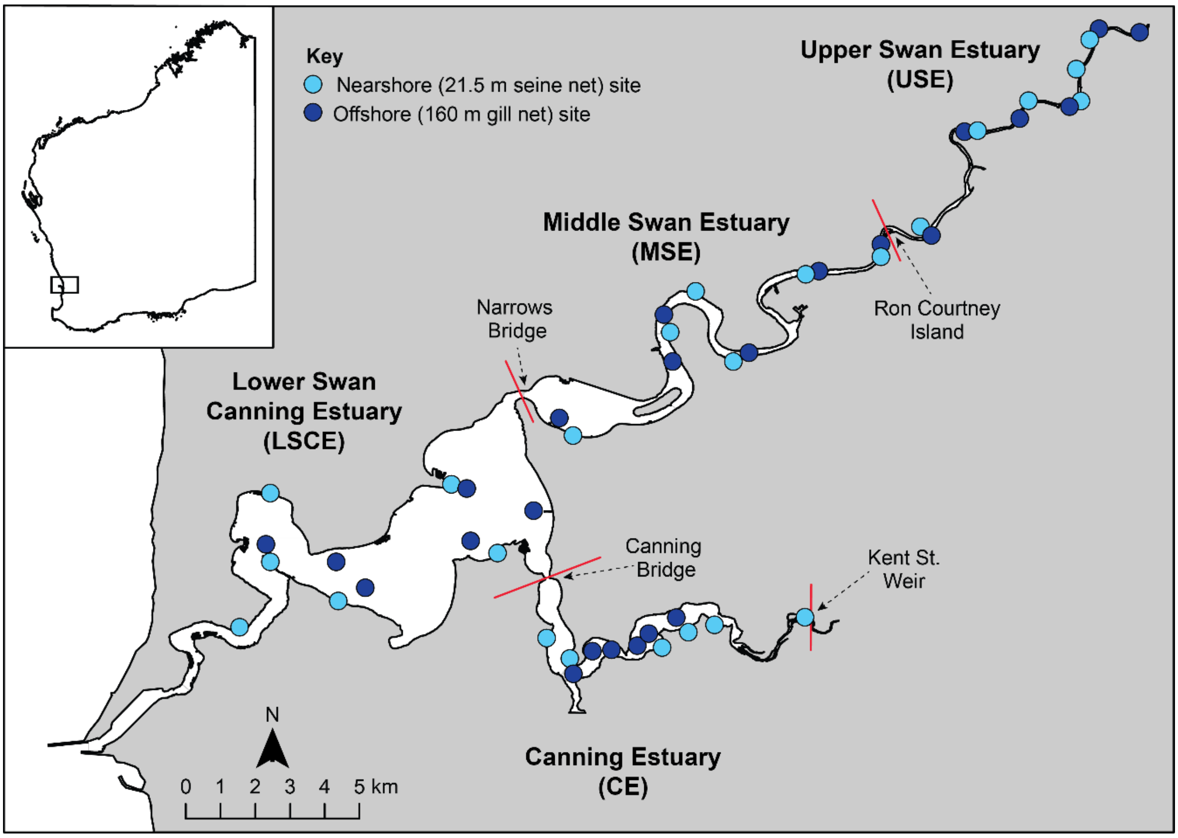


Figure 2. Locations of nearshore (light blue circles) and offshore (dark blue circles) sampling sites for the Fish Community Index of estuarine condition.

Table 2. Fish Community Index (FCI) scores comprising each of the five condition grades for both nearshore and offshore waters of the Swan Canning Estuary. Intermediate grades, e.g. B/C (good/fair) or C/B (fair/good) are awarded if the index score lies within one point on either side of a grade threshold.

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

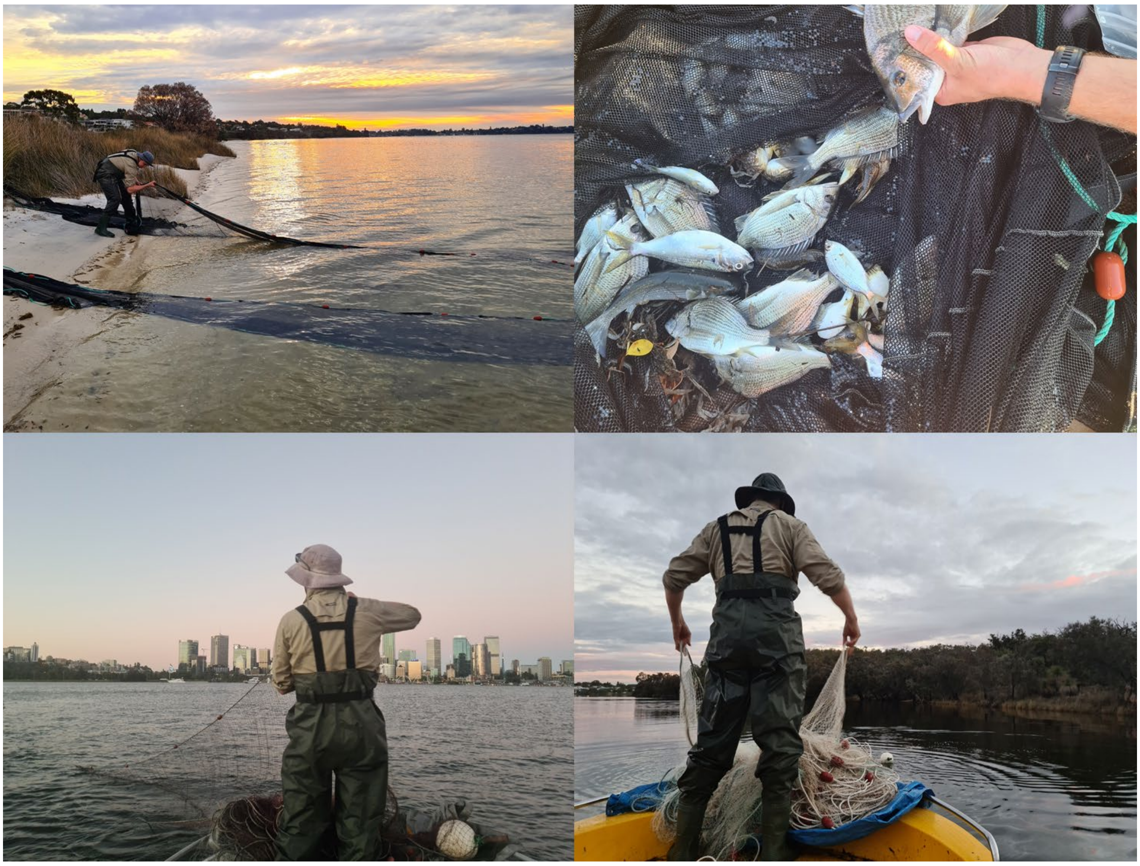


Figure 3. Photographs of the beach seine netting (upper row) used to sample the fish community in shallow, nearshore waters and the multimesh gill netting (lower row) used to sample fish communities in deeper, offshore waters of the Swan Canning Estuary. Images courtesy of Kurt Krispyn, Murdoch University.

5. Results and discussion

5.1 Water quality and environmental conditions influencing the 2023 monitoring period

Total annual flow at Walyunga on the Swan River in 2022 was 424 GL, which is less than the 605 GL recorded in 2021, but the 12th highest over the 51 years of records and a 244% increase over the median since 1996 (Appendix iv). The timing of the flow corresponded with the traditional monthly pattern, where the majority occurs between May and September (Hodgkin and Hesp, 1998; Hallett et al., 2018). In 2022, 96% of the total annual flow occurred between these months, with particularly high values in August and September (265 and 96 GL, respectively). This is the second year in a row where substantial freshwater flow has occurred in winter (Tweedley et al., 2022). A significant rainfall event (39.8 mm at Perth Airport and 25-50mm of rain to large parts of the catchment) occurred on 31 March 2023 (Bureau of Meteorology, 2023). This resulted in the first flow of 2023 passing through the Walyunga gauging station producing a total of 13,456 ML in April and was the highest flow in April since 1974, 49 years earlier. Total annual flow at Seaforth in the Canning River in 2022 was 9.7 GL, slightly above the median of ~8.4 GL (Appendix v). In 2022, flow was greatest in August and represented 46% of the annual total (Appendix v).

The environmental conditions present in the Swan Canning Estuary during the monitoring period are shown as vertical contour plots of interpolated salinities, dissolved oxygen (DO) concentrations, chlorophyll levels and water temperatures (Appendix vi). The text below describes the key environmental conditions in the Swan and Canning axes of the estuary in each season.

Swan axis: physicochemical conditions

Summer: The water column of the USE was brackish (salinity = 6 - 18) in early January 2023, becoming more saline into mid-February (minimum of 12) as the salt wedge moved upstream. Salinities in the LSCE and MSE were around that of full-strength seawater (~35) throughout summer ranging from 30 to 40. No hypoxia (i.e. dissolved oxygen concentrations < 2 mg/L) was observed. However, areas of low dissolved oxygen (2 - 4 mg/L) were present in the upper parts of the USE in most weeks in January and February, with infrequent occurrences in the deeper waters of the MSE in the latter month. Both the Caversham and Guildford Oxygenation plants were in operation in each week of January and February. Water temperature increased in an upstream direction from ~25 °C in the LSCE to 29 - 30 °C in the USE in early February and had reduced by ~1-2 °C by the end of the month.

Autumn: Significant flow as a result of the March storm event resulted in a plume of oligohaline water (salinity = ≤ 4) extending the depth of the water column as far downstream as Reg Bond Reserve in the USE, beyond which the water column was stratified until the upstream reaches of the LSCE (Heathcote). By 11 April a layer of brackish water (salinity = 8 – 12) occurred in the surface waters of the entire extent of the USE and although less marked was also present throughout much of the MSE. The spatial extent of the stratification changed throughout the duration of autumn sampling (11 April – 3 May 2023) and at its most pronounced included all of the MSE and the lower parts of the USE (Appendix vi). Despite the operation of the Guildford and Caversham oxygenation plants, there were widespread low oxygen and hypoxic conditions throughout much of the USE and MSE early in April, which became more restricted to the downstream reaches of the USE and upstream reaches of the MSE later in that month. The stratification and associated hypoxia had dissipated by 8 May, by which time sampling was completed.

Canning axis: physicochemical conditions

Summer: The water column of the upper part of the CE (Riverton to Castledare) was stratified by freshwater flows overlying denser, saltier water in January and February with the degree of stratification decreasing over time as more of this zone became saline (Appendix vi). Low levels of daytime dissolved oxygen (2 - 4 mg/L) were detected on 31 January (immediately before the initiation of sampling) extending from halfway between the Salter Point and Riverton sites upstream to Kent Street Wier. This body of water with low oxygen levels persisted throughout February, with the extent and magnitude changing slightly. For example, sampling on 7 and 14 of February indicated that the plume was restricted to between Riverton and Kent Street Wier but that oxygen levels in parts of that area had declined to hypoxic levels.

Autumn: Flow from the March storm was less pronounced in the CE during autumn, but stratification was present in the upper parts of the CE resulting in hypoxia. This hypoxia lasted until ~2 May and thus around the time sampling was completed.

Swan axis: harmful algae

Summer: *Karlodinium* spp. (including *Karlodinium veneficum* and *Karlodinium armiger*) were detected in Maylands (MSE) and Ron Courtney Island (28,900 cells/mL) at the lower end of the USE on 16

January 2023 (DBCA, unpublished data), which was two weeks before sampling commenced. Cell densities declined below levels of concern throughout February. Plumes of the *Alexandrium* spp. were initially observed in Matilda Bay (LSCE) on 13 February. This non-ichthyotoxic dinoflagellate was present across the LSCE, MSE and USE throughout February with the largest integrated densities of 383 cells/mL recorded at Nile St (MSE) on 20 February 2023 (DBCA, unpublished data).

Autumn: No blooms of *Karlodinium* occurred during March or April, with the highest densities of 2,000 cells/mL recorded at West Midland Pool in the USE on 13 March (DBCA, unpublished data). Similarly, *Alexandrium* spp. was not detected at levels of concern during March (maximum 4 cells/mL) and was not detected throughout April. Blooms of other harmful species periodically exceeded triggers but were short-lived; for example, *Dinophysis acuminata* at Nile St. (MSE) on 24 April (66 cells/mL) and *Pseudonitzchia seriata* at Heathcote and Narrows (15 and 11 cells/mL, respectively on 11 April; DBCA, unpublished data).

Canning axis: harmful algae

Summer: *Karlodinium* spp. (including *K. veneficum* and *K. armiger*) bloomed in the Canning in January, with densities at Castledare (upper part of the CE) reaching trigger levels of 26,230 cells/mL on 17 January 2023 (DBCA, unpublished data). Lower densities of 12,960 and 7,980 cells/mL were recorded at Kent Street Weir and Castledare, respectively, on 21 February. These were below the DBCA response trigger values and densities declined thereafter. Only very low levels of *Alexandrium* spp. were recorded in the CE, with a maximum of 2 cells/mL in February.

Autumn: *Karlodinium* spp. was present in the CE through March with Castledare being the location with the highest densities, i.e. 6,380 cells/mL on 21 March. These levels were all below DBCA response triggers. By April, densities had declined with the maximum across this month being 780 cells/mL at Riverton (DBCA, unpublished data). There was no evidence of *Alexandrium* spp. or harmful blooms (DBCA, unpublished data).

5.2 Fish community of the Swan Canning Estuary during 2023

Nearshore waters

An estimated total of 28,583 fish, belonging to 35 species, were caught in seine net samples collected from nearshore waters during the summer and autumn of 2023. The total number of fish recorded in 2023 was slightly greater than the average of 25,241 from previous monitoring between 2012 and 2022 (range = 16,905 - 42,935). The 35 species recorded in 2023 was similar to the 36 and 35 in 2022 and 2021 and above the annual average of 32.2 (range = 25 – 36). A total of 64 fish species have been collected in seine nets as part of this annual monitoring since 2012 and no new species were recorded in 2023. The greatest number of species recorded in the nearshore waters was in the LSCE (26), followed by the CE and MSE (both 23) and least in the USE (18; Table 3). This pattern of decline in the number of species along the longitudinal (downstream – upstream) axis has been recorded in the nearshore waters of Swan Canning Estuary previously and in similar estuaries in south-western Australia (Veale et al., 2014; Valesini et al., 2017). The total number of species in each zone except the CE was greater than the average recorded between 2012 and 2022 by 1-2 species. This can be explained by the presence of a wider range of marine-spawning species occurring further upstream with species like the Western Striped Grunter (*Helotes octolineatus*) and the Blowfish (*Torquigener pleurogramma*) being recorded as far upstream as the USE (Table 3).

Hardyheads (family = Atherinidae; five species) and gobies (family = Gobiidae; seven species) once again dominated catches from the nearshore waters of the estuary in 2023, representing 82% of all fish recorded and containing the four most abundant nearshore species and six of the top eight. Wallace's Hardyhead (*Leptatherina wallacei*) was the most abundant species overall (Table 3) and although its abundance decreased by ~50% from 2022, it was the third highest recorded annually and 1.5 times the average. Among zones of the estuary, this species ranked first in terms of density in the CE and USE, comprising 55 and 53% of all fish, respectively, reflecting the preference of this species for upstream areas where salinities are less than in other parts of the estuary (Prince and Potter, 1983; Potter et al., 2015b). Another atherinid species, the Spotted Hardyhead (*Craterocephalus mugiloides*), which prefers slightly more saline waters than Wallace's Hardyhead, was the most abundant species in the LSCE and MSE and amongst the most abundant in the CE. Together with *C. mugiloides* two other atherinids, the Common Hardyhead (*Atherinomorus vaigiensis*) and the Elongate Hardyhead (*Atherinosoma elongatum*) both of which prefer more saline waters dominated the fish found in the LSCE (Valesini et al., 2009; 2017). Other abundant species recorded in 2023 included the Red-spot Goby (*Favonigobius punctatus*) in the MSE and USE, the Blue-spot Goby (*Pseudogobius olorum*) in the USE where they typically occur (Hogan-West et al., 2019), the Yelloweye Mullet (*Aldrichetta forsteri*) in the CE and the Perth Herring (*Nematalosa vlaminghi*) in the MSE (Table 3).

Compared to previous years, larger abundances of juveniles of several marine-spawning species, including several whitings but most notably the Western Trumpeter Whiting (*Sillago burrus*) and the Yellow-eye mullet (*Aldrichetta forsteri*) and Sea Mullet (*Mugil cephalus*) were recorded. The increase in these species by factors of 3.7, 2.5 and 1.3, respectively, could be due to the increased riverine flows in 2022, which are known to increase productivity and fish populations (Gillanders and Kingsford, 2002; Broadley et al., 2022). In contrast, far lower numbers of the atherinid, Silverfish (*Leptatherina presbyteroides*), were recorded compared to previous years, i.e. 98 vs an average of 794, and of the Blowfish, i.e. 205 vs an average of 381.

The Largemouth Goby (*Redigobius macrostoma*) and the Dusky Frillgoby (*Bathygobius fuscus*) were recorded in 2023 and have now been recorded in three of the last four years of FCI sampling. While both are native to Australia, they were only recently recorded in the Swan-Canning Estuary. The former species is abundant along the coasts of New South Wales and Victoria and an isolated population was found in Adelaide (Hammer, 2006). It is thought that this species may have been translocated to Western Australia via shipping. In contrast, the Dusky Frillgoby is a tropical species whose distribution in Western Australia was thought to extend only as far south as Exmouth (Atlas of Living Australia, 2022). However, it is known to occur in Cockburn Sound (Whisson and Hoschke, 2021) likely due to climate-changed induced increases in water temperature. Given the relatively limited sampling regime employed in this study (i.e. only six samples per management zone), the regular occurrence of these species may indicate populations have become established in the Swan Canning Estuary. In the case of the Largemouth Goby the 46 individuals recorded in 2023 was the greatest yet.

Two non-native fish species were recorded namely: the Eastern Gambusia (*Gambusia holbrooki*), in the CE and USE; and the Pearl Cichlid (*Geophagus brasiliensis*) in the MSE and CE (Table 3). These species occur regularly in this annual monitoring program, being recorded in 12 and 10 of the years of annual monitoring, respectively. However, numbers of the Eastern Gambusia, which is known to act antagonistically to native species (Beatty et al., 2022) caught in 2023 were the lowest recorded (i.e. 28; average = 535; range = 28 – 1,633) and those of the Pearl Cichlid were also low (i.e. 5; average = 19; range = 0 – 60).

Table 3. Compositions of the fish communities (D = Average density fish/100 m^2 and %C = percentage composition) observed across the six nearshore sites sampled in each zone of the Swan Canning Estuary during the summer and autumn of 2023. Data for the three most abundant species in the catches from each zone are shaded in grey for emphasis. Species are ordered by total abundance throughout the estuary. LSCE = Lower Swan Canning Estuary, CE = Canning Estuary, MSE = Middle Swan Estuary, USE = Upper Swan Estuary. * denotes non-native species.

		LSCE (*n* = 12)		**CE** (*n* = 12)		**MSE** (*n* = 12)		**USE** (*n* = 12)	
Species	**Common name**	D	%C	D	%C	D	%C	D	%C
Leptatherina wallacei	Wallace's Hardyhead	2.37	0.49	533.76	55.43	8.84	2.69	143.75	52.56
Craterocephalus mugiloides	Mugil's Hardyhead	185.42	37.99	242.39	25.17	116.09	35.31	6.32	2.31
Atherinosoma elongatum	Elongate Hardyhead	162.93	33.38	11.14	1.16	1.15	0.35		
Favonigobius punctatus	Red-spot Goby	0.29	0.06	7.90	0.82	53.23	16.19	42.60	15.58
Helotes octolineatus	Western Striped Grunter	4.31	0.88	38.72	4.02	32.18	9.79	13.22	4.83
Aldrichetta forsteri	Yellow-eye Mullet	15.95	3.27	60.63	6.30	1.22	0.37	0.07	0.03
Atherinomorus vaigiensis	Ogilby's Hardyhead	61.85	12.67	0.50	0.05	7.69	2.34	1.51	0.55
Pseudogobius olorum	Blue-spot / Swan River Goby			17.89	1.86	7.61	2.32	35.92	13.13
Sillago burrus	Western Trumpeter Whiting	16.95	3.47	8.55	0.89	18.25	5.55		
Gerres subfasciatus	Roach	3.23	0.66	2.73	0.28	25.86	7.87	7.69	2.81
Nematalosa vlaminghi	Perth Herring			1.22	0.13	33.98	10.33	1.80	0.66
Amniataba caudavittata	Yellow-tail Trumpeter	1.22	0.25	10.13	1.05	4.53	1.38	9.34	3.41
Mugil cephalus	Sea Mullet	1.72	0.35	13.65	1.42	2.51	0.76	0.36	0.13
Torquigener pleurogramma	Blowfish / Banded Toadfish	8.98	1.84	2.16	0.22	3.45	1.05	0.14	0.05
Favonigobius lateralis	Long-finned Goby	9.70	1.99	1.44	0.15				
Arenigobius bifrenatus	Bridled Goby			3.74	0.39	3.09	0.94	0.72	0.26
Afurcagobius suppositus	Southwestern Goby					0.57	0.17	6.97	2.55
Leptatherina presbyteroides	Presbyter's Hardyhead	6.03	1.24	0.43	0.04	0.57	0.17		
Acanthopagrus butcheri	Southern Black Bream			0.07	0.01	4.67	1.42	0.86	0.32
Sillago schomburgkii	Yellow-finned Whiting	1.94	0.40	1.80	0.19	0.65	0.20	0.14	0.05
Redigobius macrostoma	Largemouth Goby			2.87	0.30	0.43	0.13		

Table 3. continued.

Species	Common name	LSCE (*n* = 12)		CE (*n* = 12)		MSE (*n* = 12)		USE (*n* = 12)	
		D	%C	D	%C	D	%C	D	%C
Ostorhinchus rueppellii	Gobbleguts	2.44	0.50	0.29	0.03	0.50	0.15		
*Gambusia holbrooki**	Mosquito Fish*			0.14	0.01			1.87	0.68
Rhabdosargus sarba	Tarwhine	0.29	0.06			1.58	0.48		
Sillago bassensis	Southern School Whiting			0.86	0.09				
Sillago vittata	Western School Whiting	0.86	0.18						
Platycephalus westraliae	Yellowtail Flathead	0.79	0.16						
*Geophagus brasiliensis**	Pearl Cichlid*					0.14	0.04	0.22	0.08
Hyperlophus vittatus	Whitebait / Sandy Sprat	0.22	0.04						
Pentapodus vitta	Western Butterfish	0.14	0.03						
Pseudorhombus jenynsii	Small-toothed Flounder	0.14	0.03						
Spratelloides robustus	Blue Sprat	0.07	0.01						
Cnidoglanis macrocephalus	Estuarine Cobbler	0.07	0.01						
Neoodax baltatus	Little Weed Whiting	0.07	0.01						
Bathygobius fuscus	Dusky Frillgoby	0.07	0.01						
	Total number of species	**26**		**23**		**23**		**18**	
	Average total fish density (fish 100m^{-2})	**488**		**963**		**329**		**273**	
	Total number of fish	**6,794**		**13,405**		**4,577**		**3,807**	

Offshore waters

Samples collected from offshore waters in summer and autumn 2023 using gill nets returned 2,705 fish, comprising 20 species (Table 4). This number of fish was similar to that recorded in 2022 and 2021 (2,768 and 2,933, respectively). Catches in these three years (2021-2023) are, however, substantially greater than those between 2012 and 2020 (average = 1,826; range = 1,125 to 2,235). The 20 species caught in 2023 was similar to that recorded over the entire monitoring period (average = 20.4 between 2012 and 2022) but less than the 23 and 24 recorded in 2021 and 2022, respectively. As has occurred in most years, the total number of species recorded from each zone in 2023 decreased in an upstream direction from 14 species in the LSCE, to 13 in the CE, to 11 in the MSE and 10 in the USE. A total of 36 fish species have been collected in gill nets as part of this annual monitoring since 2012 and, using this fishing method, no new species were recorded in 2023.

As in all previous years of monitoring, Perth Herring was among the dominant species in offshore waters in 2023 representing 42% of all fish recorded, albeit the contribution from this species was lower than the average of 58%. This species comprised 23–75% of the total catches in each zone, ranking first in all except the USE where it ranked second (Table 4). The Yellowtail Grunter (*Amniataba caudavittata*) was the second most abundant species overall and while found in all zones was particularly abundant in the MSE and USE. The Southern Eagle Ray (*Myliobatis tenuicaudata*) and Tailor (*Pomatomus saltatrix*) were abundant in the LSCE (19 and 16% of the catch, respectively). The latter species was also abundant in the CE, representing 12% of all fish caught. Other abundant species included the Black Bream (*Acanthopagrus butcheri*) in the MSE and the Roach (*Gerres subfasciatus*) in the USE (both ~3%). Catches of several species were relatively high in 2023, including the Hawaiian Giant Herring (*Elops hawaiensis*), Yellowtail Grunter and Sea Mullet, with values of 2.5, 2.8 and 3.7 times more than the average between 2012 and 2022, respectively.

Table 4. Compositions of the fish communities (CR = Average catch rate [fish/net set] and %C = percentage composition) observed across the six offshore sites sampled in each zone of the Swan Canning Estuary during the summer and autumn of 2023. Species ranked by total abundance. Data for the three most abundant species in the catches from each zone are shaded in grey for emphasis. Species are ordered by total abundance throughout the estuary. 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**	CR	%C	CR	%C	CR	%C	CR	%C
Nematalosa vlaminghi	Perth Herring	8.33	24.88	32.42	75.10	34.67	52.72	19.17	23.09
Amniataba caudavittata	Yellow-tail Trumpeter	2.00	5.97	0.92	2.12	25.25	38.40	37.00	44.58
Mugil cephalus	Sea Mullet							14.25	17.17
Pomatomus saltatrix	Tailor	5.50	16.42	5.25	12.16	1.25	1.90	0.67	0.80
Acanthopagrus butcheri	Black Bream			0.17	0.39	1.92	2.92	8.17	9.84
Myliobatis tenuicaudatus	Southern Eagle Ray	6.42	19.15	0.58	1.35				
Platycephalus westraliae	Yellowtail Flathead	2.50	7.46	0.42	0.97	0.67	1.01	1.25	1.51
Gerres subfasciatus	Roach	1.25	3.73	1.33	3.09	0.42	0.63	0.08	0.10
Helotes octolineatus	Western Striped Grunter	2.00	5.97	0.67	1.54	0.17	0.25		
Elops hawaiensis	Hawaiian Giant Herring	0.17	0.50	0.83	1.93	0.92	1.39	0.67	0.80
Rhabdosargus sarba	Tarwhine	2.33	6.97	0.17	0.39				
Argyrosomus japonicus	Mulloway					0.33	0.51	1.58	1.91
Sillago burrus	Western Trumpeter Whiting	1.42	4.23			0.08	0.13		
Arripis georgianus	Australian Herring	0.67	1.99						
Cnidoglanis macrocephalus	Estuarine Cobbler	0.42	1.24						
Sillago schomburgkii	Yellow-finned Whiting	0.33	1.00			0.08	0.13		
Torquigener pleurogramma	Blowfish / Banded Toadfish	0.17	0.50	0.08	0.19				
Carcharinas leucas	Bull Shark							0.17	0.20
Engraulis australis	Southern Anchovy			0.17	0.39				
Pseudocaranx wrightii	Skipjack Trevally			0.17	0.39				
	Total number of species	**14**		**13**		**11**		**10**	
	Average catch rate (fish/net set)	**33.5**		**43.2**		**65.8**		**83.0**	
	Total number of fish	**402**		**518**		**789**		**996**	

5.3 Ecological condition in 2023

Nearshore waters

The ecological condition, based on fish communities, of the nearshore waters of the Swan Canning Estuary was good/fair (B/C; FCI score 65) in both summer and autumn (Fig. 4). The condition of each zone varied substantially during summer (mean FCI scores of 58–69), being best in the MSE and LSCE (good; B) and lowest in the CE with a fair (C) score. By autumn, scores in the CE improved by 7 points to good/fair, the MSE remained in good condition, and the USE and LCSE declined from good/fair to fair and from good to fair/good, respectively (Fig. 4).

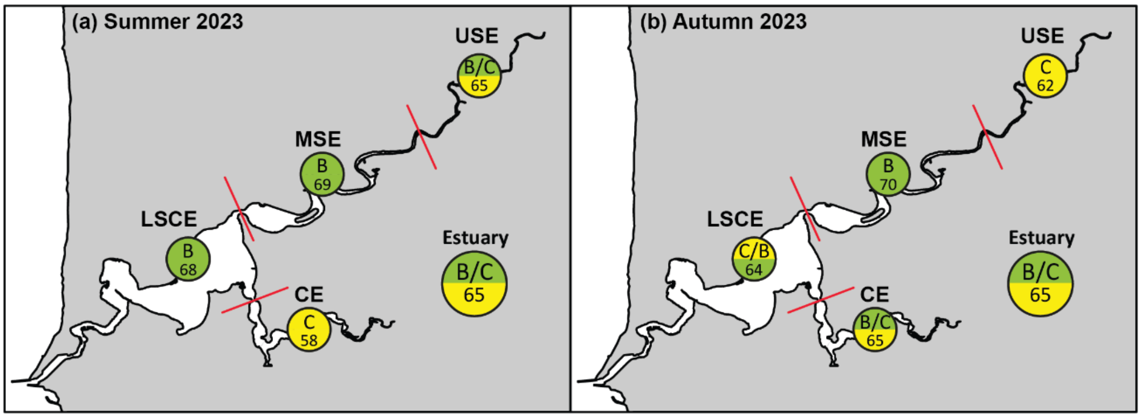
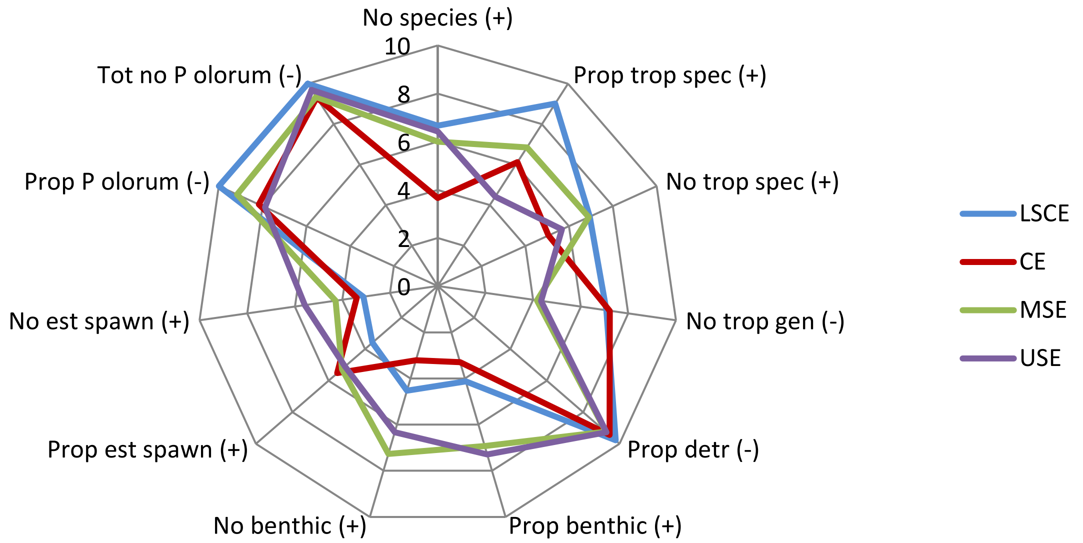


Figure 4. Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2023.

Radar plots of the nearshore metric scores for each zone in summer revealed that, in general, all four zones of the estuary scored well across the *Total number of P. olorum, Proportion of P. olorum* and *Proportion of detritivores* (all negative metrics; Fig. 5a). These reflect the relatively low densities of the Blue-spot Goby that feeds on detritus and is highly tolerant of poor-water and sediment quality. The LSCE scored well in the *Proportion of trophic specialists, Number of trophic specialist species* (positive metrics) and the *Number of trophic generalist species* (negative metric) likely caused by a reduction in the abundance and frequency of opportunistic feeding species such as the Blowfish. In contrast, this zone (and the CE) received lower scores for the *Proportion of benthic-associated individuals* and *Number of benthic-associated species* (both positive metrics) than the MSE and USE. For several years the LSCE, while receiving relatively good condition grades, has scored relatively poorly in these metrics. The LSCE also scored lower than the MSE and USE for the *Number of estuarine-spawning species* and *Proportion of estuarine-spawning individuals* (positive metrics) due to the presence of 'marine-like' salinities in the LSCE which restricts the spatial distribution of estuarine-spawning species to areas further upstream. These higher salinities did, however, result in the scores for the *Number of species* (positive metric) being moderate in all zones except the CE as the relatively saline conditions allowed marine species to occur in areas further upstream than in some other years (see Potter et al., 2016; Valesini et al., 2017).

The fair condition of the CE in summer reflects the lower scores this zone received for the *Number of species* and all other positive metrics based on the number of species of particular types, e.g. *benthic-associated species, estuarine-spawning species and trophic specialists*.

(a) Summer 2023



(b) Autumn 2023

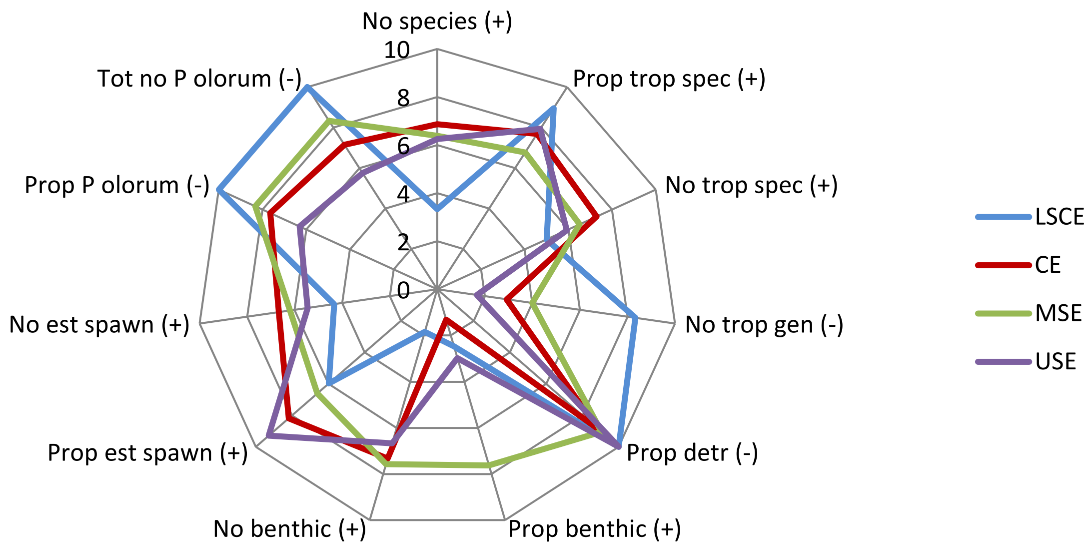


Figure 5. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2023. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Full metric names and explanations are given in Table 1.

By autumn scores for the CE increased, while those for the LSCE and USE decreased. Radar plots showed that the increase in the CE was due mainly to higher metric scores for the *Number of species*, *Proportion of estuarine-spawning individuals, Number of trophic specialist species* and *Proportion of trophic specialists* (Fig 5b). It should be noted, however, that the metric scores for the *Proportion of benthic-associated individuals* decreased. The decline in the LSCE was caused by a reduction in the metric score for the *Number of species* from ~7 to ~4 out of 10, commensurate with the mean number of species declining from 8.7 to 6.3 in summer and autumn, respectively. Values for the *Total number of P. olorum, Proportion of P. olorum* remained the same as the Blue-spot Goby was not recorded in this zone in either season and, therefore, these metric scores were always at their maximum value (10; Fig 5).

The decline in condition in the USE was due to several of the metric scores being different in each season. Greater abundances of the Blue-spot Goby (i.e. 69 and 431 individuals in summer and autumn, respectively) lowered the scores for the *Total number of P. olorum, Proportion of P. olorum* in autumn. Despite the increased abundance of this tolerant benthic species, the *Proportion of benthic-associated individuals* declined. This was due in part to the increased abundance of small pelagic species such as Wallace's Hardyhead (i.e. 84 in summer compared to 1,917 in autumn) that would help account for the increase in the *Proportion of trophic specialists* and, together with the Blue-spot Goby, also the higher metric score for the *Proportion of estuarine-spawning individuals.* Across these two seasons in the USE the hypoxia that occurred following the March storm event in autumn resulted in a shift away from benthic fish (except highly tolerant species) to pelagic ones that are more mobile and found in the more oxygenated surface waters. Trends in metric scores were consistent across both seasons in the MSE, potentially due to the fact that although hypoxia was recorded in this region it was less pronounced than in the USE and restricted to the deeper waters.

Offshore waters

The ecological condition, based on fish communities, of the offshore waters of the Swan Canning Estuary was good (B) in summer and good/fair (B/C) in autumn (Fig. 6). The condition of each zone varied substantially during summer (mean FCI scores of 47-69), being good (B) in the LSCE, MSE and USE and poor (D) in the CE. By autumn, scores in the MSE and USE declined from good to good/fair, while the CE improved slightly from poor to fair/poor with its mean FCI score increasing from 47 to 51 (Fig. 6). The score in the LSCE increased from 61 to 69 and just below the 69.7 cut-off to be rated as good/very good (B/A) and therefore, the offshore water of this zone remained in good condition in both seasons.

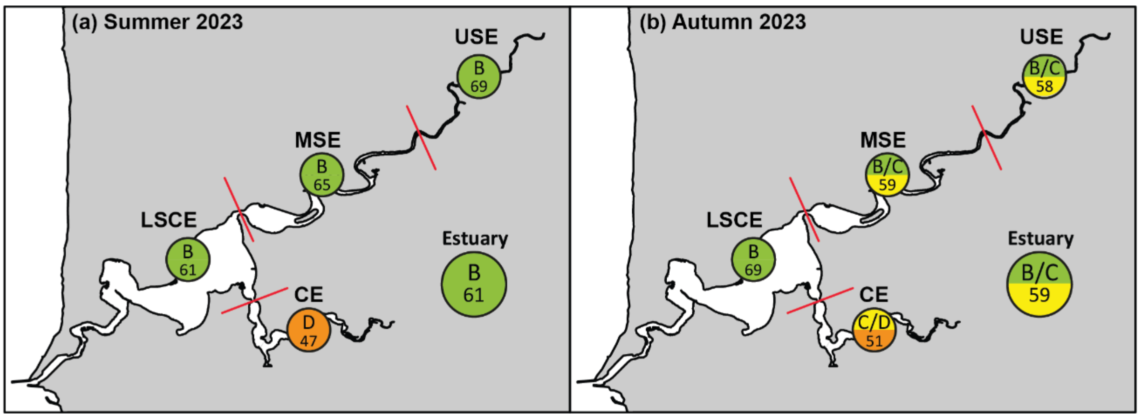


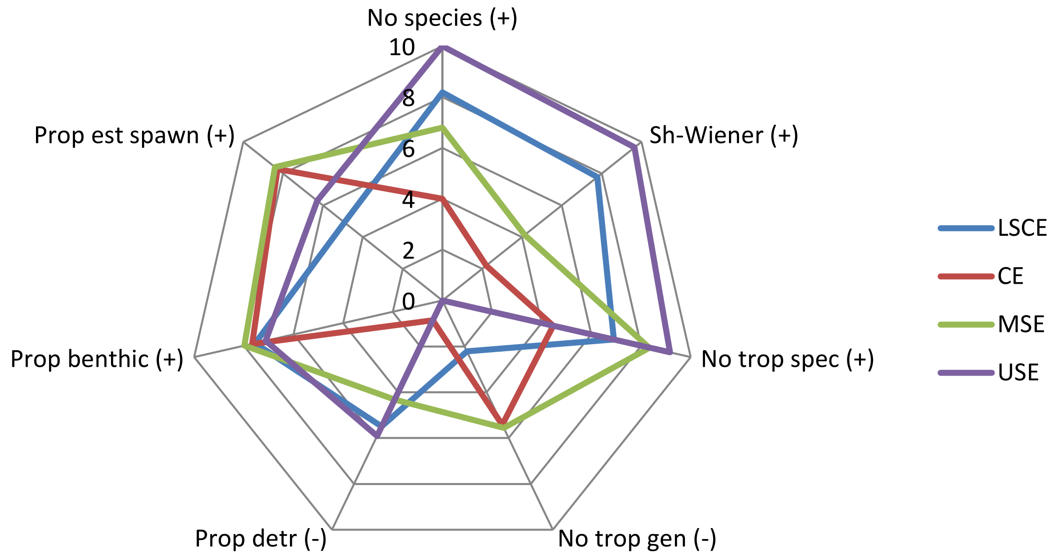
Figure 6. Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2023.

Radar plots of the offshore metric scores for the highest scoring zones in summer (LSCE, MSE and USE; Fig. 7a) showed very high scores (i.e. > 8 out of 10) in several of the following metrics, the

Number of species, Shannon-Wiener diversity, Number of trophic specialists, Proportion of benthic individuals and the *Proportion of estuarine-spawning individuals* (all positive metrics). Although *Alexandrium* spp. was present through the Swan axis of the estuary during summer, densities were relatively low during the monitoring period and there is no evidence that this dinoflagellate, which is not thought to be toxic to fish, influenced fish communities. Larger scale blooms occurred in 2020 and similarly did not impact fish communities (Trayler and Cosgrove, 2021; Tweedley et al., 2021). The poor condition of the CE was due to very low metric scores for the *Number of species, Shannon-Wiener diversity* (both positive metrics) and the *Proportion of detritivores* (negative metric), albeit very high scores were recorded for the *Proportion of estuarine-spawning individuals* and *Proportion of benthic species.* These trends are due to the fact that, on average, only four species were caught per sample and that ~70% of all fish recorded were Perth Herring, therefore explaining the low measures of diversity and high proportion of detritivores.

Between summer and autumn, the biggest change in the mean offshore FCI scores occurred in the USE, which declined from good (69) to good/fair (58), influenced by reductions in the *Number of species, Shannon-Wiener diversity, Number of trophic specialist species* and the *Number of trophic generalist species* (Figs 6; 7b). This reflects the fact that four tolerant species dominated the catches, i.e. the detritivores Perth Herring and Sea Mullet and the opportunistic Yellowtail Grunter and Black Bream in autumn. Other more sensitive species such as the larger piscivorous Mulloway (*Argyrosomus japonicus*), Hawaiian Giant Herring and Yellowtail Flathead (*Platycephalus westraliae*) all declined. This is likely a response from these species to avoid the stratification-induced low oxygen and hypoxia in this zone. Nighttime oxygen concentrations measured at the same time as sampling occurred on the 13 and 24 April ranged from 0.16 to 2.98 and from 0.50 to 5.55 mg/L, respectively. The reduction in the score for the MSE was caused by very low catches during one of the sampling nights (17 April) when waters in large parts of this zone were hypoxic (spot measurements ranged from 0.27 to 0.45 mg/L). On this occasion one of the samples contained no fish and, in each of the other two samples, only two individual fish from two species were caught. The mean scores of the CE increased due to higher values for the *Number of species*, *Shannon-Wiener diversity* and the *Proportion of detritivores* (Fig. 7b). This may reflect, in part, the movement of benthic species such as the Southern Eagle Ray and Yellowtail Flathead into the CE.

(a) Summer 2023



(b) Autumn 2023

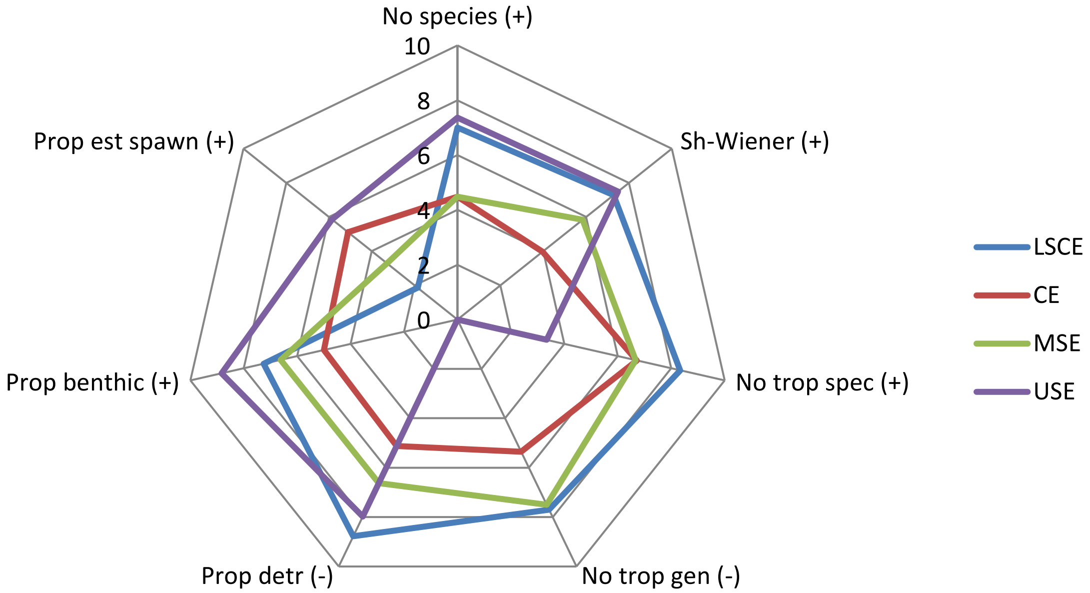


Figure 7. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2023. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying variable, whereas an increase in the score for negative metrics (-) reflects a decrease in the underlying variable. Therefore, the larger the area covered by the radar plot the better the condition in that zone. Metric names and explanations are given in Table 1.

Longer term trends in ecological condition

Results indicate that the nearshore waters of the Swan Canning Estuary as a whole were in good/fair condition (B/C) during 2023 due to no zones in either season receiving a score below fair (C). This is a minimal decrease from 2022, but slightly better than the relatively consistent overall trend since 2011 (Fig 8). Aside from 2022, good conditions have only occurred in 2014 and 2016. The mean offshore FCI score for the estuary overall indicated good (B) condition during 2023, and so the current score of good is in line with the generally upward trend from 2016 onwards (Fig. 9). Moreover, the score in 2023, was only the fifth time good condition has been obtained (i.e. 2012, 2015, 2020, 2022 and 2023), with the mean FCI score in 2022 being the fourth highest ever recorded across the 15 years. These good overall scores reflect the consistent good (B) to fair (C) scores throughout all zones, except for the offshore waters of the CE in summer and autumn (poor; D and fair/poor, respectively).

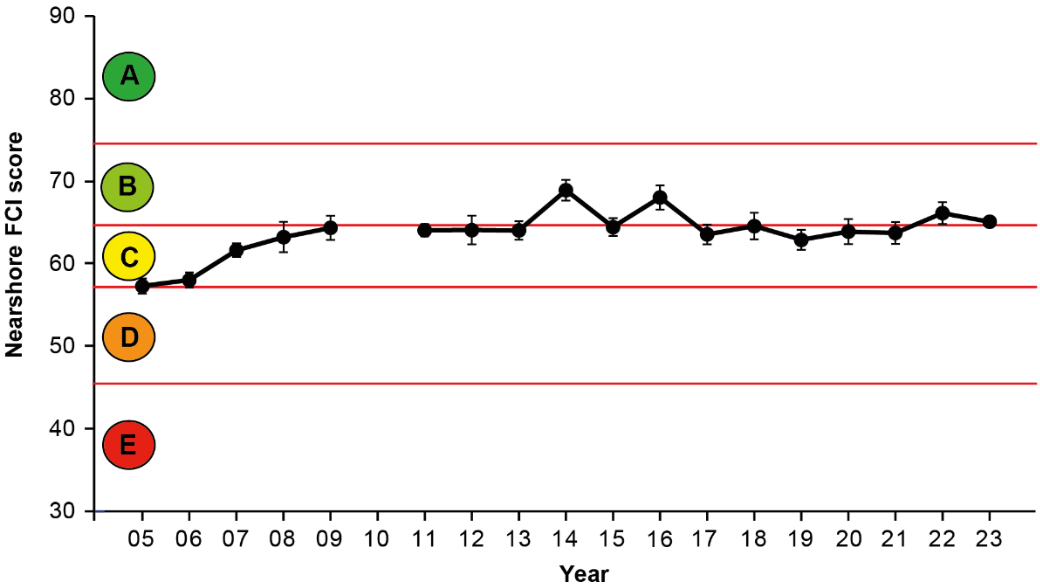


Figure 8. Trend plot of average (±SE) nearshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary between 2005 and 2023. Red lines denote boundaries between condition grades. No data were collected in 2010.

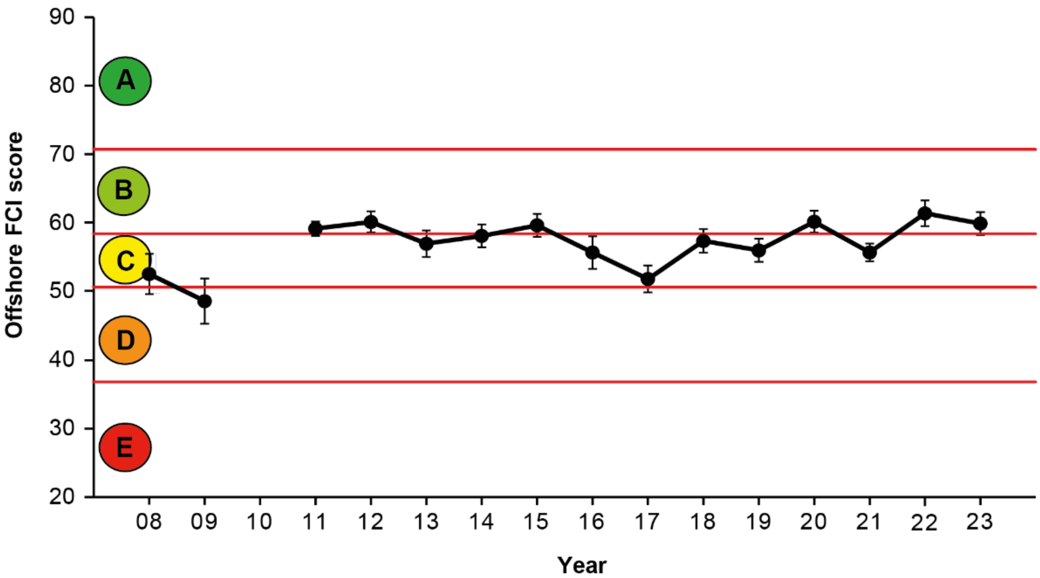


Figure 9. Trend plot of average (±SE) offshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary between 2008 and 2023. Red lines denote boundaries between condition grades. No data were collected in 2010.

5.4 Ecological condition in the deeper waters of the Canning Estuary zone

Offshore waters of the CE have consistently scored poorly relative to other zones across both summer and autumn, receiving a poor (D) grade in > 50% of monitored seasons (2012-2022), with this also being the case in 2023, i.e. poor in summer and fair/poor (C/D) in autumn. To investigate the causes of these low scores, FCI scores and component metric scores were calculated from the catch rate of each species in each of the 574 samples collected between 2012 to 2023. The values for the offshore FCI score and the seven component metrics were used to create separate Euclidean distance matrices and subjected to one-way PERMANOVA in PRIMER v7 and PERMANOVA+ (Anderson et al., 2008) to determine if they varied among zones ($P < 0.05$; Appendix vii).

The offshore FCI scores differed significantly among zones ($P = 0.001$) with that for the CE (i.e. 48.9; poor) being significantly lower than those for the LSCE and USE (both good) and the MSE (fair; Fig. 10a). PERMANVOVA also detected significant differences in each of the seven component metrics among zones ($P = 0.0001 – 0.0043$; Fig. 10; Appendix vii). In three of those, i.e. *Number of species, Shannon-Wiener diversity* and the *Number of trophic specialist species* values for the CE were significantly lower than those for all other zones. Moreover, in the case of the *Proportion of detritivores*, values in the CE were similar to those in the MSE and substantially lower than those in the LSCE and USE and for the *Proportion of benthic-associated individuals* scores in the CE were lower than those in the USE (Fig. 10). It should be noted that the CE scored relatively well in the *Number of trophic generalist species* and the *Proportion of estuarine-spawning individuals* where values in this zone were significantly greater than those in the USE and LSCE, respectively.

The fish faunal data were standardised to percentage contribution, square-root transformed and visualised using Canonical Analysis of Principal coordinates (CAP) and shade plots (Anderson et al., 2008; Clarke et al., 2014). The point representing each gill net sample were broadly separated by zone, but there was some overlap between the CS and the MSE and between the MSE and the USE (Fig. 11). The vectors demonstrated there was a correlation between the CAP axes and Perth Herring indicating this species was characteristic of samples from the CE and MSE. This assertion is supported by the shade plot that clearly shows that the fish fauna of the CE in all years was heavily dominated by Perth Herring (a detritivore), with minor and less frequent occurrences of species such as Sea Mullet (another detritivore) as well as trophic specialists such as Tailor and Roach and the trophic generalists Yellow-tail Trumpeter and Western Striped Grunter (Fig. 12). This plot also highlights that, despite the CE being adjacent to the LSCE, there are a number of species that less common in the CE including relatively large benthic species like the Southern Eagle Ray and Yellowtail Flathead and some demersal species like the Western Trumpeter Whiting and Tarwhine. The relatively few species and high dominance of Perth Herring explain the low scores for the *Number of species*, *Shannon-Wiener diversity* and, together with the Sea Mullet, the *Proportion of detritivores*. The relative absence or rare occurrence of other species e.g. Roach, Southern Eagle Ray, Tarwhine, Yellowtail Flathead and species of whiting contribute to the low metric scores for the *Number of trophic specialist species.*

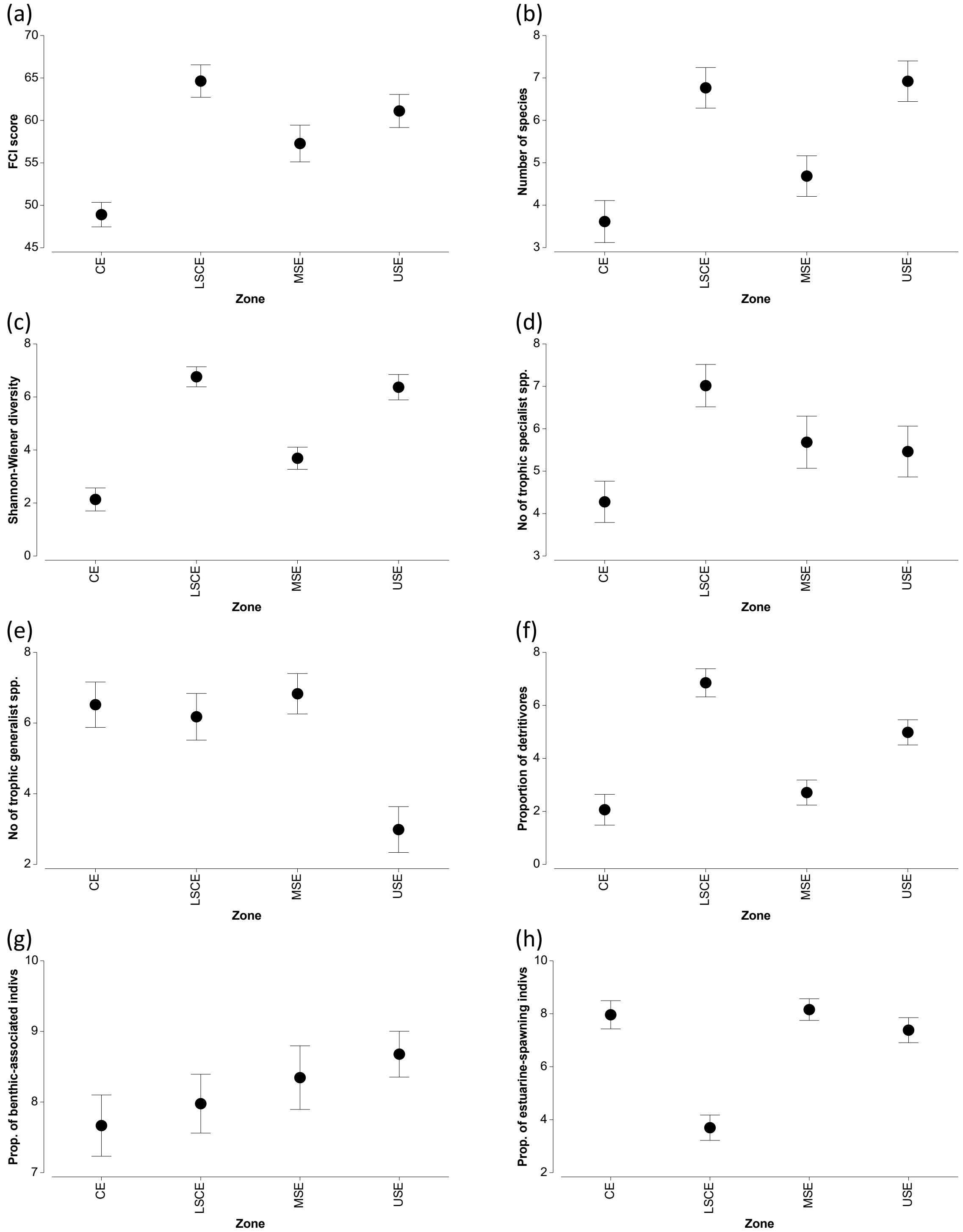


Figure 10. Mean and (±95% confidence limits) for the (a) offshore Fish Community Index (FCI) scores (range = 0-100) and (b-h) component scores (range = 0-10) for each of the seven metrics among the four zones using data from 2012 to 2023.

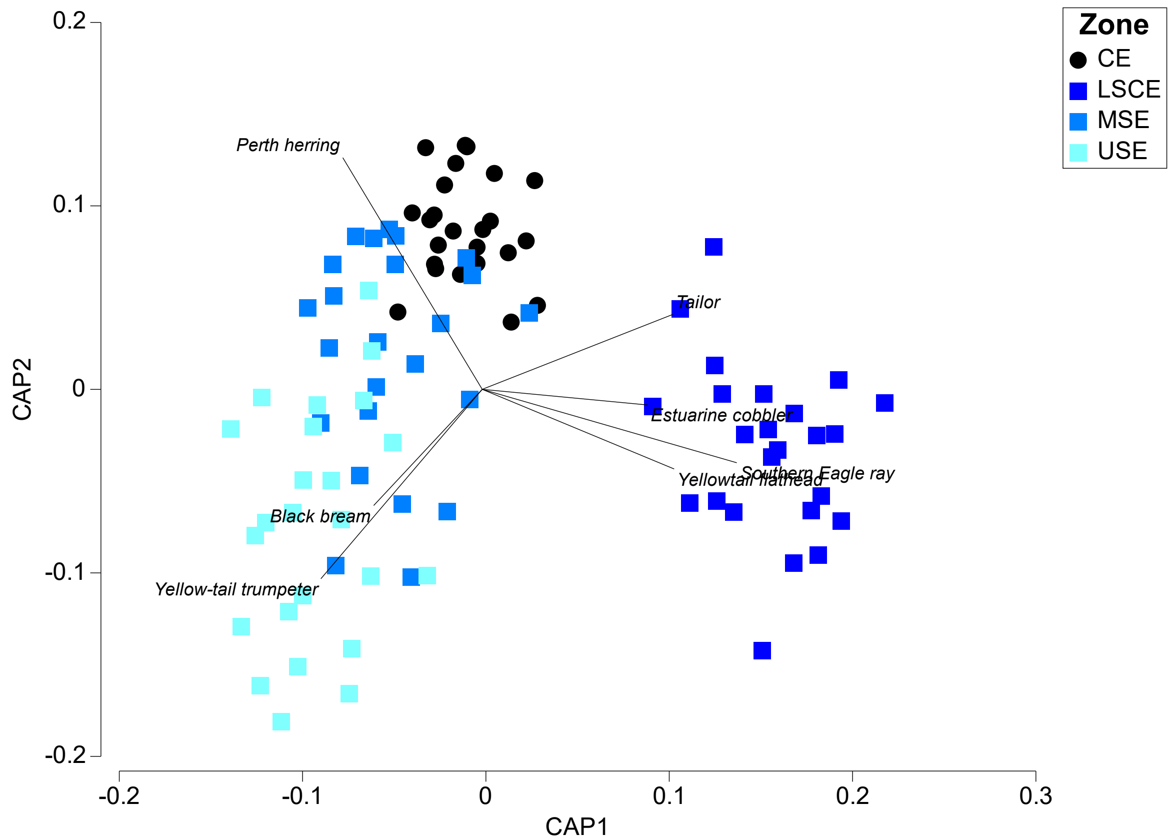


Figure 11. Canonical analysis of principal coordinates (CAP) plot illustrating differences in the fish faunal composition in offshore waters among the four zones of the Swan Canning Estuary. Superimposed onto the plot are vectors for species whose abundance changes in a linear direction (Pearson correlation > 0.5) relative to the CAP axes.

It is not clear why these species, many of which are common in the adjacent LSCE and MSE are not found regularly in the CE, but it is likely related to water quality (e.g. salinity and night-time hypoxia), the lack of complex habitat and/or reduced food resources. Each of these is considered separately, but likely work in combination.

- **Salinity:** Salinities decrease in an upstream direction; being greatest in the LSCE (at around full-strength seawater), followed by the CE and the MSE and many species are known to partition their distribution along this gradient based on tolerances and preferences (Valesini et al., 2018). Therefore, marine species such as the Southern Eagle Ray may restrict their distribution to mainly the LSCE based on its greater and more-consistent salinities. There are also more euryhaline species, such as Black Bream and Yellowtail Grunter that tend to prefer more "estuarine" salinities and typically occur in areas further upstream, i.e. MSE and USE, although the distribution of these species is also influenced by habitat complexity (see below).

- **Hypoxia:** Median day-time oxygen concentrations in this zone are not generally below 4 mg/L, but the area is not monitored at night when respiration from plants and animals lowers oxygen concentrations. Preliminary evaluation of oxygen levels using modelled data (UWA, unpublished data) derived from the Swan Canning Estuarine Response Model (Huang et al., 2019) appear to suggest that hypoxia is not an underlying factor (Taljaard, unpublished report). However, there would be value in deploying dissolved oxygen loggers in the deeper waters of the CE to validate the model predictions. Deeper waters of the Canning can become hypoxic at times and influence the availability of mobile invertebrates like prawns (Poh et al., 2019) that are fed on by larger benthic predators e.g. flathead (Coulson et al., 2015) and the Southern Eagle Ray (Taljaard, unpublished data).

- **Habitat complexity:** The relatively narrow channel and proximity of woody debris (snags) and riparian vegetation that are present in the MSE and USE provide habitat for fish species like Black Bream and Yellowtail Grunter. Such habitats are lacking in the CE. Furthermore, the majority of the seagrass beds in the Swan Canning Estuary occur in the LSCE with only small isolated beds in the CE and MSE (Forbes and Kilminster, 2014). These areas provide habitat for seagrass-associated species such as the Western Striped Grunter and Cobbler, which are more abundant and more commonly recorded in the LSCE than either the CE or MSE (Fig 12).

- **Food resources:** Most fish species are adapted to consume particular types of food and a reduction in the availability of that food source can cause predators to switch diet or move to alternative feeding areas. Studies on the invertebrate communities in the deeper waters of the CE, MSE and USE were last sampled in 1995-97 (Kanandjembo et al., 2001) and so it is difficult to predict how they might have changed over the intervening years. However, benthic macroinvertebrates are known to be negatively affected by hypoxia (Tweedley et al., 2016), which occurs more frequently in the CE (and MSE) compared to the LSCE, and so could reduce the food availability for zoobenthic fish species such as Roach and Yellowtail Grunter. Moreover, the aforementioned lack of hard substrates and woody debris in the CE compared to the MSE prevents the settlement of pygmy mussels and some other bivalves that are fed on by species such as Black Bream. Similarly, seagrass is consumed by Western Striped Grunter and the extent of this habitat/food source is substantially lower in the CE than the LSCE potentially explaining the reduced abundance of this species in the CE.

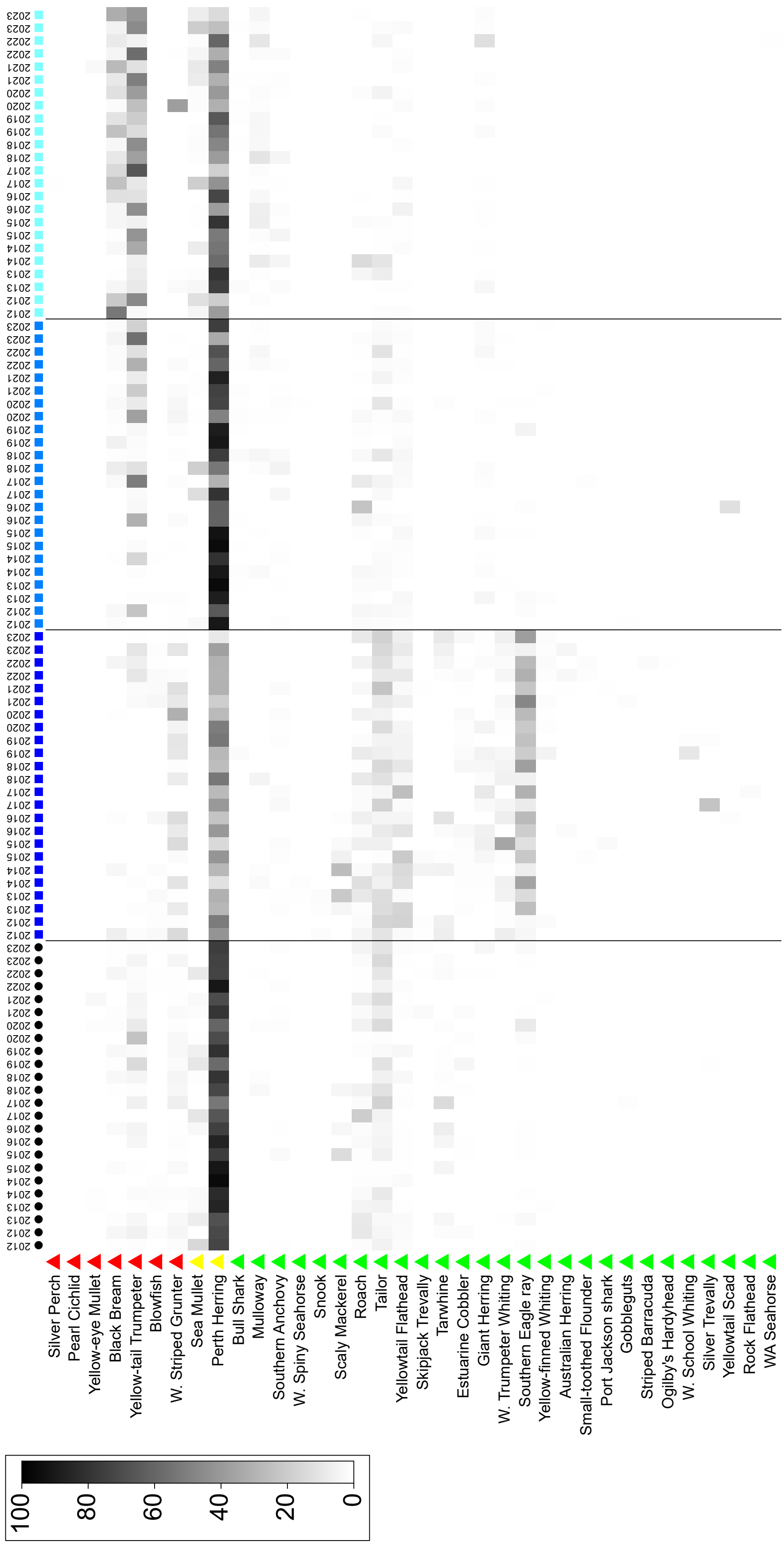


Figure 12. Shade plot of the percentage composition of each of the 36 species recorded in the offshore waters in each zone of the Swan Canning Estuary in each year between 2012 and 2023. Zone (*x*-xis); ● CE, ■ LSCE, ■ MSE and ■ USE. Trophic guild (*y*-axis) ▲ specialist ▲, detritivore and ▲ generalist.

6. Summary

The Fish Community Index (FCI) considers the fish community as a whole and provides an objective means to assess how the structure and function of these communities in shallow, nearshore (< 1.5 m deep) and deeper, offshore waters (> 1.5 m deep) 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 (in comparison to e.g. Cottingham et al., 2014; Crisp et al., 2018), nor does it provide information on the size or status of the fish stocks in the estuary (e.g. Smith and Lenanton, 2021; Obregón et al., 2022).

Across the entire estuary, the ecological condition of both nearshore and offshore waters in 2023 was assessed as good/fair (B/C) based on their fish communities (Table 5). Combined, the nearshore and offshore index scores are among the highest ever recorded. As with 2022, the good scores in 2023 were influenced by relatively strong winter flows in most regions. However, the slight reduction from 2022 is due to the occurrence of a substantial autumn rainfall event on 31 March which brought 25-50mm of rain to large parts of the catchment and led to stratification, low oxygen and hypoxia in the USE and parts of the MSE.

Overall, the offshore waters of the CE exhibited by far the lowest scores of any zone in 2023. As flows in the Canning River are significantly reduced by regulation (Radin et al., 2007; Norton et al., 2010), this axis of the estuary did not receive the same scale of increases in flow that the USE, MSE and LSCE did in association with the March rainfall event. Waters in the CE did become and hypoxic at times, but these were generally contained to areas above Riverton Bridge. This same area was affected by moderate levels of the toxic dinoflagellate *Karlodinium* spp. in mid-February. The poor grades received by the offshore waters of this zone in both seasons are reflective of the trend since the start of regular fish community monitoring in 2012. Over these years the offshore waters of this zone have consistently scored poorly relative to other zones across both seasons, receiving a poor (D) grade in > 50% of monitored seasons. The poor scores are likely related to the low range of species present in the offshore waters of this zone and the dominance by Perth Herring. It appears that some fish species that occur in adjacent zones are either not recorded in the CE or do so less frequently and in lower abundances. A range of hypotheses have been proposed including localised hypoxia, a lack of complex habitats and/or reduced food resources.

Table 5. Fish Community Index (FCI) scores and corresponding ecological condition grades for each zone of the estuary, and the estuary as a whole, during the 2023 monitoring period (mean of all summer and autumn of 2023). LSCE = Lower Swan Canning Estuary, CE = Canning Estuary, MSE = Middle Swan Estuary, USE = Upper Swan Estuary.

	Nearshore		**Offshore**	
	Mean FCI score	*Condition*	*Mean FCI score*	*Condition*
LSCE	65.96	B	65.19	B
CE	61.96	C	49.04	D
MSE	69.46	B	61.82	B
USE	63.73	C/B	63.57	B
Estuary	**65.28**	**B/C**	**59.90**	**B**

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8. Appendices

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.* 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 29 January 2021.

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; OP, Opportunist; HV, Herbivore. See Potter et al. (2015a); Whitfield et al. (2022) for descriptions of the guilds.

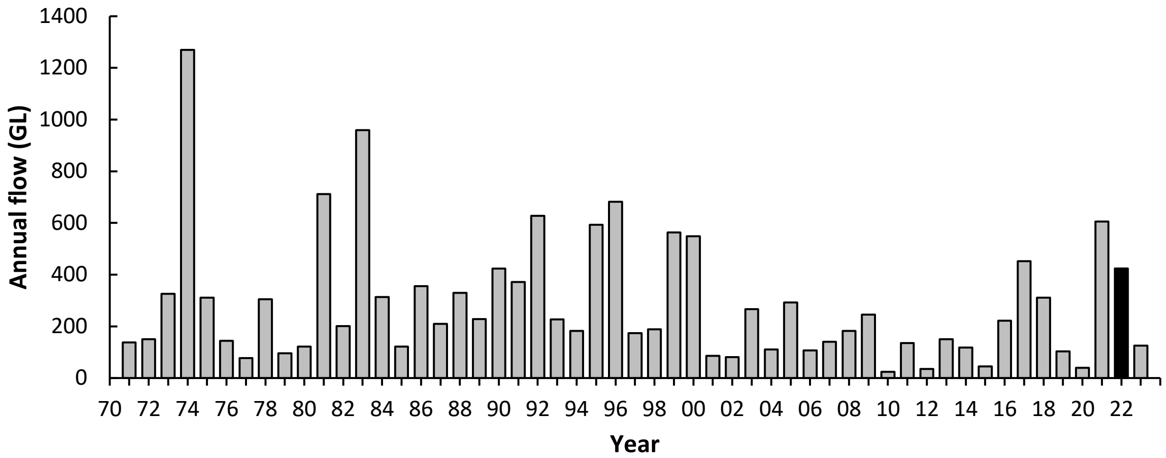
Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Heterodontus portusjacksoni	Port Jackson Shark	Heterodontidae	D	MS	ZB
Carcharhinus leucas	Bull Shark	Carcharhinidae	P	MS	PV
Myliobatis tenuicaudatus	Southern Eagle Ray	Myliobatidae	D	MS	ZB
Elops hawaiensis	Hawaiian Giant Herring	Elopidae	BP	MS	PV
Sardinops sagax	Australian Sardine	Clupeidae	P	MS	ZP
Spratelloides robustus	Blue Sprat	Clupeidae	SP	MM	ZP
Hyperlophus vittatus	Sandy Sprat	Clupeidae	SP	MM	ZP
Nematalosa vlaminghi	Perth Herring	Clupeidae	BP	SA	DV
Sardinella lemuru	Scaly Mackerel	Clupeidae	P	MS	ZP
Engraulis australis	Australian Anchovy	Engraulidae	SP	ES	ZP
Galaxias occidentalis	Western Galaxias	Galaxiidae	SB	FM	ZB
Carassius auratus	Goldfish	Cyprinidae	BP	FM	OV
Cnidoglanis macrocephalus	Estuary Cobbler	Plotosidae	D	MM	ZB
Tandanus bostocki	Freshwater Cobbler	Plotosidae	D	FM	ZB
Hyporhamphus melanochir	Southern Garfish	Hemiramphidae	P	ES	HV
Hyporhamphus regularis	River Garfish	Hemiramphidae	P	FM	HV
Gambusia holbrooki	Eastern Gambusia	Poeciliidae	SP	FM	ZB
Leptatherina presbyteroides	Silver Fish	Atherinidae	SP	MM	ZP
Atherinomorus vaigiensis	Common Hardyhead	Atherinidae	SP	MM	ZB
Atherinosoma elongatum	Elongate Hardyhead	Atherinidae	SP	ES	ZB
Leptatherina wallacei	Western Hardyhead	Atherinidae	SP	ES	ZP
Craterocephalus mugiloides	Spotted Hardyhead	Atherinidae	SP	ES	ZB
Cleidopus gloriamaris	Australian Pineapplefish	Monocentrididae	D	MS	ZB
Phyllopteryx taeniolatus	Common Seadragon	Syngnathidae	D	MS	ZB
Hippocampus subelongatus	West Australian Seahorse	Syngnathidae	D	MS	ZP
Urocampus carinirostris	Hairy Pipefish	Syngnathidae	D	ES	ZP
Stigmatopora argus	Spotted Pipefish	Syngnathidae	D	MS	ZP
Stigmatopora nigra	Widebody Pipefish	Syngnathidae	D	MS	ZB
Pugnaso curtirostris	Pugnose Pipefish	Syngnathidae	D	MS	ZP
Vanacampus phillipi	Port Phillip Pipefish	Syngnathidae	D	MS	ZB
Filicampus tigris	Tiger Pipefish	Syngnathidae	D	MS	ZP
Gymnapistes marmoratus	Soldier	Tetrarogidae	D	MS	ZB
Chelidonichthys kumu	Red Gurnard	Triglidae	D	MS	ZB
Leviprora inops	Longhead Flathead	Platycephalidae	D	MS	PV
Platycephalus laevigatus	Rock Flathead	Platycephalidae	D	MS	PV
Platycephalus westraliae	Yellowtail Flathead	Platycephalidae	D	ES	PV
Pegasus lancifer	Sculptured Seamoth	Pegasidae	D	MS	ZB
Nannoperca vittata	Western Pygmy Perch	Percichthyidae	BP	FM	ZB
Amniataba caudavittata	Yellowtail Grunter	Terapontidae	BP	ES	OP
Bidyanus bidyanus	Silver Perch	Terapontidae	BP	FM	OV
Helotes octolineatus	Western Striped Grunter	Terapontidae	BP	MM	OV

Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Pelsartia humeralis	Sea Trumpeter	Terapontidae	BP	MS	OV
Siphamia cephalotes	Wood's Siphonfish	Apogonidae	BP	MS	ZB
Ostorhinchus rueppellii	Western Gobbleguts	Apogonidae	BP	ES	ZB
Sillaginodes punctatus	King George Whiting	Sillaginidae	D	MM	ZB
Sillago bassensis	Southern School Whiting	Sillaginidae	D	MS	ZB
Sillago burrus	Western Trumpeter Whiting	Sillaginidae	D	MM	ZB
Sillago schomburgkii	Yellowfin Whiting	Sillaginidae	D	MM	ZB
Sillago vittata	Western School Whiting	Sillaginidae	D	MM	ZB
Pomatomus saltatrix	Tailor	Pomatomidae	P	MM	PV
Trachurus novaezelandiae	Yellowtail Scad	Carangidae	P	MS	ZB
Scomberoides tol	Needleskin Queenfish	Carangidae	P	MS	PV
Pseudocaranx georgianus	Silver Trevally	Carangidae	BP	MM	ZB
Pseudocaranx wrighti	Skipjack Trevally	Carangidae	BP	MM	ZB
Arripis georgianus	Australian Herring	Arripidae	P	MM	PV
Pentapodus vitta	Western Butterfish	Nemipteridae	BP	MS	ZB
Gerres subfasciatus	Common Silverbiddy	Gerreidae	BP	MM	ZB
Acanthopagrus butcheri	Black Bream	Sparidae	BP	ES	OP
Rhabdosargus sarba	Tarwhine	Sparidae	BP	MM	ZB
Argyrosomus japonicus	Mulloway	Sciaenidae	BP	MM	PV
Parupeneus spilurus	Blacksaddle Goatfish	Mullidae	D	MS	ZB
Neatypus obliquus	Footballer Sweep	Scorpididae	P	MS	ZP
Scorpis aequipinnis	Sea Sweep	Scorpididae	P	MS	ZP
Enoplosus armatus	Old Wife	Enoplosidae	D	MS	ZB
Geophagus brasiliensis	Pearl Cichlid	Cichlidae	BP	FM	OV
Aldrichetta forsteri	Yelloweye Mullet	Mugilidae	P	MM	OV
Mugil cephalus	Sea Mullet	Mugilidae	P	MM	DV
Sphyraena novaehollandiae	Snook	Sphyraenidae	P	MS	PV
Sphyraena obtusata	Striped Barracuda	Sphyraenidae	P	MS	PV
Neoodax balteatus	Little Weed Whiting	Labridae	D	MS	OV
Siphonognathus radiatus	Longray Weed Whiting	Labridae	D	MS	OV
Haletta semifasciata	Blue Weed Whiting	Labridae	D	MS	OV
Heteroscarus acroptilus	Rainbow Cale	Labridae	D	MS	OV
Parapercis haackei	Wavy Grubfish	Pinguipedidae	D	MS	ZB
Lesueurina platycephala	Flathead Sandfish	Leptoscopidae	D	MS	ZB
Istiblennius meleagris	Peacock Rockskipper	Blenniidae	D	MS	HV
Omobranchus germaini	Germain's Blenny	Blenniidae	SB	MS	ZB
Parablennius intermedius	Horned Blenny	Blenniidae	D	MS	ZB
Parablennius postoculomaculatus	False Tasmanian Blenny	Blenniidae	SB	MS	OV
Petroscirtes breviceps	Shorthead Sabretooth Blenny	Blenniidae	SB	MS	OV
Cristiceps australis	Southern Crested Weedfish	Clinidae	D	MS	ZB
Pseudocalliurichthys goodladi	Longspine Dragonet	Callionymidae	D	MS	ZB
Eocallionymus papilio	Painted Stinkfish	Callionymidae	D	MS	ZB
Callogobius mucosus	Sculptured Goby	Gobiidae	SB	MS	ZB
Favonigobius lateralis	Southern Longfin Goby	Gobiidae	SB	MM	ZB
Nesogobius pulchellus	Sailfin Goby	Gobiidae	SB	MS	ZB
Arenigobius bifrenatus	Bridled Goby	Gobiidae	SB	ES	ZB

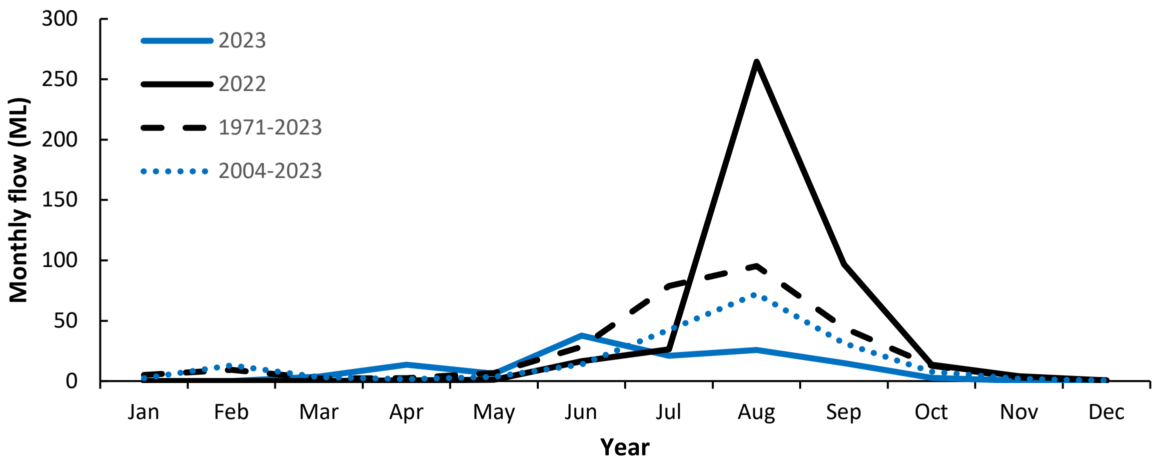
Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Pseudogobius olorum	Bluespot Goby	Gobiidae	SB	ES	OV
Bathygobius fuscus	Dusky Frillgoby	Gobiidae	SB	MM	ZB
Callogobius depressus	Flathead Goby	Gobiidae	SB	MS	ZB
Favonigobius punctatus	Yellowspotted Sandgoby	Gobiidae	SB	ES	ZB
Afurcagobius suppositus	Southwestern Goby	Gobiidae	SB	ES	ZB
Redigobius macrostoma	Largemouth Goby	Gobiidae	SB	ES	ZB
Tridentiger trigonocephalus	Trident Goby	Gobiidae	SB	MS	ZB
Pseudorhombus jenynsii	Smalltooth Flounder	Paralichthyidae	D	MM	ZB
Ammotretis rostratus	Longsnout Flounder	Pleuronectidae	D	MM	ZB
Ammotretis elongatus	Elongate Flounder	Pleuronectidae	D	MM	ZB
Cynoglossus broadhursti	Southern Tongue Sole	Cynoglossidae	D	MS	ZB
Acanthaluteres brownii	Spinytail Leatherjacket	Monacanthidae	D	MS	OV
Acanthaluteres vittiger	Toothbrush Leatherjacket	Monacanthidae	D	MS	OV
Eubalichthys mosaicus	Mosaic Leatherjacket	Monacanthidae	D	MS	OV
Scobinichthys granulatus	Rough Leatherjacket	Monacanthidae	D	MS	OV
Monacanthus chinensis	Fanbelly Leatherjacket	Monacanthidae	D	MM	OV
Chaetodermis penicilligerus	Tasselled Leatherjacket	Monacanthidae	D	MS	OV
Brachaluteres jacksonianus	Southern Pygmy Leatherjacket	Monacanthidae	D	MS	OV
Meuschenia freycineti	Sixspine Leatherjacket	Monacanthidae	D	MM	OV
Acanthaluteres spilomelanurus	Bridled Leatherjacket	Monacanthidae	D	MM	OV
Torquigener pleurogramma	Weeping Toadfish	Tetraodontidae	BP	MM	OP
Contusus brevicaudus	Prickly Toadfish	Tetraodontidae	BP	MS	OP
Polyspina piosae	Orangebarred Puffer	Tetraodontidae	BP	MS	OP
Diodon nicthemerus	Globefish	Diodontidae	D	MS	ZB

Appendix (iv). (a) Total annual flow between 1971 and 2023 and (b) total monthly flow in 2022 and 2023 compared to longer-term averages at Walyunga on the Swan River (gauging station 16401). Data from 2022 highlighted in black in (a) and as the solid black line in (b). Data recorded by the Department of Water and Environmental Regulation and extracted from https://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx.

(a)

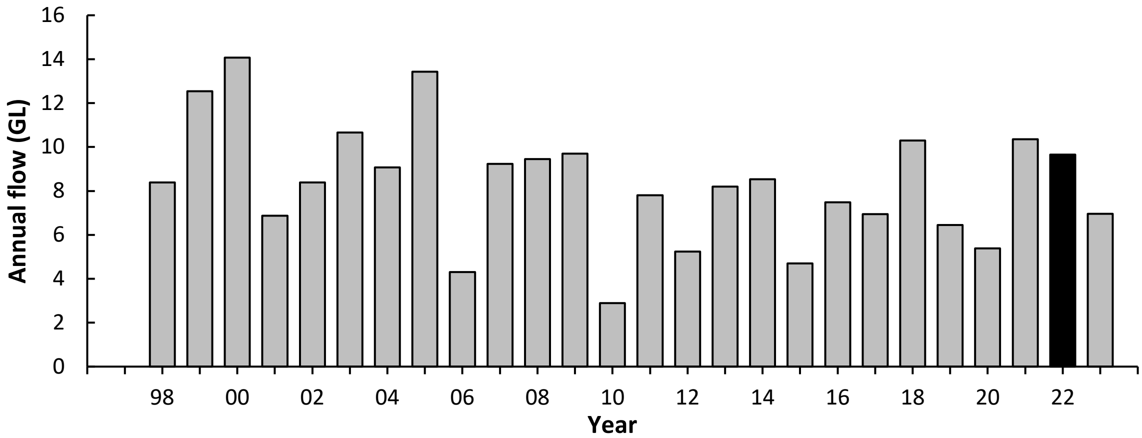


(b)

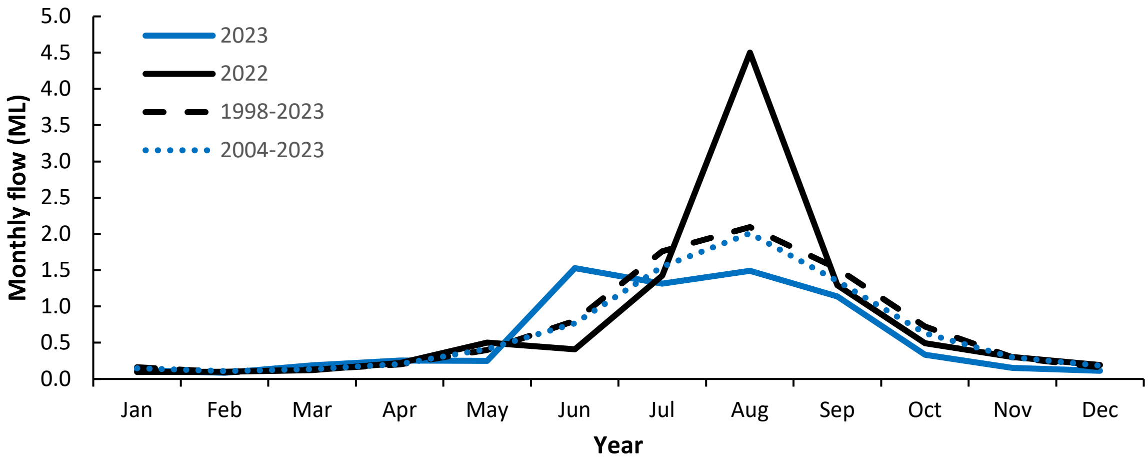


Appendix (v). (a) Total annual flow between 1998 and 2023 and (b) total monthly flow in 2022 and 2023 compared to longer-term averages at Seaforth on the Canning River (gauging station 16417). Data from 2022 highlighted in black in (a) and as the solid black line in (b). Data recorded by the Department of Water and Environmental Regulation and extracted from https://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx.

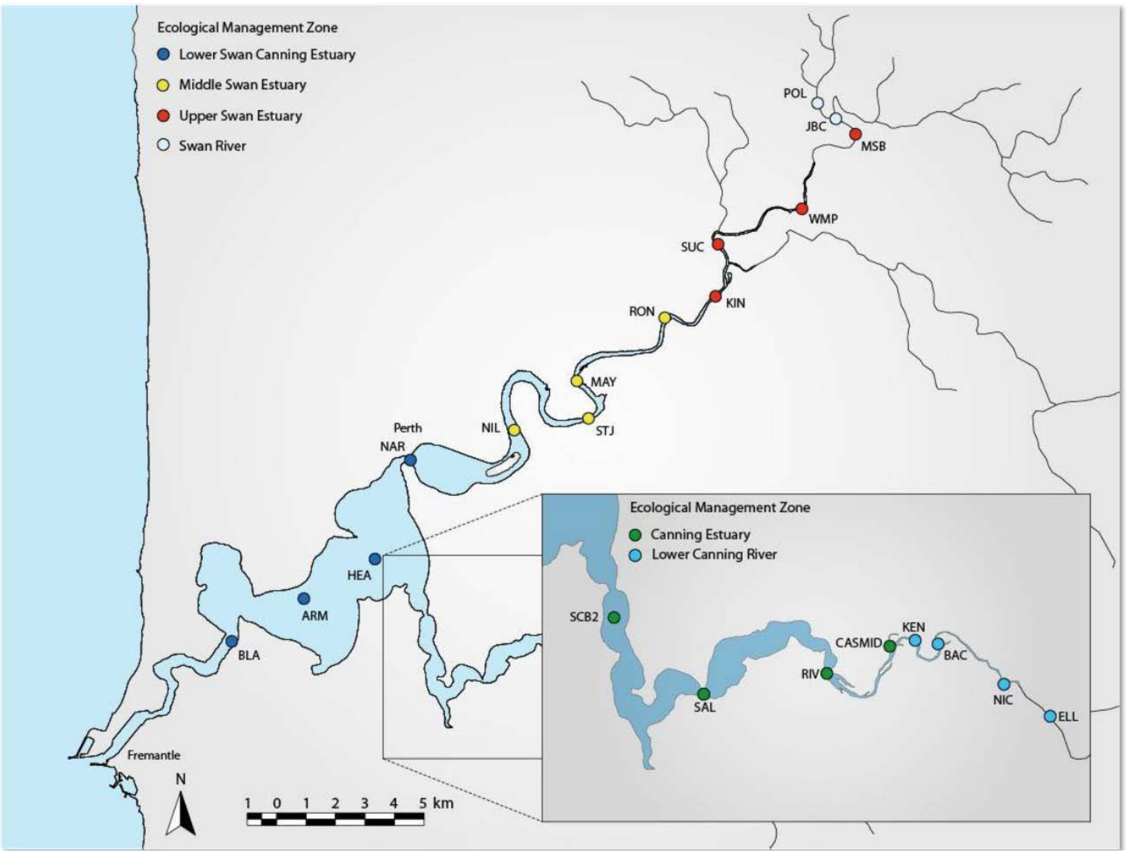
(a)



(b)

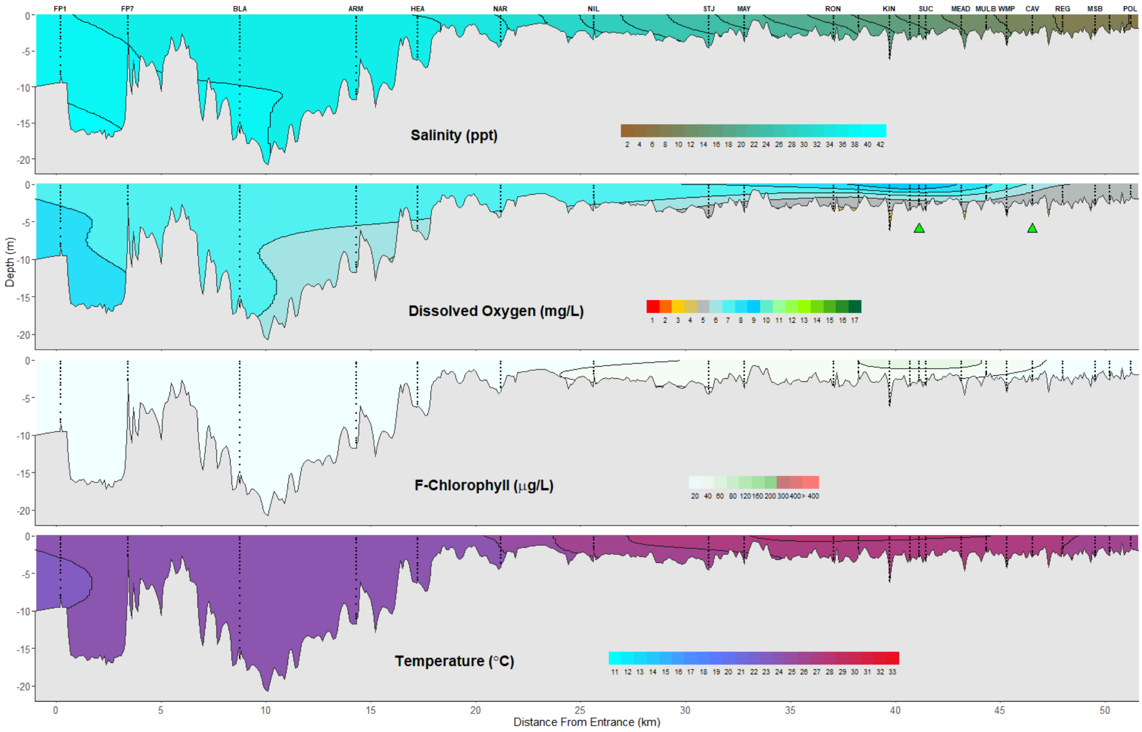


Appendix (vi). A representative selection of vertical contour plots of salinity, dissolved oxygen concentrations (mg/L), Chlorophyll fluorescence (µg/L) and water temperature (°C) measured at monitoring stations along the length of the Swan Canning Estuary (see map) on occasions throughout the summer to autumn period of fish community sampling. Prepared by the Department of Biodiversity, Conservation and Attractions (https://www.dbca.wa.gov.au/science/riverpark-monitoring).

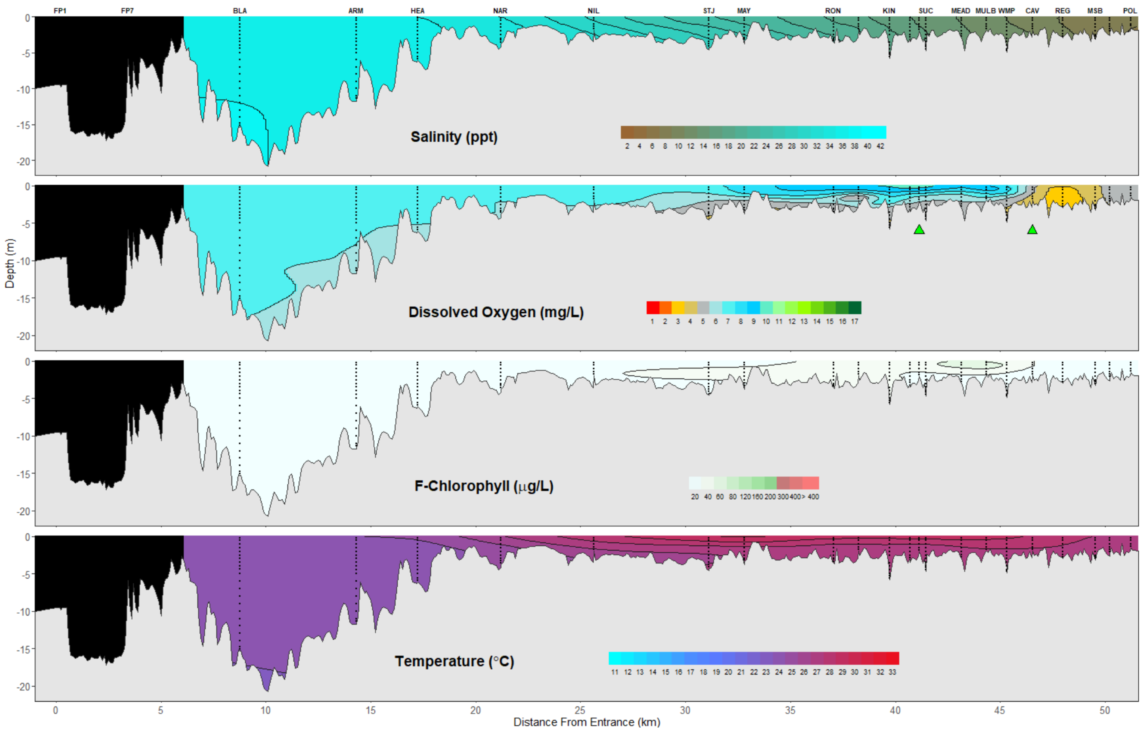


LSCE, MSE and USE zones in summer through autumn 2023

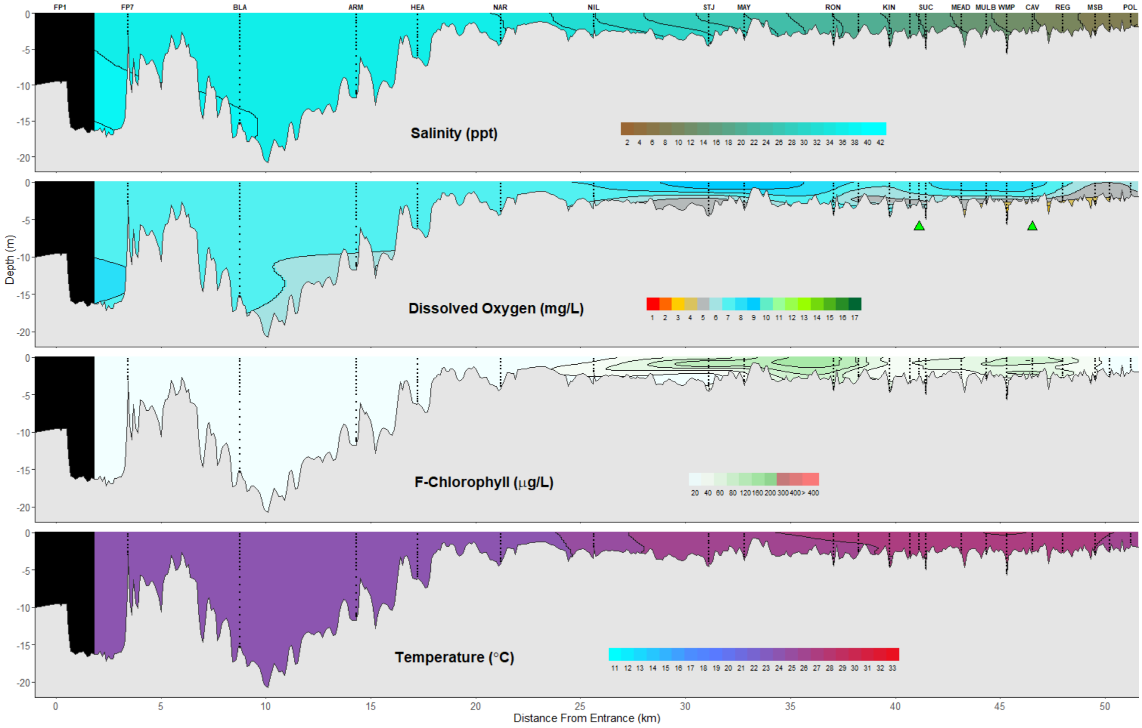
3th January 2023



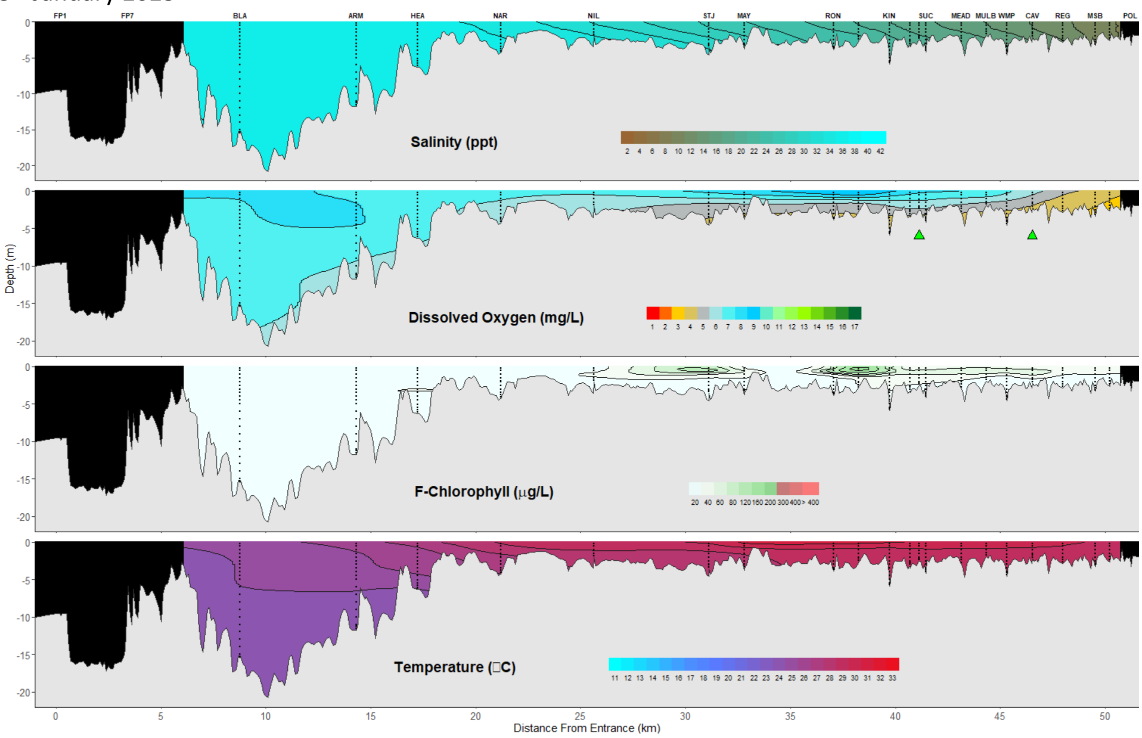
9th January 2023



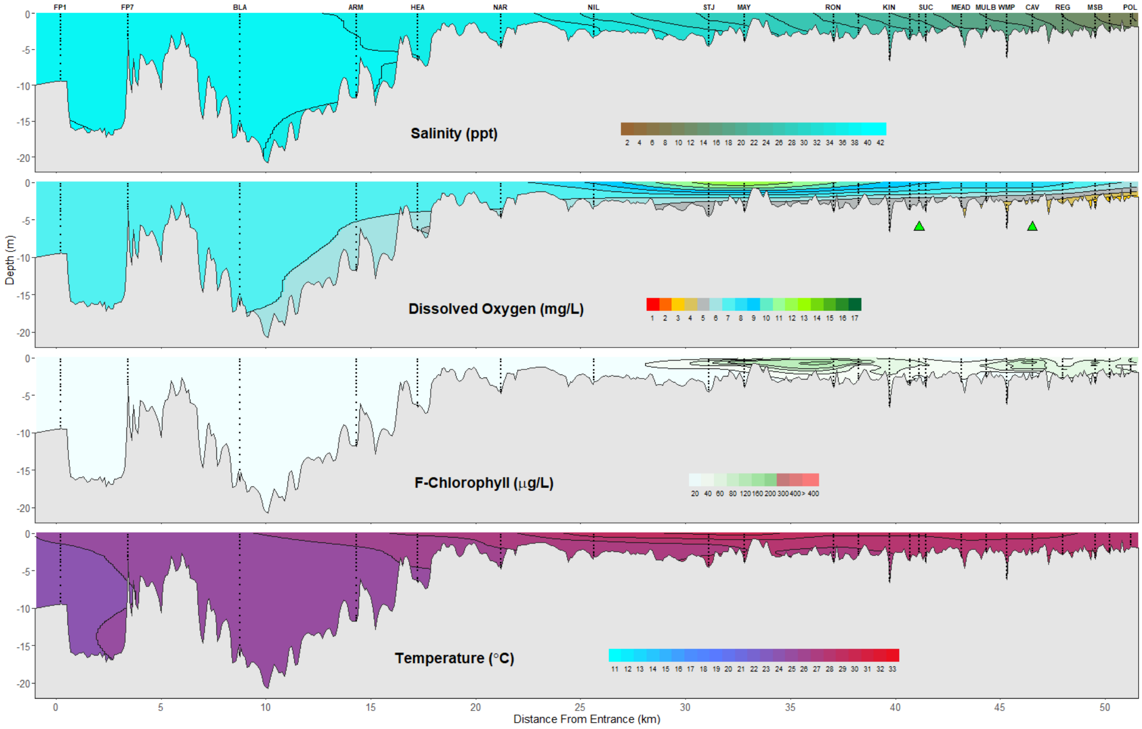
16th January 2023



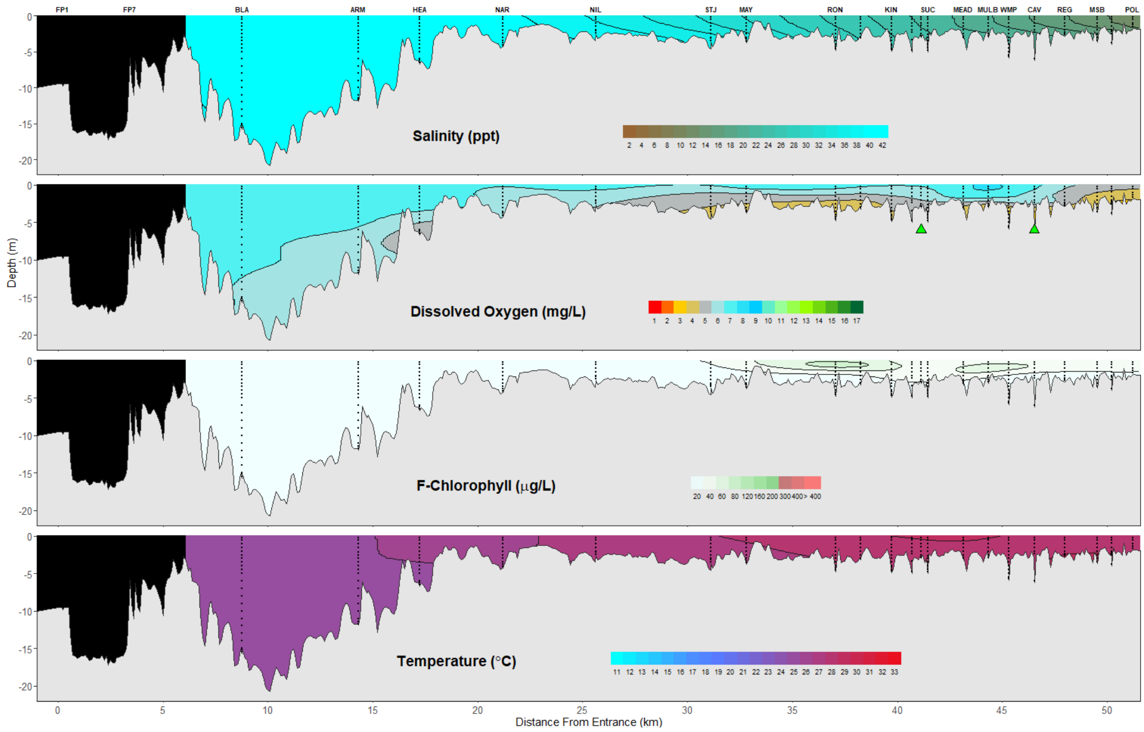
23th January 2023



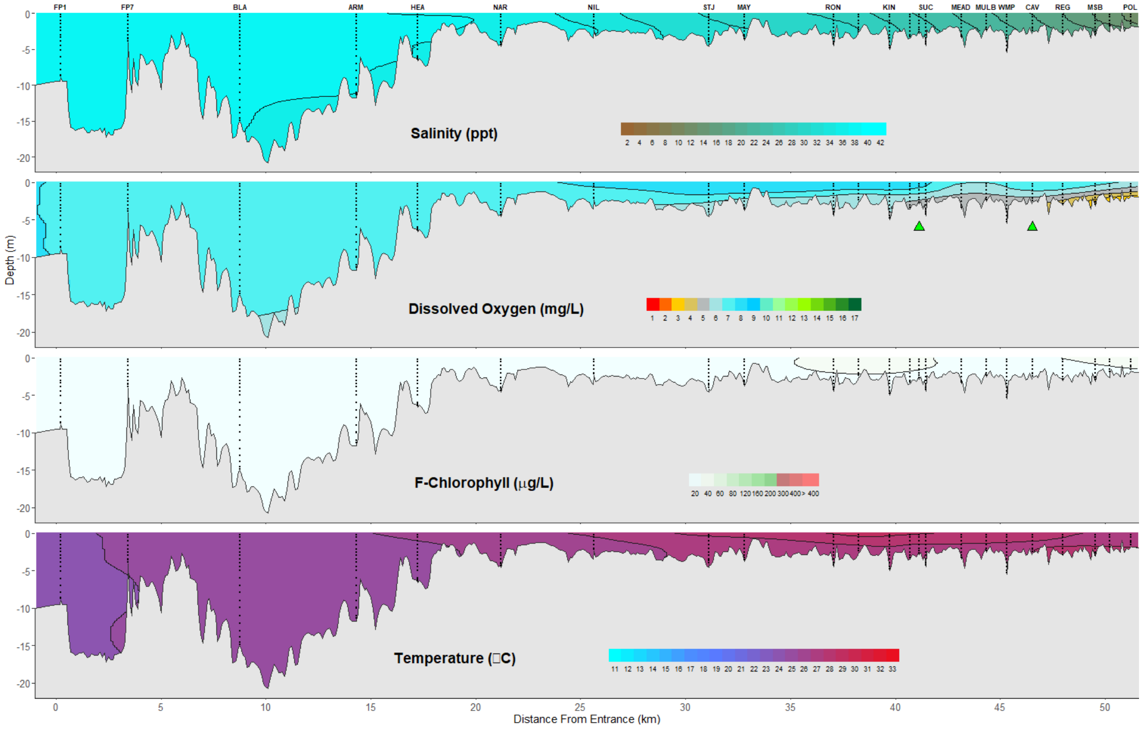
30th January 2023



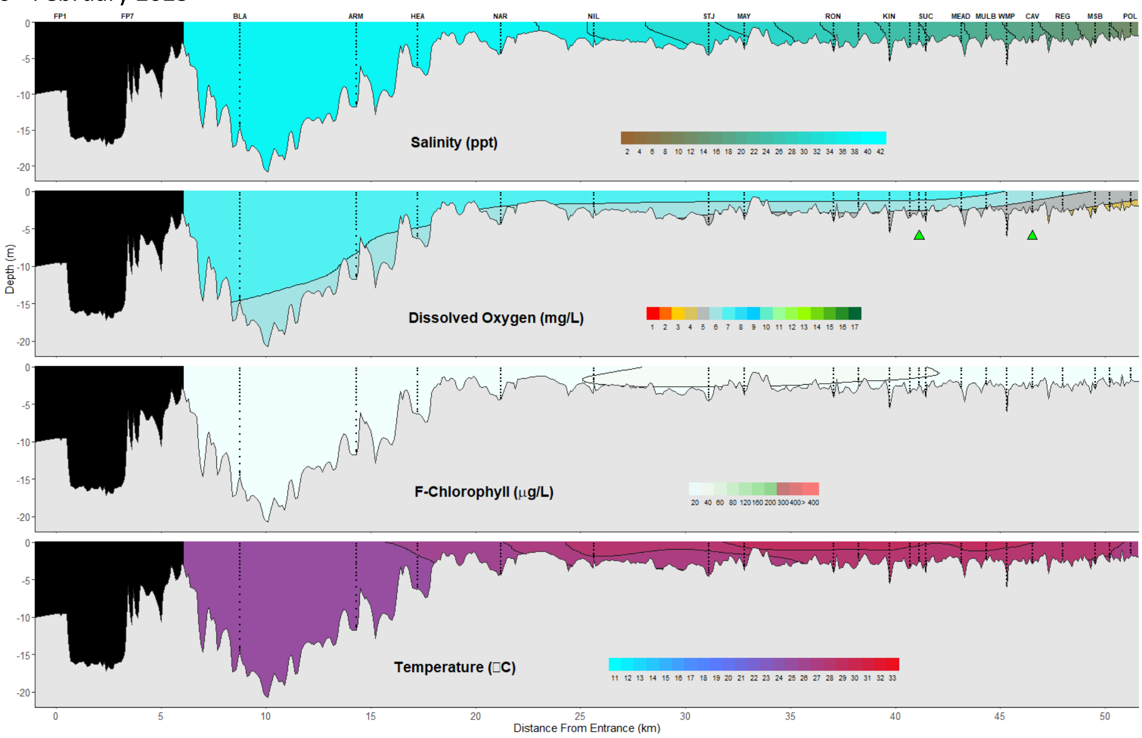
6th February 2023



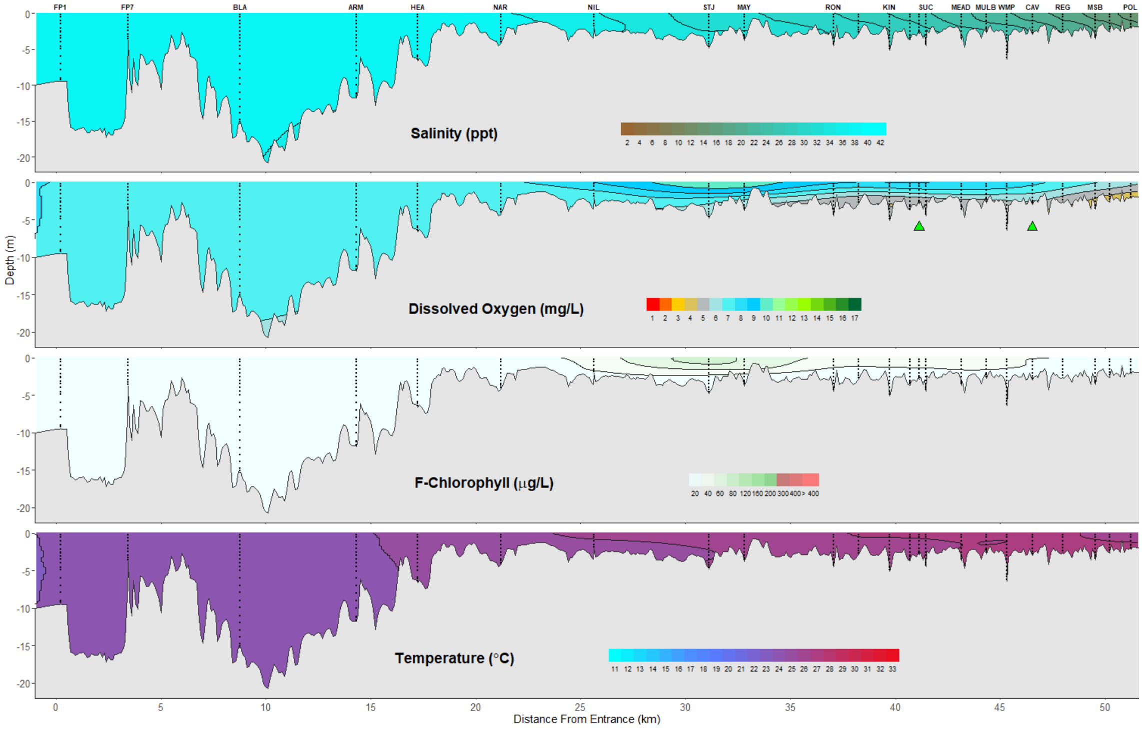
13th February 2023



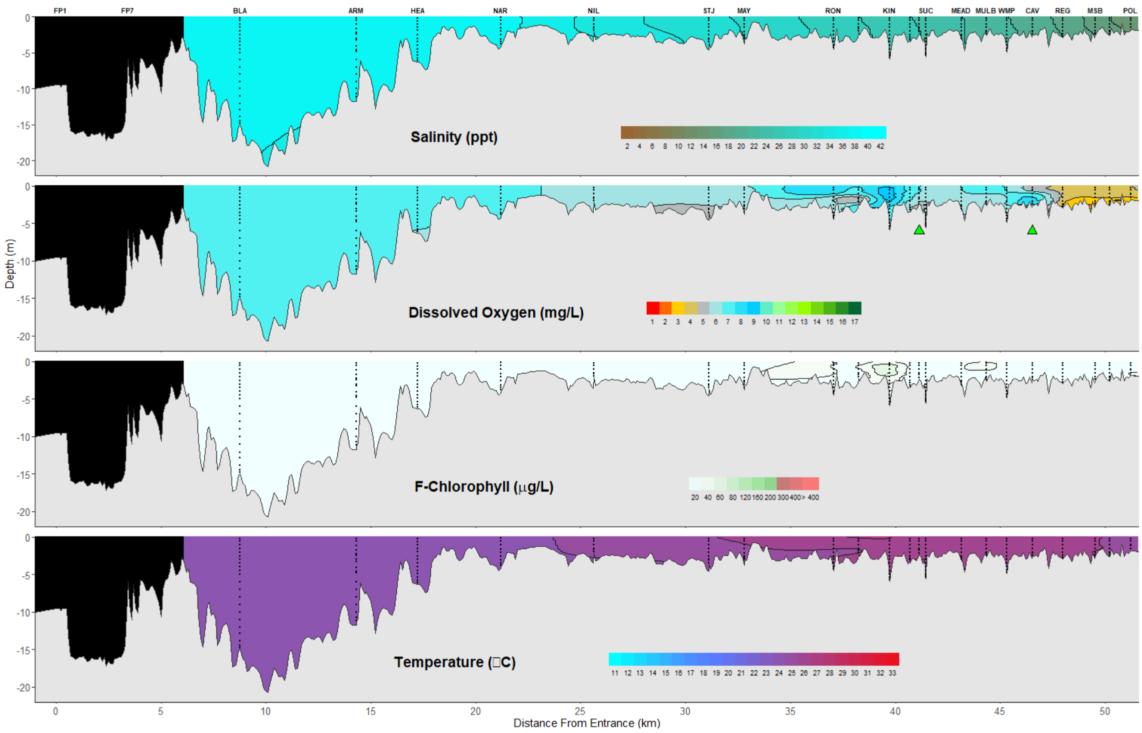
20th February 2023



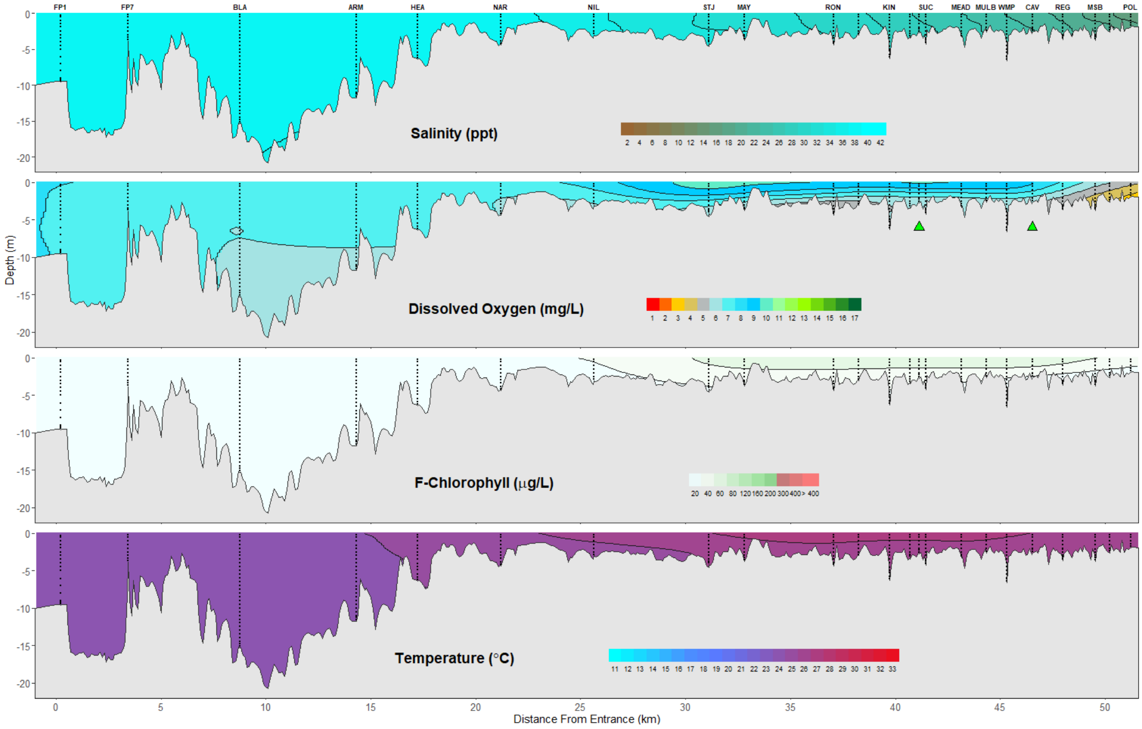
27th February 2023



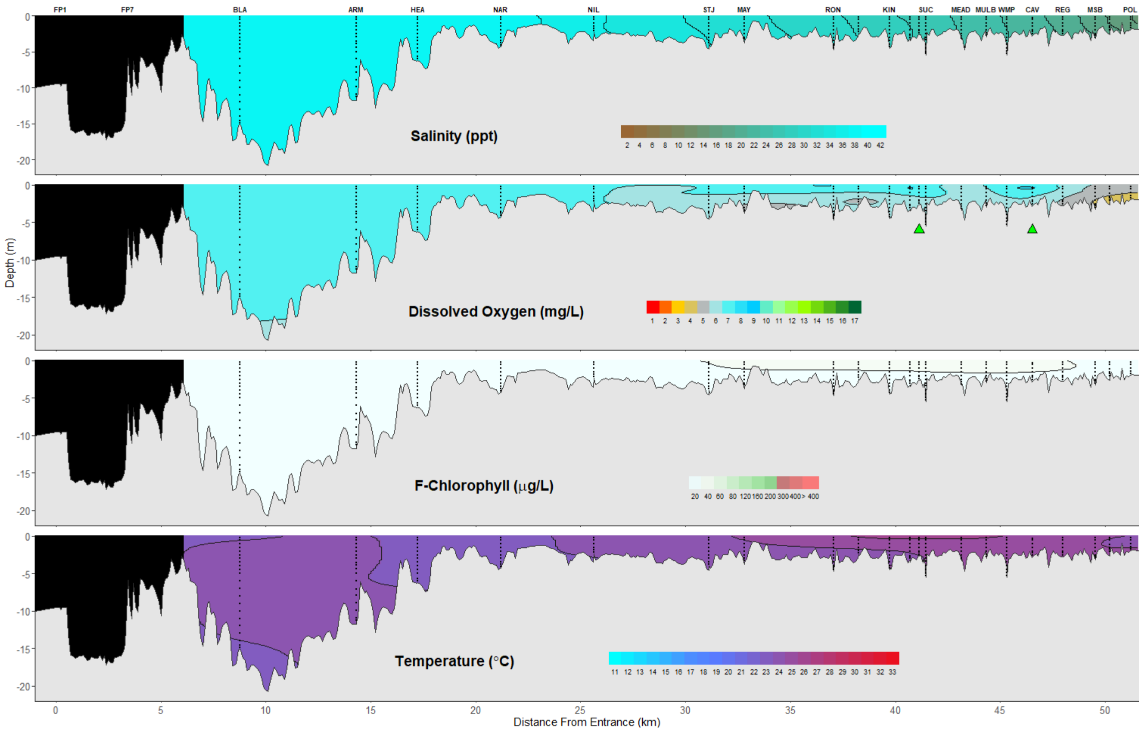
7th March 2023



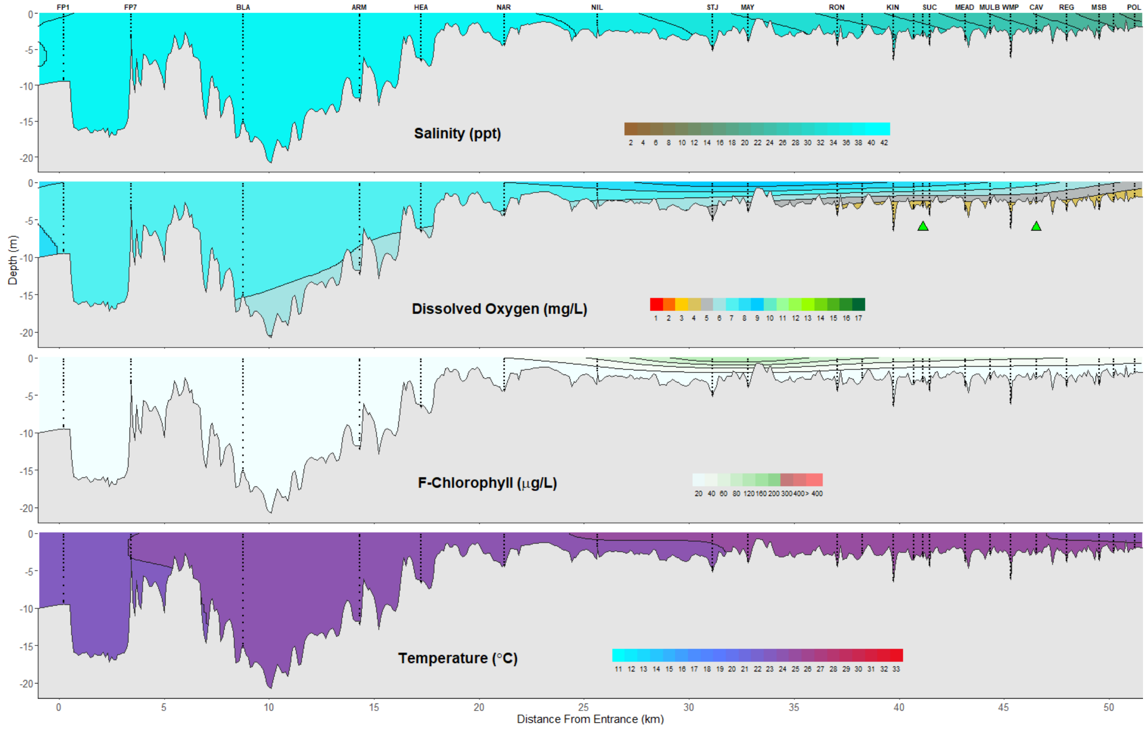
13th March 2023



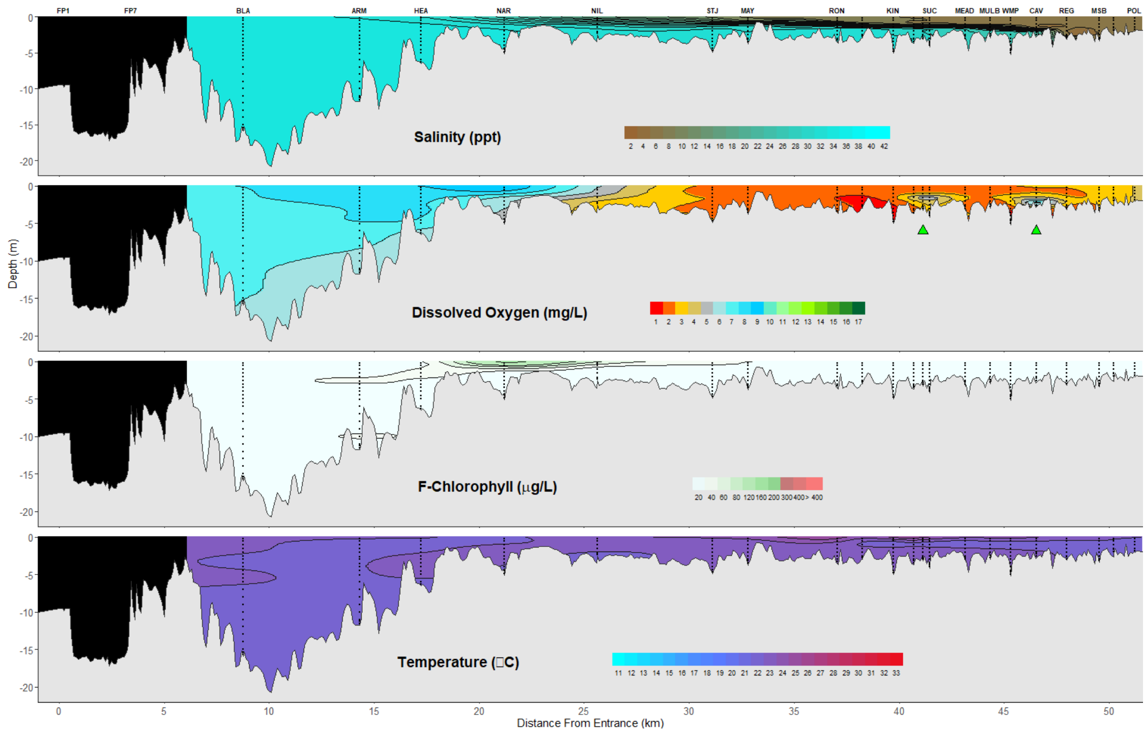
20th March 2023



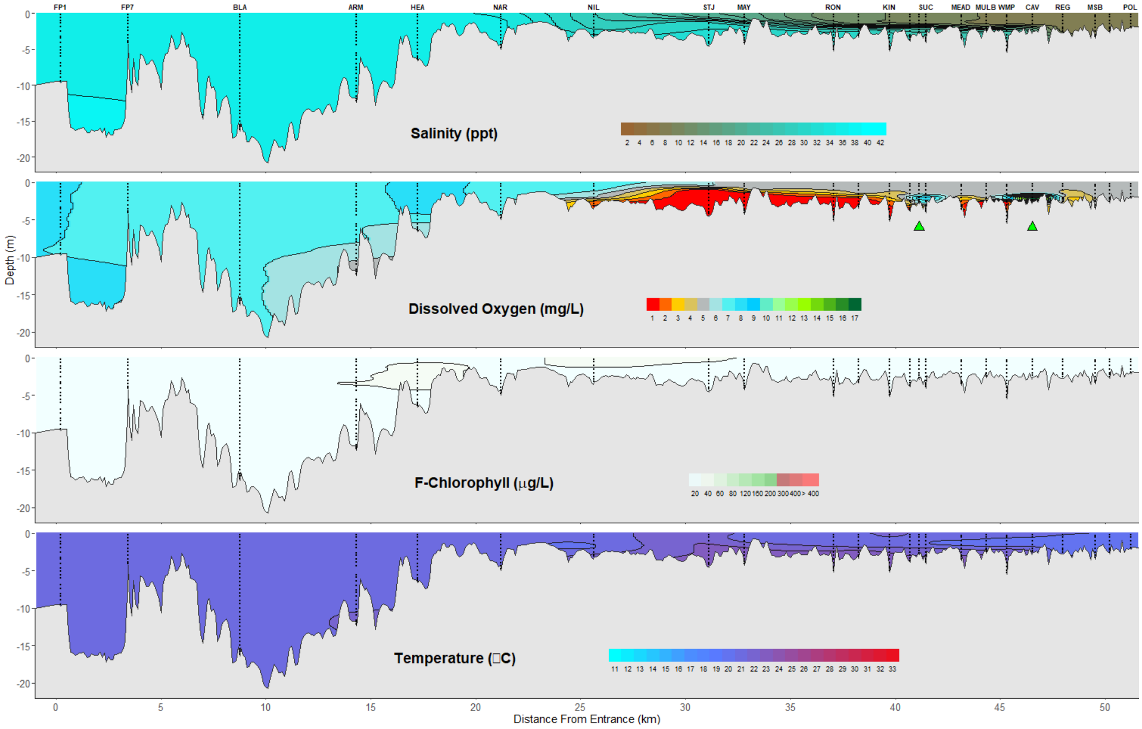
27th March 2023



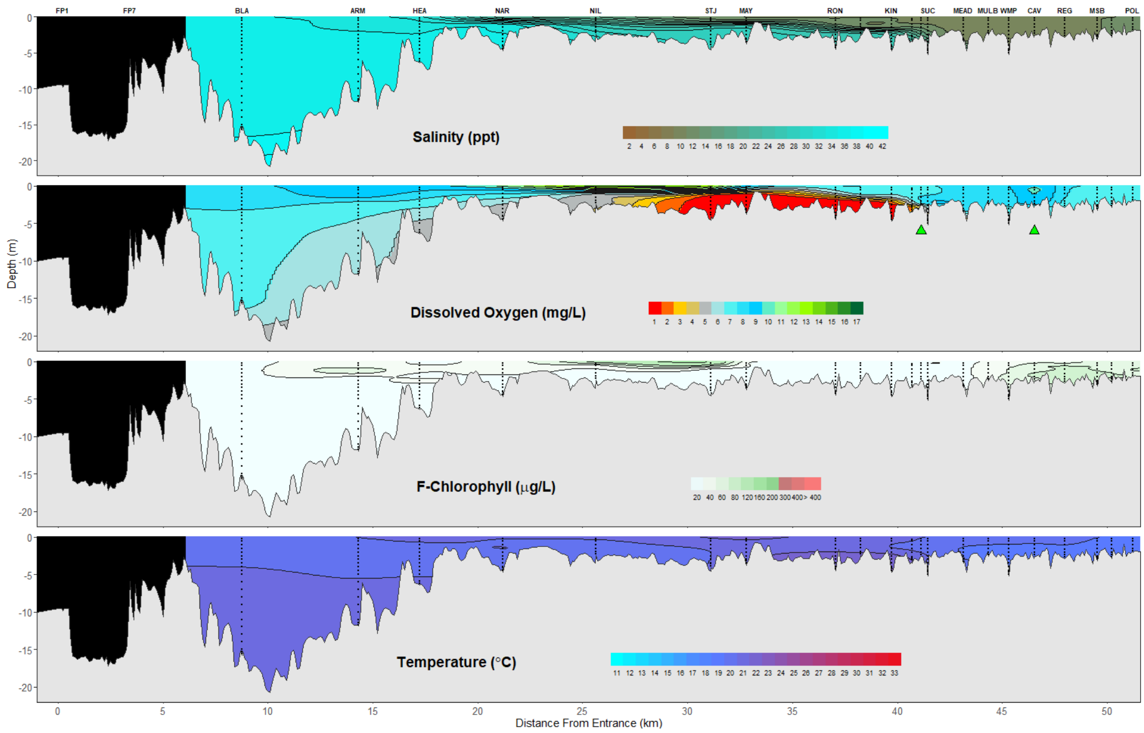
3rd April 2023



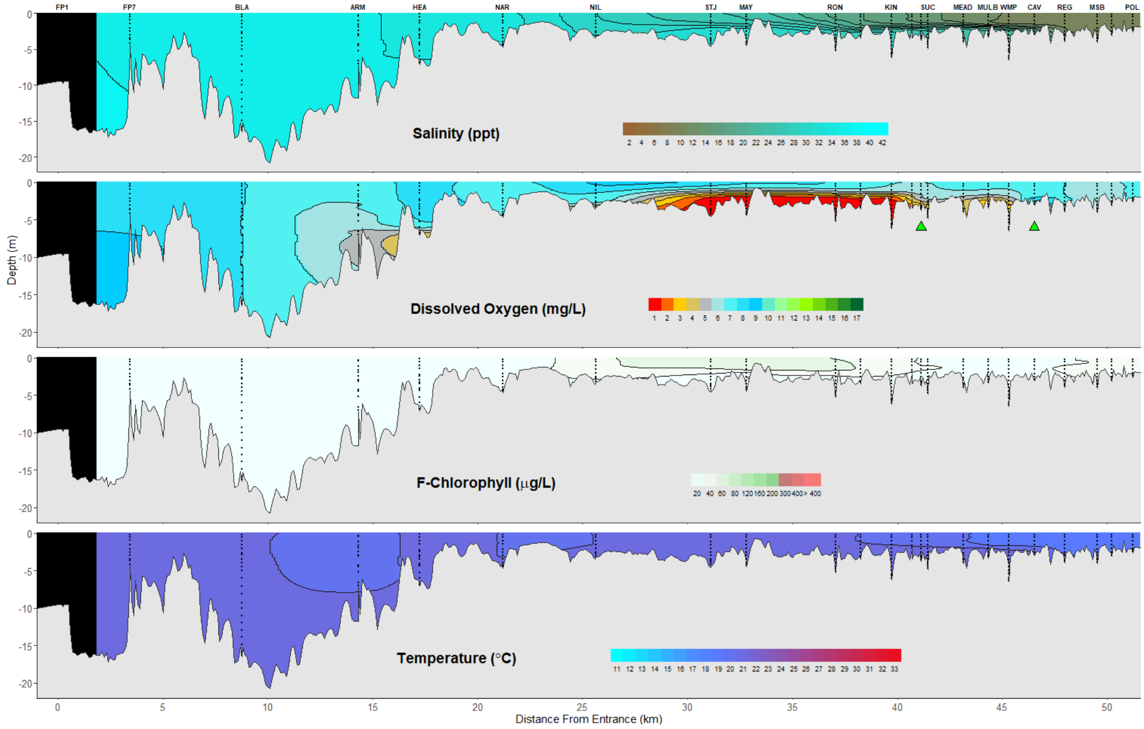
11th April 2023



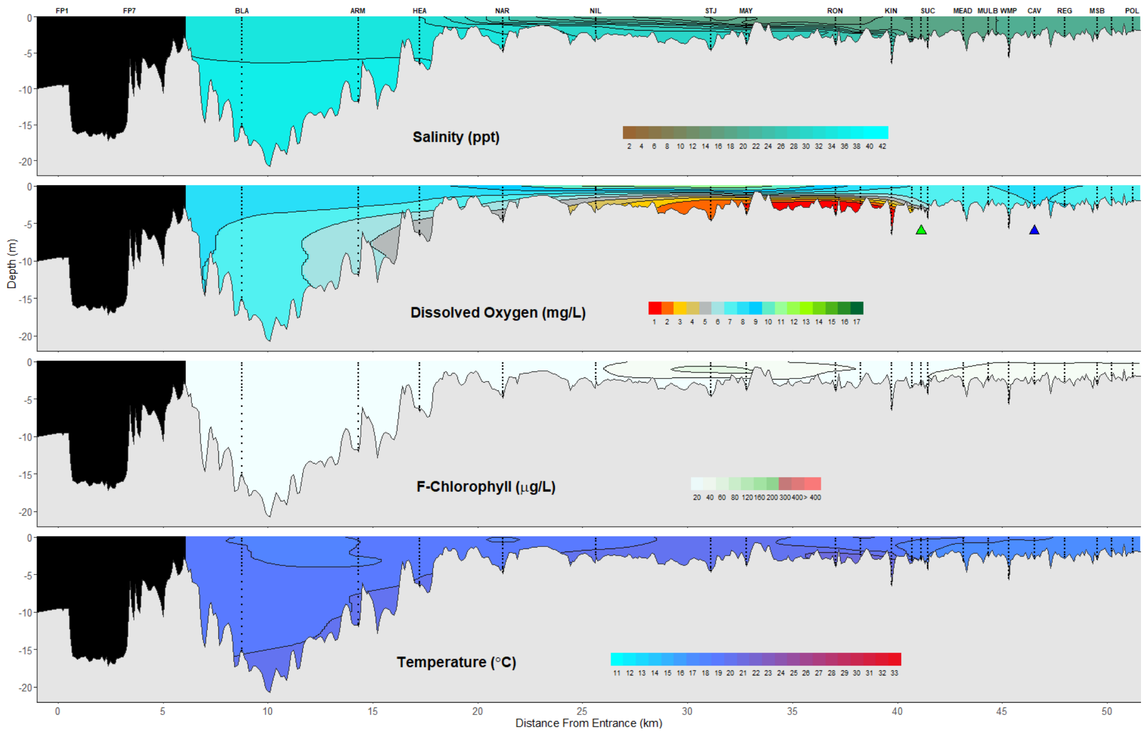
17th April 2023



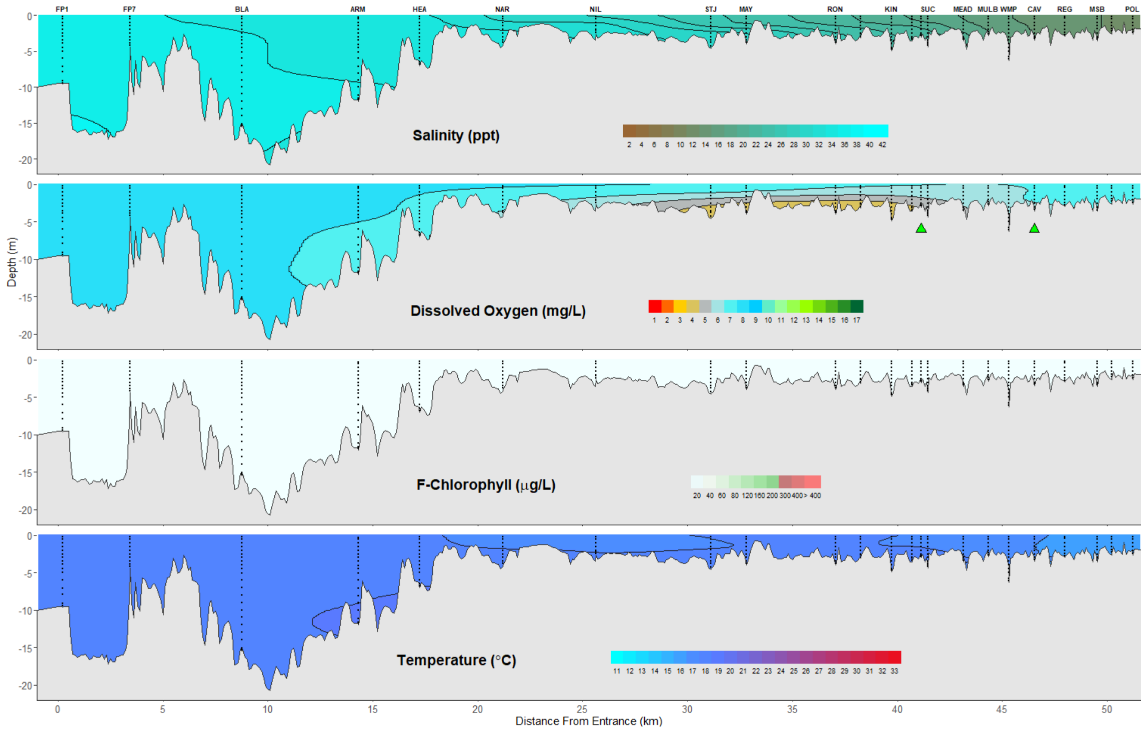
24th April 2023



1st May 2023



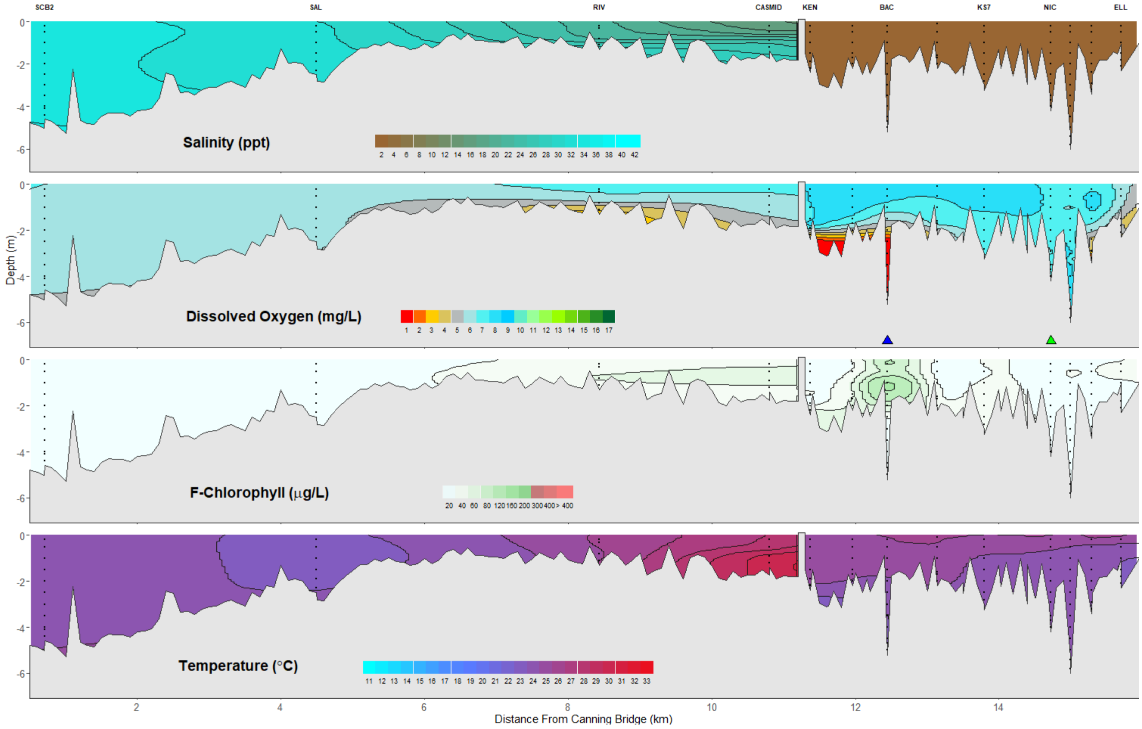
8th May 2023



FP1
FP7
BLA
ARM
HEA
NAR
NIL
STJ
MAY
RON
KIN
SUC
MEAD
MULB
WMP
CAV
REG
MSB
POL
Salinity (ppt)
Dissolved Oxygen (mg/L)
F-Chlorophyll (µg/L)
Temperature (°C)
Depth (m)
Distance From Entrance (km)

CE zone in summer through autumn 2023

4th January 2023



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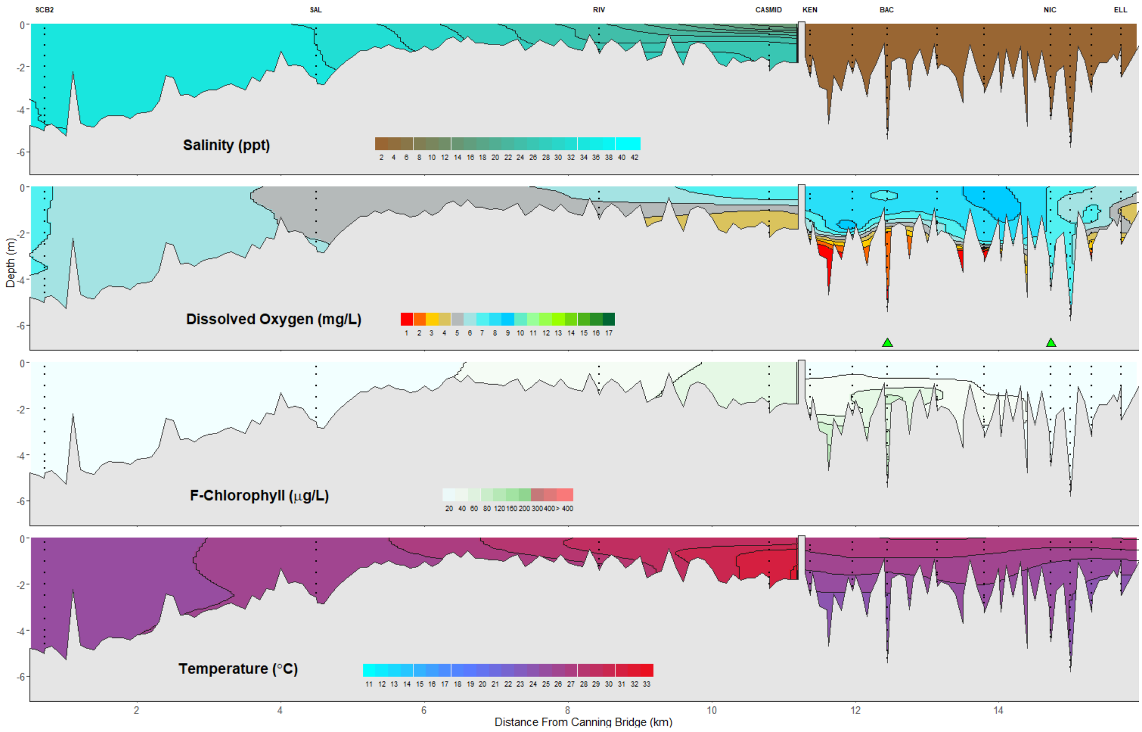

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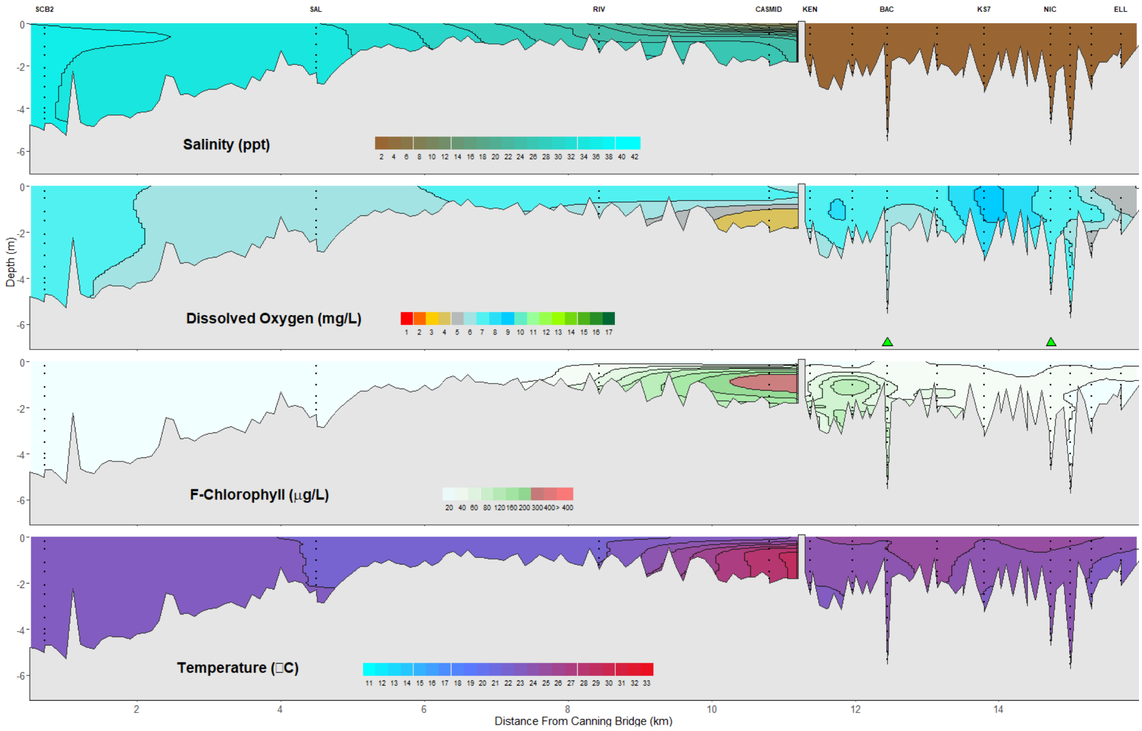

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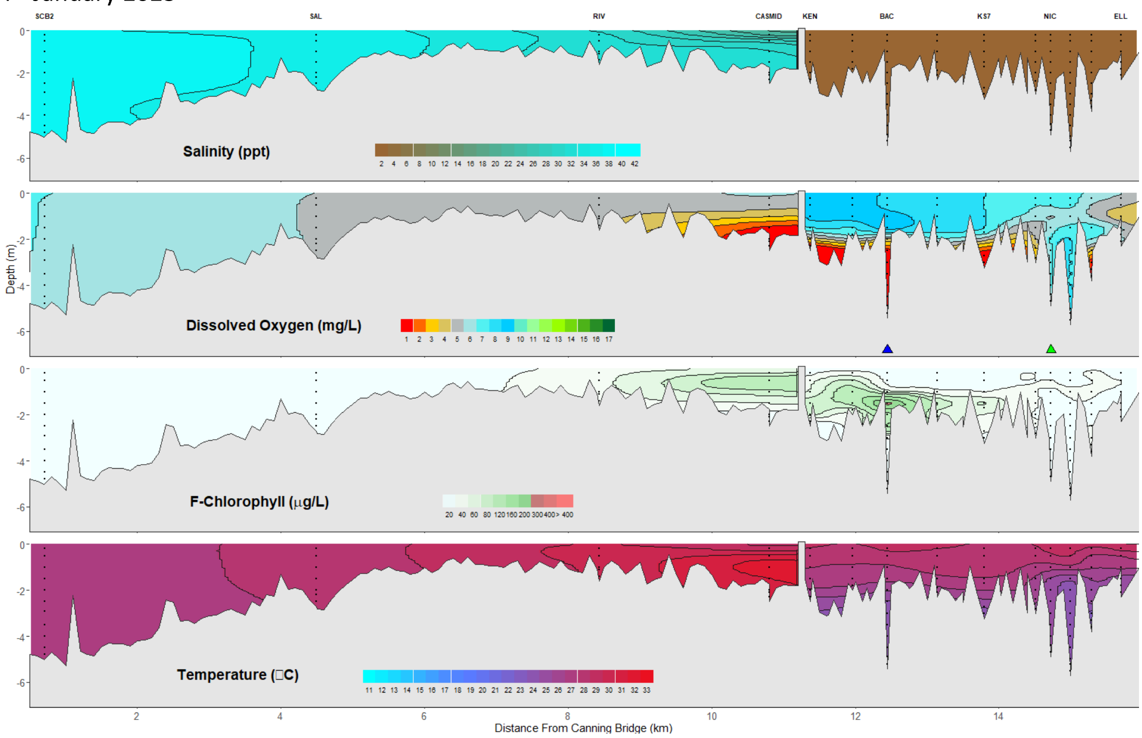
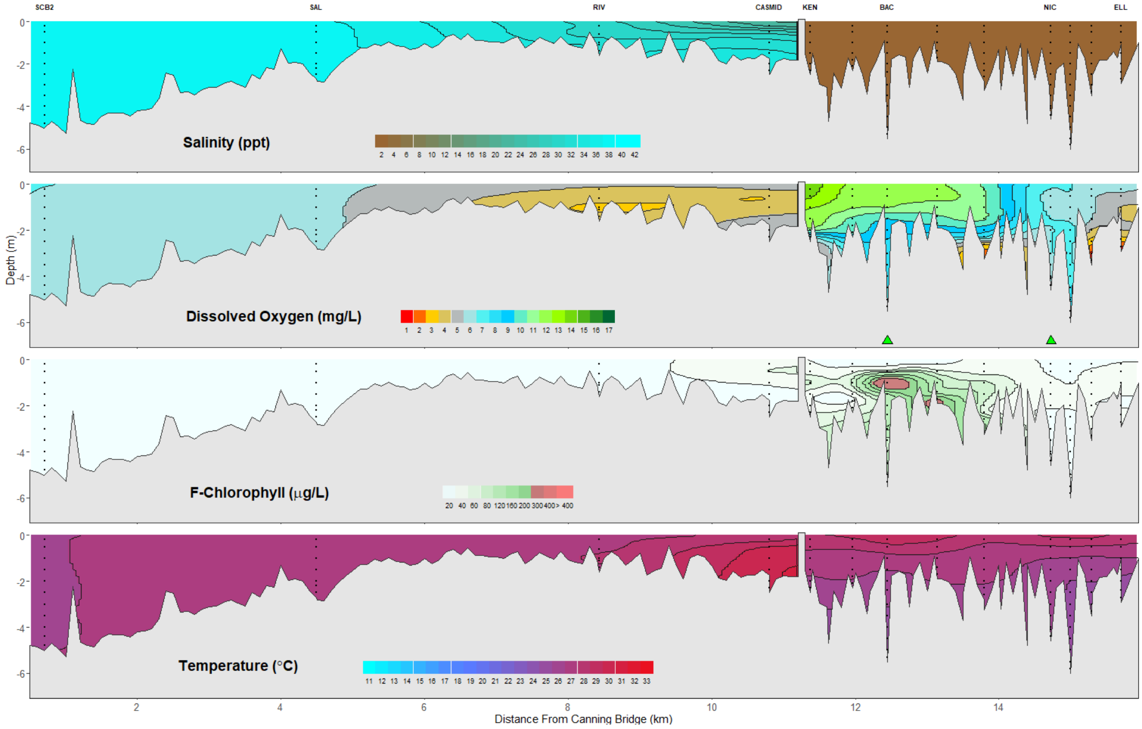
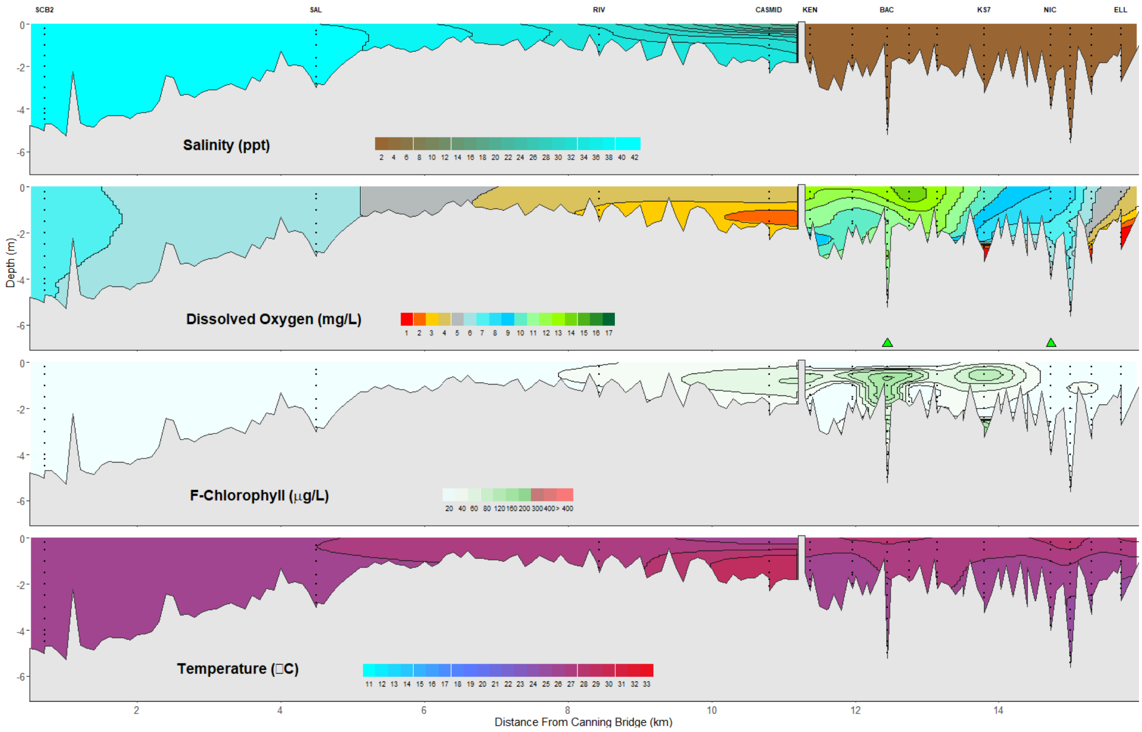


31st January 2023



7th February 2023



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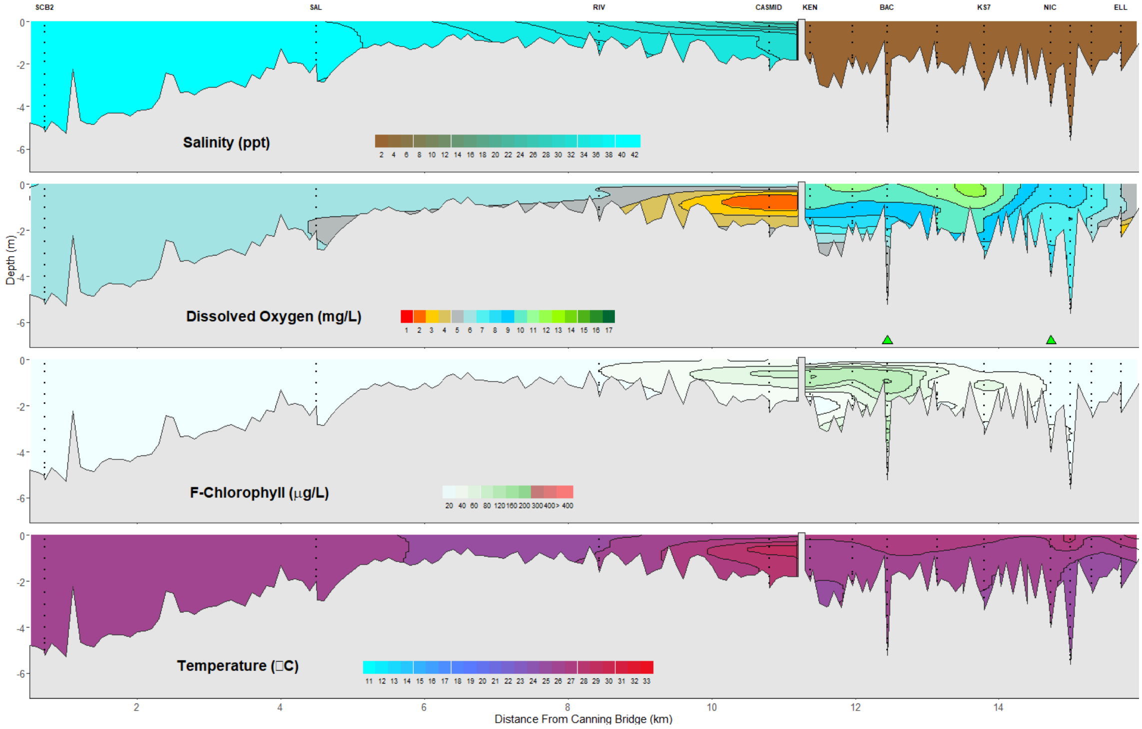

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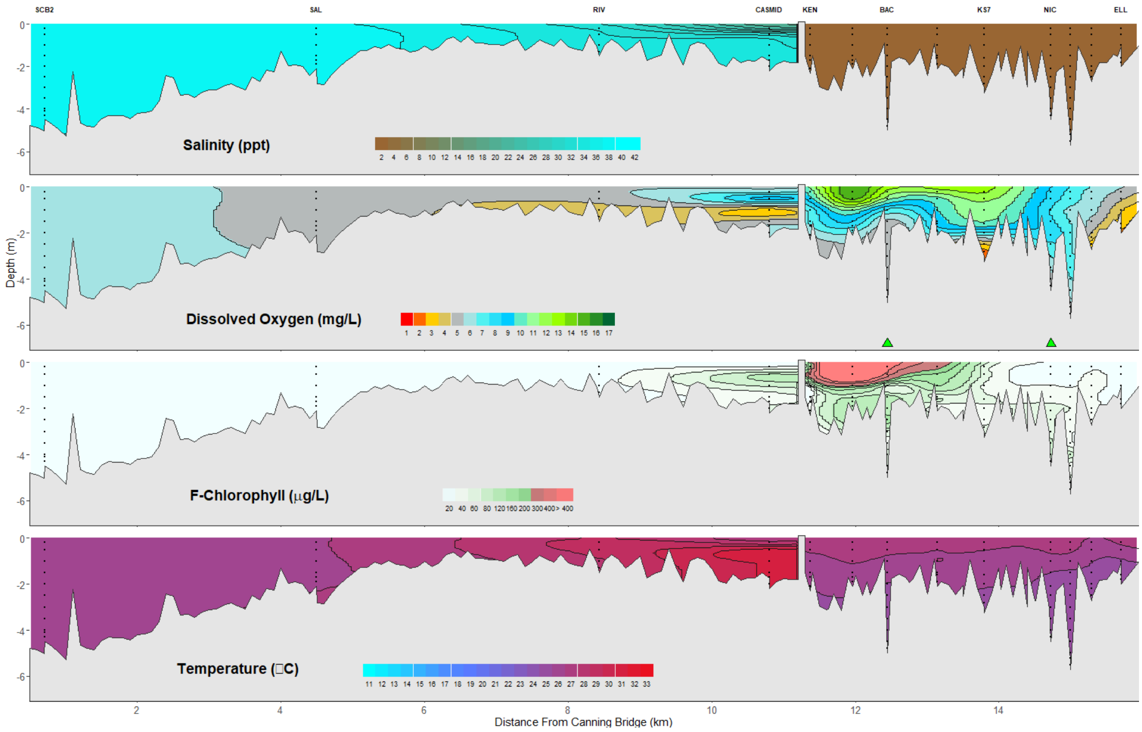

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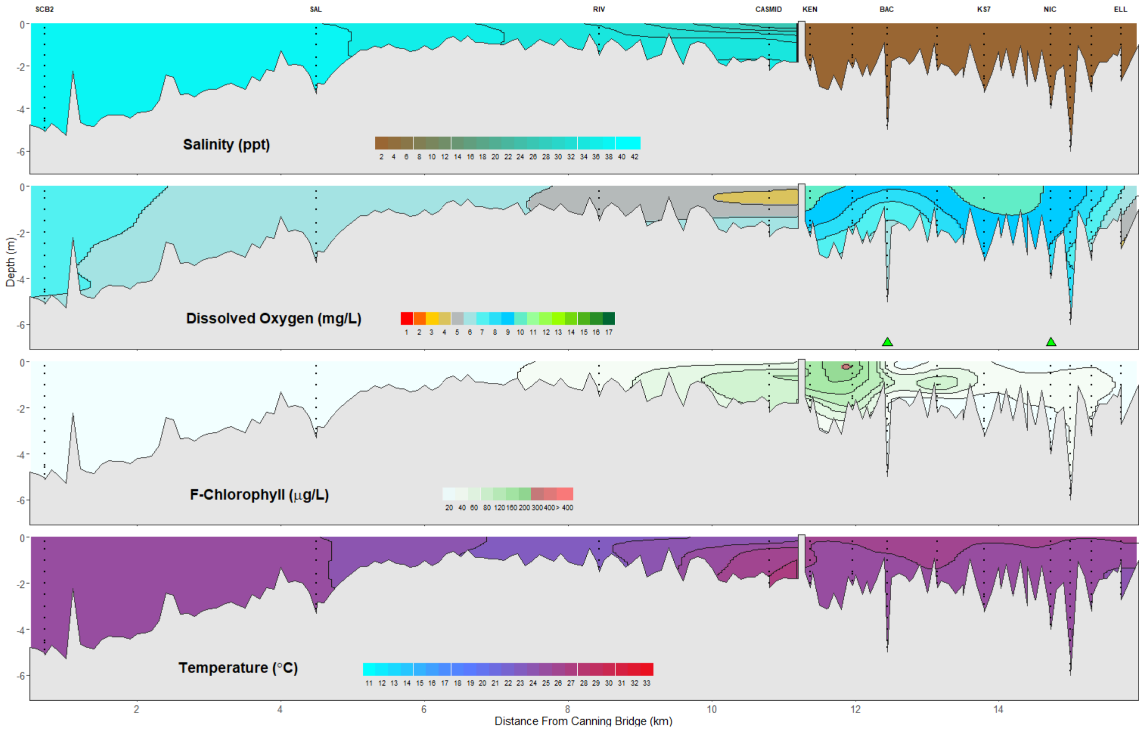

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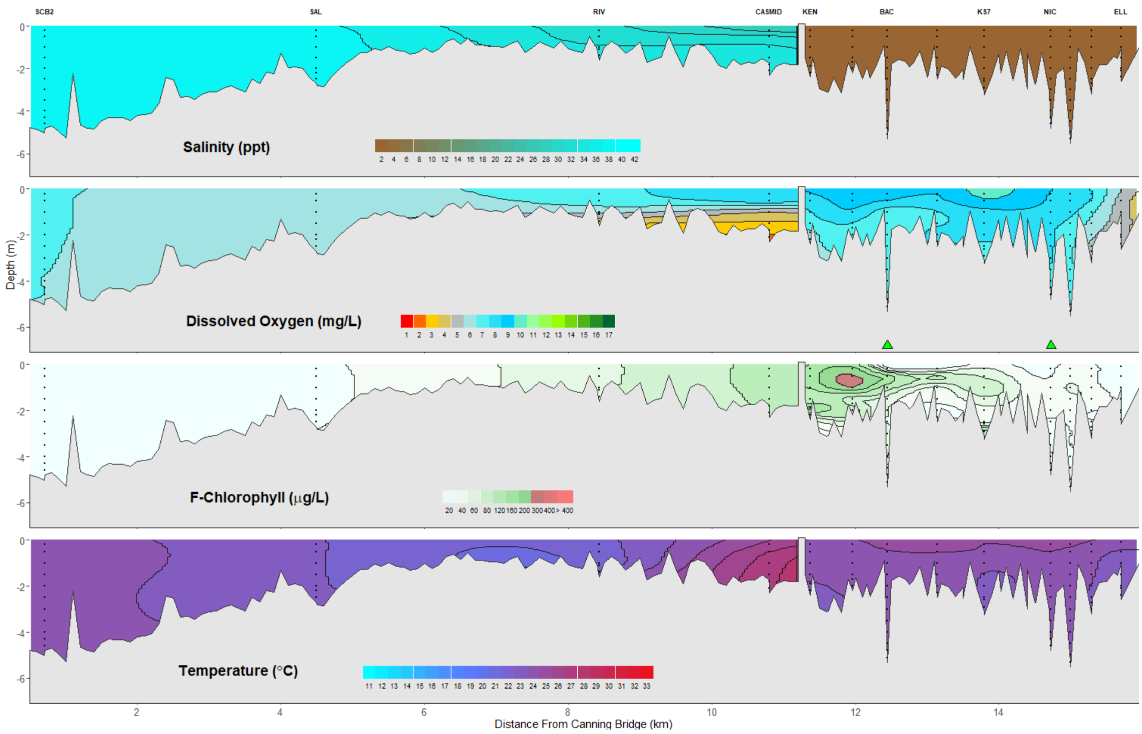

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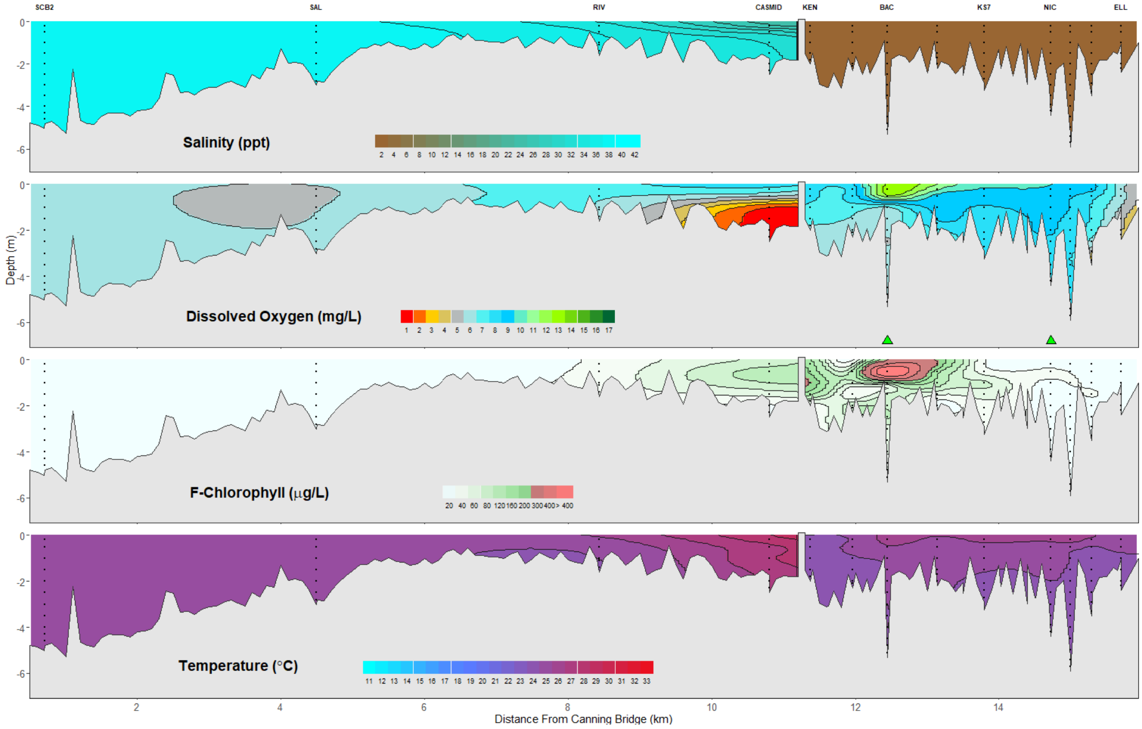

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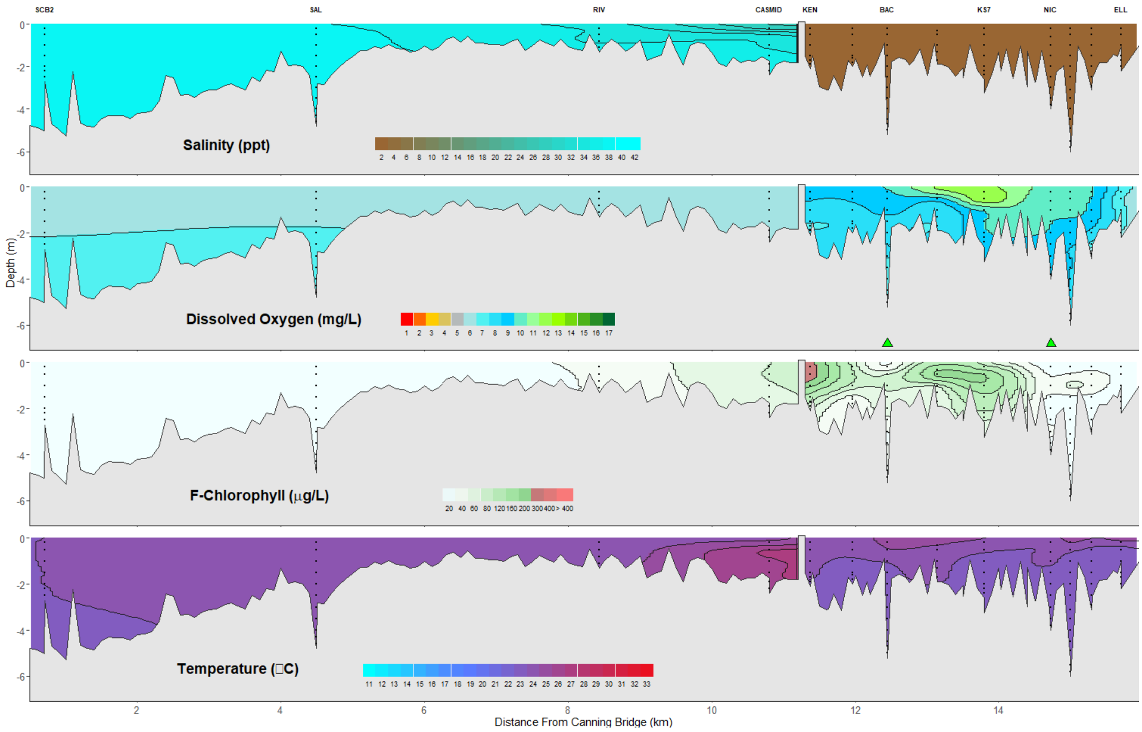

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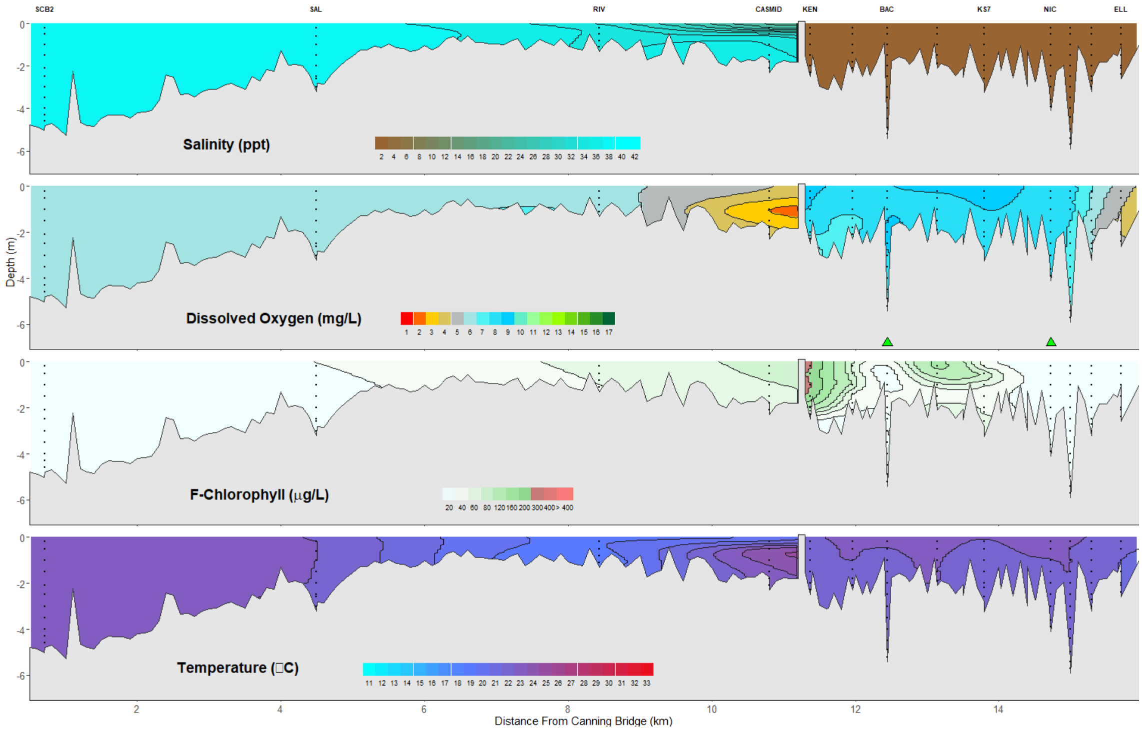

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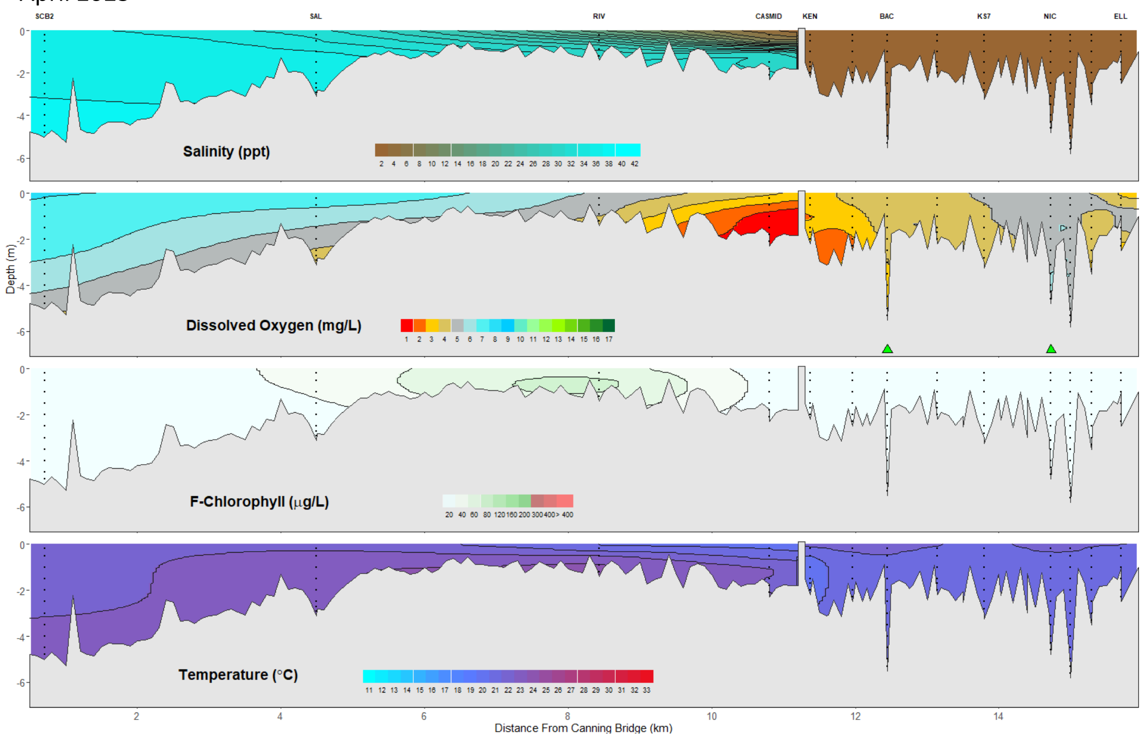

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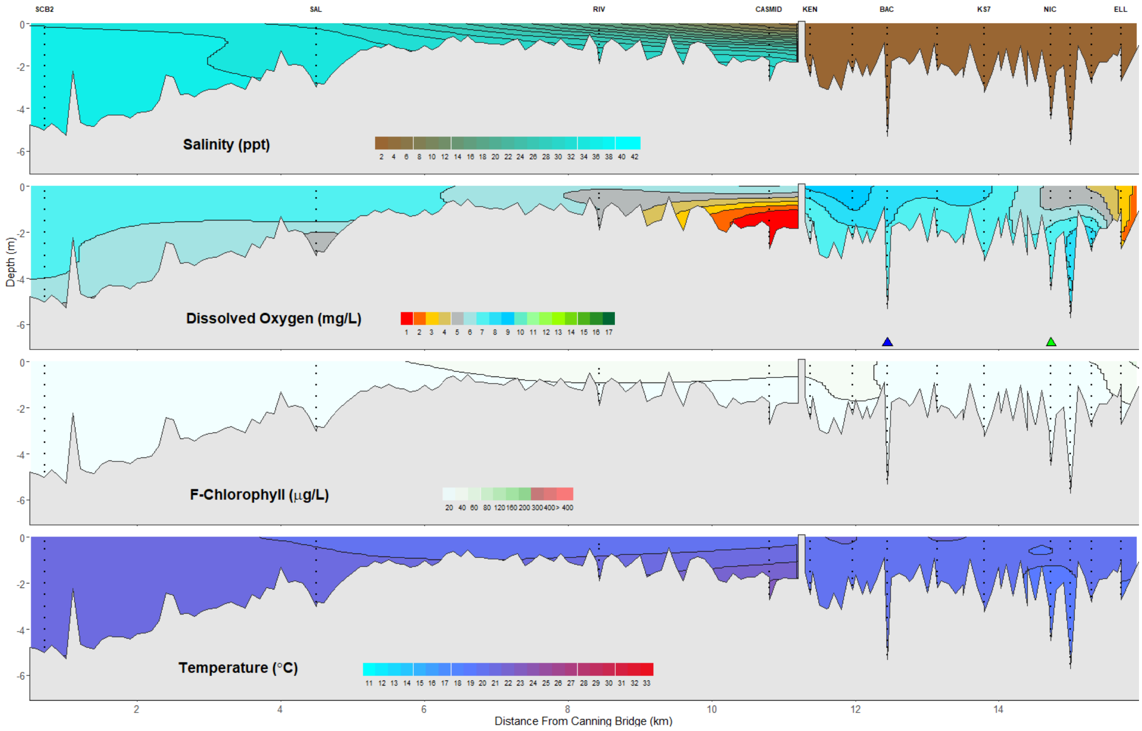

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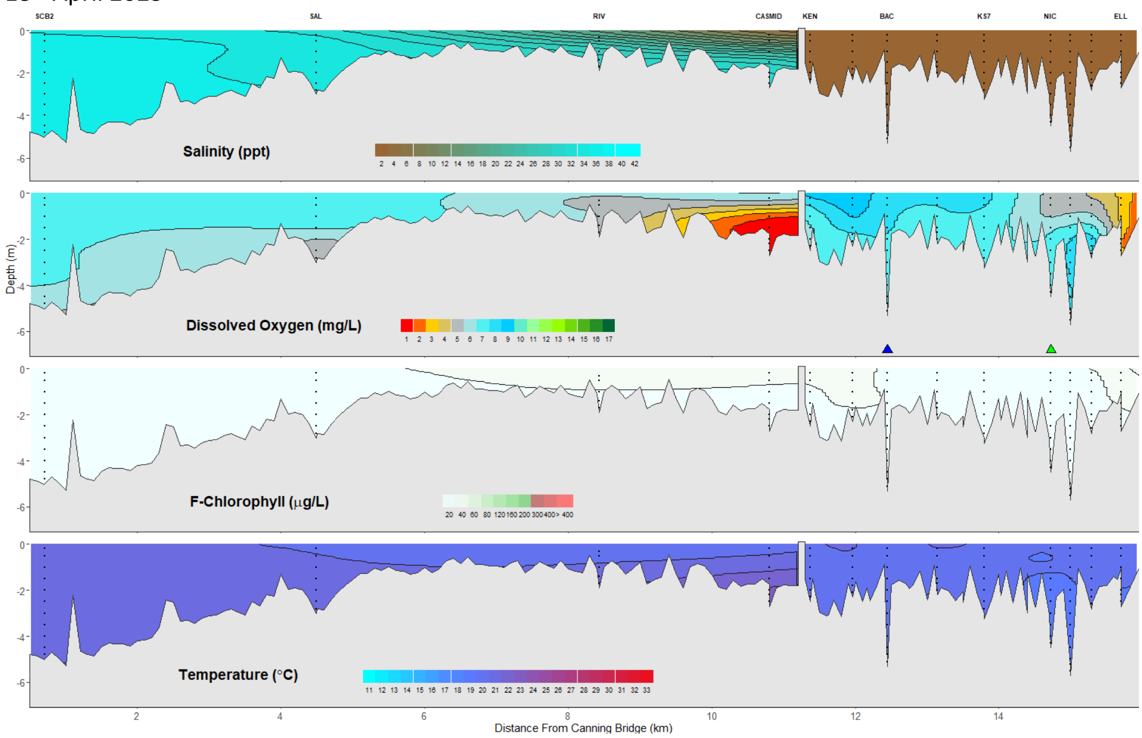

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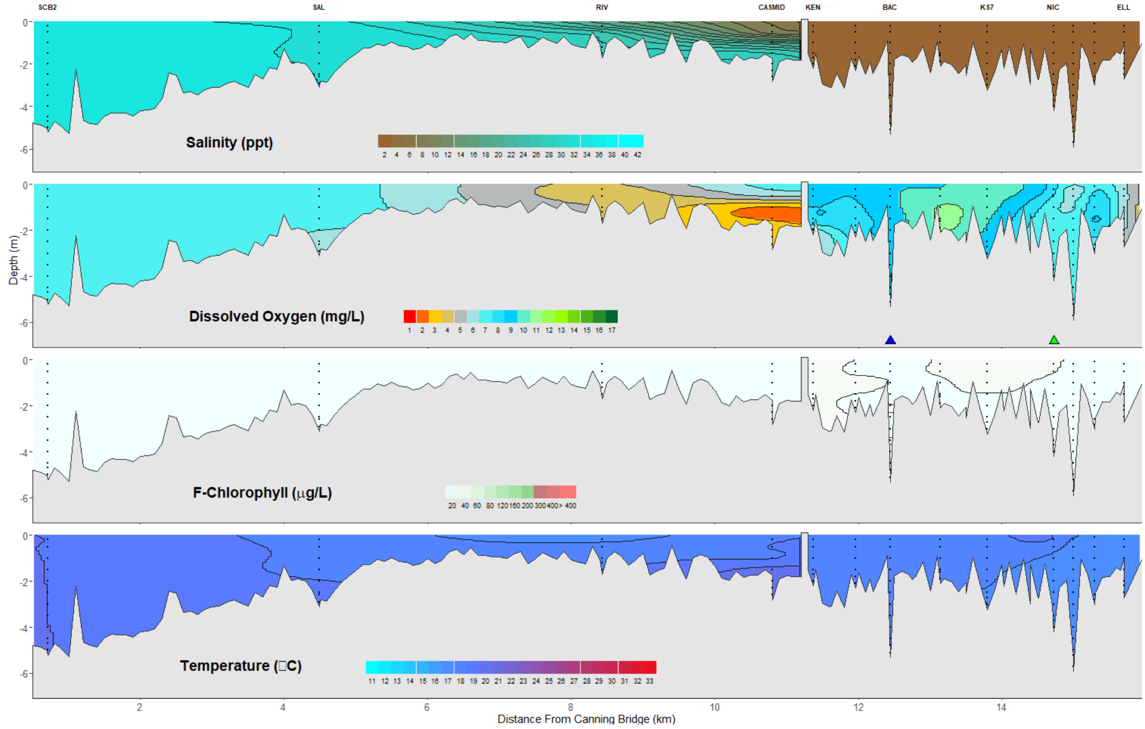
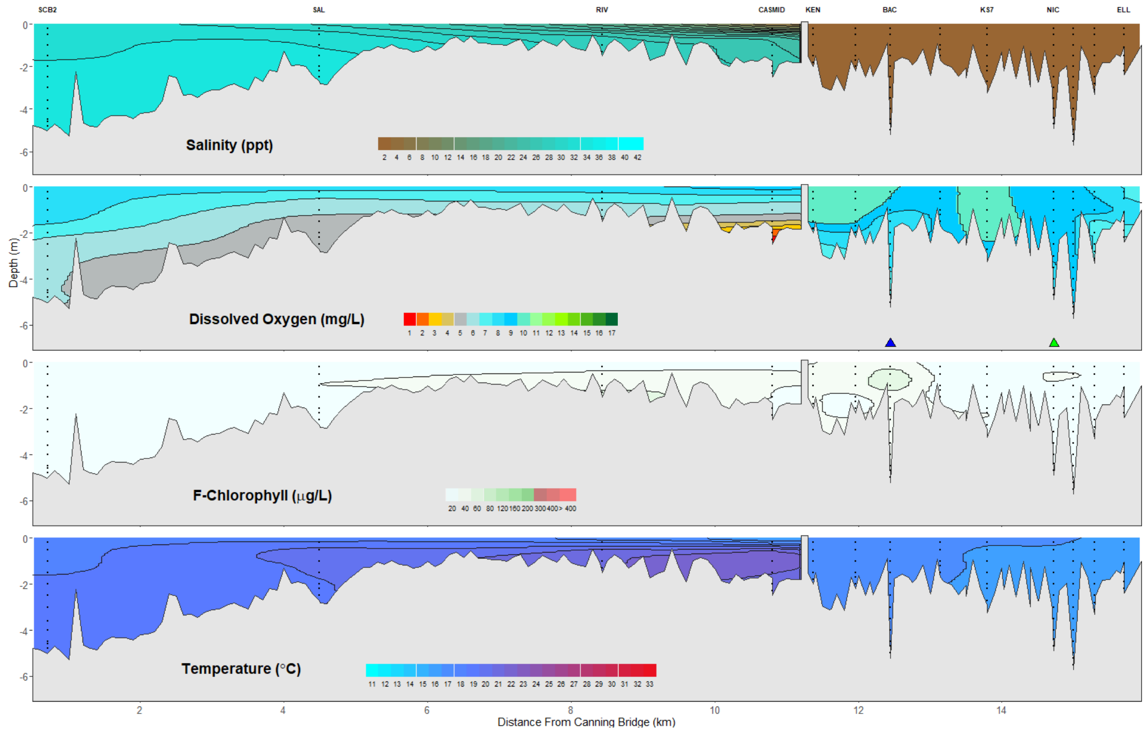


2nd May 2023



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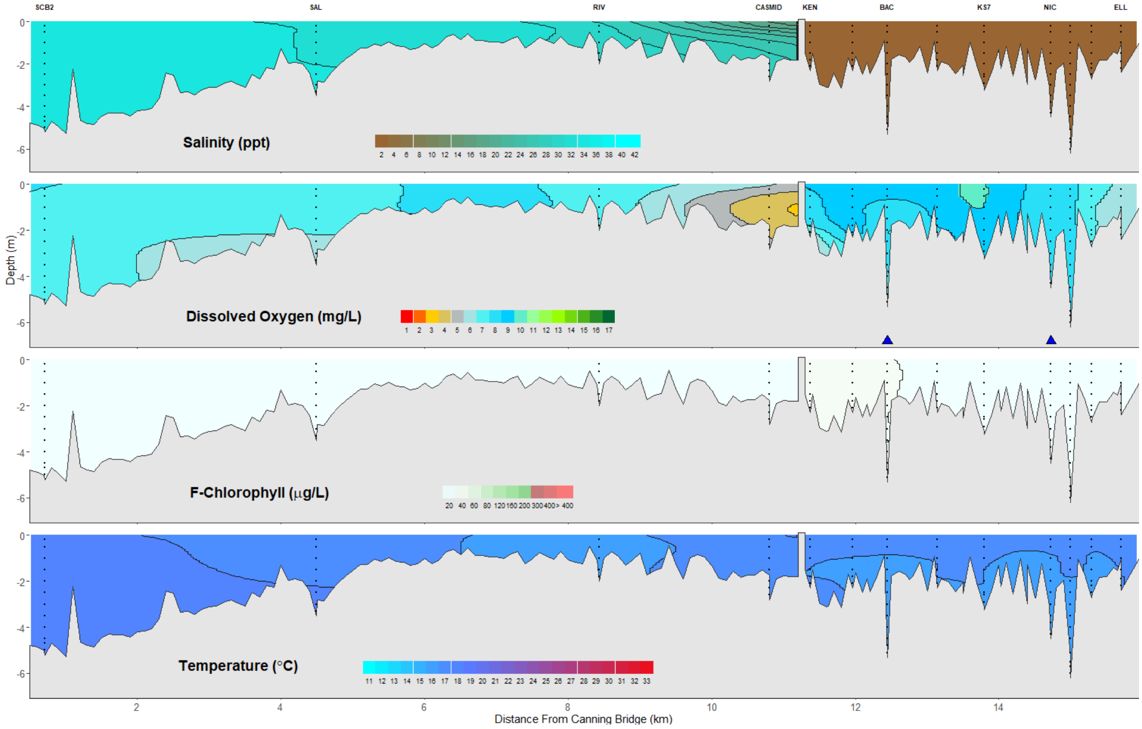

SCB2
SAL
RIV
CASMID
KEN
BAC
KS7
NIC
ELL
Salinity (ppt)
Dissolved Oxygen (mg/L)
F-Chlorophyll (µg/L)
Temperature (°C)
Depth (m)
Distance From Canning Bridge (km)

Appendix (vii). Results from PERMANOVA and pairwise PERMANOVA tests on the (a) offshore Fish Community Index (FCI) scores and the (b-h) component scores for each of the seven metrics among the four zones using data from 2012 to 2023. For pairwise tests values are t-statistics and the grey shading represents those comparisons that do not differ significantly (*P* > 0.05).

(a) FCI Score

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	19681	6560.5	50.151	0.0001
Residual	571	74695	130.81		

	CE	LSCE	MSE
LSCE	12.98		
MSE	6.37	5.03	
USE	9.95	2.55	2.60

(b) Number of species

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	1128.3	376.09	43.821	0.0001
Residual	571	4900.6	8.5824		

	CE	LSCE	MSE
LSCE	9.04		
MSE	3.07	6.07	
USE	9.49	0.45	6.53

(c) Shannon-Wiener diversity

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	2104	701.19	103.57	0.0001
Residual	571	3866	6.7702		

	CE	LSCE	MSE
LSCE	15.87		
MSE	5.10	10.76	
USE	12.96	1.27	8.34

(d) Number of trophic specialist species

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	542.5	180.83	16.06	0.0001
Residual	571	6429.4	11.26		

	CE	LSCE	MSE
LSCE	7.76		
MSE	3.54	3.32	
USE	3.04	3.93	0.51

(e) Number of trophic generalist species

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	1370	456.7	31.121	0.0001
Residual	571	8379	14.675		

	CE	LSCE	MSE
LSCE	0.73		
MSE	0.71	1.47	
USE	7.65	6.82	8.78

(f) Proportion of detritivores

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	2069.7	689.9	70.239	0.0001
Residual	571	5608.5	9.8222		

	CE	LSCE	MSE
LSCE	12.04		
MSE	1.71	11.52	
USE	7.69	5.19	6.69

(g) Proportion of benthic-associated individuals

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	83.37	27.79	4.5083	0.0043
Residual	571	3520	6.164		

	CE	LSCE	MSE
LSCE	1.02		
MSE	2.15	1.19	
USE	3.69	2.63	1.18

(h) Proportion of benthic-associated individuals

Source	df	SS	MS	Pseudo-F	*P*
Zone	3	1884.7	628.24	75.502	0.0001
Residual	571	4751.2	8.3209		

	CE	LSCE	MSE
LSCE	11.76		
MSE	0.58	14.01	
USE	1.61	10.82	2.45