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Final Report

Prepared for the Department of Biodiversity, Conservation and Attractions

Disclaimer

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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 2022 and applies the Fish Community Index (FCI) that was developed as a measure of the ecological condition of the Swan Canning 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 2022. As many fish as possible were returned to the water alive after they had been identified and counted. The resulting data on the abundances of each fish species from each sample were used to calculate a Fish Community Index score (0–100). These index scores were then compared to established scoring thresholds to determine ecological condition grades (A–E) for each zone and for the estuary as a whole, based on the composition of the fish community.

Nearshore Fish Communities

The nearshore waters of the estuary as a whole were in good (B) and good/fair condition (B/C) during summer and autumn 2022, respectively, which is consistent with the overall trend in condition since 2011. The average nearshore FCI scores for each zone of the estuary varied during summer, being best, i.e. good, in the LSCE, MSE and USE and lowest in the CE resulting in a fair (C) score. By autumn, scores in the CE increased to good, while those in the LSCE and MSE declined slightly from good to good/fair in the LSCE and good to fair in the MSE. While the mean score for the USE dropped the grade remained the same, i.e. good. There were no notable algal blooms in the MSE or USE and although some stratification was present, oxygen concentrations did not decline sufficiently to cause hypoxia.

Small-bodied, schooling species of hardyheads (Atherinidae) and gobies (Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2021, representing 77% of all fish recorded and constituting the six of the seven 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 2022 monitoring period. Juvenile Western Striped Grunter made an unusually large contribution to the fish fauna, driven by good recruitment from the ocean where they spawn. Other abundant species of small, schooling fish included the Spotted Hardyhead, Common Hardyhead and Silverfish, each of which prefer more saline waters than Wallace's Hardyhead. The Perth Herring was abundant in the MSE and USE, as were the Bluespot Goby, Black Bream and the Australian Anchovy in the USE.

The total number of fish caught in nearshore waters in 2022 was 1.4 to 2.6 times more than that recorded previously (2012-2021). This marked increase in the density of fish is likely the result of flows from the Swan River in 2021 being the largest for 25 years. Strong flows are known to increase productivity and fish populations. Stable salinities and oxic conditions during the 2022 monitoring period, combined with good recruitment, resulted in the largest number of species (36) being recorded.

Offshore fish communities

The offshore waters of the Swan Canning Estuary were in good (B) condition in summer and fair/good (C/B) during autumn 2022. The overall score of good was an increase on the fair (C) grade it received in 2021 and represents only the fourth time in 14 years good condition was achieved. Scores in the LSCE, MSE and USE were either very good (A) or good, except for fair/good in the MSE in autumn, likely driven by relatively saline and oxic conditions and the absence of toxic algal blooms. However, once again the offshore waters of the CE exhibited by far the lowest scores of any zone. As the Canning River is more regulated than the Swan, for example by the presence of the Canning Dam, this axis of the estuary did not receive the substantial increase in flow that the USE, MSE and to some extent the LSCE did. Waters in the CE were stratified, hypoxic, and at times, contained the toxic dinoflagellate *Karlodinium* spp..

As in most previous years of monitoring, Perth Herring was among the dominant species in offshore waters from all four zones comprising 29–80% of the total catches. Other abundant species included the Southern Eagle Ray and Tailor in the LSCE (29 and 10%, respectively, of the catch) and the Yellowtail Grunter in the MSE (24%) and USE (38%) and Black Bream in the USE (5%). The number of species and individuals recorded from the offshore waters in 2022 were amongst the greatest in any monitoring year. Catches of several species were relatively high in 2022, including the Southern Eagle Ray, Mulloway and Australian Giant Herring.

Overall

Across the entire estuary, the ecological condition of both nearshore and offshore waters in 2022 was assessed as good (B) based on their fish communities. Combined, the nearshore and offshore index scores for 2022 are the highest ever recorded since annual monitoring began in 2012. The good scores for zones along the Swan axis were likely influenced by the strong freshwater flows that occurred in the winter of 2021. Such flows, which were the greatest for 25 years, increased productivity in both the estuary and also nearby coastal waters and facilitated the recruitment of fish species. Moreover, the absence of atypical summer rainfall events and low phytoplankton densities in most regions facilitated the maintenance of relatively saline and oxic conditions in most zones except the CE where some stratification-induced hypoxia occurred and the toxic dinoflagellate *Karlodinium* spp. was detected.

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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 the condition of the Swan Canning Estuary based on fish communities. The FCI has been subjected to extensive testing and validation over a period of many 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 are scored from 0–10 according to the numbers and proportions of the various fish species present in samples collected from the estuary using either seine or gill nets. These metric scores are summed to generate an 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. Summary of the metrics comprising the nearshore and offshore Fish Community Indices developed for the Swan Canning Estuary (Hallett et al., 2012).

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

[a] A measure of 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 sea/river bed

[f] The Bluespot 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 2022 for the purposes of applying 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.

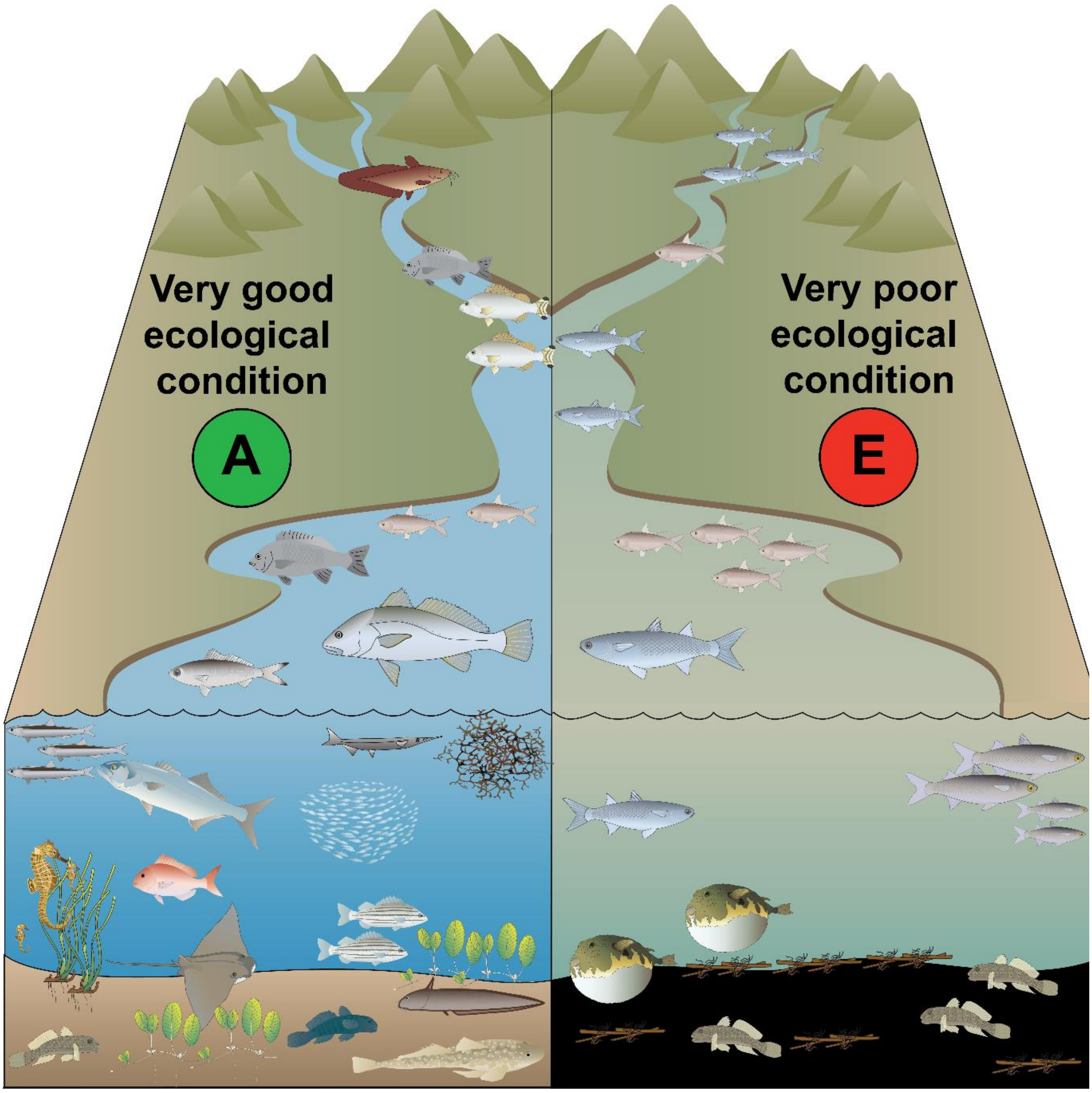


Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of very good (A) and very poor (E) ecological condition. Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].

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 (31 January – 17 February) and autumn (19 April – 4 May) of 2022. 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 3585) and Department of Biodiversity, Conservation and Attractions (permit number FO25000254-3).

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 abundances of fishes 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 2022 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.

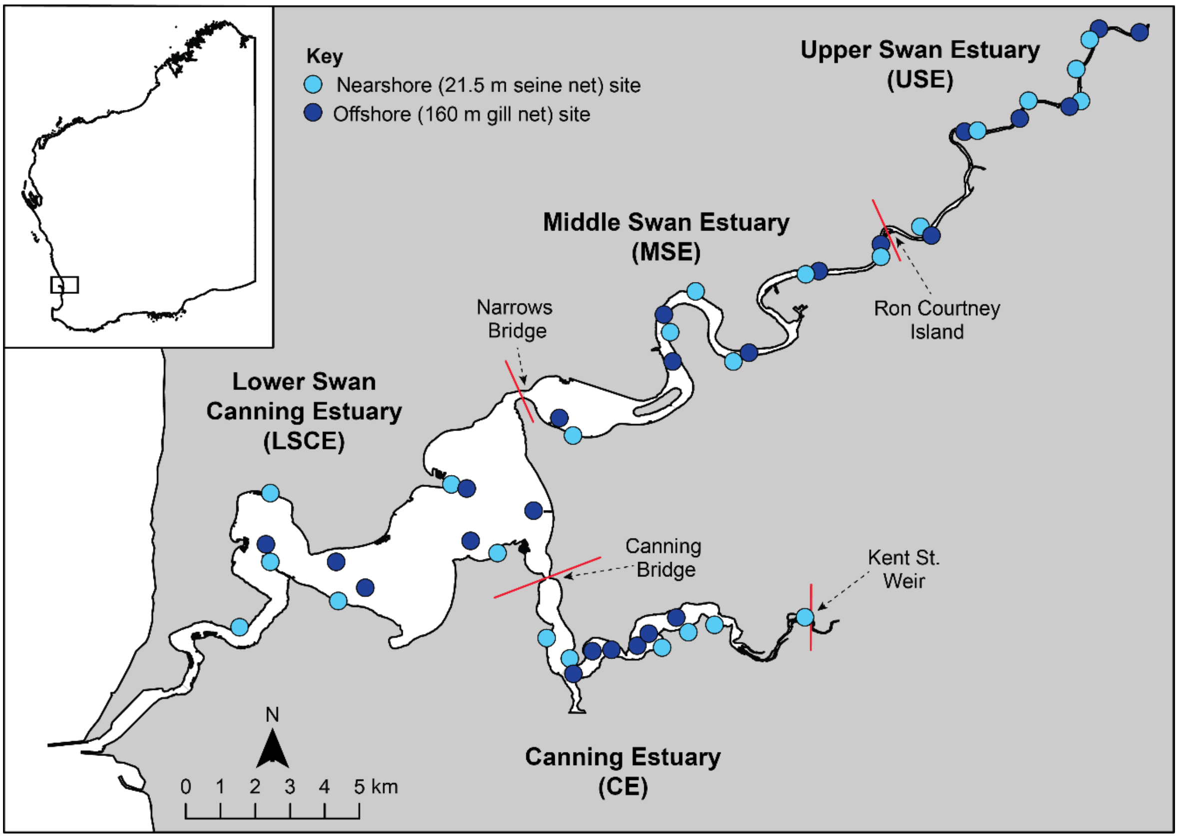


Figure 2. Locations of nearshore (light blue circles) and offshore (dark blue circles) sampling sites for the Fish Community Index of estuarine condition.

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 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

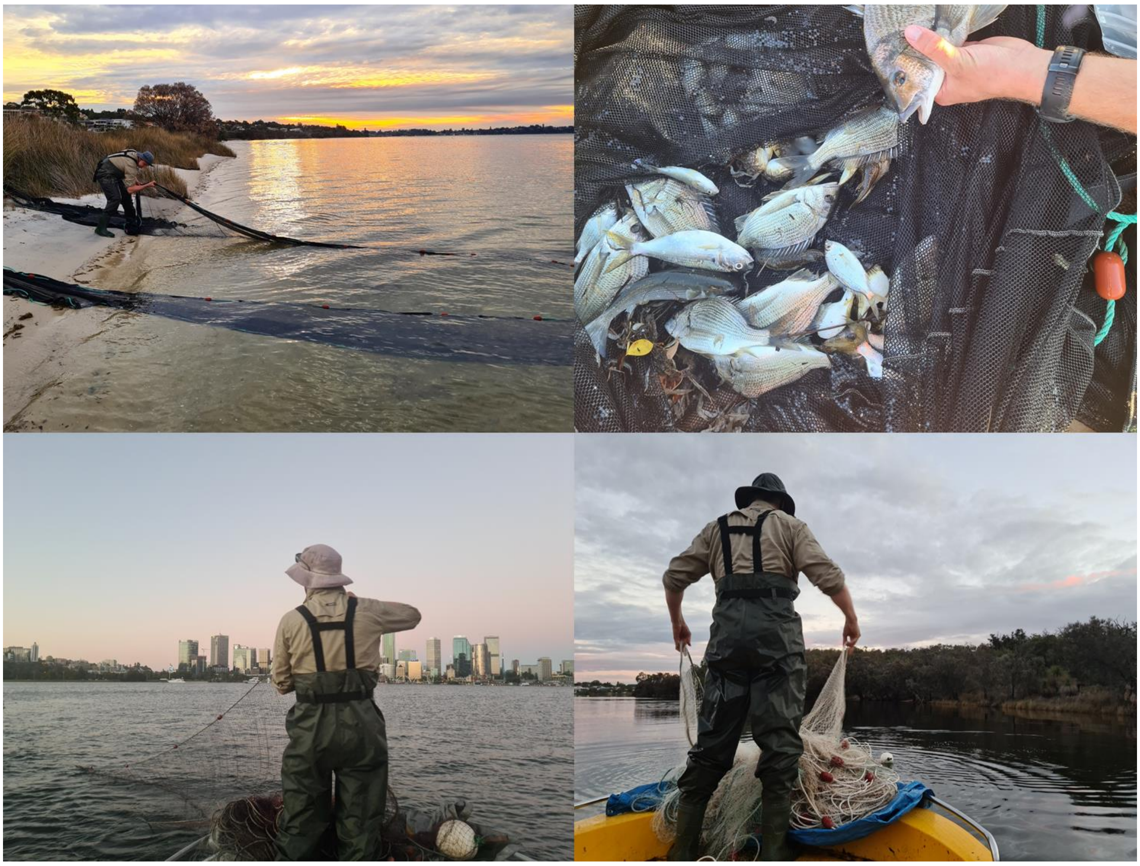


Figure 3. Photographs of the beach seine netting (upper row) used to sample the fish community in shallow, nearshore waters and the multimesh gill netting (lower row) used to sample fish communities in deeper, offshore waters of the Swan Canning Estuary. Images courtesy of Kurt Krispyn, Murdoch University.

5. Results and discussion

5.1 Context: water quality and environmental conditions during the 2022 monitoring period

Total annual flow at Walyunga on the Swan River in 2021 was 605 GL, the highest recorded since 1996 some 25 years earlier and sixth highest since records began in 1971 and 303% increase over the average between 1996 and 2020 (Appendix iv). The timing of the flow corresponded with the traditional monthly pattern, where the majority of flow occurs between May and September (Hodgkin and Hesp, 1998; Hallett et al., 2018). In 2022, 92% of the total annual flow occurred between these months, with particularly high values recorded in July and August (235 and 248 GL, respectively). The volume of flow in each of these two months was the greatest since February 2017 (Appendix iv), following one of the wettest days recorded in Perth and that resulted in widespread hypoxia and one of the lowest offshore FCI scores (Hallett, 2017).

Total annual flow at Seaforth in the Canning River in 2021 was 10.4 GL, with 39% occurring in July, which is over twice the average for this month (Appendix v). Although the volume of flow in the Canning River in 2021 was 24% greater than the median (~8.4 GL) recorded since 1996, this increase was far less that that recorded at Walyunga. This marked difference in the increases of flow between the Swan and Canning rivers in 2021 compared to the longer-term is likely influenced by the fact that the Canning is heavily regulated by two major water supply dams, (Canning Reservoir and Wungong

Reservoir), two smaller dams (Churchman Brook Reservoir and Victoria Reservoir) and a number of smaller weirs (Radin et al., 2007; Norton et al., 2010).

The environmental conditions present in the system during the monitoring period are shown as vertical contour plots of interpolated salinities, dissolved oxygen (DO) concentrations, chlorophyll levels and water temperatures measured at regular water quality monitoring sites along the length of both the Swan and Canning axes of the estuary on a weekly basis (Appendix vi). The water column of the USE was brackish (salinity 6 - 18) in early January 2021, 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 sea water (~35) throughout summer ranging from 30 to 40. Areas of low dissolved oxygen (2 - 4 mg/L) and smaller pockets of hypoxia (< 2 mg/L) occurred in parts of the MSE and USE during some weeks in January and February. 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 ~22 °C in the LSCE to 27 - 29 °C in the USE. In terms of phytoplankton, densities were low during the summer sampling period in the LCSE, with moderate levels of the dinoflagellates *Heterocapsa* spp. (5,300 cells/mL), *Karlodinium* spp. (5,400 cells/mL) and *Gymnodinium-Karenia* Complex (1,200 cell/mL) with values of the first two taxa being recorded in greater densities at Ron Courtney Island at the lower end of the USE (i.e. 7,760 and 5,240 cells/mL, respectively; DBCA, unpublished data). Densities of the dinoflagellates *Heterocapsa minima* and *Heterocapsa lanceolata* at Meadow Street in the USE exceeded management trigger values, but this event occurred towards the very end of the sampling program in summer and so would have been unlikely to have influenced the results.

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). Pronounced stratification was detected on 25 January (immediately prior to the initiation of sampling) and again two weeks later on 8 February, resulting in the presence of hypoxic conditions (< 2 mg/L) in these weeks. Phytoplankton densities were moderate through January and early February in the CE, with the highest densities of > 30,000 cells/mL recorded on 25 January at Shelley Riverton and Castledare in the upper CE. In these samples, moderate levels of densities of *Karlodinium* spp. (8,500 cells/mL) and *Heterosigma akashiwo* (17,380 cells/mL) were recorded (DBCA, unpublished data).

During autumn sampling (19 April – 4 May), marine conditions, i.e. salinities of ~35, were found throughout the LSCE and salinities decreased in an upstream direction to a minimum of ~20 in the upper parts of the USE (Appendix vi). The waters of the MSE and USE were stratified, caused by the salt wedge at the bottom of the water column moving upstream during these months, however, this did not lead to the development of hypoxia. The absence of low dissolved oxygen concentrations could also be due to the continued operation of the Guildford and Caversham oxygenation plants during the sampling period. Total phytoplankton densities were low to moderate with peak densities across the estuary recorded at Ron Courtney Island (16,800 cells/mL) and West Midland Pool (17,725 cells/mL) in the USE on 19 and 26 April (DBCA, unpublished data). Densities declined substantially in this zone in early May, with the highest value in the estuary of 12,700 cells/mL being recorded at Maylands in the MSE. No blooms of harmful species were detected over the sampling period.

Environmental conditions in the CE during autumn were affected by the pronounced stratification present in the upper parts of the CE, which resulted in hypoxia. This hypoxia lasted until ~10 May and thus after sampling was completed. Total phytoplankton densities were low in the lower reaches of the CE (Canning Bridge and Salter Point) but increased to moderate levels at Riverton and Castledare. There was no evidence of harmful blooms (DBCA, unpublished data).

5.2 The fish community of the Swan Canning Estuary during 2022

Nearshore waters

An estimated total of 42,935 fish, belonging to 36 species, were caught in seine net samples collected from the nearshore waters during the summer and autumn of 2022. The total number of fish caught in that year (i.e. 42,935) was 1.4 to 2.6 times more than recorded in any years previously (range = 16,905 - 30,825). This marked increase in the density of fish is likely the result of the increased riverine flows in 2022, which are known to increase productivity and fish populations (Gillanders and Kingsford, 2002; Broadley et al., 2022). The 36 species recorded in 2022 was slightly greater than the 35 and 32 in 2021 and 2020 and above the annual average of 31.8 (range = 25 – 35). A total of 64 fish species have been collected in seine nets as part of this annual monitoring since 2012. One new addition to the nearshore fish fauna was recorded in 2022, i.e. the Tailor (*Pomatomus saltatrix*), albeit larger-bodied individuals of this species are common in offshore waters. The greatest number of species recorded in the nearshore waters was in the LSCE and CE (both 25), followed by the MSE (24) and least in the USE (20; 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 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 LSCE, was significantly greater than those between 2012 and 2021. This can be explained by the presence of a wider range of marine-spawning species occurring further upstream than usual, such as Yellowtail Flathead (*Platycephalus westraliae*), Western Trumpeter Whiting (*Sillago burrus*) and Whitebait (*Hyperlophus vittatus*).

Hardyheads (family = Atherinidae; five species) and gobies (family = Gobiidae; seven species) once again dominated catches from the nearshore waters of the estuary in 2022, representing 77% of all fish caught and containing six of the seven most abundant nearshore species. In particular, Wallace's Hardyhead (*Leptatherina wallacei*) was again the most abundant species overall (Table 3) but with densities in 2022 being three times higher than the average, likely due to good recruitment following spawning at the end of 2021. Among zones of the estuary, this species ranked first in terms of density in the CE and USE, comprising 53 and 39 % 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 amongst the most abundant species in the LSCE and amongst the most abundant in the MSE and CE. Together with *C. mugiloides* three other atherinids, Common Hardyhead (*Atherinomorus vaigiensis*) and Silverfish (*Leptatherina presbyteroides*) all of which prefer more saline waters dominated the fish found in the LSCE (Valesini et al., 2009; 2017). One species that made a large contribution to the fish fauna of the LSCE was the Western Striped Grunter (*Helotes octolineatus*) at 26%, furthermore, the abundance of this commonly-recorded species was eight times greater in 2022 than the average between 2012 and 2021. Individuals of this species in 2022 were small and likely new recruits spawned in the marine waters in spring (Veale et al., 2015). Other abundant species included the Bluespot goby (*Pseudogobius olorum*) in the USE and the Redspot Goby (*Favonigobius punctatus*) in the MSE where they typically occurs (Hogan-West et al., 2019), the Yelloweye Mullet (*Aldrichetta forsteri*) in the MSE, the Perth Herring (*Nematalosa vlaminghi*) in the MSE and USE and (Australian Anchovy (*Engraulis australis*) and Black Bream (*Acanthopagrus butcheri*) in the USE (Table 3).

Two non-native fish species were recorded namely the Eastern Gambusia (*Gambusia holbrooki*), which is known to act antagonistically to native species (Beatty et al., 2022), in the CE and USE as was the Pearl Cichlid (*Geophagus brasiliensis*) in the CE (Table 3). These species occur regularly in this annual monitoring program, being found in eleven and nine of the last eleven years, respectively. Numbers of the Eastern Gambusia caught in all samples collected in 2022 were the third highest recorded (i.e. 1,092; range = 37 – 1,633) and those of the Pearl Cichlid were the second greatest (i.e. 51; range = 0 – 60). The two recently recorded species of goby in the Swan Canning Estuary, i.e. the Largemouth Goby (*Redigobius macrostoma*) and Dusky Frillgoby (*Bathygobius fuscus*) were once again recorded in 2022. Despite the focused sampling regime employed in this study (i.e. only six samples per management zone), both species have been recorded in two of the last three years, which may indicate populations have become established. Future sampling will help confirm this hypothesis.

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 summer and autumn of 2022. Data for the three most abundant species in the catches from each zone are emboldened for emphasis. Species 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	0.22	0.05	**1,209.27**	**53.23**	12.07	8.18	**75.43**	**38.65**
Craterocephalus mugiloides	Mugil's Hardyhead	**190.09**	**40.46**	**461.06**	**20.29**	**16.59**	**11.25**	0.93	0.48
Helotes octolineatus	Western Striped Grunter	**123.99**	**26.40**	**198.35**	**8.73**	**15.52**	**10.52**	2.37	1.21
Atherinosoma elongatum	Elongate Hardyhead	20.19	4.30	113.07	4.98	0.72	0.49		
Favonigobius punctatus	Red-spot Goby	15.23	3.24	62.14	2.74	11.85	8.03	10.27	5.26
Atherinomorus vaigiensis	Common Hardyhead	**51.01**	**10.86**	2.44	0.11	3.45	2.34	0.14	0.07
Pseudogobius olorum	Blue-spot / Swan River Goby			72.99	3.21	2.95	2.00	12.00	6.15
Gambusia holbrooki *	Mosquito Fish *			72.92	3.21			5.53	2.83
Sillago burrus	Western Trumpeter Whiting	23.06	4.91	13.00	0.57	9.77	6.62	0.65	0.33
Nematalosa vlaminghi	Perth Herring			5.24	0.23	10.63	7.21	**31.75**	**16.27**
Leptatherina presbyteroides	Presbyter's Hardyhead	16.02	3.41	1.08	0.05	0.36	0.24		
Engraulis australis	Southern Anchovy					0.72	0.49	**28.95**	**14.83**
Acanthopagrus butcheri	Southern Black Bream	0.14	0.03	8.55	0.38	9.41	6.38	11.28	5.78
Amniataba caudavittata	Yellow-tail Trumpeter	1.44	0.31	14.66	0.65	5.60	3.80	4.31	2.21
Hyperlophus vittatus	Whitebait / Sandy Sprat	9.70	2.06			3.88	2.63	1.87	0.96
Aldrichetta forsteri	Yellow-eye Mullet	0.36	0.08	4.31	0.19	**19.40**	**13.15**	0.14	0.07
Favonigobius lateralis	Long-finned Goby	8.19	1.74	4.60	0.20				
Ostorhinchus rueppellii	Gobbleguts	4.74	1.01			9.34	6.33		
Gerres subfasciatus	Roach	1.08	0.23	2.01	0.09	7.61	5.16	3.74	1.91
Torquigener pleurogramma	Blowfish / Banded Toadfish	0.65	0.14	7.83	0.34	1.58	1.07		
Mugil cephalus	Sea Mullet	0.43	0.09	4.17	0.18	3.23	2.19	1.29	0.66

Table 3. continued.

Species	Common name	**LSCE** (*n* = 12) D	%C	**CE** (*n* = 12) D	%C	**MSE** (*n* = 12) D	%C	**USE** (*n* = 12) D	%C
Afurcagobius suppositus	Southwestern Goby			3.45	0.15	0.65	0.44	3.81	1.95
Geophagus brasiliensis *	Pearl Cichlid *			3.16	0.14			0.50	0.26
Arenigobius bifrenatus	Bridled Goby			2.95	0.13	0.50	0.34	0.07	0.04
Sillago schomburgkii	Yellow-finned Whiting	0.29	0.06	2.30	0.10	0.50	0.34		
Rhabdosargus sarba	Tarwhine	1.65	0.35						
Redigobius macrostoma	Largemouth Goby			1.58	0.07				
Pomatomus saltatrix	Tailor					1.15	0.78		
Haletta semifasciata	Blue Weed Whiting	0.57	0.12						
Gymnapistes marmoratus	Devilfish	0.14	0.03	0.72	0.03				
Bathygobius fuscus	Dusky Frillgoby	0.29	0.06						
Contusus brevicaudus	Prickly Toadfish	0.14	0.03						
Platycephalus westraliae	Yellowtail Flathead					0.07	0.05	0.14	0.07
Siphonognathus radiatus	Long-rayed Weed Whiting	0.07	0.02						
Scobinichthys granulatus	Rough Leatherjacket	0.07	0.02						
Pseudocaranx wrightii	Skipjack Trevally			0.07	0.00				
	Total number of species	**25**		**25**		**24**		**20**	
	Average total fish density (fish 100m^{-2})	**470**		**2272**		**148**		**195**	
	Total number of fish	**6,539**		**31,625**		**2,054**		**2,717**	

Offshore waters

Samples collected from offshore waters in summer and autumn 2022 using gill nets returned 2,768 fish, comprising 24 species (Table 4). This number of fish was similar to that recorded in 2021 (2,933), which was the highest recorded since monitoring began in 2012 and almost 50% more than in 2018 and 2019 (range = 1,125 to 2,933). The 24 species caught in 2022 was also the greatest recorded (range = 17 to 23) and represented almost 70% of all species caught in this monitoring since 2012. As has occurred in most years, the total number of species recorded from each zone in 2022 decreased in an upstream direction from 18 species in the LSCE, to 15 and 13 in the CE and MSE, respectively and 11 in the USE. Values in all zones except the CE were amongst the highest recorded.

As in the ten previous years of monitoring, Perth Herring was among the dominant species in offshore waters overall (55%) and from all four zones, comprising 29–80% of the total catches (Table 4). The Southern Eagle Ray (*Myliobatis tenuicaudata*) and Tailor (*Pomatomus saltatrix*) were abundant in the LSCE (29 and 10% of the catch, respectively). The latter species was also abundant in the CE and MSE, representing 8 and 5% of all fish caught. The Yellowtail Grunter (*Amniataba caudavittata*) was also caught in substantial numbers in the MSE (24%) and USE (38%) as was the Black Bream (*Acanthopagrus butcheri*) in the USE (5%). Catches of several species were relatively high in 2022, including the Southern Eagle Ray, Mulloway (*Argyrosomus japonicus*) and Australian Giant Herring (*Elops machnata*), with values of two, four and five times more than the average between 2012 and 2021, 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 summer and autumn of 2022. Species ranked by total abundance. Data for the three most abundant species in the catches from each zone are emboldened for emphasis. Species 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	**156**	**29.89**	**616**	**79.69**	**426**	**62.83**	**334**	**42.01**
Amniataba caudavittata	Yellowtail Grunter	43	8.24	11	1.42	**164**	**24.19**	**301**	**37.86**
Pomatomus saltatrix	Tailor	**52**	**9.96**	**62**	**8.02**	**34**	**5.01**	10	1.26
Myliobatis tenuicaudatus	Southern Eagle Ray	**153**	**29.31**						
Acanthopagrus butcheri	Black Bream	8	1.53	17	2.20	10	1.47	**44**	**5.53**
Mugil cephalus	Sea Mullet			**42**	**5.43**	1	0.15	21	2.64
Argyrosomus japonicus	Mulloway			2	0.26	15	2.21	36	4.53
Elops machnata	Australian Giant Herring	3	0.57	2	0.26	8	1.18	36	4.53
Platycephalus westraliae	Yellowtail Flathead	36	6.90	3	0.39	6	0.88	3	0.38
Sillago burrus	West. Trumpeter Whiting	14	2.68			1	0.15		0.00
Rhabdosargus sarba	Tarwhine	8	1.53	7	0.91				
Engraulis australis	Australian Anchovy			2	0.26	4	0.59	8	1.01
Helotes octolineatus	Western Striped Grunter	4	0.77	2	0.26	7	1.03	1	0.13
Gerres subfasciatus	Common Silverbiddy	10	1.92	3	0.39	1	0.15		0.00
Arripis georgianus	Australian Herring	9	1.72						
Torquigener pleurogramma	Weeping Toadfish	7	1.34	2	0.26				
Cnidoglanis macrocephalus	Estuary Cobbler	6	1.15	1	0.13				
Sillago schomburgkii	Yellowfin Whiting	5	0.96						
Pseudorhombus jenynsii	Smalltooth Flounder	4	0.77						
Sphyraena obtusata	Yellowtail Barracuda	3	0.57						
Carcharhinus leucas	Bull Shark					1	0.15		0.00
Atherinomorus vaigiensis	Common Hardyhead	1	0.19						
Hippocampus subelongatus	West Australian Seahorse							1	0.13
Pseudocaranx wrighti	Skipjack Trevally			1	0.13				
	Total number of species	**18**		**15**		**13**		**11**	
	Average catch rate (fish/net set)	**44**		**64**		**57**		**66**	
	Total number of fish	**522**		**773**		**678**		**795**	

5.3 Ecological condition in 2022

Nearshore waters

The ecological condition, based on fish communities, of the nearshore waters of the Swan Canning Estuary was good (B) in summer and good/fair (B/C) in autumn (Fig. 4). The condition of each zone varied substantially during summer (mean FCI scores of 62–72), being best in the USE, MSE and LSCE (good; B) and lowest in the CE with a fair (C) score. By autumn, scores in the CE improved to good, the USE remained in good condition and the LSCE and MSE, declined from good (both zones) to good/fair and fair, respectively (Fig. 4).

Radar plots of the nearshore metric scores for each zone in summer revealed that, in general, zones on the Swan axis of the estuary scored well across all metrics but particularly the *Number of species* (positive metric) and the *Total number of P. olorum, Proportion of P. olorum* and *Proportion of detritivores* (all negative metrics; Fig. 5a). High values for the number of species reflect the relatively saline conditions in all zones allowing marine species to occur in areas further upstream than in previous years (see Potter et al., 2016; Valesini et al., 2017). The LSCE scored better in the *Number of trophic generalist species* (negative metric) than the MSE and USE due to large catches of the Western Striped Grunter, a species which spawns in the marine environment and consumes mainly plant material and so is classified as a trophic specialist (Veale et al., 2015; Poh et al., 2018). These fish were fairly small (0+; K. Krispyn, personal observation) and their recruitment could be linked to the strong flows recorded in the preceding year. However, the LSCE scored lower than the MSE and USE for the *Number of estuarine-spawning species, Proportion of estuarine-spawning individuals* and *Number of benthic-associated species*. This also occurred in previous years, is due to the presence of 'marine-like' salinities in the LSCE which restrict the spatial distribution of estuarine spawning species to areas further upstream.

The fair condition of the CE reflects the lower scores this zone received for the *Proportion of benthic-associated individuals* and the *Total number of P. olorum.* This is driven, in part, by 620 individuals of the Blue Spot Goby caught in the CE, compared to 0, 39 and 149 in the LSCE, MSE and USE, respectively in 2022.

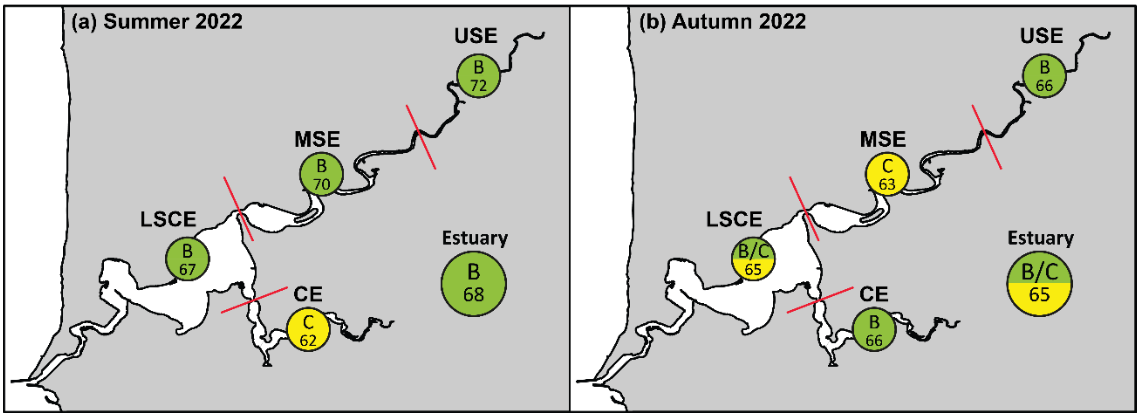
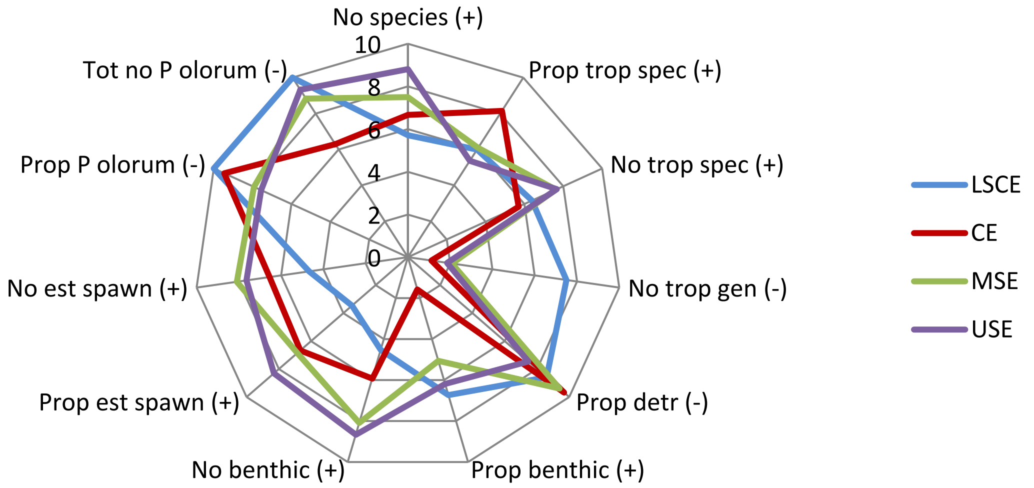


Figure 4. Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2022.

(a) Summer 2022



(b) Autumn 2022

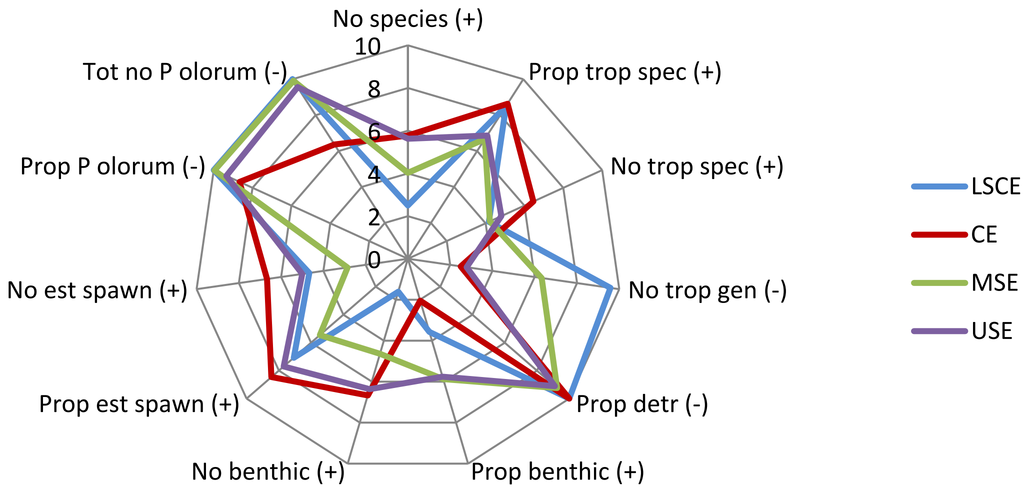


Figure 5. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2022. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying 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.

In autumn, scores for the CE increased, while those for the LSCE and MSE decreased. Radar plots showed the increase in CE was due mainly to an increase metric scores for the *Number of trophic generalist species* (negative metric) and *Proportion of estuarine-spawning individuals* (positive metric) and to a lesser extent the *Number of trophic specialist species* and *Number of benthic-associated species* (both positive metrics; Fig 5b). It should be noted, however, that the metric scores for the *Proportion of P. olorum* and *Number of species*, both decreased. Trends in some metric scores were consistent across the LSCE, MSE and USE, for example, scores for the *Number of species, Number of trophic specialist species* and *Number of benthic-associated species* all declined markedly (i.e. ~3 out of 10), while the *Proportion of trophic specialists, Number of trophic generalist species* increased. In the LSCE, there was also a marked increase in the *Proportion of estuarine-spawning individuals,* which was caused by the absence of the marine-spawning Western Striped Grunter in autumn compared to summer and converse shift in the abundance of the estuarine-spawning Spotted Hardyhead. The *Number of estuarine-spawning species* decreased in both the MSE and USE, reflecting the increasing saline conditions as the salt wedge penetrated further upstream and this was accompanied by a decrease in the Bluespot Goby, increasing scores for the *Proportion of P. olorum* and the *Total number of P. olorum.* Note that there was no increase in these two metrics in the LSCE as the Bluespot Goby was not recorded in this zone in either season and therefore, these metric scores were at their maximum value (10) in both seasons (Fig 5).

Offshore waters

The ecological condition, based on fish communities, of the offshore waters of the Swan Canning Estuary was good (B) in summer and fair/good (C/B) in autumn (Fig. 6). The condition of each zone varied substantially during summer (mean FCI scores of 49–74), being best in the LSCE and USE (very good; A) and lowest in the CE with a poor (D) score. The MSE received a condition of good (B). By autumn, scores in the LSCE and USE declined from very good to good as did that in the MSE from good to fair/good. While the CE remained in poor condition, its mean FCI score declined from 49 to 45 (Fig. 6).

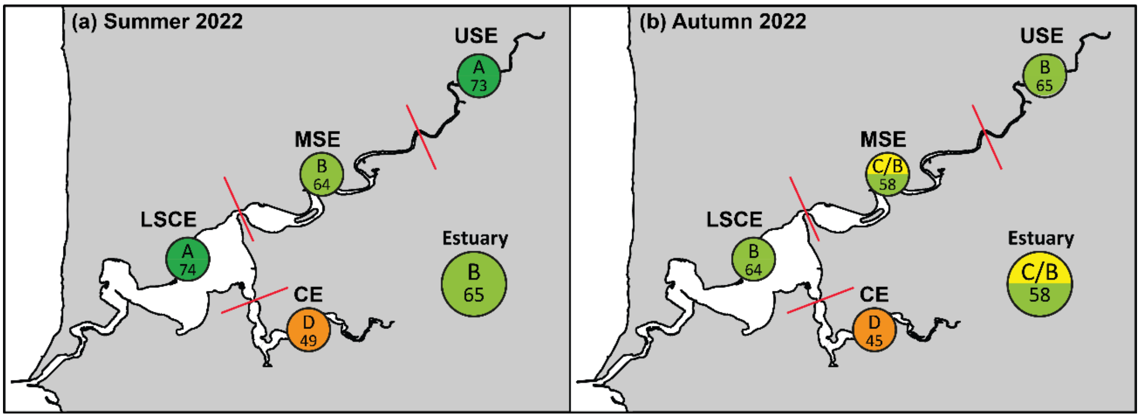
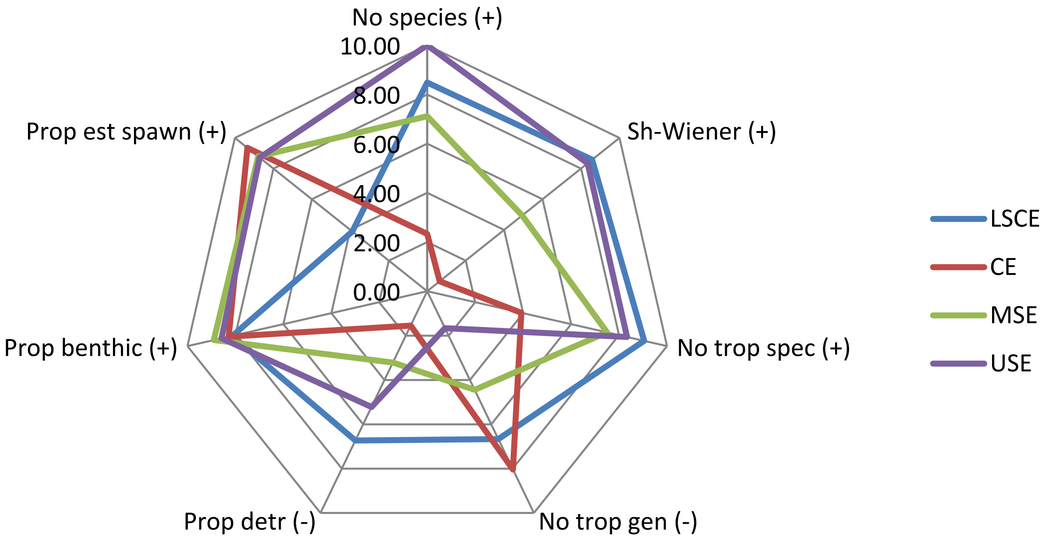


Figure 6. Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2022.

Radar plots of the offshore metric scores for the highest scoring zones in summer (LSCE and USE; Fig. 7a) showed very high scores (i.e. > 8 out of 10) for the *Number of species, Shannon-Wiener diversity, Number of trophic specialists* and the *Proportion of benthic species* (all positive metrics). Values of the first three of these metrics were slightly lower in the MSE, but in excess of those in the CE. 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) all typically < 2, 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 three species were caught per sample and that > 90% of all fish recorded were Perth Herring, therefore explaining the low measures of diversity and high proportion of detritivores. Hypoxic conditions were also present through much of the CE during sampling in this season together with the dinoflagellate *Karlodinium* spp. and the raphidophyte *Heterosigma akashiwo* (Appendix vi).

(a) Summer 2022



(b) Autumn 2022

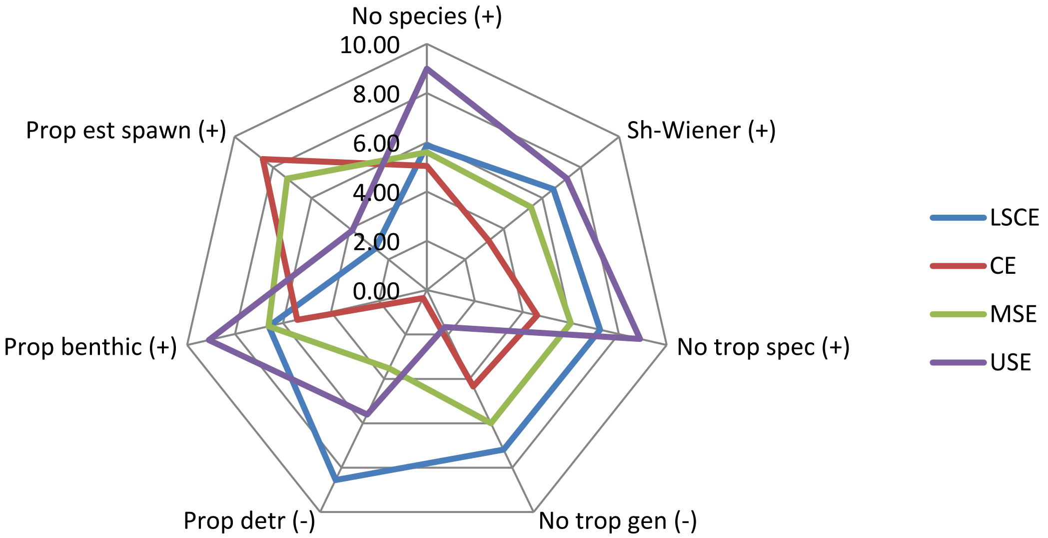


Figure 7. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2022. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying 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.

Whilst the mean offshore FCI scores the LSCE, MSE and USE all declined, they were still greater than that for the CE (Fig. 6). The low scores in the CE reflect very low values for metrics such as the *Proportion of detritivores, Number of trophic generalist species* (both negative metrics) and the *Number of trophic specialist species* (positive metric). These were caused by the dominance of detritivores, i.e. Perth Herring and Sea Mullet, which represented 81% of all fish recorded, and the absence of species such as the Southern Eagle Ray that target benthic invertebrates and are abundant in the adjacent LSCE. The presence of hypoxia in the bottom waters in large extents of the CE during autumn would have deterred benthic species of fish and potentially reduced the availability of their infaunal prey (Tweedley et al., 2016). Although the scores in the LSCE and USE declined, these zones were in good condition and scored well in all metrics except the *Proportion of estuarine-spawning individuals*, due to lower catches of Yellowtail Grunter, particularly in the USE. Condition in the MSE declined to fair/good, with a relatively low metric score for the *Proportion of detritivores* and a decline in the *Number of trophic specialist species* once again reflecting the dominance of Perth Herring. It is relevant, that, although no hypoxia was detected, low concentrations of dissolved oxygen (3-4 mg/L) were recorded in this zone in autumn and may have caused some less tolerant species to move away to more oxic waters.

Longer term trends in ecological condition

Results indicate that the nearshore waters of the Swan Canning Estuary as a whole were in good condition (B) during 2022, which is better than the relatively consistent overall trend since 2011 of fair/good condition (Fig 8). Aside from 2022, good conditions have only occurred in 2014 and 2016 (Fig. 8). The good scores for 2022 was likely influenced by the strong freshwater flows that occurred in the winter of 2021. Such flows, which were the greatest for 25 years, increased productivity in both the estuary and also nearby coastal waters and facilitated the recruitment of juveniles of large-bodied marine fish species and adults of smaller-bodied and shorter-lived estuaries species.

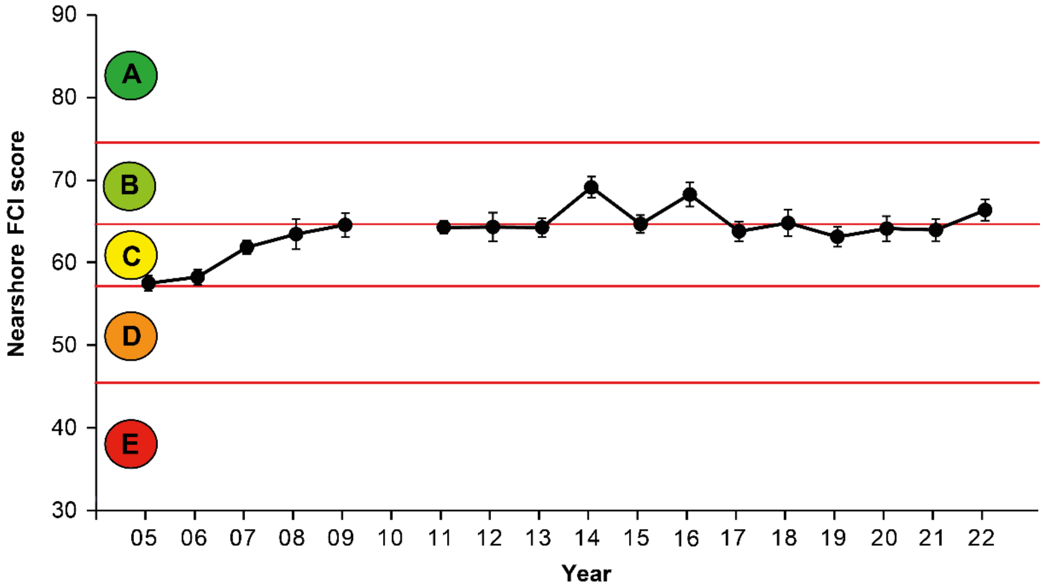


Figure 8. Trend plot of average (±SE) nearshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary between 2005 and 2022. Red lines denote boundaries between condition grades.

The mean offshore FCI score for the estuary overall also indicated good condition during 2022, thus the current score of good is in line with the generally upward trend from 2016 onwards (Fig. 9). Moreover, the score in 2022, was only the fourth time good condition has been obtained (i.e. 2012, 2015, 2020 and 2022), with the mean FCI score in 2022 being the highest ever recorded (i.e. 61.4 vs 48.6 to 60.2 in the other 13 years). These good overall scores reflect the consistent very good (A) to fair (C) scores throughout all zones, except for the offshore waters of the CE in summer and autumn (poor; D). It is hypothesised that these good scores in 2022 were driven by the relatively saline and oxic conditions throughout much of the system, particularly in summer, when flows were low. Similarly, good scores in 2012, 2015 and 2020 all coincided with relatively low flow during the January to May period when sampling occurs (i.e. mean = 0.69 ML vs 30.43 GL from 2011-2022). These low levels of flow allow the upstream penetration of saline water facilitating increases in species richness and preventing the occurrence of hypoxia associated with stratification. Conversely, flow was greatest by far in the summer of 2017 (i.e. 282 ML), which had amongst the lowest FCI score due to large spatial extents of hypoxia.

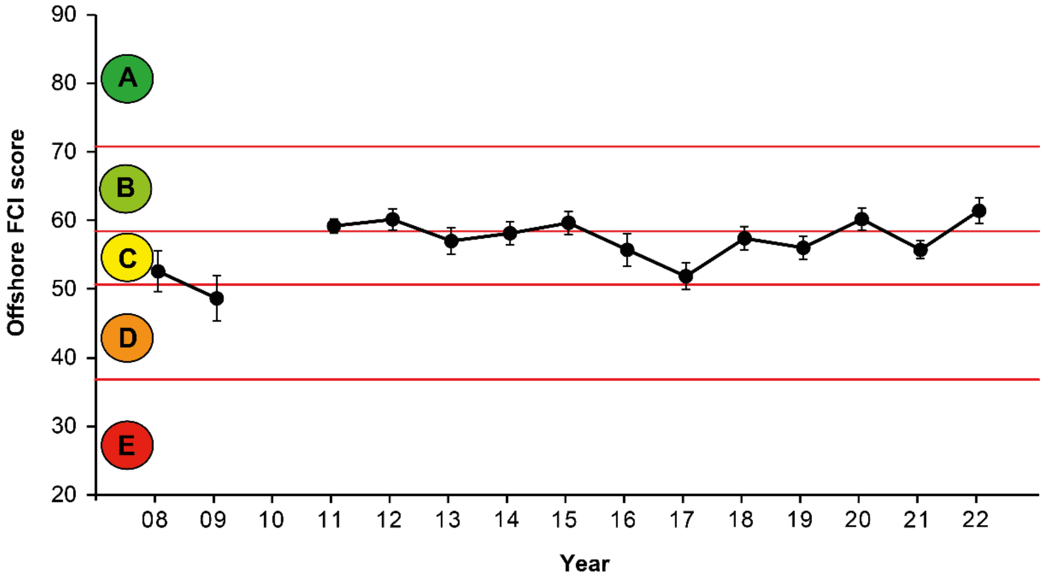


Figure 9. Trend plot of average (±SE) offshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary as a whole, between 2008 and 2022. Red lines denote boundaries between condition grades.

Summary

The Fish Community Index (FCI) considers the fish community as a whole and provides a 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 2022 was assessed as good (B) based on their fish communities (Table 5). Combined, the nearshore and offshore index scores are the highest ever recorded (closely followed by those in 2014), reflecting the fact that the condition in both water depths was good, rather than one good and one fair/good as in 2014 (Hallett and Tweedley, 2014).

The good scores in 2022 were influenced by strong winter flows in most regions combined with the absence of summer rainfall events, relatively saline and oxic conditions and generally low phytoplankton densities through summer and autumn. Along the Swan axis of the estuary the strong freshwater flows that occurred in the winter of 2021 were the greatest for 25 years and will have increased productivity in both the estuary and nearby coastal waters and facilitated the recruitment of fish species. This is evidenced by the number of fish (most of which have an annual lifecycle) recorded in the nearshore waters being by far the largest ever recorded since FCI sampling began.

Overall, the offshore waters of the CE exhibited by far the lowest scores of any zone in 2022. 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. Waters in the CE were once again stratified, hypoxic and, at times, contained moderate levels of the toxic dinoflagellate *Karlodinium* spp.. 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. Additional monitoring water quality in this zone has been initiated by DBCA since May 2020 to better understand the factors underlying this trend.

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 2022 monitoring period (mean of all summer and autumn of 2022). 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	66.02	B	68.74	B
CE	63.64	C/B	46.87	D
MSE	66.70	B	60.94	B
USE	68.98	B	68.76	B
Estuary	**66.33**	**B**	**61.41**	**B**

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7. 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.

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Appendix (iii). List of species caught from the Swan Canning Estuary, and their functional guilds: D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic; MS, Marine straggler; MM, Marine migrant; SA, Semi-anadromous; ES, Estuarine species; FM, Freshwater migrant; ZB, Zoobenthivore; PV, Piscivore; ZP, Zooplanktivore; DV, Detritivore; OV, Omnivore/Opportunist; HV, Herbivore. See Potter et al. (2015a); Whitfield et al. (2022) for descriptions of the guilds.

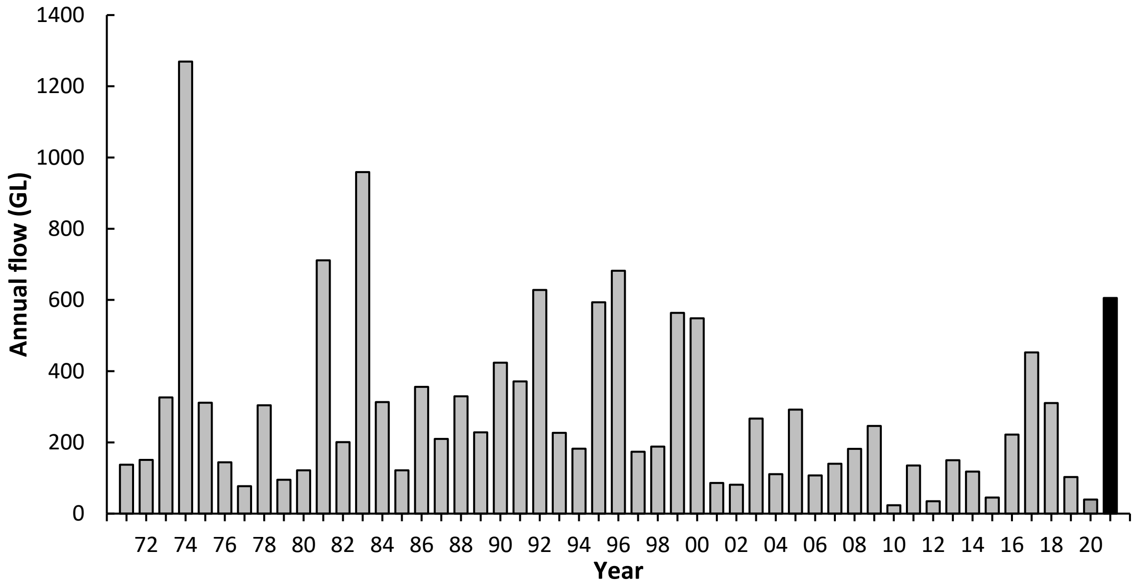
Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Heterodontus portusjacksoni	Port Jackson Shark	Heterodontidae	D	MS	ZB
Carcharhinus leucas	Bull Shark	Carcharhinidae	P	MS	PV
Myliobatis tenuicaudatus	Southern Eagle Ray	Myliobatidae	D	MS	ZB
Elops machnata	Australian Giant 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 angustus	Western Spiny 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	[a 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

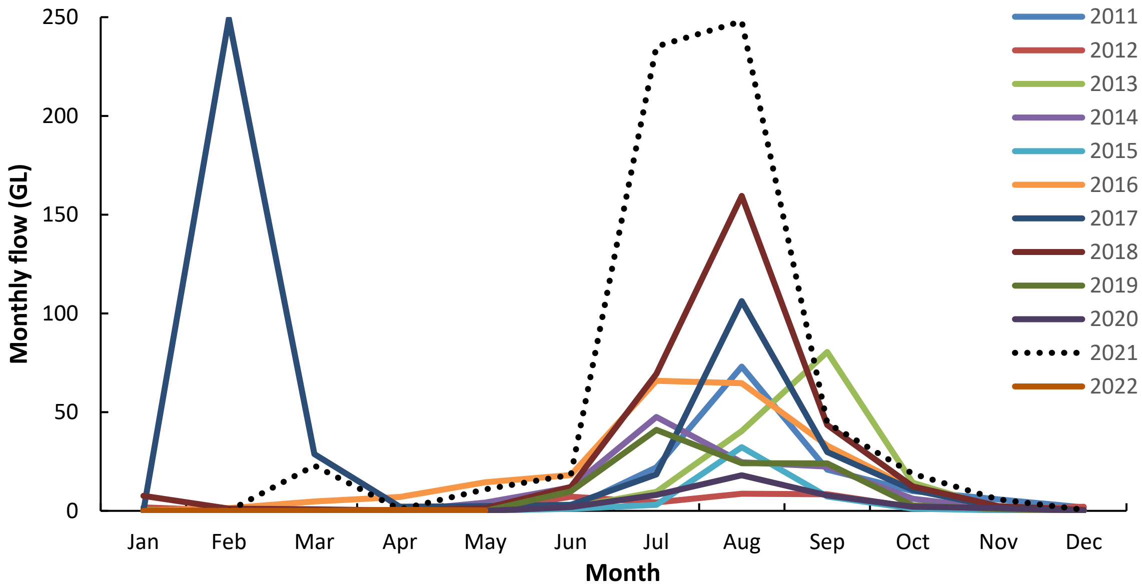
Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Pseudogobius olorum	Bluespot Goby	Gobiidae	SB	ES	OV
Bathygobius krefftii	Krefft's Frillgoby	Gobiidae	SB	MM	ZB
Callogobius depressus	Flathead Goby	Gobiidae	SB	MS	ZB
Favonigobius punctatus	Yellowspotted Sandgoby	Gobiidae	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 2021 and (b) total monthly flow between January 2011 and May 2022 at Walyunga on the Swan River (gauging station 16401). Data from 2021 highlighted in black in (a) and as a dashed 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)

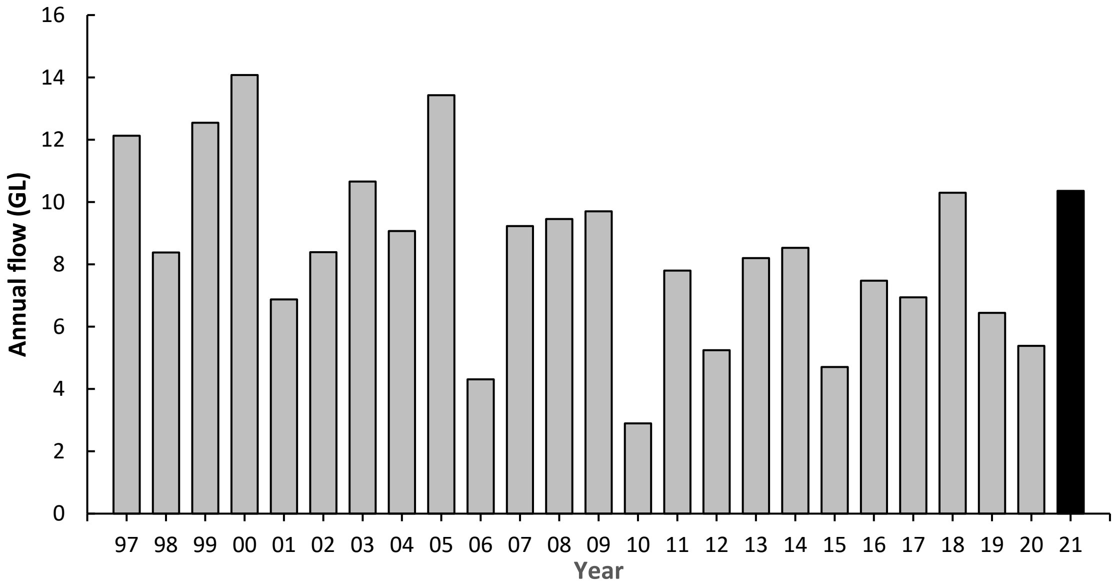


(b)

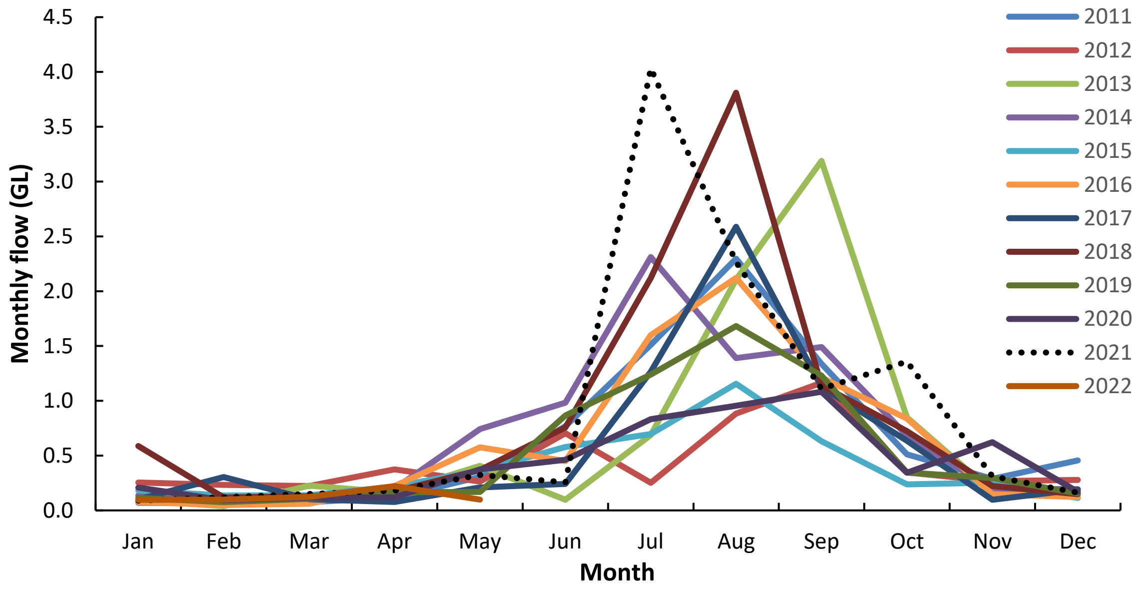


<u>Appendix (v).</u> (a) Total annual flow between 1971 and 2021 and (b) total monthly flow between January 2011 and May 2022 at Seaforth on the Canning River (gauging station 16417).). Data from 2021 highlighted in black in (a) and as a dashed line in (b). Data recorded by the Department of Water and Environmental Regulation and extracted from https://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx.

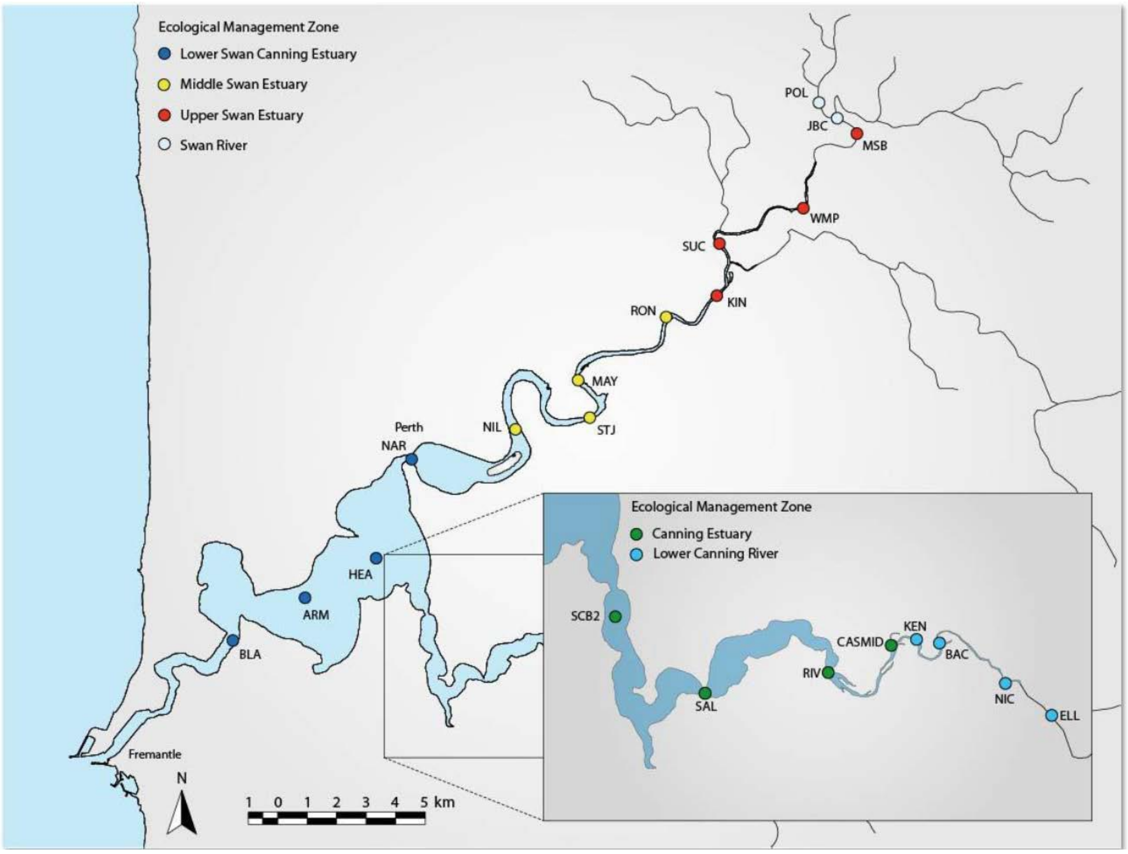
(a)



(b)

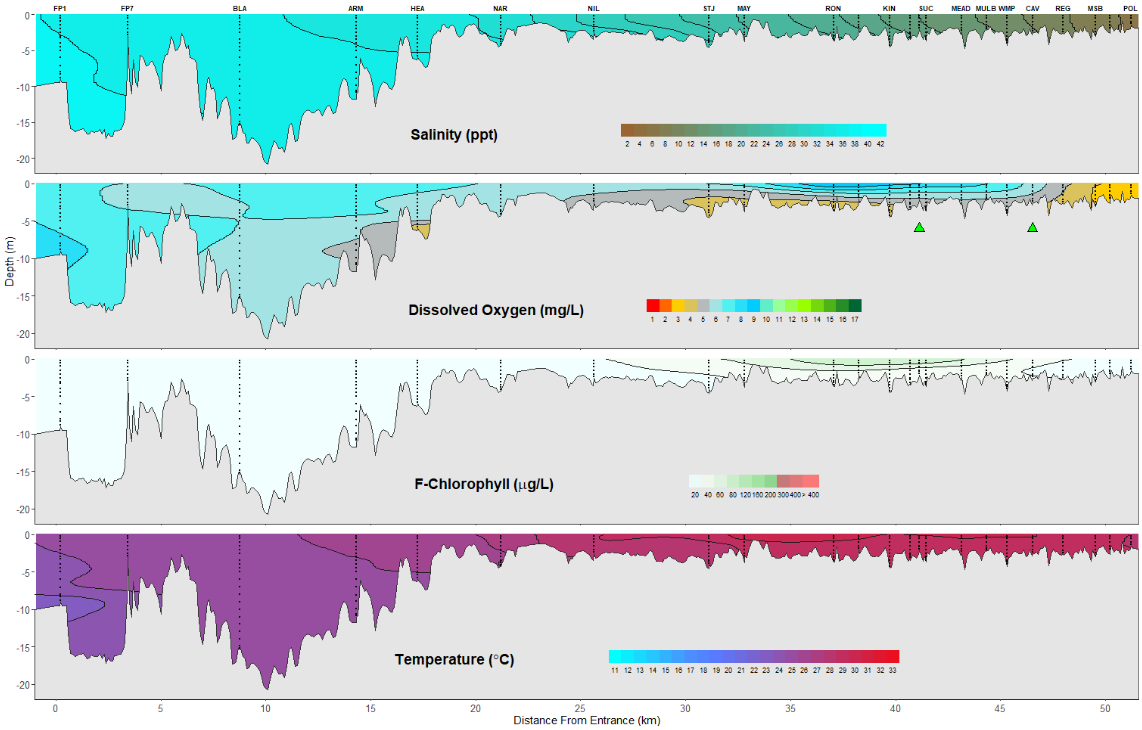


Appendix (vi). A representative selection of vertical contour plots of salinity, dissolved oxygen concentrations (mg/L), Chlorophyll fluorescence (µg/L) and water temperature (°C) measured at monitoring stations along the length of the Swan Canning Estuary on occasions throughout the summer to autumn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

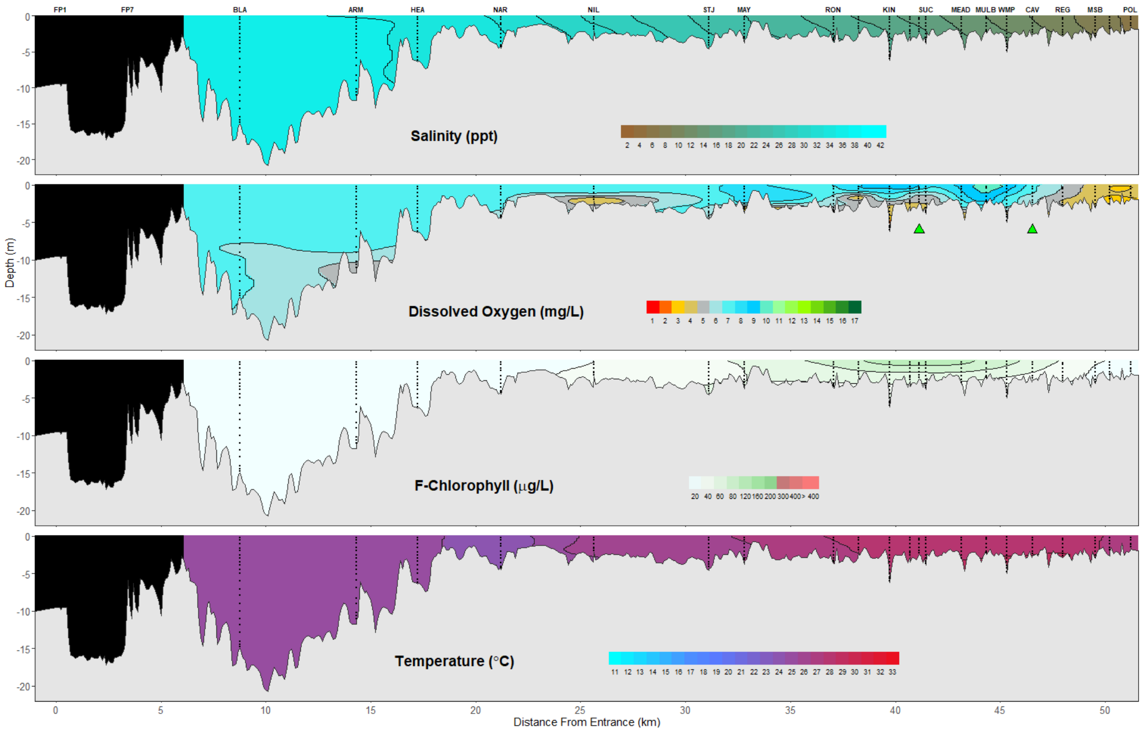


LSCE, MSE and USE zones in summer through autumn 2022

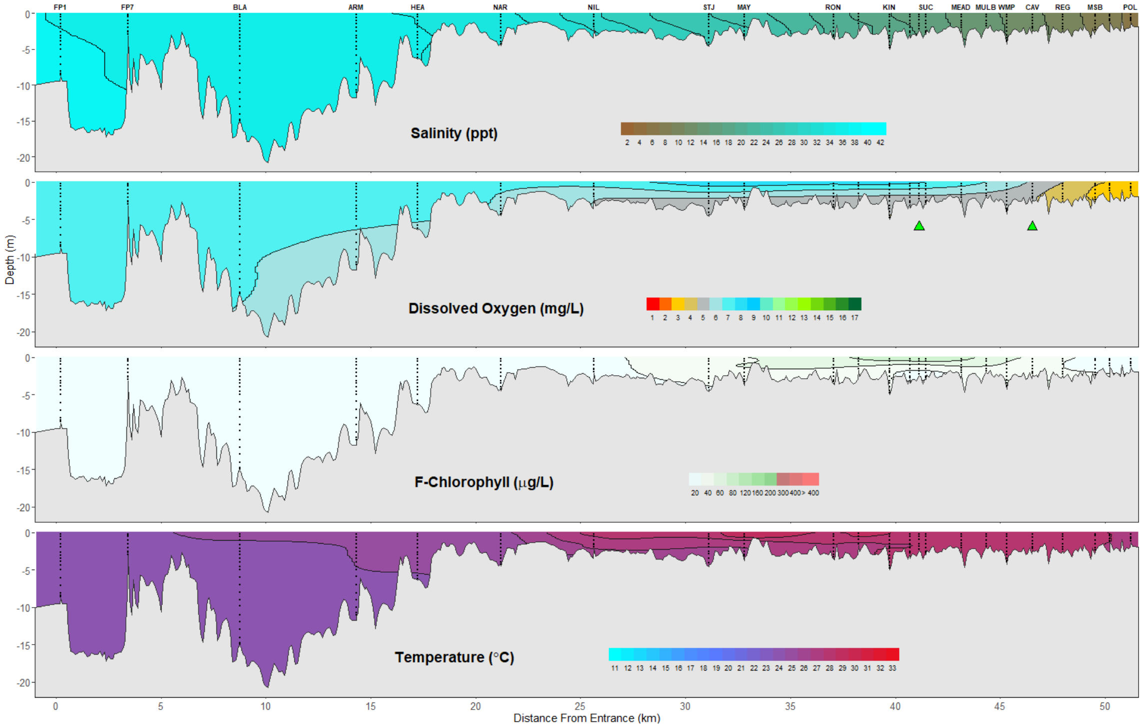
4th January 2022



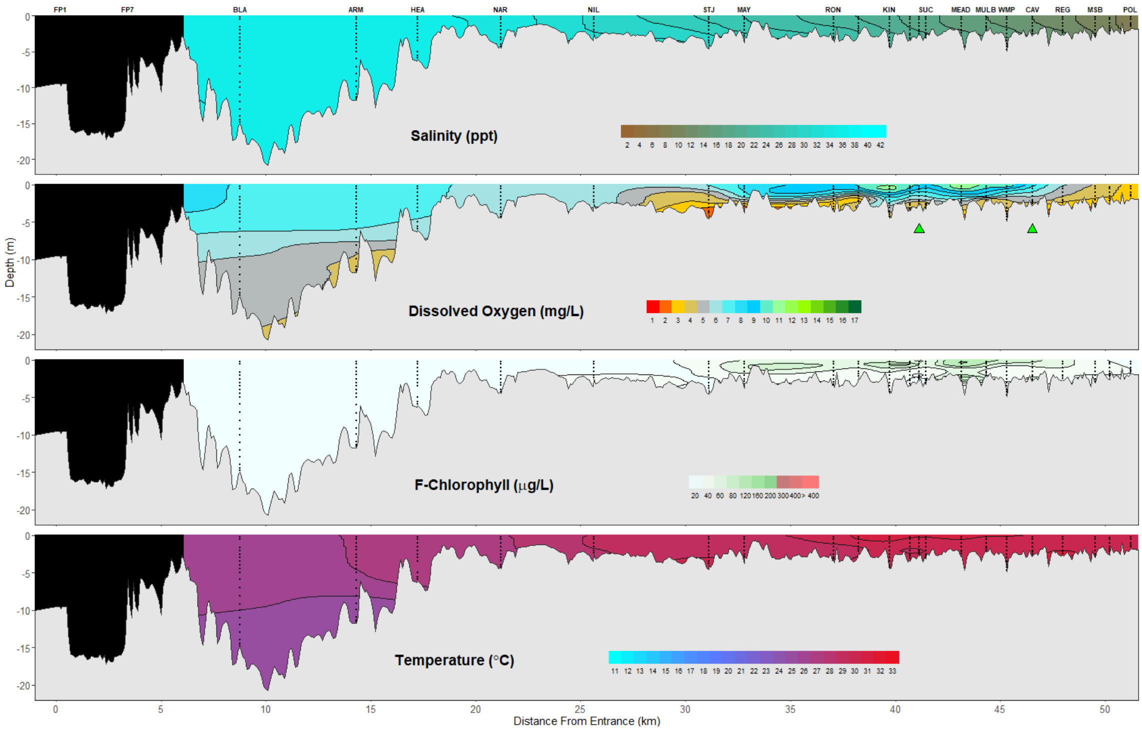
10th January 2022



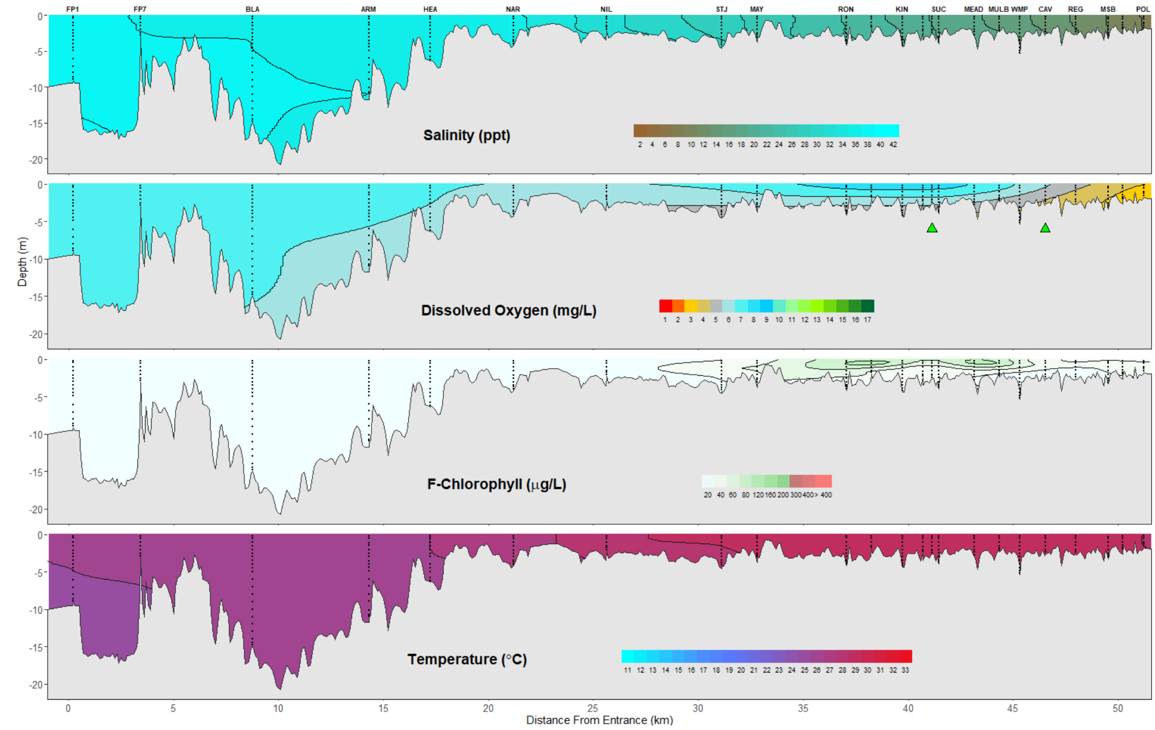
17th January 2022



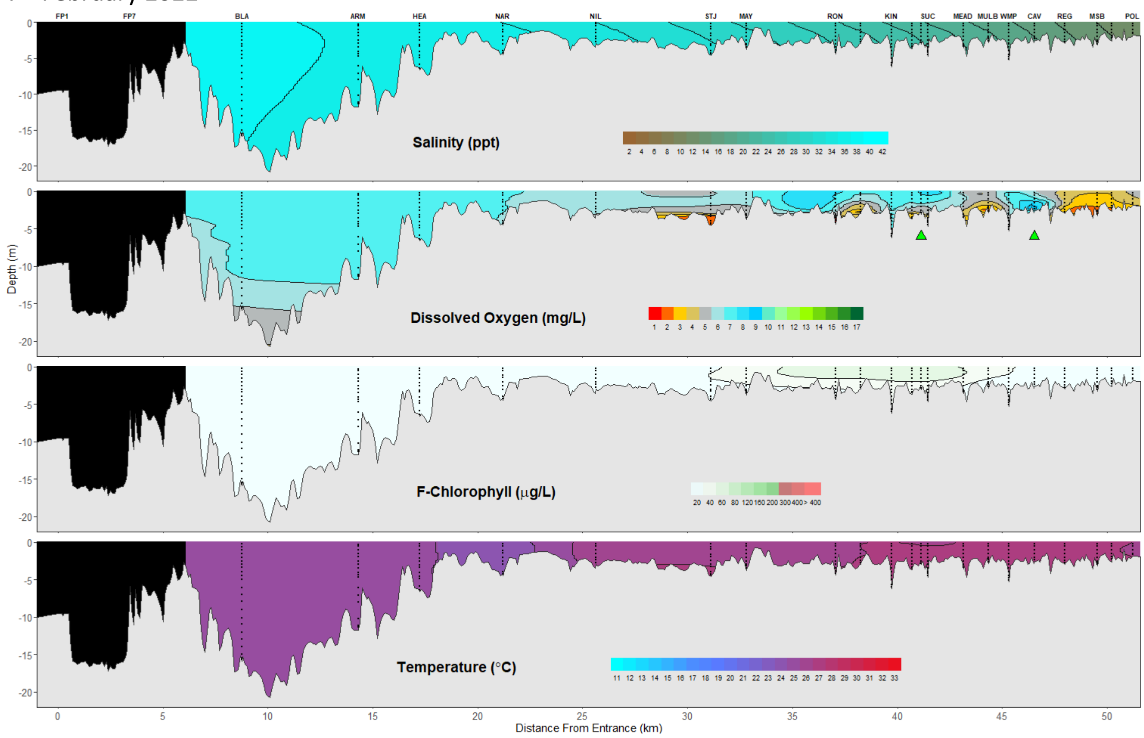
24th January 2022



31st January 2022



7th February 2022



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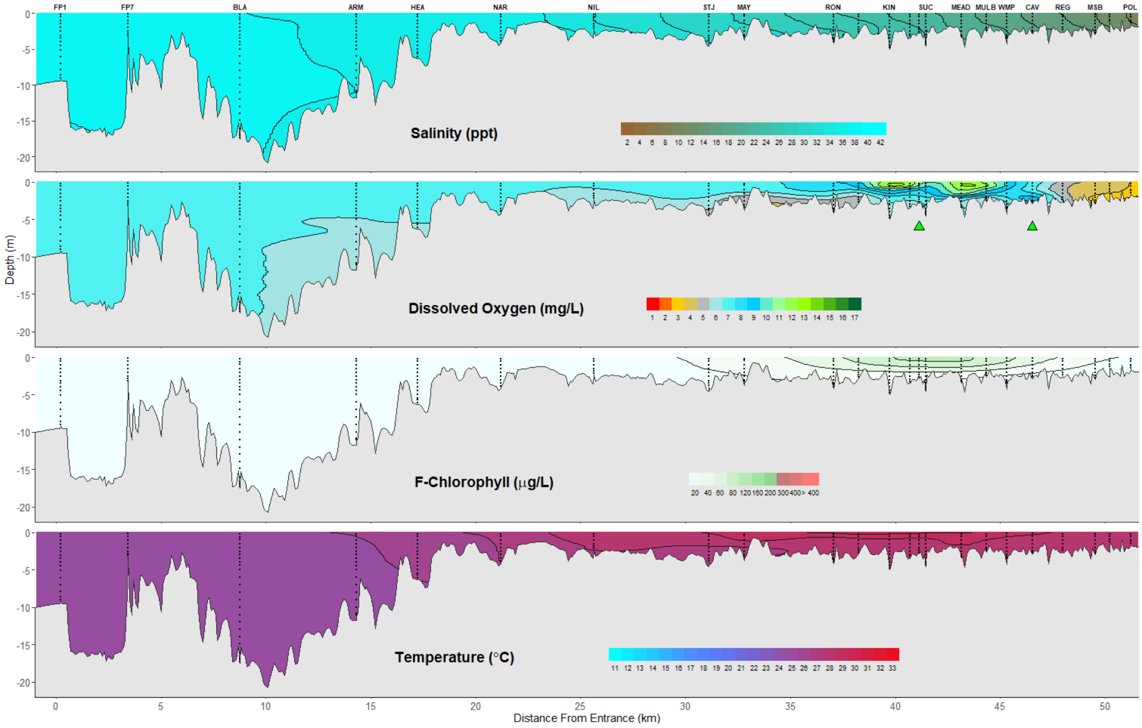

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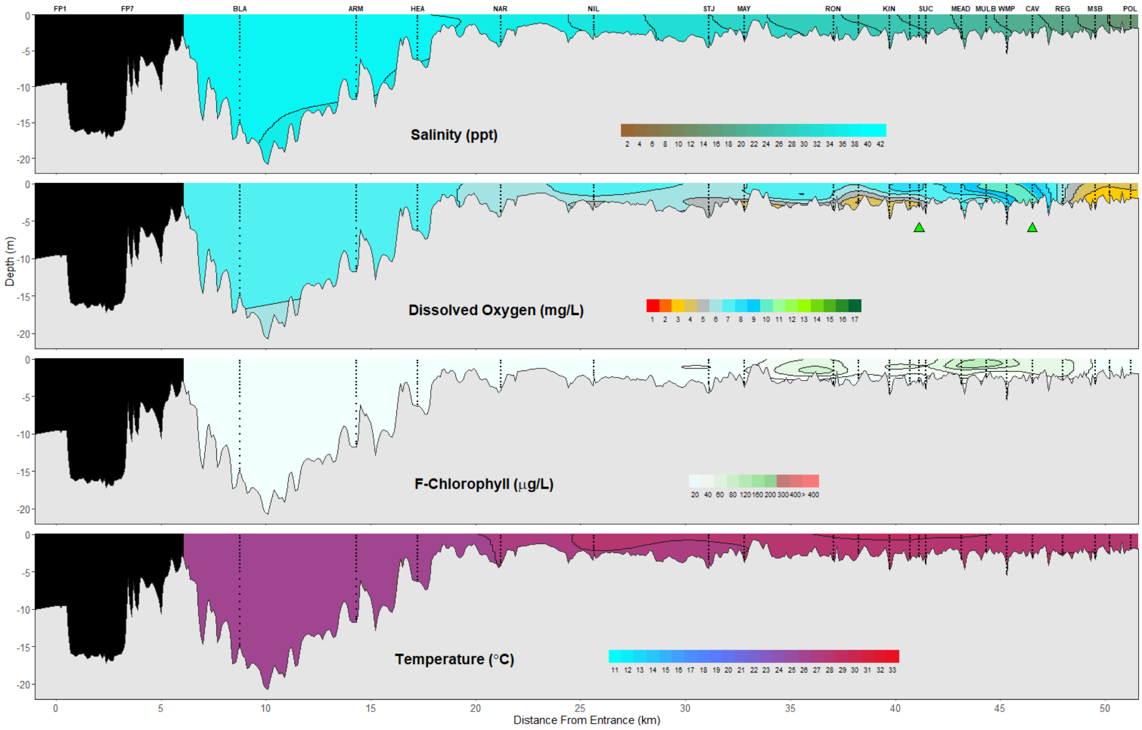

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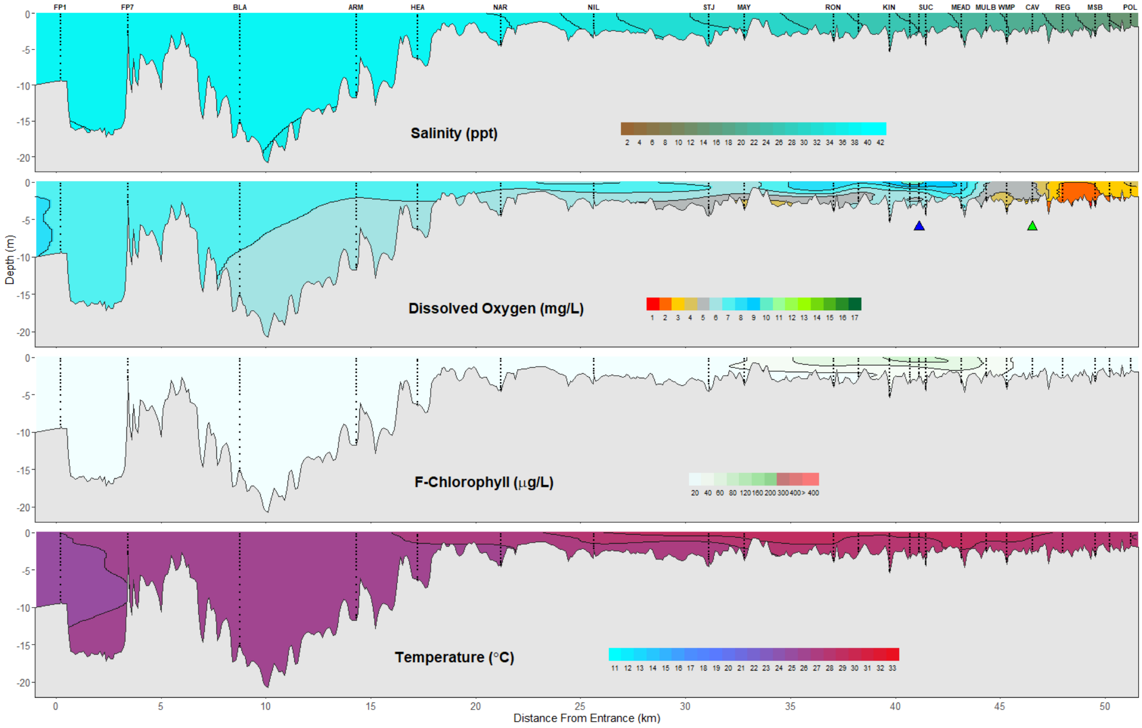
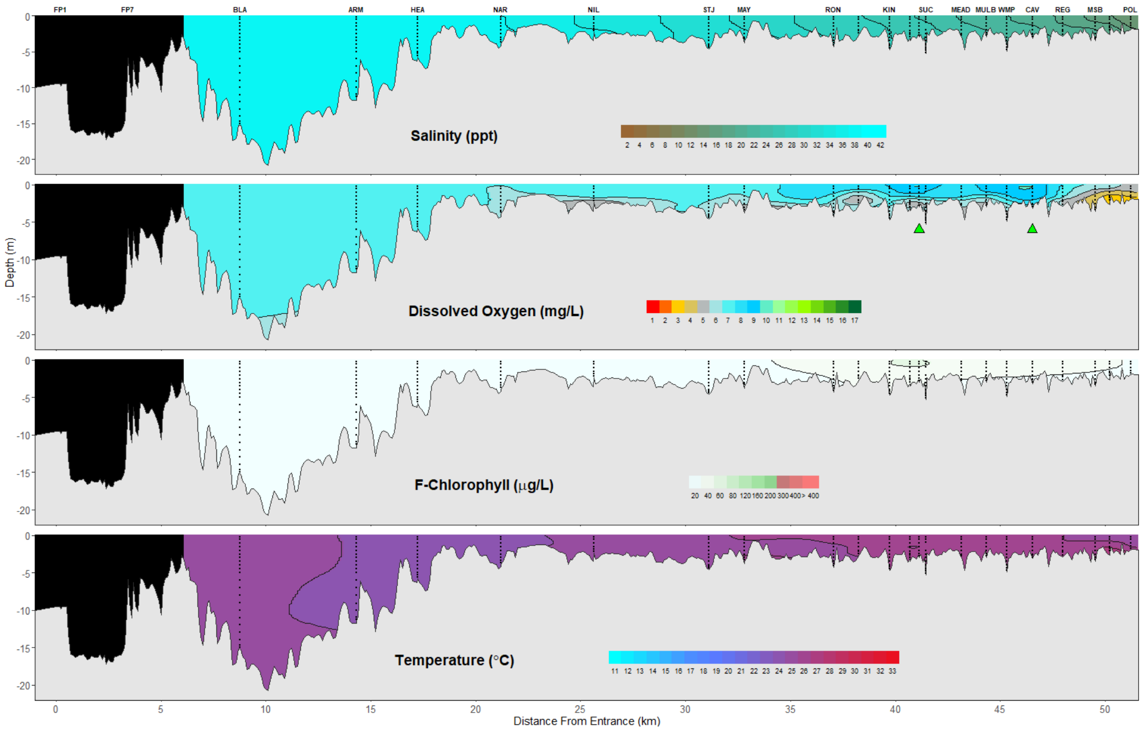


8th March 2022



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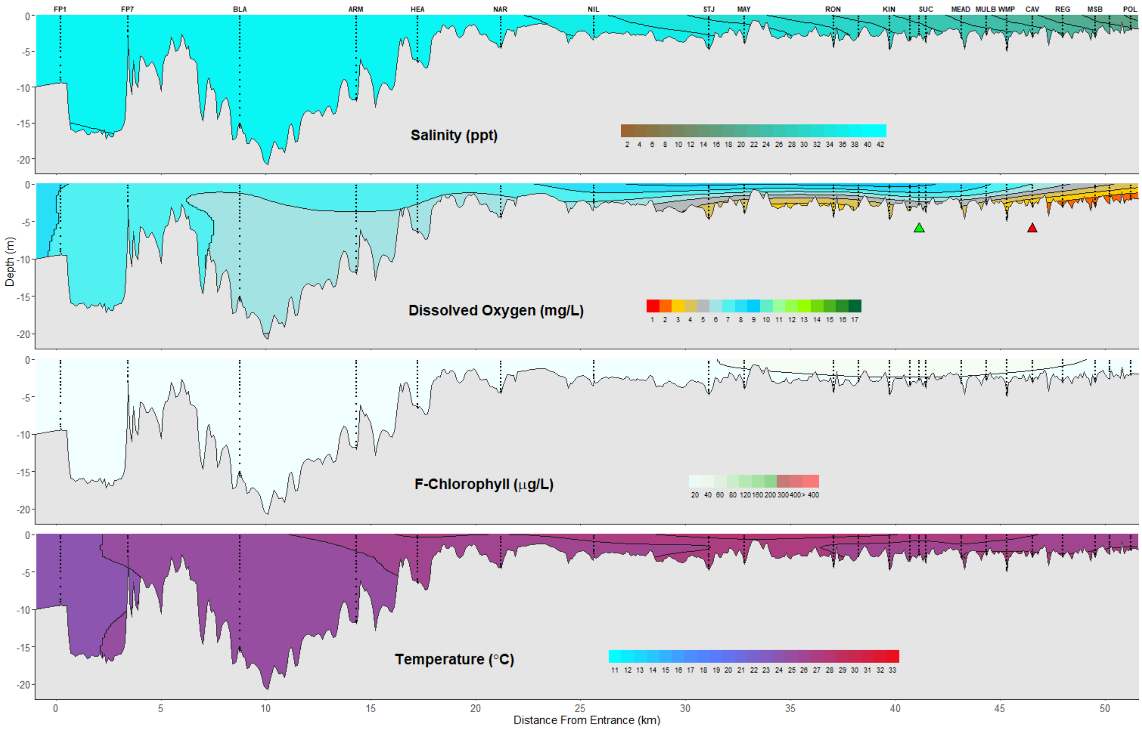
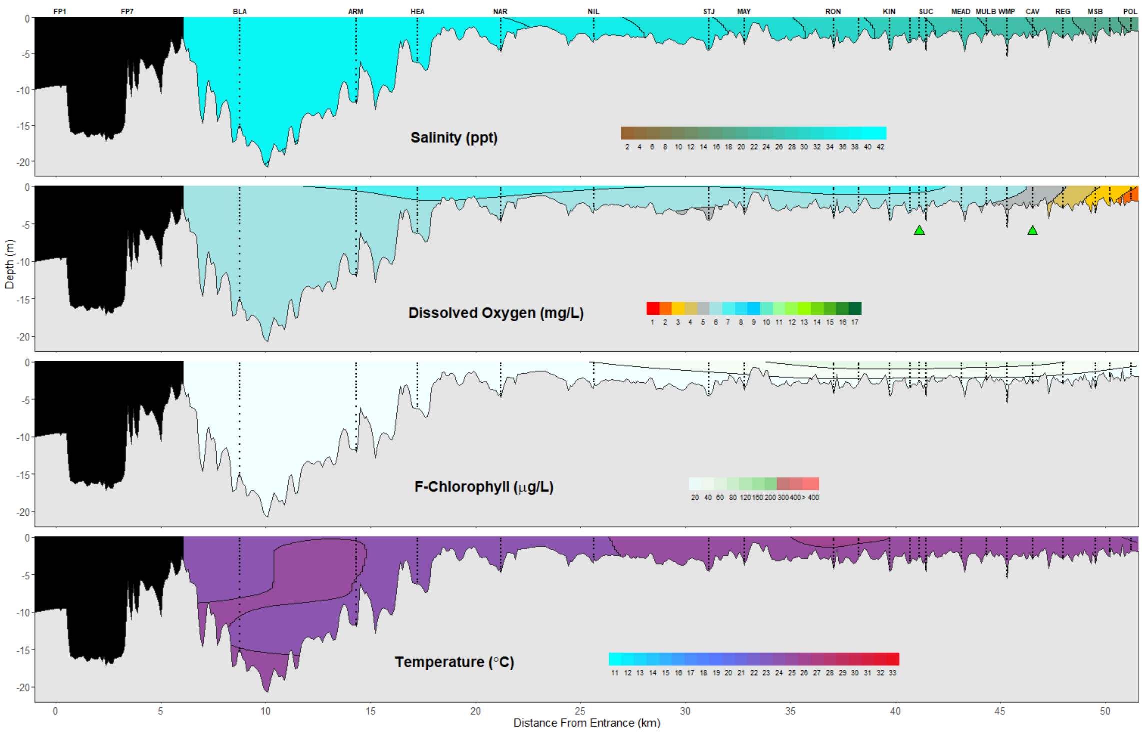
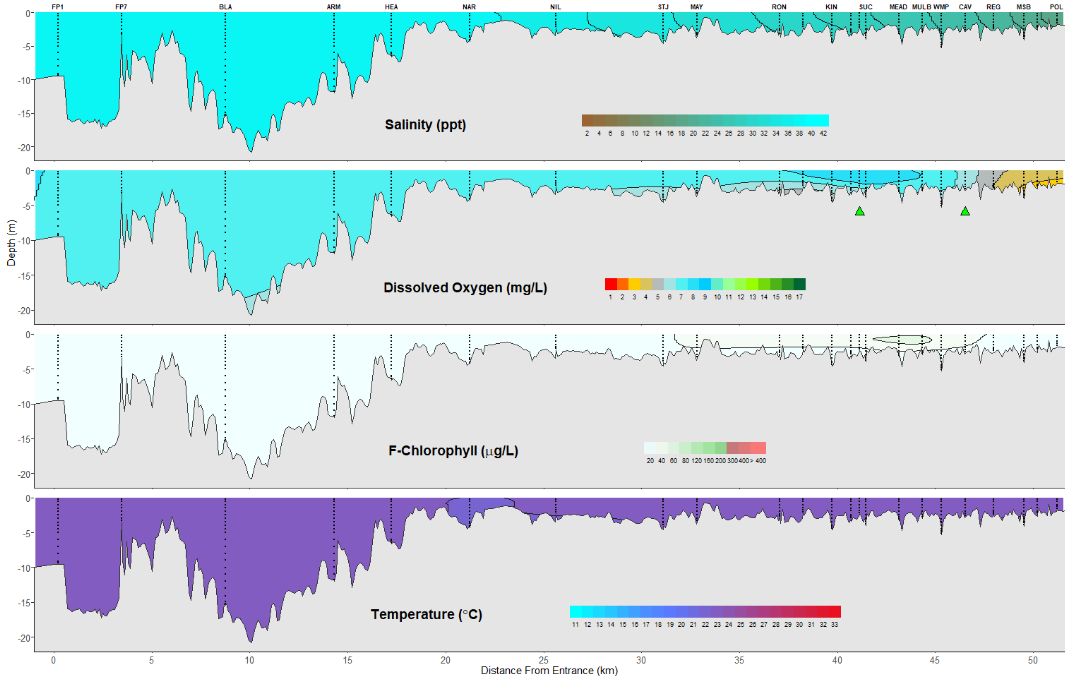


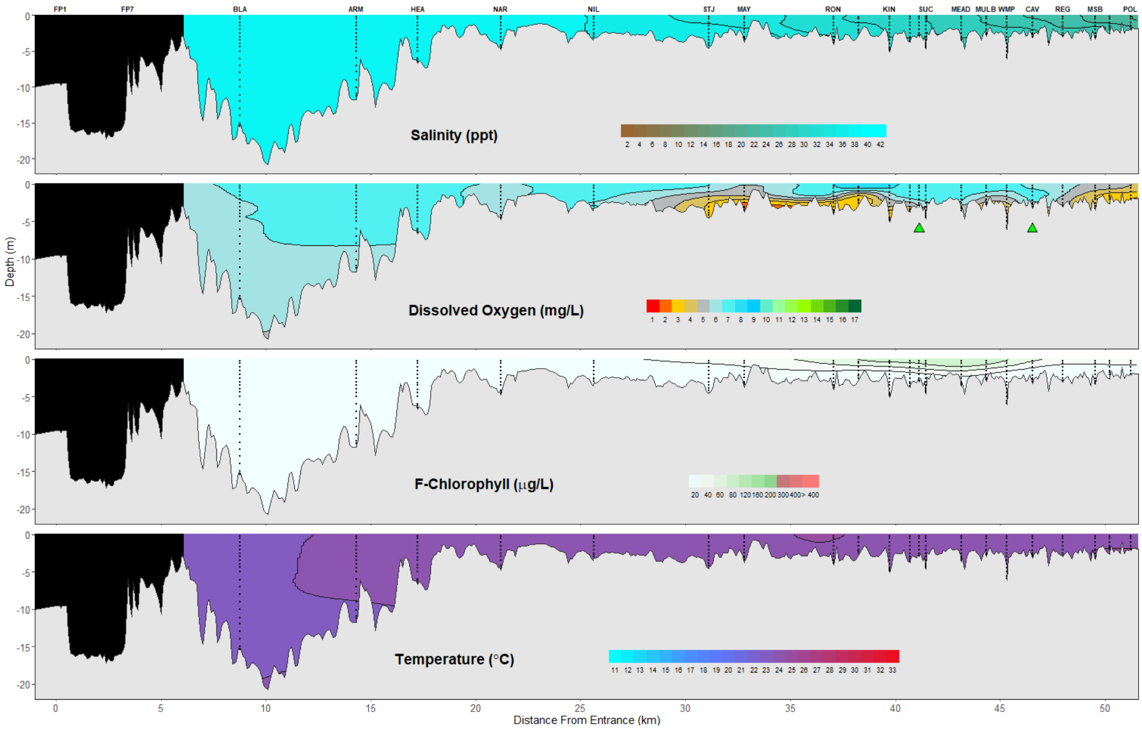
21st March 2022



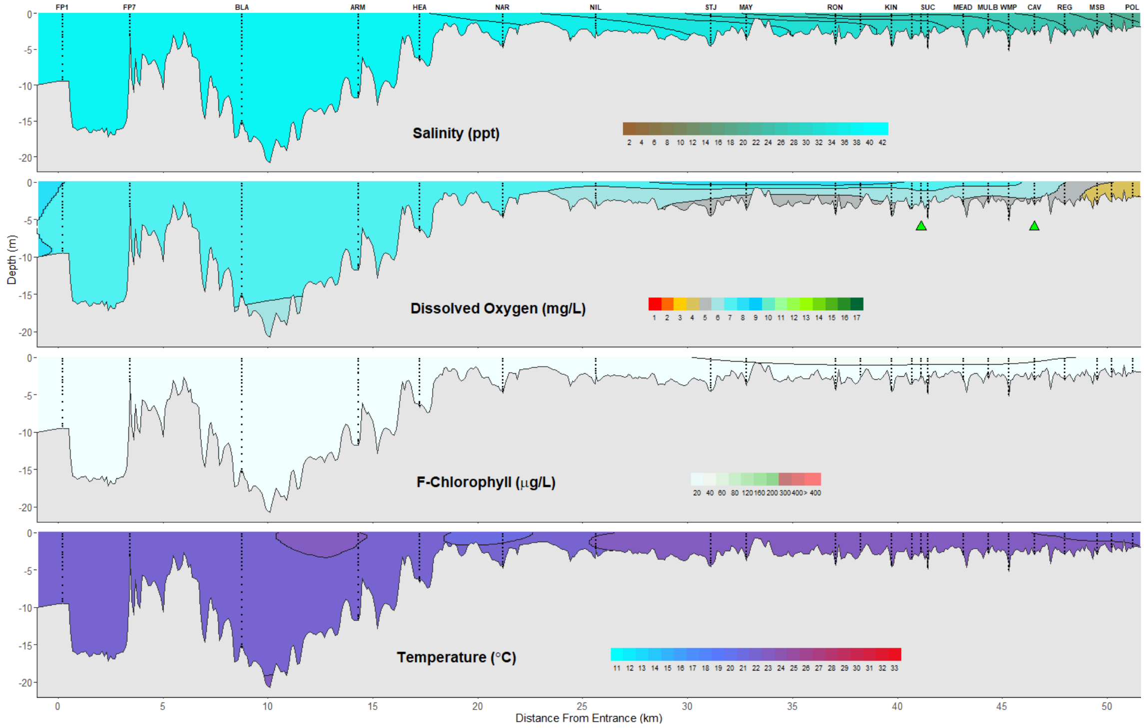
28th March 2022



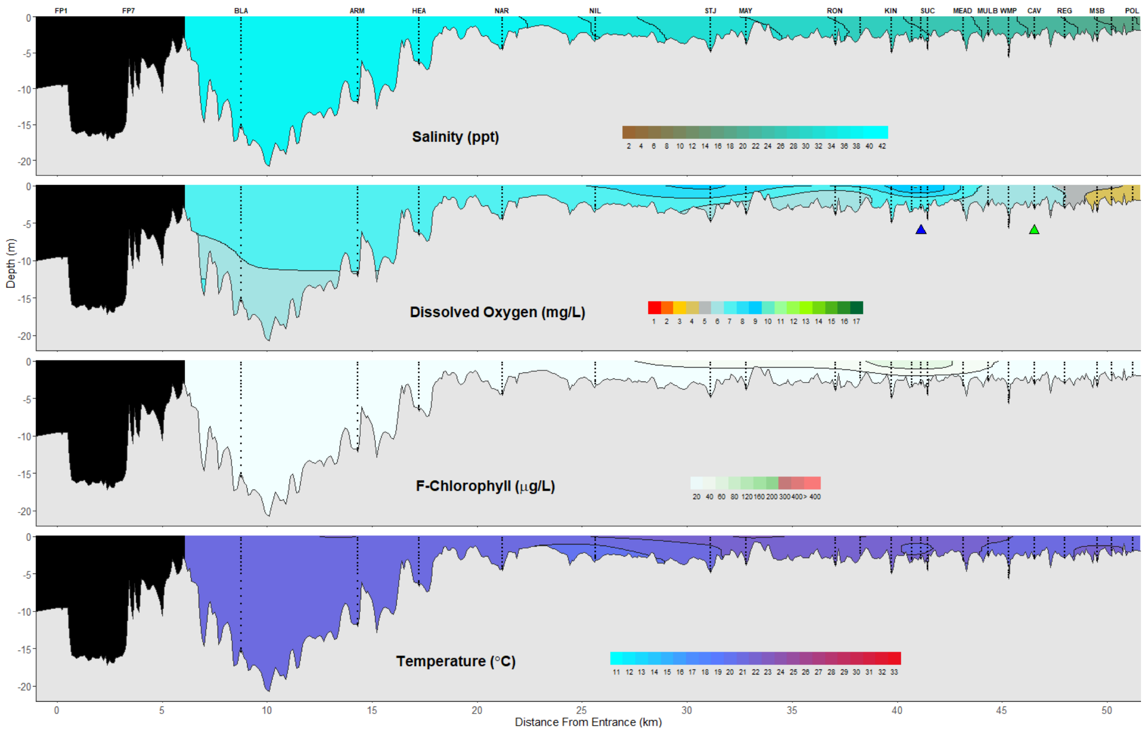
4th April 2022



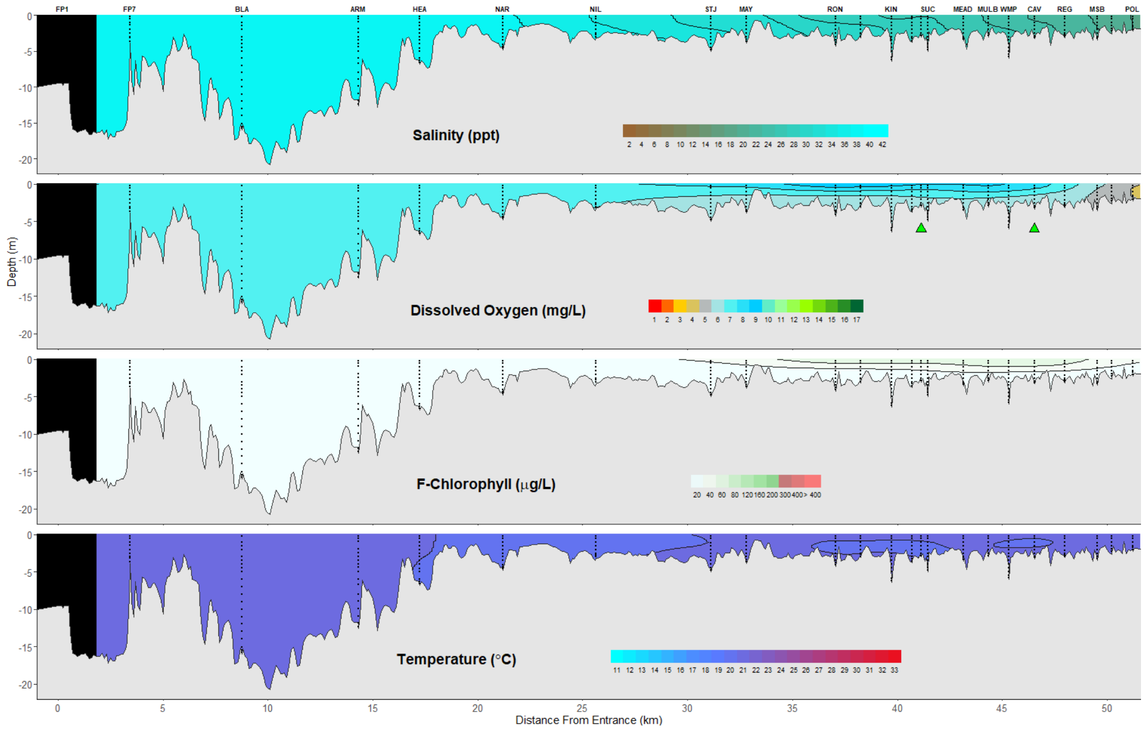
11th April 2022



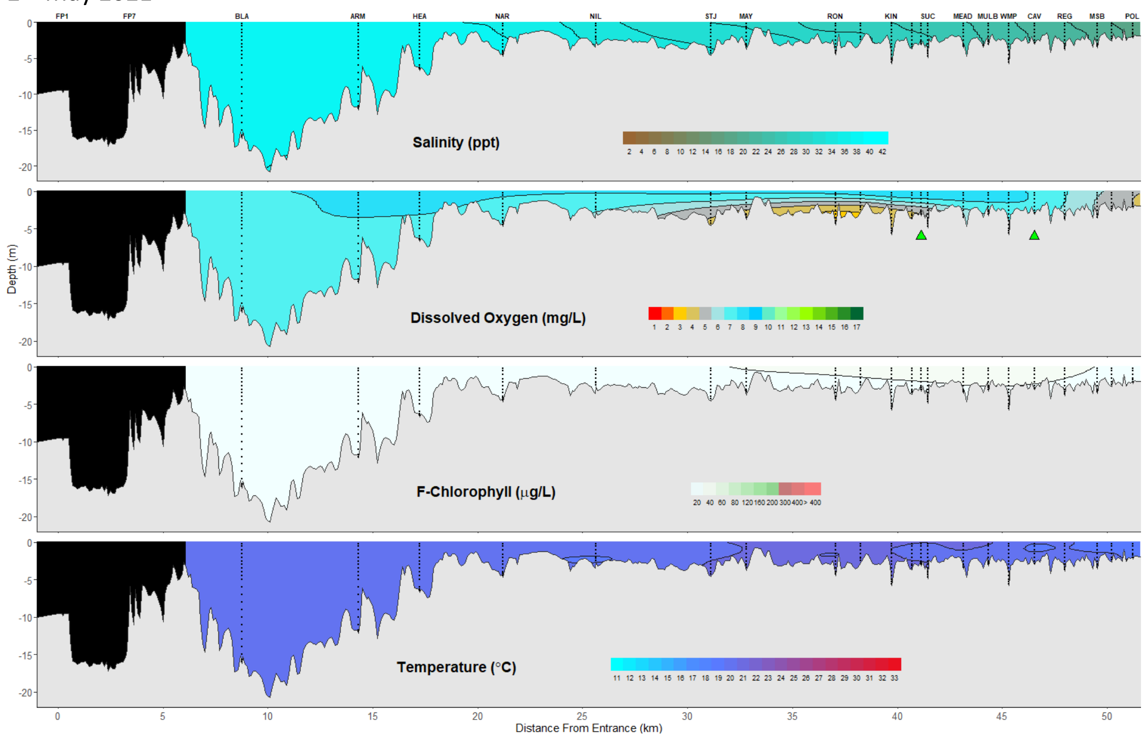
19th April 2021



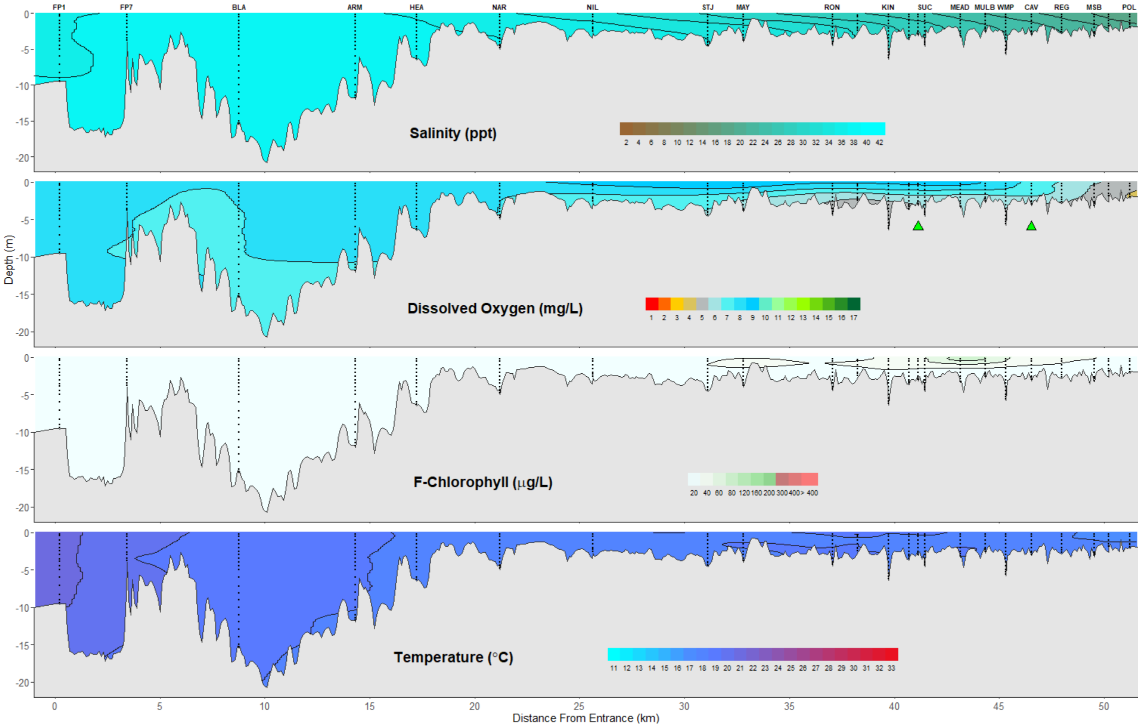
26th April 2021



2nd May 2021



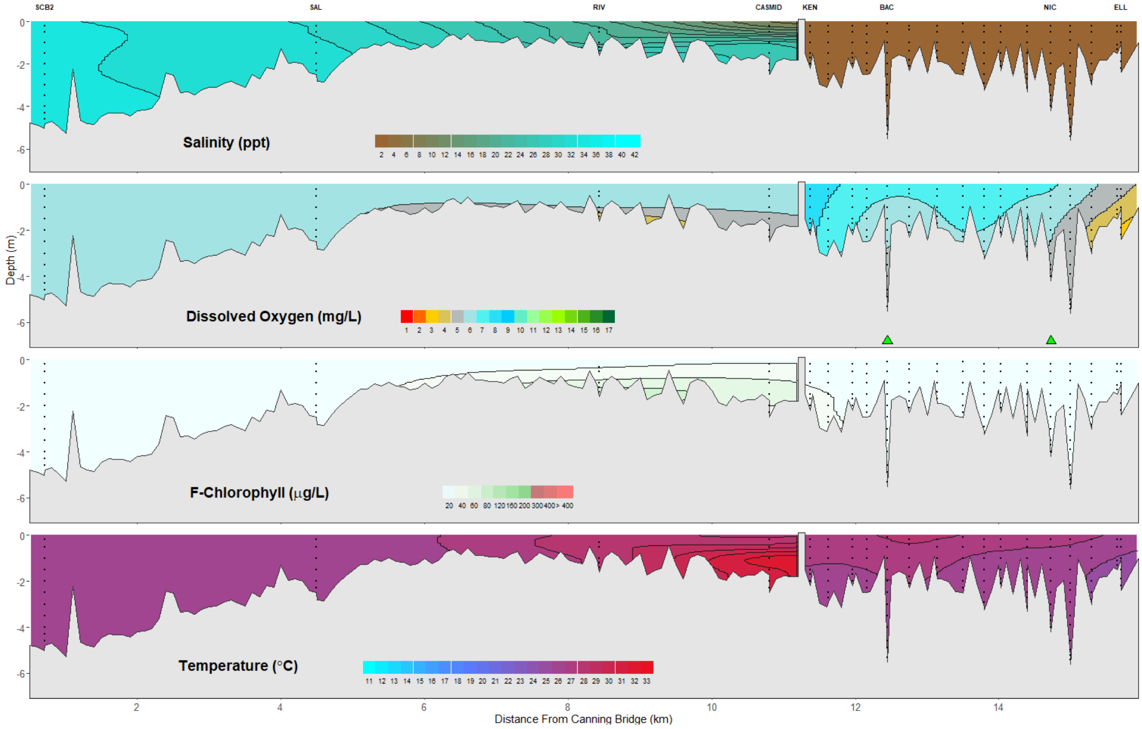
9th May 2021



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 2022

5th January 2022



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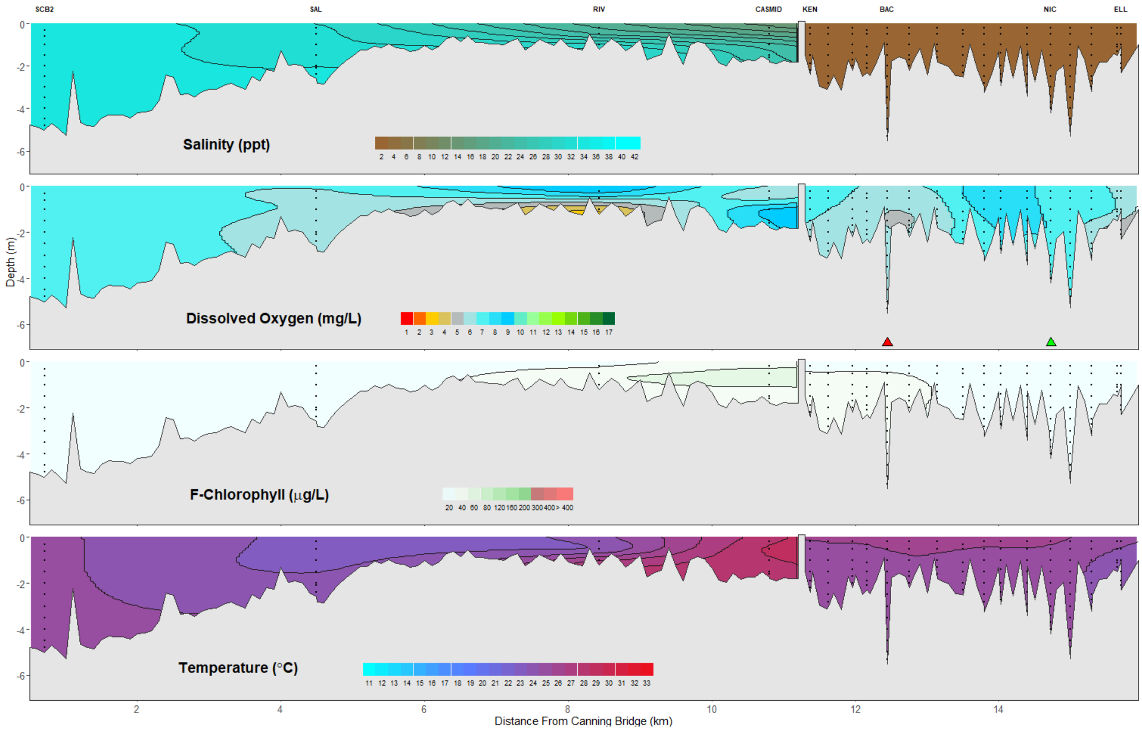

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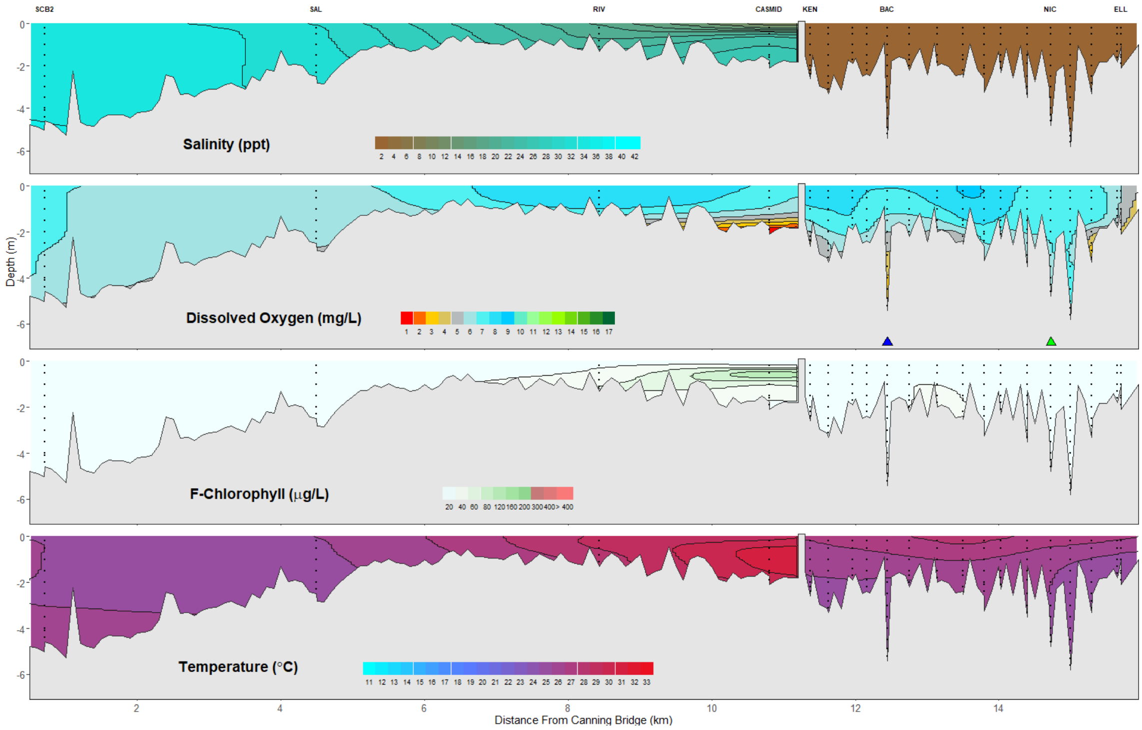

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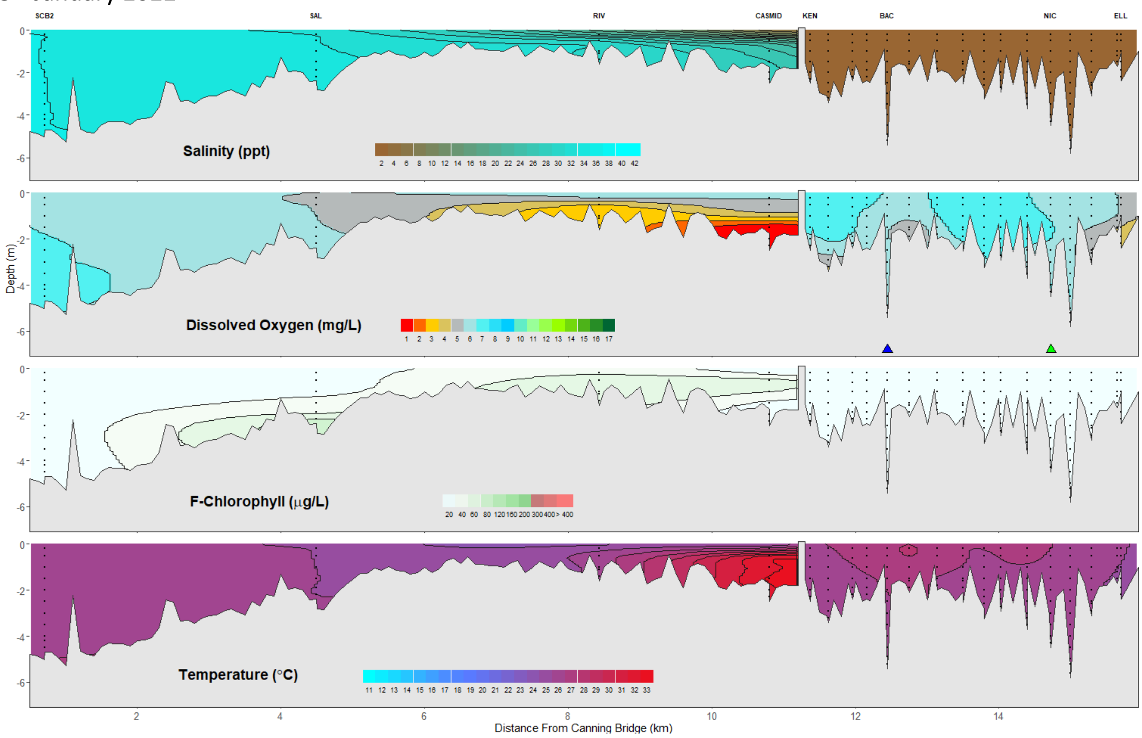

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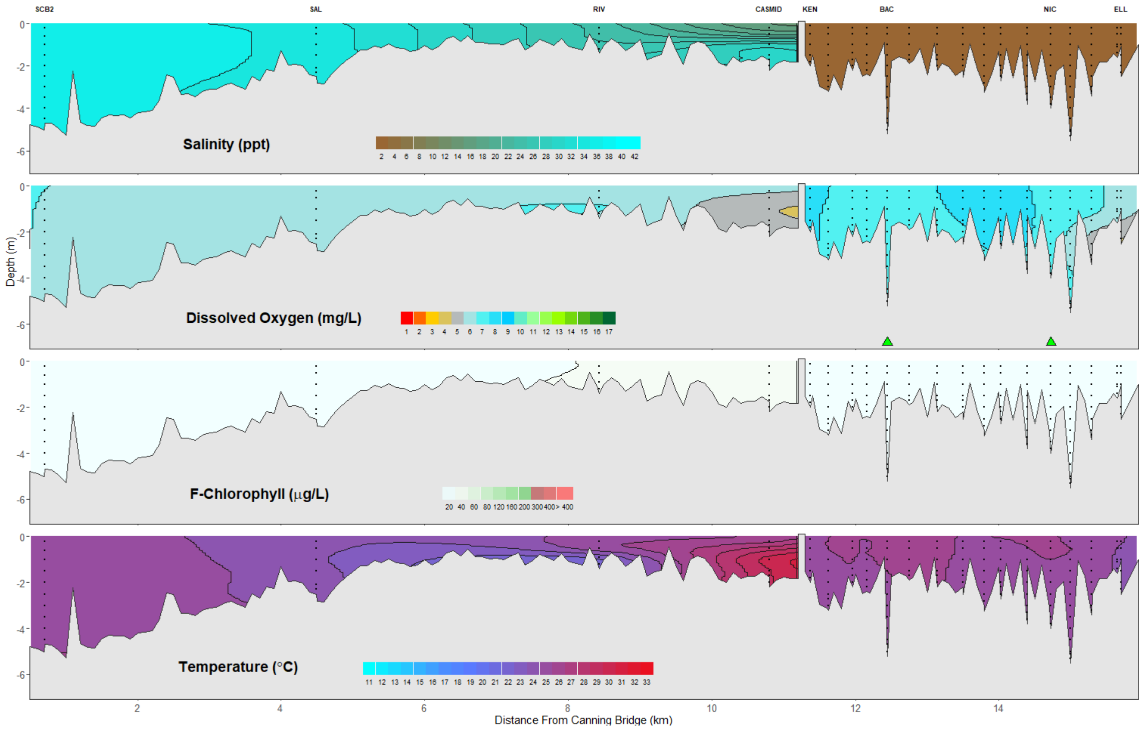

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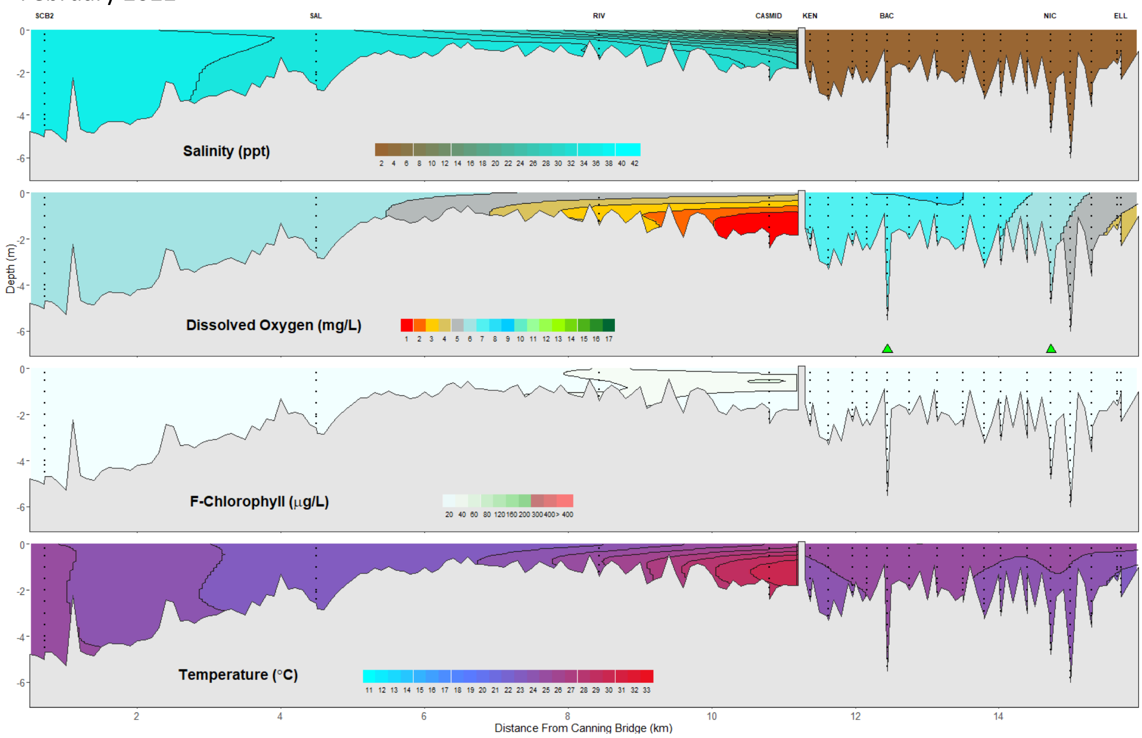

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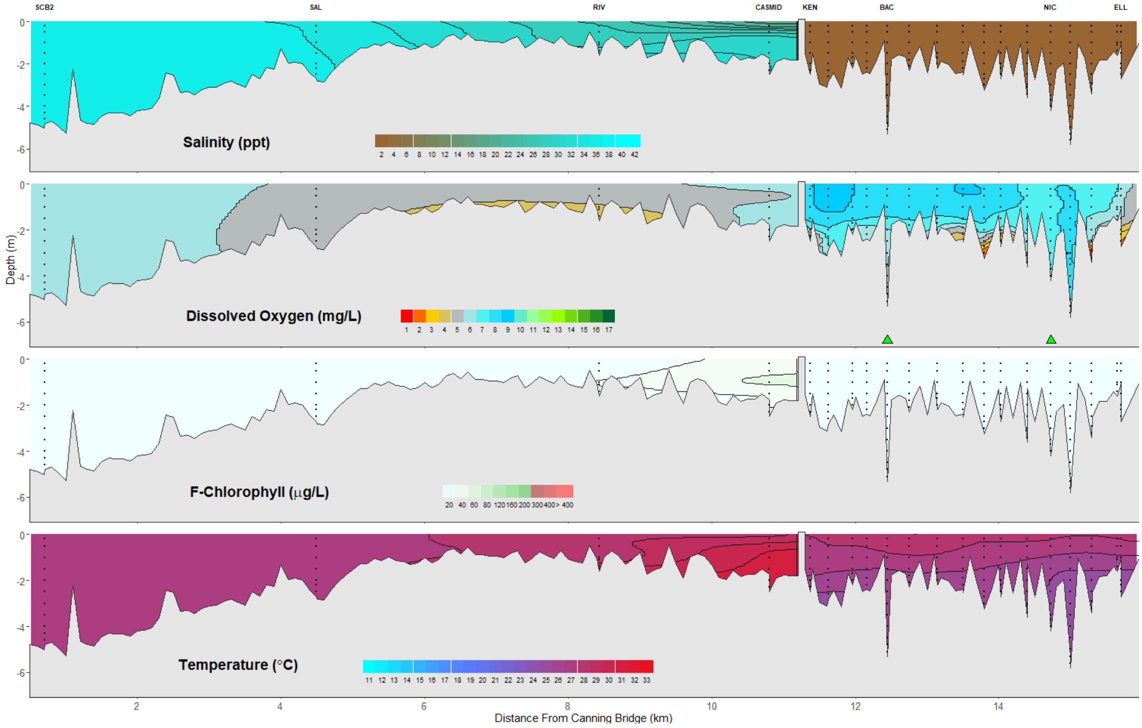

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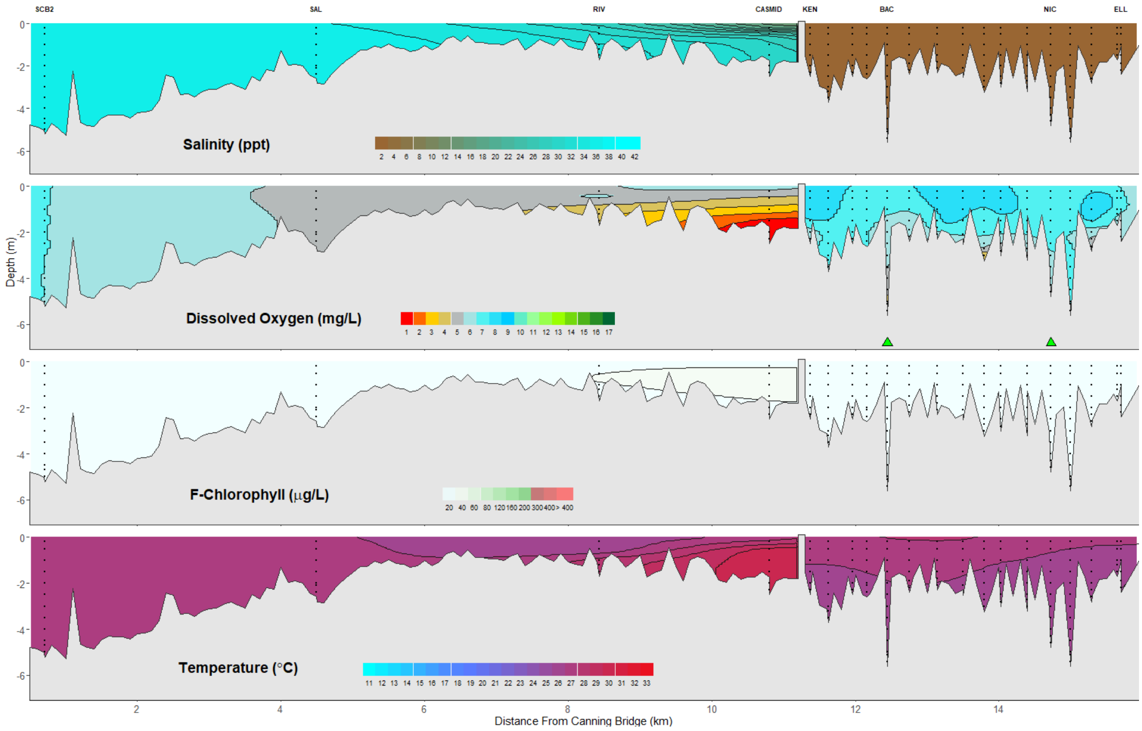

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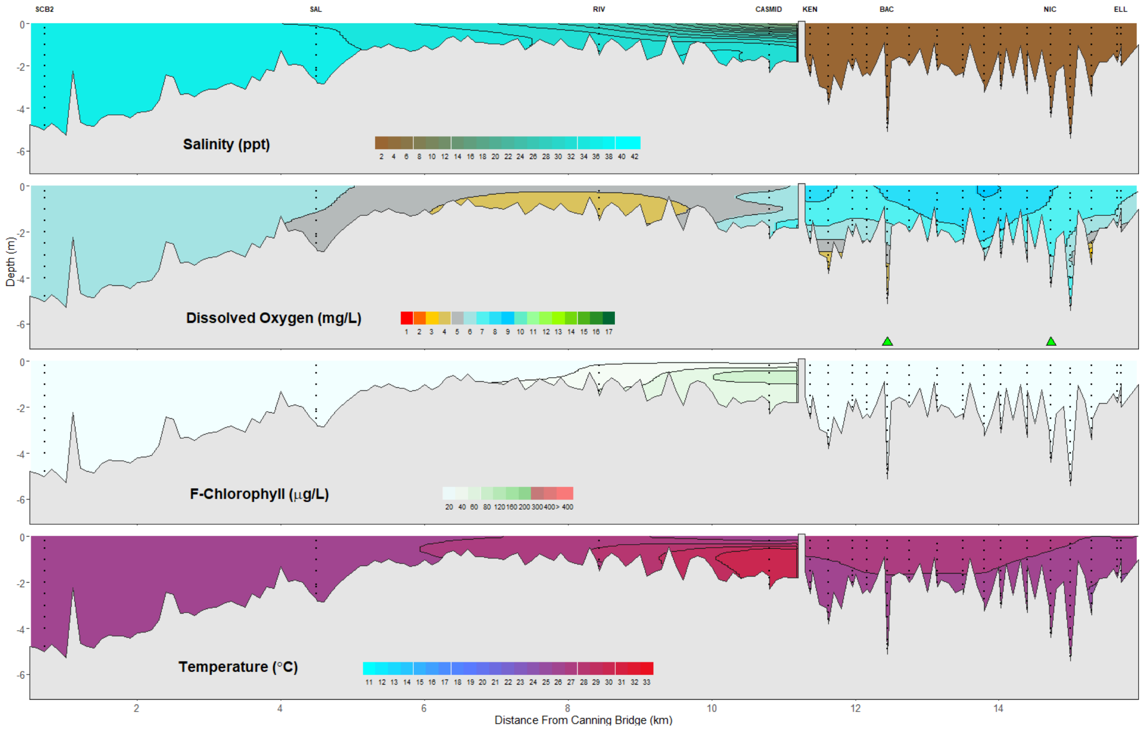

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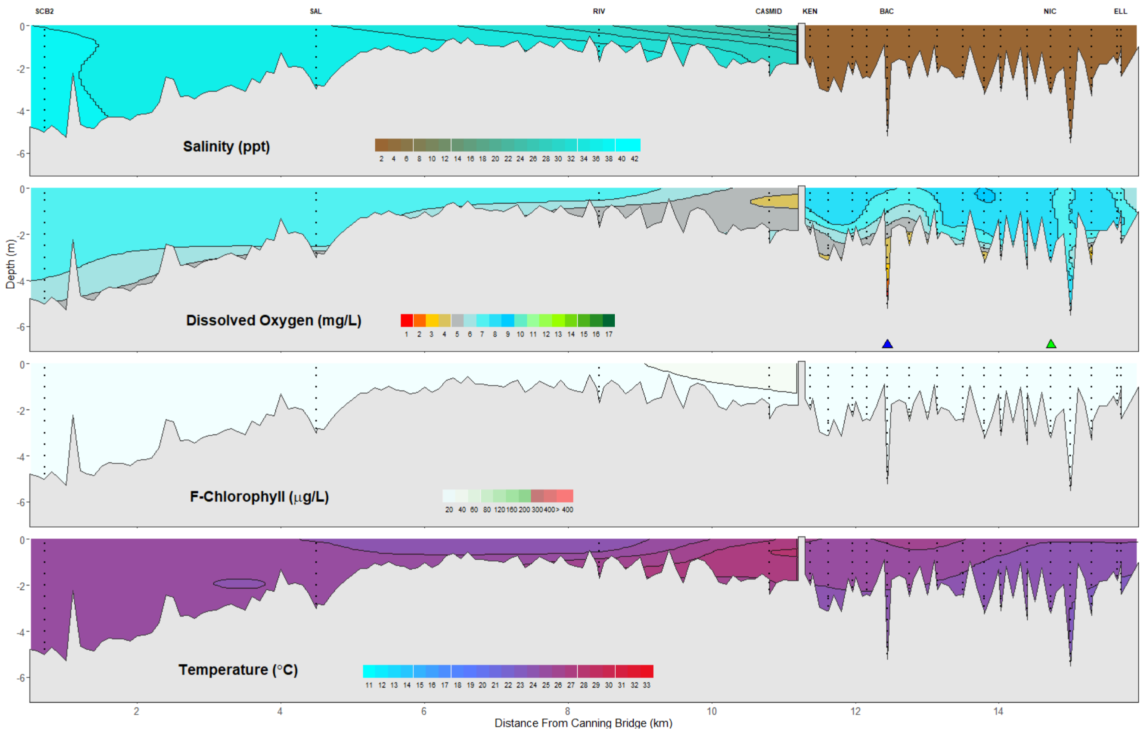

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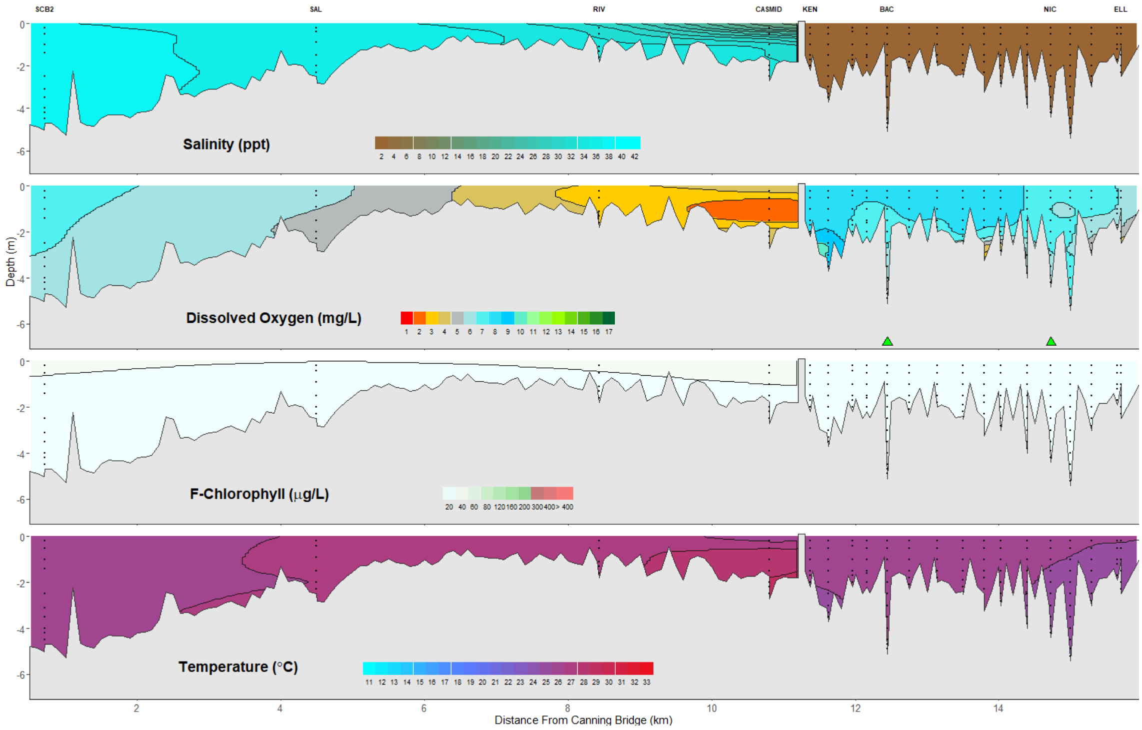

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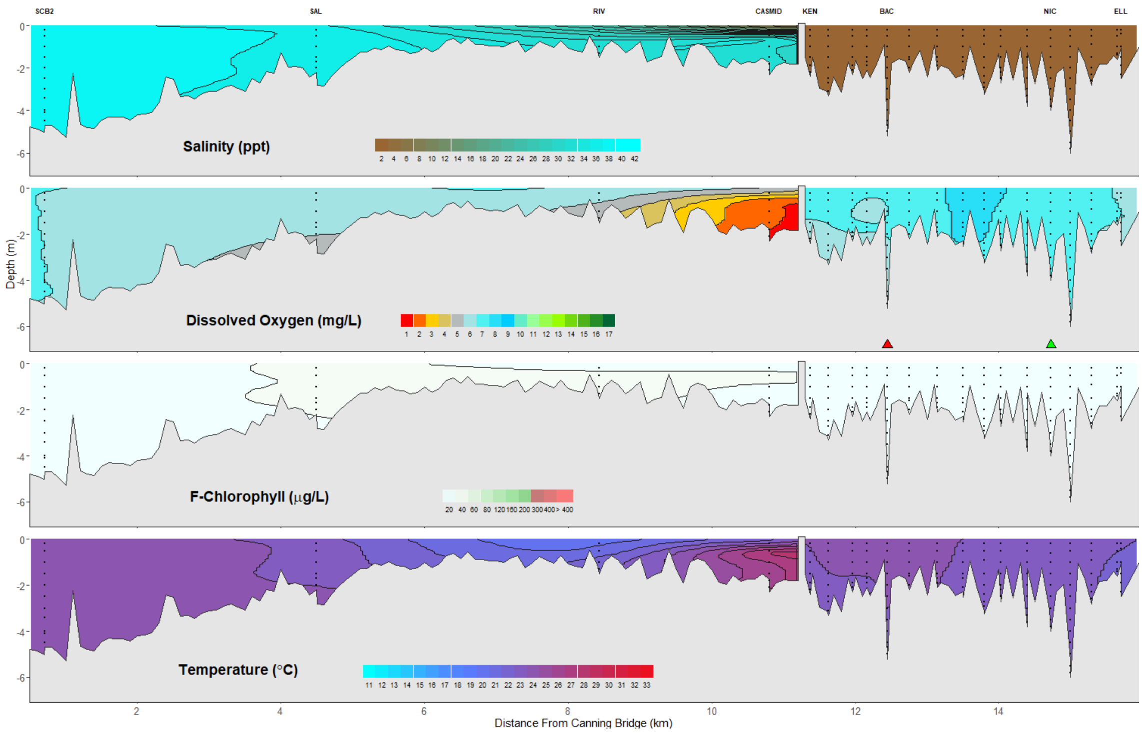

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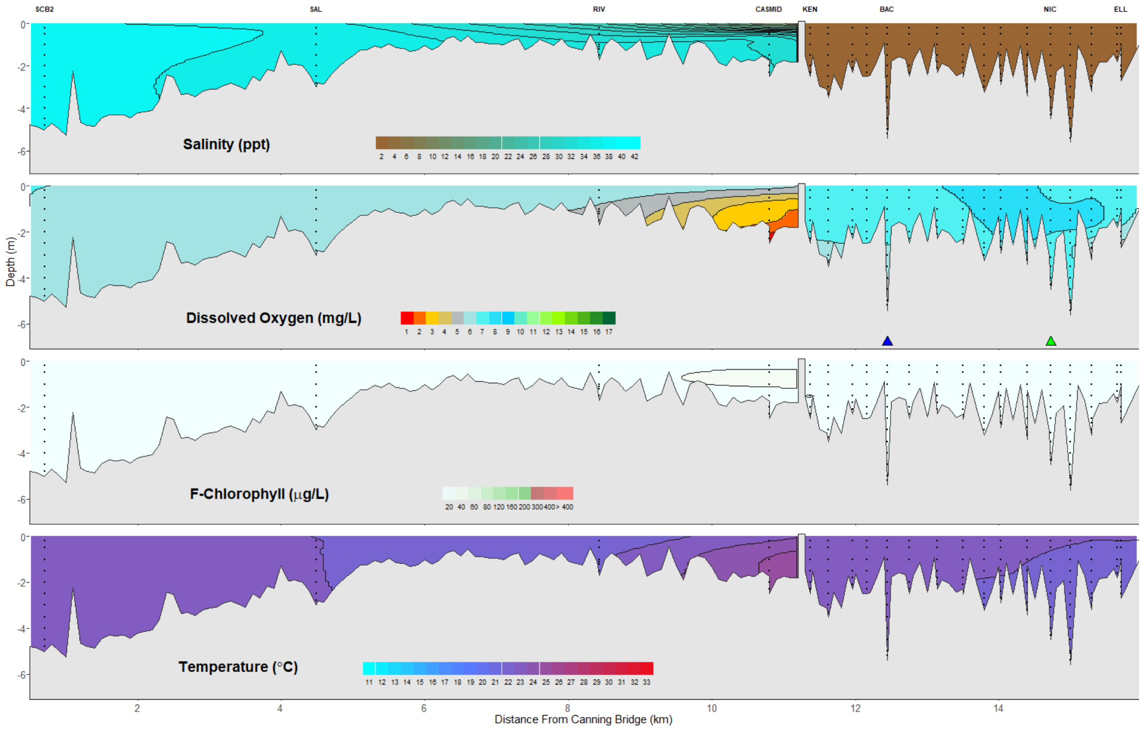
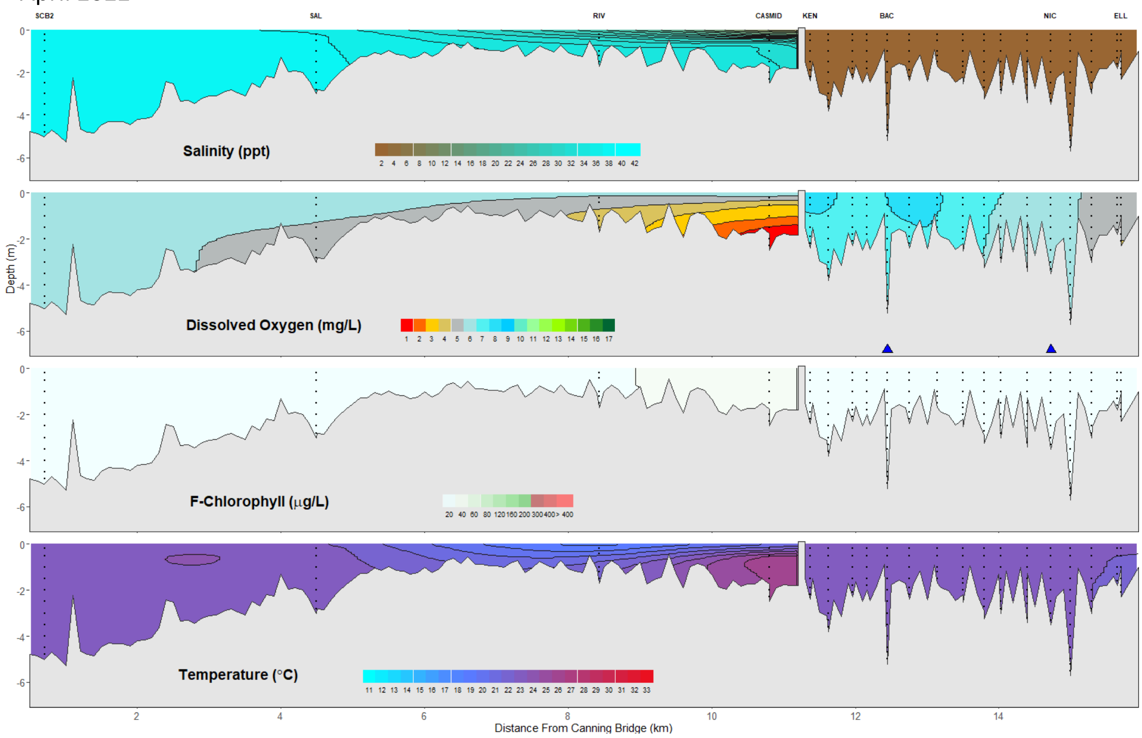


5th April 2022



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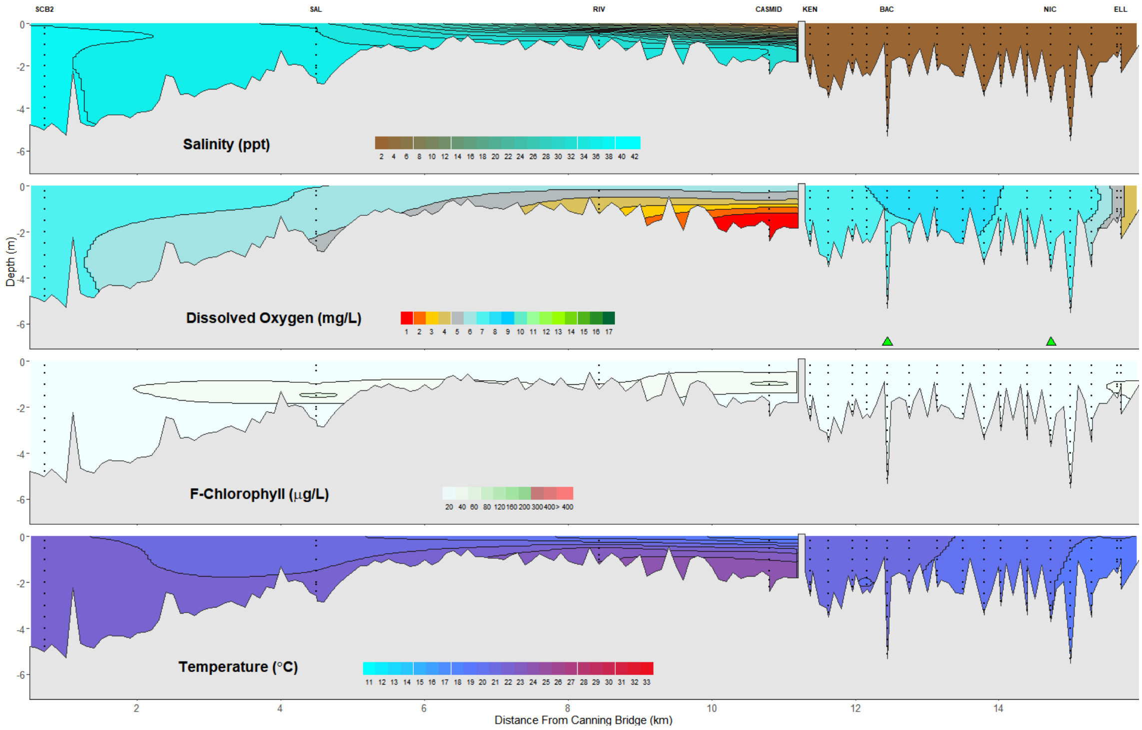
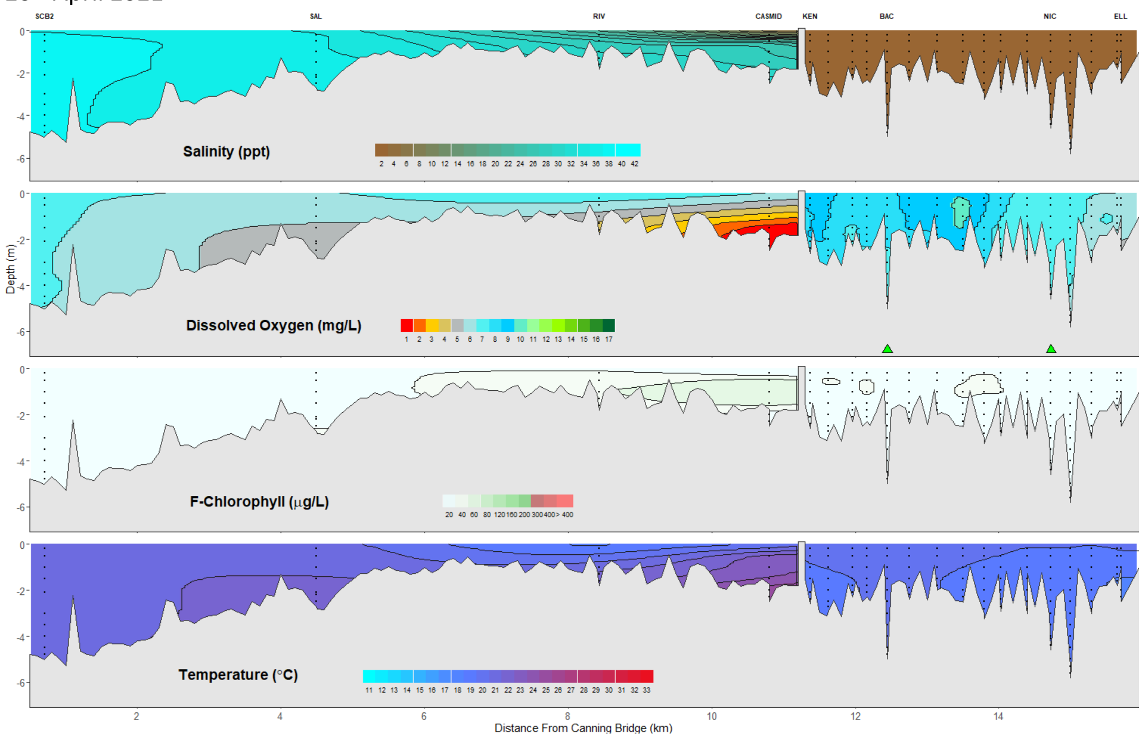


20th April 2021



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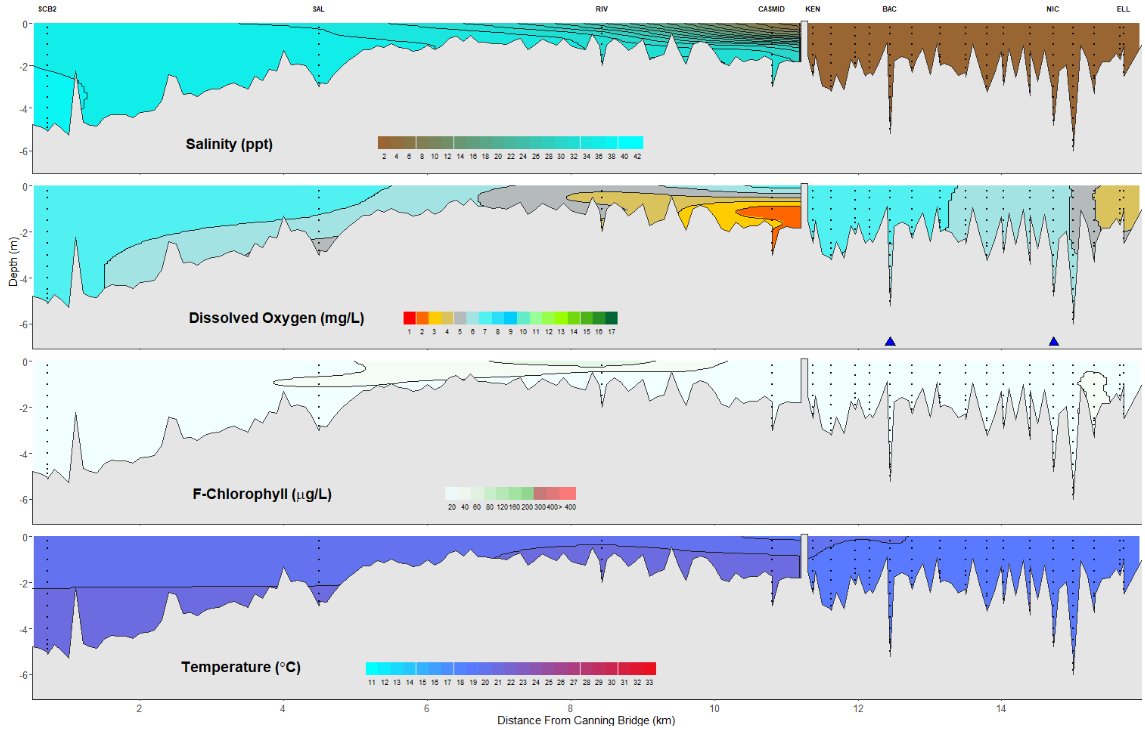
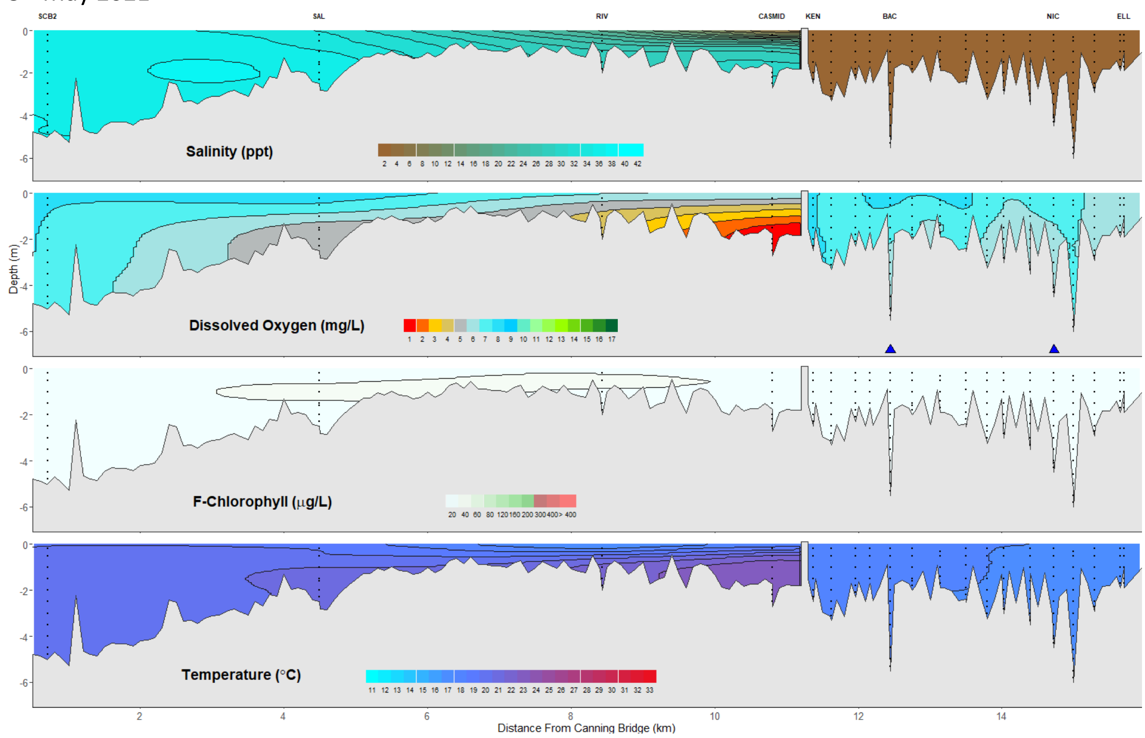


3rd May 2021



10th May 2021