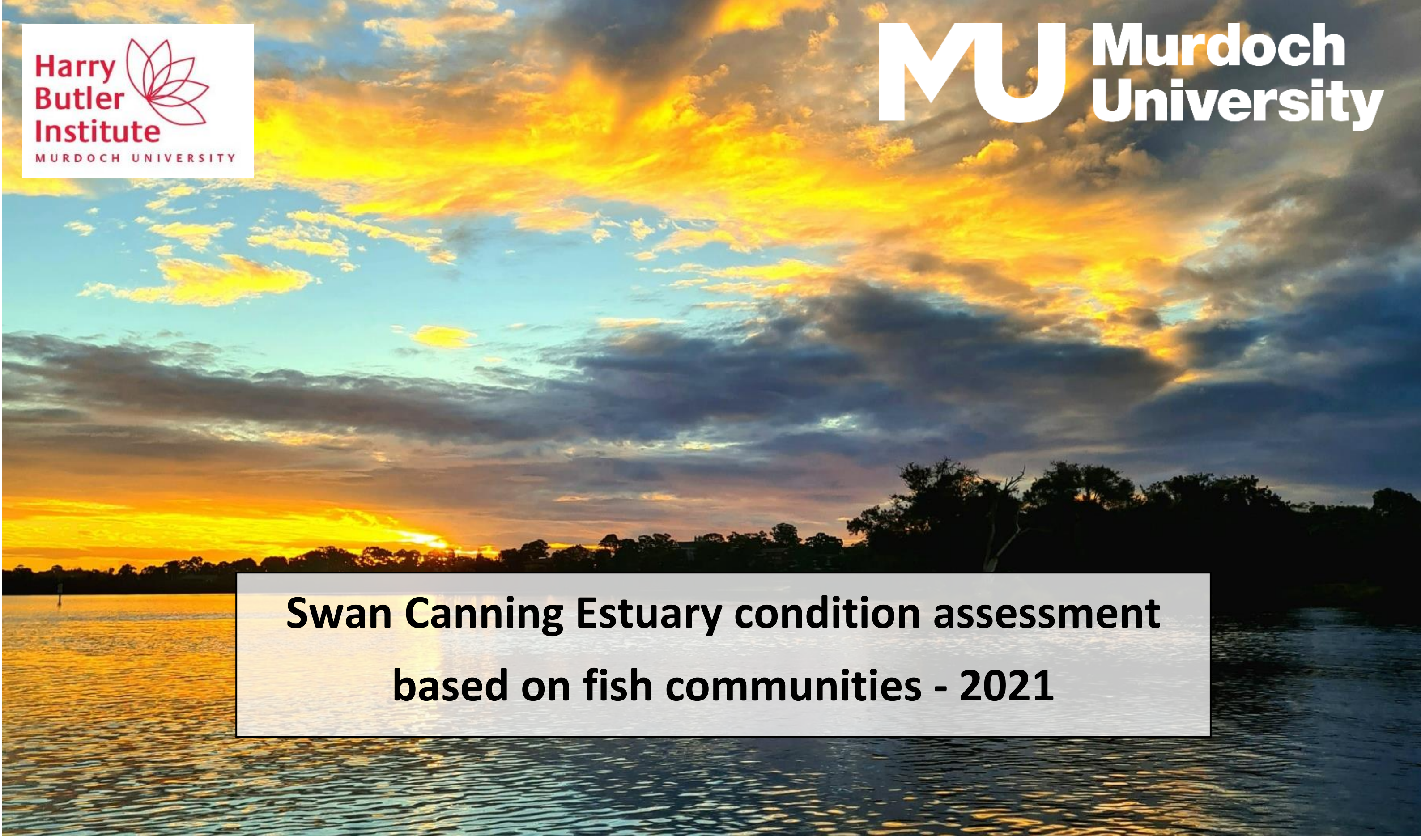

Swan Canning Estuary condition assessment based on fish communities - 2021

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Department of Biodiversity, Conservation and Attractions

GOVERNMENT OF WESTERN AUSTRALIA

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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 2021 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, nearshore waters of the estuary and also for its deeper, offshore waters, integrates information on various biological variables (metrics). Each of these metrics quantifies an aspect of the structure and/or function of estuarine fish communities, and together they respond to a range of stressors affecting the ecosystem.

Fish communities were sampled using different nets at six nearshore and six offshore sites in each of four management zones of the estuary (LSCE, Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE, Upper Swan Estuary) during summer and autumn of 2021. As many fish as possible were returned to the water alive after they had been identified and counted. The resulting data on the abundances of each fish species from each sample were used to calculate a Fish Community Index score (0–100). These index scores were then compared to established scoring thresholds to determine ecological condition grades (A–E) for each zone and for the estuary as a whole, based on the composition of the fish community.

Nearshore Fish Communities

The nearshore waters of the estuary as a whole were in fair/good (C/B) and fair condition (C) during the summer and autumn of 2021, respectively, 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 in the USE (good) and lowest in the MSE with a fair/poor (C/D) score. Both the LSCE and CE were borderline good and fair. By autumn, scores in the LSCE and MSE increased to good and fair, respectively, while those in the other two zones declined slightly from good to fair/good in the USE and good/fair to fair in the CE. Declines in the USE and CE were most likely related to stratification-induced hypoxia and algal blooms including that of the toxic dinoflagellate *Karlodinium* spp.. Scores in the MSE may have been supplemented due to the movement of fish from hypoxic deeper waters into shallower waters in that zone.

Small-bodied, schooling species of hardyheads (Atherinidae) and gobies (Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2021, representing 61% of all fish recorded and constituting four of the five most abundant nearshore species overall. The dominance of these species was slightly less in 2021 than in previous years due to large catches of the Australian Anchovy. Wallace's Hardyhead was the most abundant species overall and in the CE and USE, reflecting the preference of this species for more brackish conditions. Other abundant species of small, schooling fish included the Spotted Hardyhead, Common Hardyhead and Silverfish, each of which prefer more saline waters, and the Bluespot Goby in the USE, the Yelloweye Mullet and Yellowtail Grunter in the MSE and the Australian Anchovy in the CE.

In 2021 the greatest overall numbers of species in nearshore waters was recorded in the MSE and CE. This trend is slightly atypical for the Swan Canning Estuary where the number of species typically declines in an upstream direction and is attributed to stable and high salinities in the MSE and CE in 2021 facilitating the occurrence of more marine-spawning species.

Offshore fish communities

Overall, the offshore waters of the Swan Canning Estuary were in fair/good (C/B) condition in summer and fair (C) during autumn 2021, a slight reduction from the good (summer) and fair/good (autumn) conditions reported in 2020. Scores in the MSE, USE and CE all declined from summer to autumn in 2021 following heavily rainfall and strong freshwater flows in March. These conditions resulted in stratification and pronounced hypoxia in the deeper waters of these zones of the estuary, which also coincided with blooms of *Karlodinium* spp. and/or *Prorocentrum* spp.. In contrast, scores increased slightly in the unaffected LSCE zone, likely due to the movement of mobile fish away from upstream areas and into this zone.

As in most previous years of monitoring, Perth Herring was among the dominant species in offshore waters from all four zones comprising 25–81% of the total catches. Other abundant species included the Southern Eagle Ray and Tailor in the LSCE (33 and 16%, respectively, of the catch) and the Yellowtail Grunter in the MSE (14%) and USE (33%) and Black Bream in the USE (17%). More species and individuals were recorded from the offshore waters in 2021 than in any other monitoring year.

Overall

In summary, and across the estuary as a whole, the ecological condition of both nearshore and offshore waters in 2021 was assessed as fair/good (C/B) and fair (C) respectively, based on their fish communities. These results are consistent with the relatively stable trends in condition that have been observed in nearshore waters since 2011. In the case of the offshore waters, the score overall is lower than 2020, but similar to those between 2016 and 2019.

Swan Canning Estuary condition assessment based on fish communities - 2021

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

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

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

[a] A measure of 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 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 2021 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 fish 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.

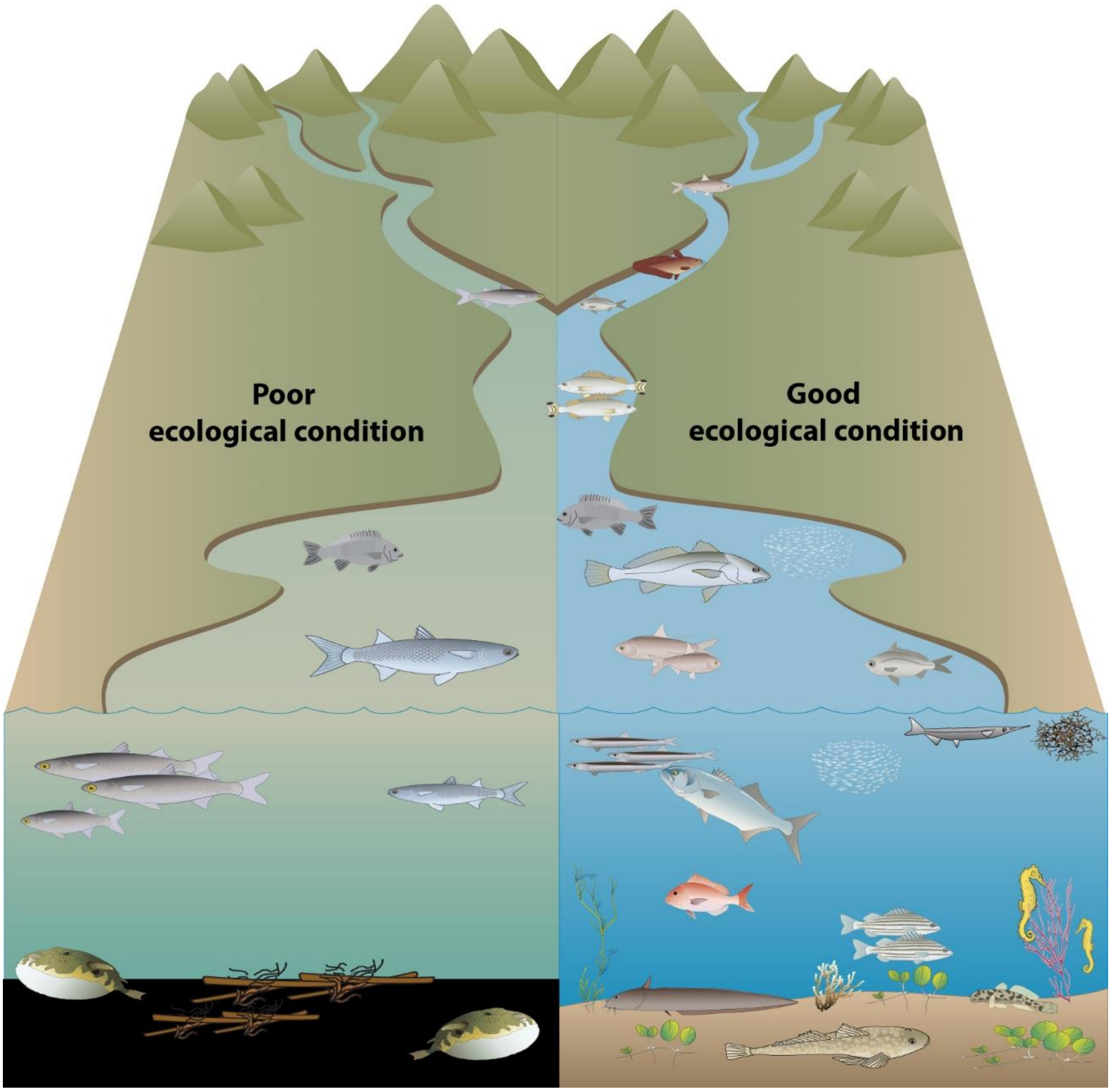


Figure 1. Conceptual diagram illustrating the predicted responses of the estuarine fish community to situations of poor and good ecological condition. Images courtesy of the Integration and Application Network [ian.umces.edu/symbols/].

4. Methods

Fish communities were sampled at six nearshore and six offshore sites in each of 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 (20 January – 4 February) and autumn (20 April – 5 May) of 2021. 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 FO25000254-2).

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 2021 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.

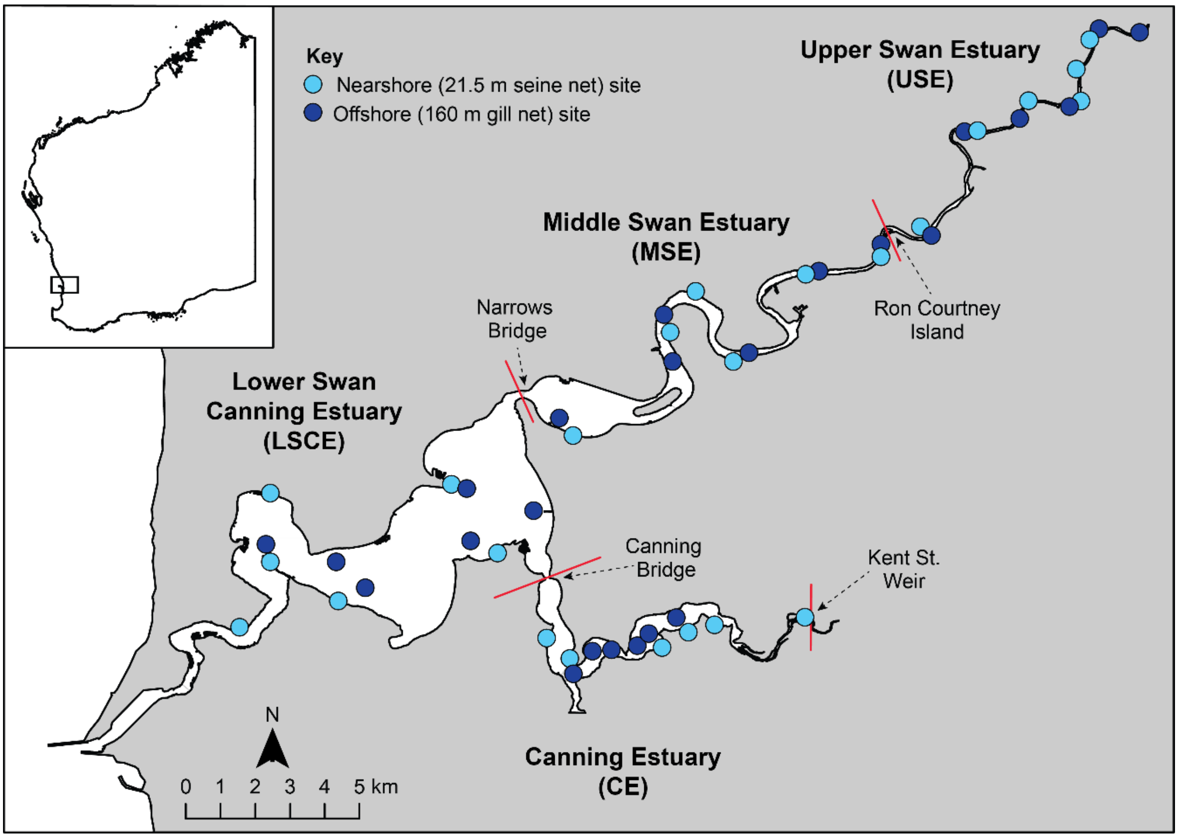


Figure 2. Locations of nearshore (light blue circles) and offshore (dark blue circles) sites in the Swan Canning Estuary where samples for the Fish Community Index of estuarine condition were collected.

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.

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

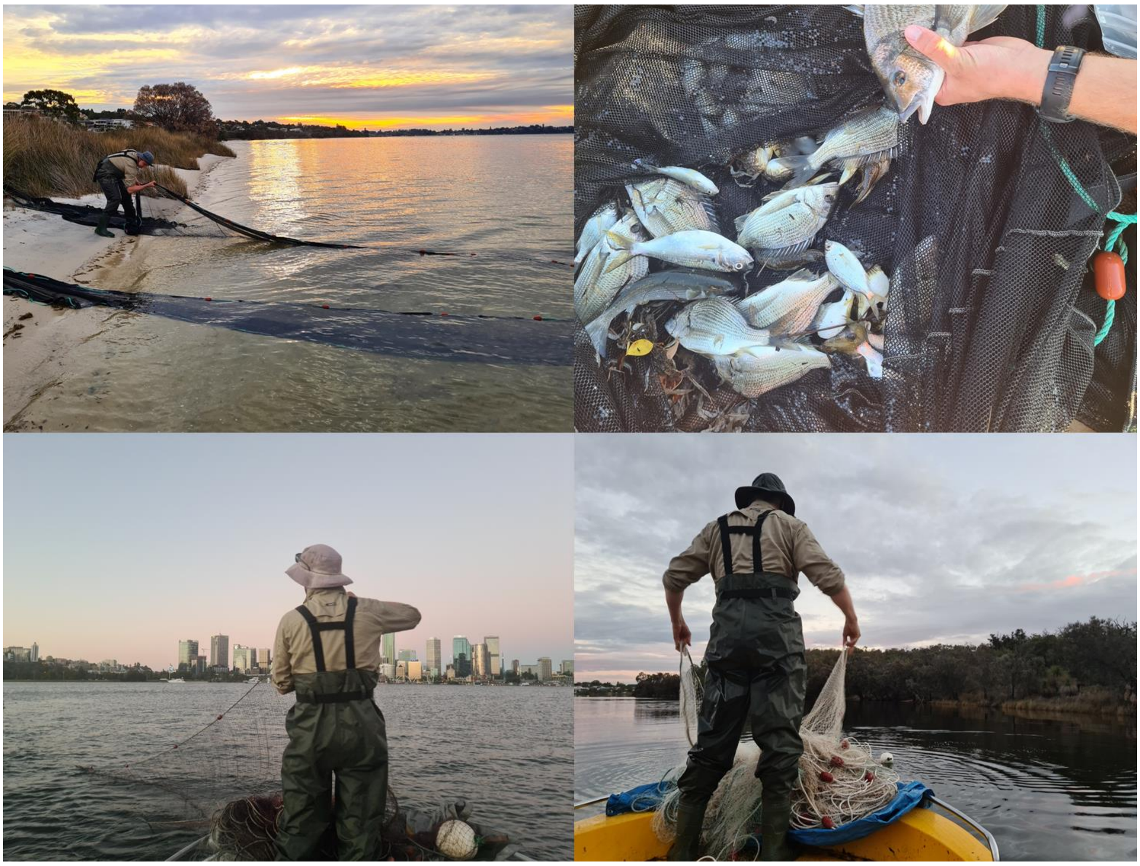


Figure 3. Photographs of the beach seine netting (upper row) used to sample the fish community in shallower, nearshore waters and the multimesh gill netting (lower row) used to sample fish communities in deeper, offshore waters of the Swan Canning Estuary. Images courtesy of Kurt Krispyn, Murdoch University.

5. Results and discussion

5.1 Context: water quality and environmental conditions during the 2021 monitoring period

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 (Appendix iv). The water column of the USE was brackish (salinity 8 - 18) in early January 2021, becoming more saline into February (minimum of 14) 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 38. Pockets of low dissolved oxygen (2 - 4 mg/L) occurred in parts of the USE upstream of the Caversham Oxygenation Plant and, during some weeks, downstream of the Guildford plant in the MSE. 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 ~23 °C in the LSCE to 27 - 28 °C in the USE. Blooms of the dinoflagellate *Alexandrium* spp. were present in December and early January but had disappeared prior to sampling occurring on 20 January (DBCA, unpublished data). *Karlodinium* spp. were detected in the LSCE, MSE and USE in January and February, but at cell densities well below DBCA trigger values.

In January the water column of the upper part of the CE (Riverton to Castledare) was influenced by temperature and salinity dynamics influencing oxygen concentration (Appendix iv) with bottom water hypoxia (low dissolved oxygen; < 2 mg/L), recorded at Castledare on 27 January. Towards the end of the summer sampling period (on 9 February), pronounced stratification influenced by freshwater flow was recorded, resulting in hypoxic conditions between Castledare and Riverton that continued into May. Relatively high levels of chlorophyll were detected in the upper part of the CE in from the end of January to the end of February with *Karlodinium* spp. recorded at sites throughout this zone in January and February (highest density 23,640 cells/mL; DBCA, unpublished data).

Significant rainfall occurred in the Swan-Avon catchment in the first week of March 2021 causing the greatest amount of flow recorded in March since 2017 and amongst the highest recorded from 1970 onwards (Department of Water and Environmental Regulation, 2021). This resulted in pronounced stratification in the LSCE, MSE, while the USE was essentially fresh (salinity < 5) in early March (Appendix iv). The sudden onset of flow and low oxygen conditions resulted in a small fish kill (~ 700 fish) in the MSE and USE comprising mainly Black Bream on 6 - 7 March (DBCA, personal communication). As flows subsided, stratification extended into the USE in the later weeks of March. The stratification was accompanied with hypoxic conditions throughout all three zones of the Swan axis of the estuary.

During autumn sampling (20 April – 5 May), marine conditions, *i.e.* salinities of ~35, were found throughout the LSCE, while both the MSE and USE were stratified (Appendix iv). Low dissolved oxygen concentrations were present in the bottom waters of the MSE and USE over this period and both the Guildford and Caversham oxygenation plants were operating. High concentrations of chlorophyll were detected in the MSE and USE, some of which were associated with a bloom of *Karlodinium* spp. (maximum density 13,760 cells/mL during the sampling period; DBCA, unpublished data). Cell densities of *Karlodinium* spp. exceeded DBCA algal bloom response trigger values at two sites in the MSE in the two weeks prior to autumn sampling occurring. Blooms of the dinoflagellate *Prorocentrum* spp. were recorded in the MSE and USE from the end of March to end of April with maximum densities of 38,120 cells/mL recorded. These blooms were associated with a red-brown discolouration of the water in these areas (DBCA, personal communication). Pronounced stratification was present in the upper parts of the CE in April and May and was associated with low dissolved oxygen concentrations. Chlorophyll levels were relatively high in April and blooms of *Karlodinium* spp. were detected in the same month with values exceeding trigger levels present at some sites (maximum 28,220 cells/mL at Castledare) in the latter half of that month (DBCA, unpublished data).

5.2 The fish community of the Swan Canning Estuary during 2021

Nearshore waters

Overall, the nearshore and offshore fish communities of the Swan Canning Estuary in 2021 were similar in composition to previous years (2012−2020). An estimated total of 16,905 fish, belonging to 35 species, were caught in seine net samples collected from the nearshore waters during summer and autumn. The total number of fish caught in 2021 (16,905) was less than in 2020 (22,699) and at the lower end of the range of values recorded annually since 2012 (*i.e.* 18,713 – 30,825). However, the 35 species recorded in 2021 was slightly greater than the 32 in 2019 and above the annual average of 31.8 (range = 25 – 35). A total of 63 fish species have been recorded in seine nets as part of this monitoring since 2012. The greatest number of species recorded in the nearshore waters was in the CE (26), followed by the MSE (24) and least in the USE (18; Table 3). Traditionally in the Swan-Canning and in similar estuaries in south-western Australia, the total number of species recorded in the nearshore waters of each zone declined in an upstream direction (Veale et al., 2014; Valesini et al., 2017). While the number of species in most zones were similar in 2021 to 2020 there was an increase from 20 to 26 in the CE. This can be explained by the presence of a wider range of marine-spawning species in the CE in 2021 than 2020, such as Tarwhine, Yellowfin Whiting and King George Whiting.

Hardyheads (family = Atherinidae) and gobies (family = Gobiidae) once again dominated catches from the nearshore waters of the estuary in 2021, representing 61% of all fish caught and containing four of the five most abundant nearshore species. In particular, Wallace’s hardyhead (*Leptatherina wallacei*) was again the most abundant species overall and in the CE and USE, comprising 25 and 41 % of all fish in these zones; Table 3). This reflects the preference of this species for fresh to brackish conditions (Prince and Potter, 1983; Potter et al., 2015b), which were evident in these zones during the 2021 monitoring period. Another atherinid species, the Spotted Hardyhead (*Craterocephalus mugiloides*), which prefers brackish salinities, was amongst the most abundant species in the CE, MSE and LSCE. 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). Other abundant species included the Bluespot goby (*Pseudogobius olorum*) in the USE where it typically occurs (Hogan-West et al., 2019), the Yelloweye Mullet (*Aldrichetta forsteri*) and Yellowtail Grunter (*Amniataba caudavittata*) in the MSE, the Australian Anchovy (*Engraulis australis*) in the CE and Perth Herring (*Nematalosa vlaminghi*) 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 all zones except the LSCE and the Pearl Cichlid (*Geophagus brasiliensis*) in the CE (Table 3). These species occur regularly in this annual monitoring program, being found in 10 and 8 of the last ten years, respectively. Numbers of the Eastern Gambusia were amongst the lowest recorded (*i.e.* 52; range = 37 – 1,633), while those of the Pearl Cichlid were higher (*i.e.*42; range = 0 – 60). It should also be noted that seine net sampling yielded a new species record for the Swan-Canning Estuary in the Dusky Frillgoby (*Bathygobius fuscus*). This species has not been formally recorded in the Swan-Canning Estuary before (Hogan-West et al., 2019) nor in any other estuary in south-western Australia (Tweedley, unpublished data). This species is generally confined to tropical waters from Exmouth (WA) to the Queensland/New South Wales border (Atlas of Living Australia, 2022), but is known to occur off Garden Island in Cockburn Sound (Whisson and Hoschke, 2021) and was also recorded in the Peel-Harvey for the first time in 2021 (Tweedley et al., 2022). This new record and the presence of the Largemouth Goby in this survey in 2020 (Tweedley et al., 2021) does highlight the benefit of an annual monitoring program in helping to

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 2021. 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	Western Hardyhead	-	-	**156.68**	**24.60**	11.06	7.28	**83.84**	**40.70**
Engraulis australis	Australian Anchovy	2.73	1.24	**217.10**	**34.08**	2.44	1.61	6.97	3.38
Craterocephalus mugiloides	Spotted Hardyhead	**22.63**	**10.29**	**144.61**	**22.70**	**14.15**	**9.31**	6.90	3.35
Leptatherina presbyteroides	Silver Fish	**82.90**	**37.68**	18.25	2.86	2.37	1.56	-	-
Atherinomorus vaigiensis	Common Hardyhead	**55.89**	**25.40**	3.95	0.62	12.00	7.89	-	-
Nematalosa vlaminghi	Perth Herring	-	-	20.98	3.29	5.17	3.40	**24.21**	**11.75**
Aldrichetta forsteri	Yelloweye Mullet	7.11	3.23	9.12	1.43	**29.31**	**19.28**	-	-
Pseudogobius olorum	Bluespot Goby	-	-	4.02	0.63	2.16	1.42	**34.99**	**16.98**
Favonigobius punctatus	Yellowspotted Sandgoby	6.47	2.94	4.09	0.64	7.90	5.20	19.83	9.63
Amniataba caudavittata	Yellowtail Grunter	0.50	0.23	6.54	1.03	**24.93**	**16.40**	3.16	1.53
Acanthopagrus butcheri	Black Bream	0.14	0.07	6.97	1.09	13.94	9.17	10.06	4.88
Atherinosoma elongatum	Elongate Hardyhead	2.37	1.08	22.13	3.47	-	-	-	-
Torquigener pleurogramma	Weeping Toadfish	15.95	7.25	1.01	0.16	3.81	2.50	-	-
Ostorhinchus rueppellii	Western Gobbleguts	4.74	2.16	9.91	1.56	0.07	0.05	0.07	0.03
Hyperlophus vittatus	Sandy Sprat	-	-	-	-	11.93	7.85	2.16	1.05
Sillago burrus	Western Trumpeter Whiting	7.54	3.43	-	-	1.65	1.09	-	-
Afurcagobius suppositus	Southwestern Goby	-	-	6.25	0.98	0.57	0.38	2.37	1.15
Favonigobius lateralis	Southern Longfin Goby	7.33	3.33	0.14	0.02	0.07	0.05	-	-
Pelates octolineatus	Western Striped Grunter	2.08	0.95	0.07	0.01	3.02	1.99	0.07	0.03
Gerres subfasciatus	Common Silverbiddy	0.14	0.07	2.44	0.38	1.01	0.66	0.79	0.38
Gambusia holbrooki *	Eastern Gambusia	-	-	0.14	0.02	0.14	0.09	3.45	1.67

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
Mugil cephalus	Sea Mullet	-	-	1.22	0.19	2.30	1.51	0.07	0.03
Arenigobius bifrenatus	Bridled Goby	-	-	-	-	-	-	3.16	1.53
Geophagus brasiliensis *	Pearl Cichlid	-	-	0.14	0.02	-	-	2.87	1.39
Pomatomus saltatrix	Tailor	-	-	0.29	0.05	1.36	0.90	0.79	0.38
Gymnapistes marmoratus	Soldier	1.15	0.52	-	-	-	-	-	-
Sillago schomburgkii	Yellowfin Whiting	0.07	0.03	0.22	0.03	0.22	0.14	-	-
Rhabdosargus sarba	Tarwhine	-	-	0.36	0.06	-	-	-	-
Haletta semifasciata	Blue Weed Whiting	0.22	0.10	-	-	-	-	-	-
Pseudorhombus jenynsii	Smalltooth Flounder	0.07	0.03	-	-	0.07	0.05	-	-
Stigmatopora argus	Spotted Pipefish	0.07	0.03	-	-	-	-	-	-
Platycephalus westraliae	Yellowtail Flathead	0.07	0.03	-	-	-	-	-	-
Sillaginodes punctatus	King George Whiting	-	-	0.07	0.01	-	-	-	-
Bathygobius fuscus	Ducky Frillgoby	0.07	0.03	-	-	-	-	-	-
Contusus brevicaudus	Prickly Toadfish	-	-	0.07	0.01	-	-	-	-

	LSCE	CE	MSE	USE
Total number of species	**22**	**26**	**24**	**18**
Average total fish density (fish 100m^{-2})	**220**	**637**	**152**	**206**
Total number of fish	**3,066**	**8,864**	**2,111**	**2,864**

detect the presence of new and/or non-native species due to climate change induced range extensions and anthropogenic activities.

Offshore waters

Samples collected from offshore waters in summer and autumn 2021 using gill nets returned 2,933 fish, comprising 23 species (Table 4). This number of fish was almost 50% more than in 2018 and 2019 and the most recorded since monitoring began in 2012 (range = 1,125 to 2352). The 23 species caught was also the greatest recorded (range = 17 to 22) 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 2021 decreased in an upstream direction from 16 in the LSCE to 14 species in the CE, and 11 in both the MSE and USE. With the exception of the MSE, the number of species were amongst the highest recorded during FCI sampling.

As in the nine previous years of monitoring, Perth Herring was among the dominant species in offshore waters overall (55%) and from all four zones, comprising 25–81% of the total catches (Table 4). The Southern Eagle Ray (*Myliobatis tenuicaudata*) and Tailor (*Pomatomus saltatrix*) were abundant in the LSCE (33 and 16% of the catch, respectively) as were the Common Silverbiddy (*Gerres subfasciatus*) in the CE (5%), Yellowtail Grunter (*Amniataba caudavittata*) in the MSE (14%) and USE (33%) and Black Bream (*Acanthopagrus butcheri*) in the USE (17%). The non-native Pearl Cichlid was caught in the USE. Catches of several species including Sea Mullet (*Mugil cephalus*), Black Bream, Yellowtail Grunter, Tailor and the Southern Eagle Ray were at least 200% greater than those that occurred on average between 2012 and 2020.

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 2021. 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	**87**	**25.14**	**502**	**73.39**	**521**	**80.78**	**491**	**39.03**
Amniataba caudavittata	Yellowtail Grunter	6	1.73	25	3.65	**88**	**13.64**	**415**	**32.99**
Acanthopagrus butcheri	Black Bream			2	0.29	4	0.62	**214**	**17.01**
Pomatomus saltatrix	Tailor	**57**	**16.47**	76	11.11	**17**	**2.64**		
Myliobatis tenuicaudatus	Southern Eagle Ray	**115**	**33.24**	1	0.15				
Mugil cephalus	Sea Mullet			13	1.90	2	0.31	100	7.95
Pelates octolineatus	Western Striped Grunter	37	10.69	7	1.02	5	0.78		
Gerres subfasciatus	Common Silverbiddy	5	1.45	**32**	**4.68**	1	0.16		
Platycephalus westraliae	Yellowtail Flathead	13	3.76	4	0.58	2	0.31	7	0.56
Aldrichetta forsteri	Yelloweye Mullet			12	1.75			14	1.11
Engraulis australis	Australian Anchovy	3	0.87	1	0.15	1	0.16	5	0.40
Torquigener pleurogramma	Weeping Toadfish	9	2.60						
Carcharinas leucas	Bull Shark					3	0.47	3	0.24
Sillago burrus	Western Trumpeter Whiting	6	1.73						
Pseudocaranx wrightii	Skipjack Trevally	1	0.29	5	0.73				
Elops machnata	Australian Giant Herring							5	0.40
Cnidoglanis macrocephalus	Estuary Cobbler	1	0.29	3	0.44				
Sillago schomburgkii	Yellowfin Whiting	2	0.58	1	0.15	1	0.16		
Argyrosomus japonicus	Mulloway							3	0.24
Ostorhinchus rueppellii	Western Gobbleguts	2	0.58						
Heterodontus portusjacksoni	Port Jackson Shark	1	0.29						
Arripis georgianus	Australian Herring	1	0.29						
Geophagus brasiliensis *	Pearl Cichlid							1	0.08
	Total number of species	**16**		**14**		**11**		**11**	
	Average catch rate (fish/net set)	**29**		**57**		**54**		**105**	
	Total number of fish	**346**		**684**		**645**		**1,258**	

5.3 Ecological condition in 2021

Nearshore waters

Based on fish communities, the ecological condition of the nearshore waters of the Swan Canning Estuary was fair/good (C/B) in summer and fair (C) in autumn (Fig. 4). The condition of each zone varied during summer (mean FCI scores 58–71), being best in the USE (good; B) and lowest in the MSE with a fair/poor score. Both the LSCE and CE were borderline, between good and fair. By autumn, scores in the LSCE and MSE increased to good and fair, respectively, while those in the other two zones declined slightly going from good to fair/good in the USE and from good/fair to fair in the CE.

Radar plots of the nearshore metric scores for each zone in summer revealed that the USE scored very well in the several positive metrics, *i.e.* the *Number of species*, *Number of estuarine spawning species*, *Proportion of estuarine-spawning individuals, Number of trophic specialist species*, *Number of benthic-associated species* (Fig. 5a). Furthermore, this zone received high scores for several negative metrics, *i.e. Proportion of detritivores* and *Total number of P. olorum.* This indicates that this zone contained estuarine-spawning benthic species, *e.g.* gobies other than *P. olorum* that do not feed on decaying organic matter. The presence and abundance of such species would be facilitated by the relatively high dissolved oxygen concentrations throughout most of this zone during summer.

The fair/poor score in the MSE reflects the relatively low score for *Number of species, Number of benthic-associated species, Number of estuarine spawning species* and the *Number of trophic specialist species,* albeit score for metrics such as *Proportion of detritivores, Proportion of P. olorum* and *Total number of P. olorum* were very high (Fig. 5a). This reflects the limited number of species recorded in this zone in this season and the dominance of pelagic species such as Yelloweye Mullet and Yellowtail Grunter that are opportunist or omnivorous feeders and the low occurrences of gobies (including *P. olorum*) and other benthic fish. Although the ichthyotoxic dinoflagellate *Karlodinium* spp. (Place et al., 2012; Adolf et al., 2015) was recorded in this zone, cell counts were lower than in the USE and all below the trigger values suggesting this was not the direct cause of the lower FCI scores.

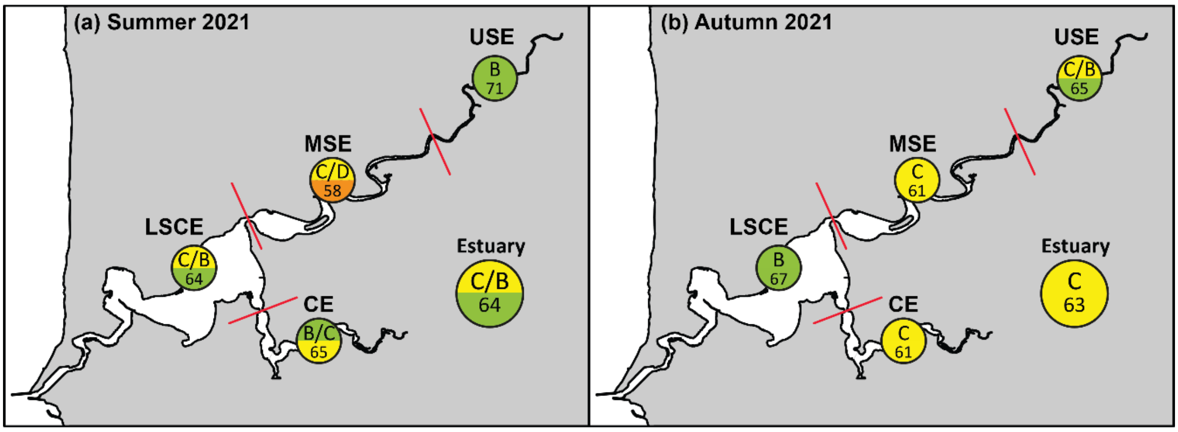


Figure 4. Average nearshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2021.

(a) Summer 2021

(b) Autumn 2021

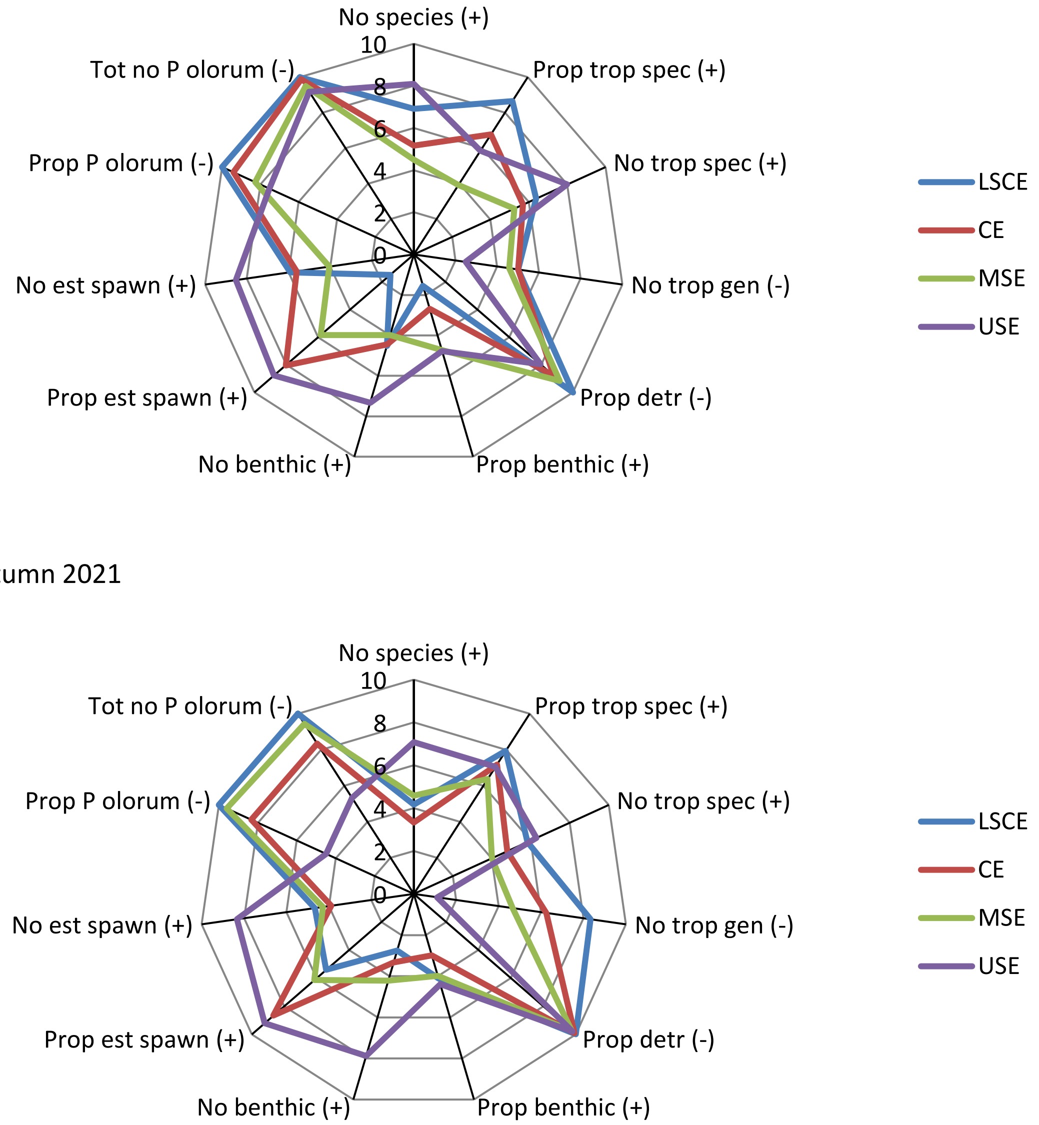


Figure 5. Average scores (0–10) for each component metric of the nearshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2021. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying 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.

Similar scores were recorded in the LSCE and CE, with these zones, like the others receiving good scores for the *Proportion of detritivores, Proportion of P. olorum* and *Total number of P. olorum* and, in the case of the former zone, the *Proportion of trophic specialist species* and *Number of trophic generalist species.* However, as in previous years, the LSCE did score relatively poorly in the *Number of estuarine-spawning species*, *Proportion of estuarine-spawning individuals* and *Number of benthic-associated species* metrics. This is likely due to the marine like salinities resulting in those species moving further upstream (se Valesini et al., 2017) and so it is relevant that scores for this metric were high in the USE.

In autumn, scores for the USE and CE had declined, while those for the LSCE and MSE increased. Radar plots showed that the lower score in the USE was due mainly to increased numbers of *P. olorum* lowering the negative metrics of *Proportion of P. olorum* and *Total number of P. olorum*. This species prefers lower salinities (Hogan-West et al., 2019), which occurred after the substantial freshwater flow in March. Moreover, these species are relatively tolerant of the hypoxic conditions present in this zone at this time as they are able to employ aquatic surface respiration and ventilate their gills at the surface to persist in waters with low oxygen (Gee and Gee, 1991). In contrast other species may have moved away, thus lowering the *Number of species.* In this zone at this time, *Karlodinium* spp. was present (up to 5,660 cells/ml at Kingsley) and *Prorocentrum* spp. (up to 36,160 cells/ml at Kingsley). Such blooms have been linked to reduced FCI scores and fish kills (Hallett, 2016, 2018) and a small number of dead fish were observed in the USE and MSE (DBCA, personal communication). Nearshore scores in the MSE remained fairly similar between summer and autumn, despite the occurrence of greater densities of *Karlodinium* spp. than in the USE, particularly in the two weeks prior to sampling (up to 45,440 cells/ml at St. John's Hospital, Rivervale) and the occurrence of associated hypoxia. The lack of a decline in metric scores (Fig. 5) may reflect the movement of fish from the deeper offshore waters into the nearshore areas (see below).

Karlodinium spp. was also present in the CE in autumn (up to 9,300 cells/ml at Castledare) together with hypoxia at the upper reaches of this zone, and these factors may have contributed to the decline in the metric scores for the *Number of species, Number of benthic-associated species* and *Proportion of benthic-associated individuals* and increased the abundance of *P. olorum.* Increased scores in the LSCE reflect increases in the *Proportion of estuarine-spawning individuals* and the *Proportion of benthic-associated individuals,* which could reflect the movement downstream of species to avoid the hypoxic and algal blooms in the more upstream zones.

Offshore waters

The ecological condition of the offshore waters of the Swan Canning Estuary ranged between good and fair during summer of 2021, being best in the LSCE (B) and worst in the CE (C; Fig. 6a). During autumn, the condition of the LSCE remained the same, but those in the other three zones decreased to fair (C) in the MSE and poor (D) in the USE and CE. Overall, the score for the estuary as a whole declined slightly from fair/good in summer to fair in autumn.

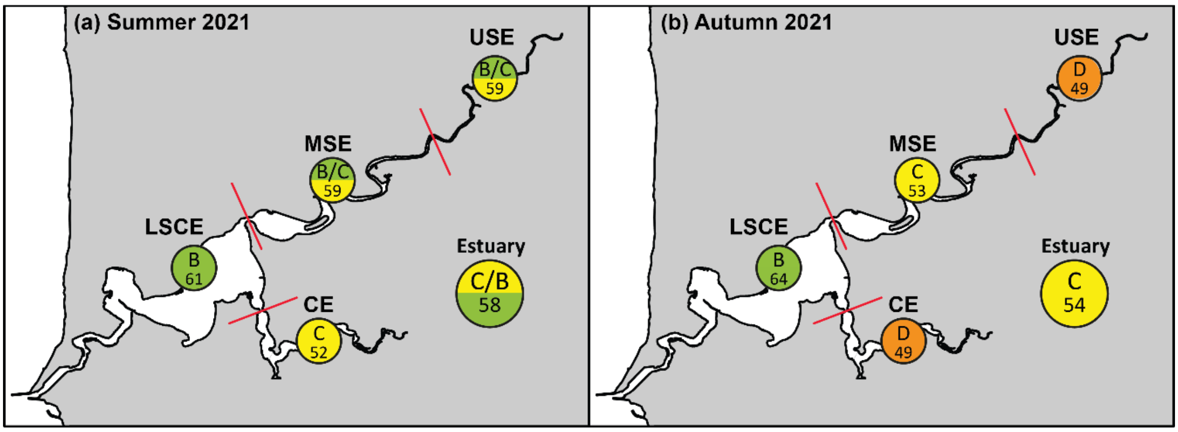
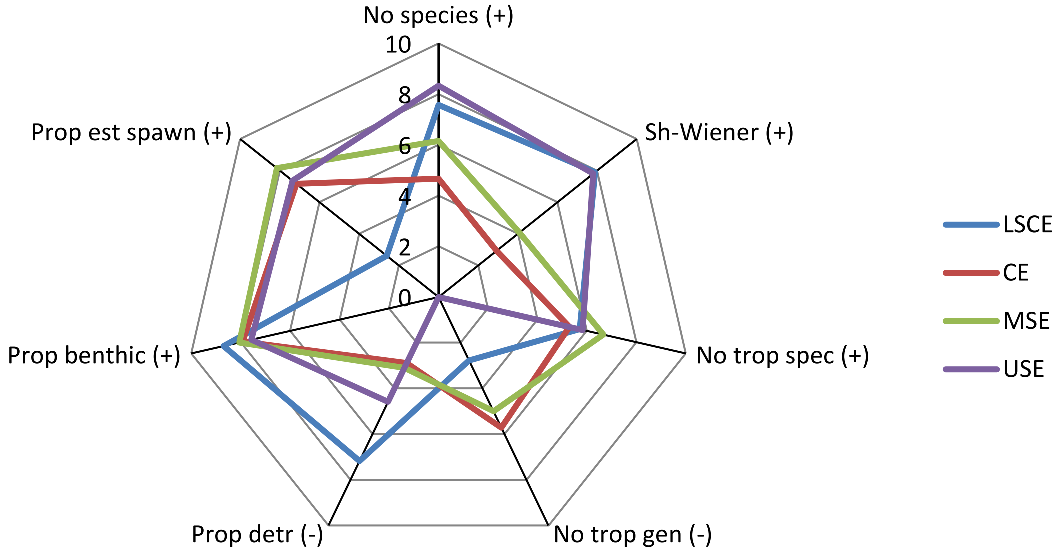


Figure 6. Average offshore Fish Community Index scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary, and for the estuary as a whole, in summer and autumn of 2021.

Radar plots of the offshore metric scores for the CE (Fig. 7) showed that the lower offshore FCI score in summer 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). Reflecting the stratification and associated hypoxic conditions combined with the presence of *Karlodinium* spp.. In contrast the LSCE scored highest in most metrics except the *Proportion of estuarine-spawning individuals,* which could be due to the marine-like salinities occurring in this region at this time favouring those species with a preference for saline conditions.

(a) Summer 2021



(b) Autumn 2021

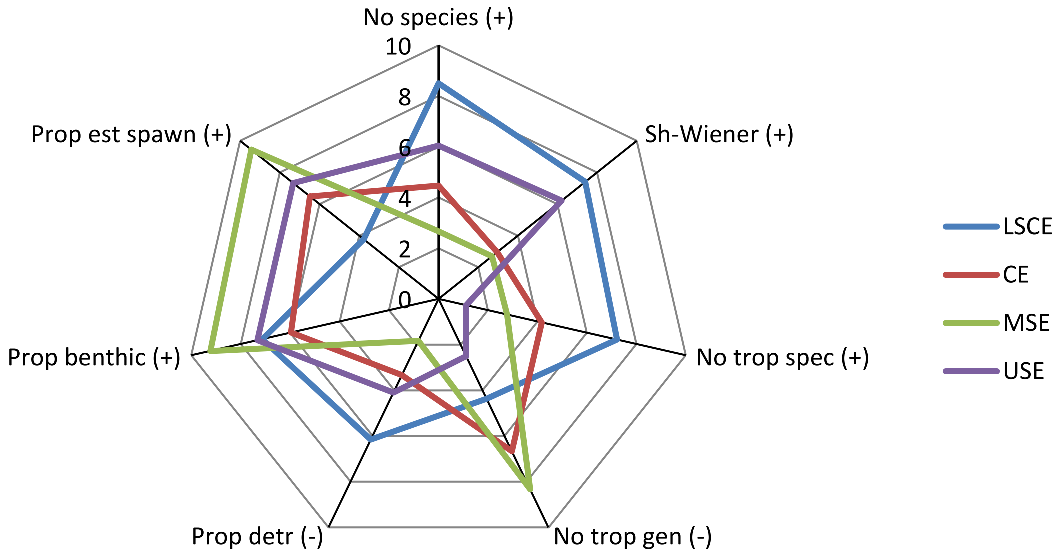


Figure 7. Average scores (0–10) for each component metric of the offshore Fish Community Index, calculated from samples collected throughout the LSCE, CE, MSE and USE zones in (a) summer and (b) autumn 2021. Note that an increase in the score for positive metrics (+) reflects an increase in the underlying 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 foe the LSCE changed by 3 points from summer to autumn, the ecological condition of the offshore waters of the MSE, CE and particularly USE declined by 10 points (Fig. 6). These patterns reflect the effects of pronounced hypoxia in the deeper waters caused by heavily rainfall and strong freshwater flows in March. This stratification coincided with blooms of *Karlodinium* spp. and/or *Prorocentrum* spp.. Metrics like the *Number of species* and *Shannon-Wiener* declined markedly in the MSE, USE and CE, but the former metric increased in the LSCE. This suggest that the more mobile species may have moved into nearshore waters where oxygen concentrations were likely higher or downstream into the LSCE where there was no stratification or hypoxia and where cell counts of *Karlodinium* spp. and *Prorocentrum* spp. were far lower. Similar avoidance behaviours and their effects of FCI scores have been documented during previous hypoxic events and algal blooms in the Swan-Canning (Cottingham et al., 2014; Hallett et al., 2016).

Longer term trends in ecological condition

Results indicate that the nearshore waters of the Swan Canning Estuary as a whole were in fair/good condition (C/B) during 2021, consistent with the overall trend since 2011, except for 2014 and 2016 when they were in good condition (B; Fig. 8). The mean offshore FCI score for the estuary as a whole indicated fair condition (C) during 2021, which is a decrease from that in 2020, *i.e.* good (B), which was the highest score since 2015. Thus, the current score of fair is in line with the trend from 2016 onwards (Fig. 9). This reflects the consistent good/fair scores throughout all zones (except the offshore waters of the CE and USE in autumn) despite the presence of widespread hypoxia at times and several algal blooms during this year's monitoring period.

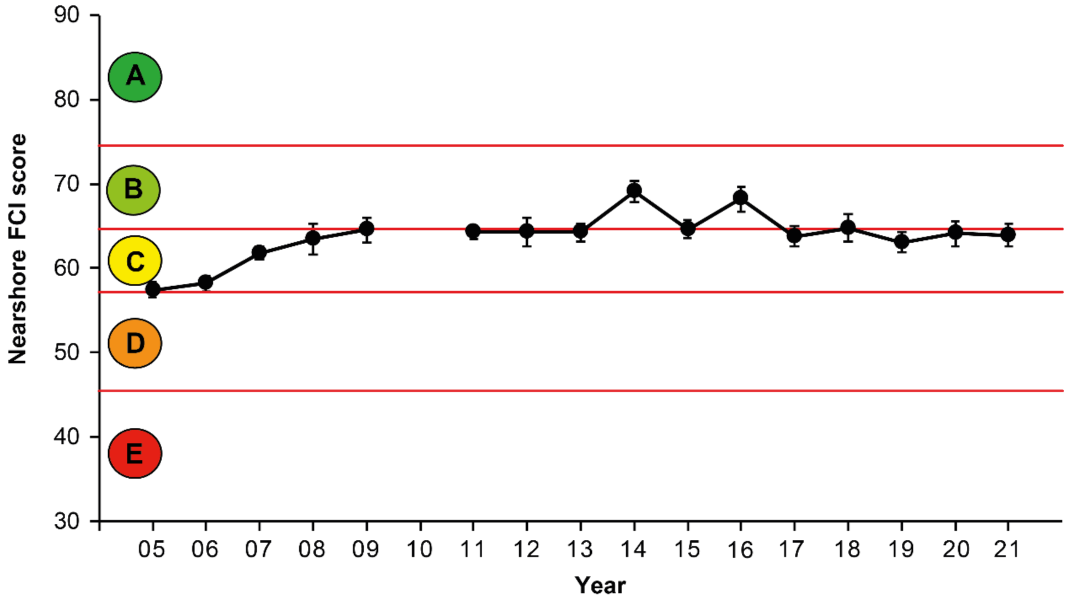


Figure 8. Trend plot of average (±SE) nearshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor) for the Swan Canning Estuary between 2005 and 2021. Red lines denote boundaries between condition grades.

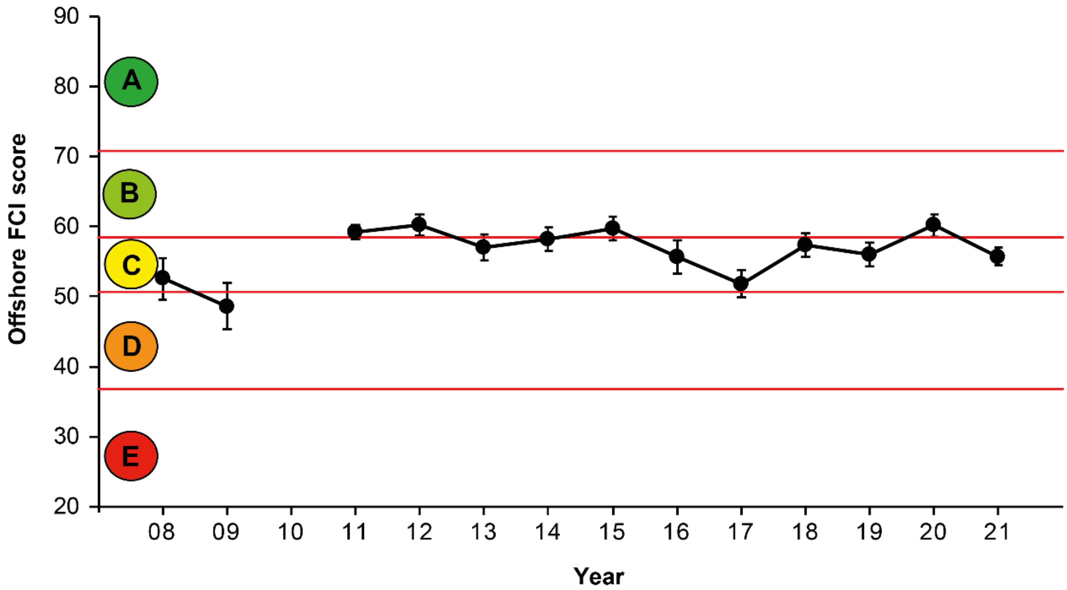


Figure 9. Trend plot of average (±SE) offshore Fish Community Index (FCI) scores and resulting condition grades (A, very good; B, good; C, fair; D, poor; E, very poor), for the Swan Canning Estuary as a whole, between 2008 and 2021. Red lines denote boundaries between condition grades.

Summary

The Fish Community Index (FCI) considers the fish community as a whole and provides a 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 estuary as a whole, the ecological condition of both nearshore and offshore waters in 2021 was assessed as fair/good (C/B) and fair (C) respectively, based on their fish communities (Table 5). These results are consistent with the relatively stable trends in condition that have been observed in nearshore waters since 2011. In the case of the offshore waters, the score overall is lower than 2020, where despite the presence of extensive blooms of *Alexandrium* spp. and, to a lesser extent, *Karlodinium* spp. there was no widespread or severe hypoxia resulting in one of the best annual scores. The slightly lower scores in 2021 reflect the presence of hypoxia and algal blooms in the MSE, USE and CE.

Overall, the offshore waters of the CE exhibited by the lowest scores of any zone in 2021. Since the start of regular fish community monitoring in 2012, 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 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 2021 monitoring period (mean of all summer and autumn of 2021). 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	65.28	B/C	62.14	B
CE	62.96	C	50.45	D/C
MSE	59.46	C	55.85	C
USE	67.94	B	54.36	C
Estuary	**63.91**	**C/B**	**55.70**	**C**

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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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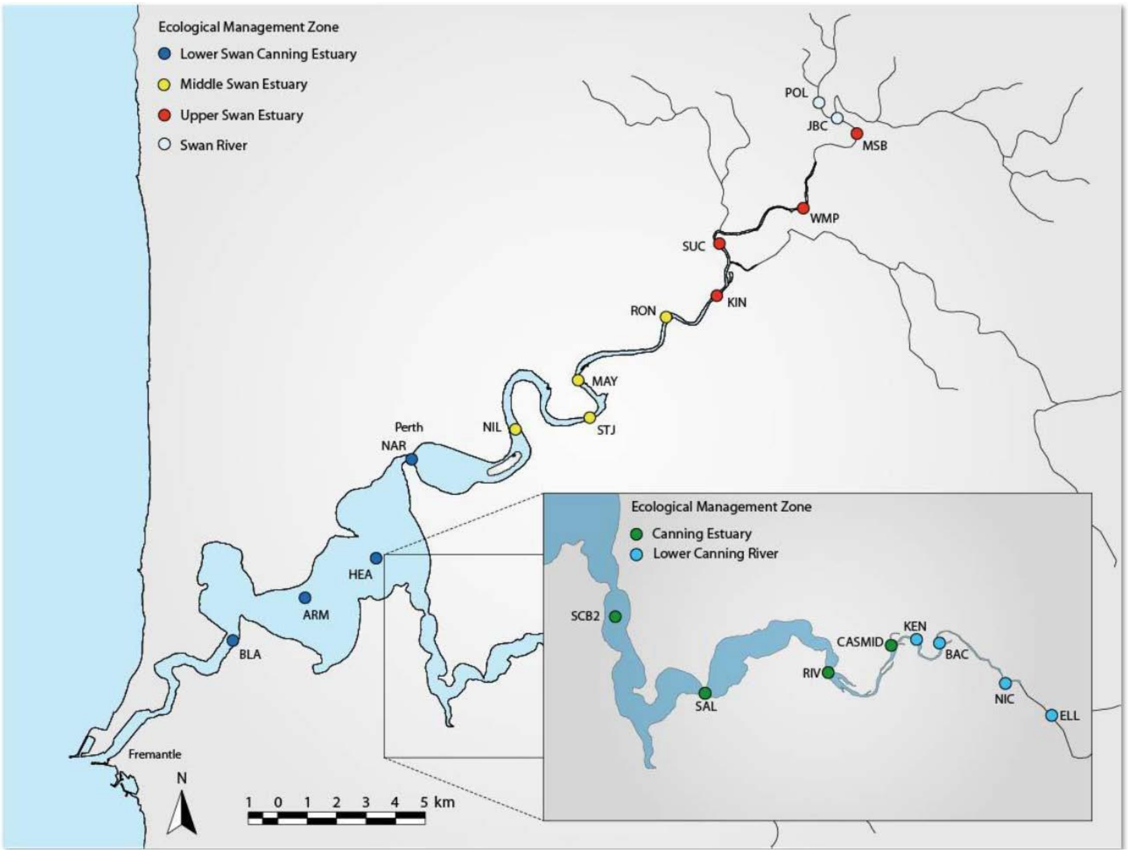
Appendix (iii). List of species caught from the Swan Canning Estuary, and their functional guilds: D, Demersal; P, Pelagic; BP, Bentho-pelagic; SP, Small pelagic; SB, Small benthic; MS, Marine straggler; MM, Marine migrant; SA, Semi-anadromous; ES, Estuarine species; FM, Freshwater migrant; ZB, Zoobenthivore; 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
Pelates 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

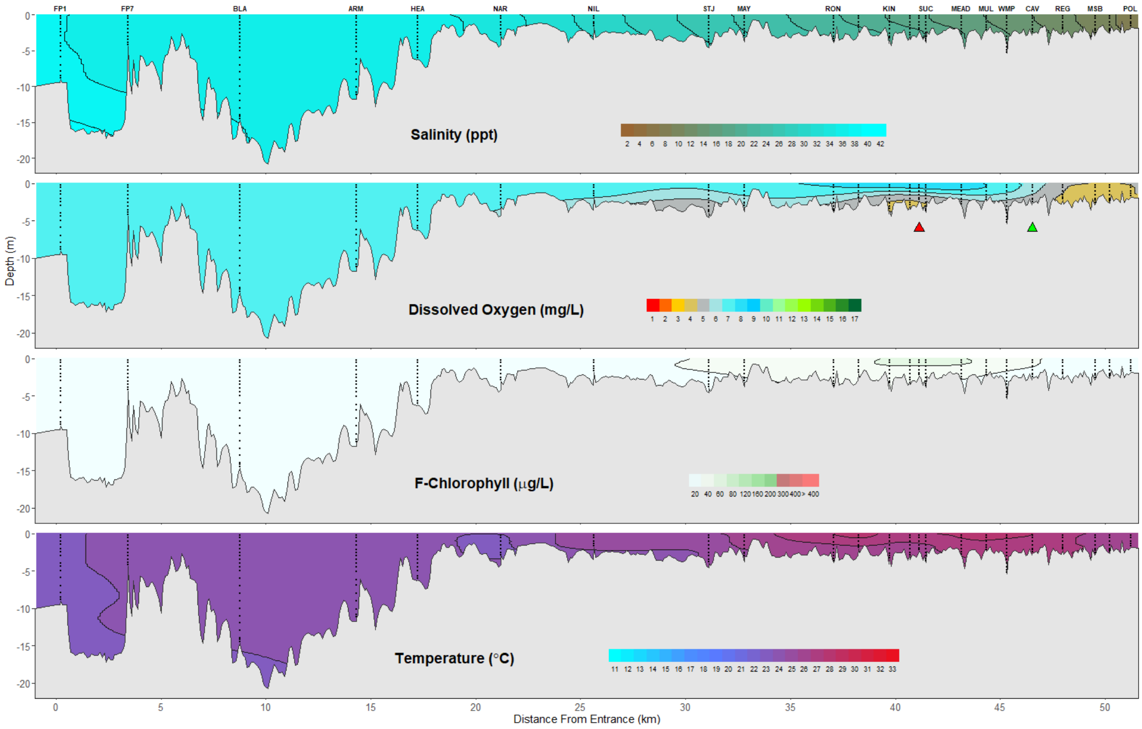
Species name	Common name	Family	Habitat Guild	Estuarine Use Guild	Feeding Mode Guild
Pseudogobius olorum	Bluespot Goby	Gobiidae	SB	ES	OV
Bathygobius krefftii	Krefft's Frillgoby	Gobiidae	SB	MM	ZB
Callogobius depressus	Flathead Goby	Gobiidae	SB	MS	ZB
Favonigobius punctatus	Yellowspotted Sandgoby	Gobiidae	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 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).

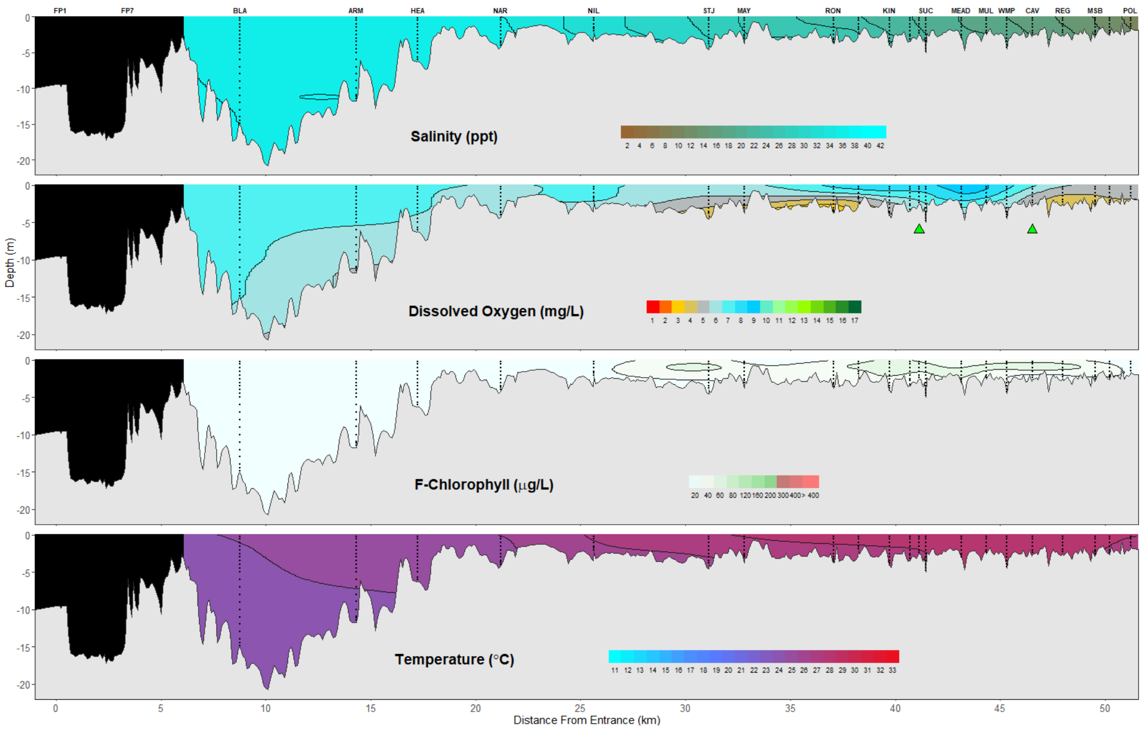


LSCE, MSE and USE zones in summer through autumn 2021

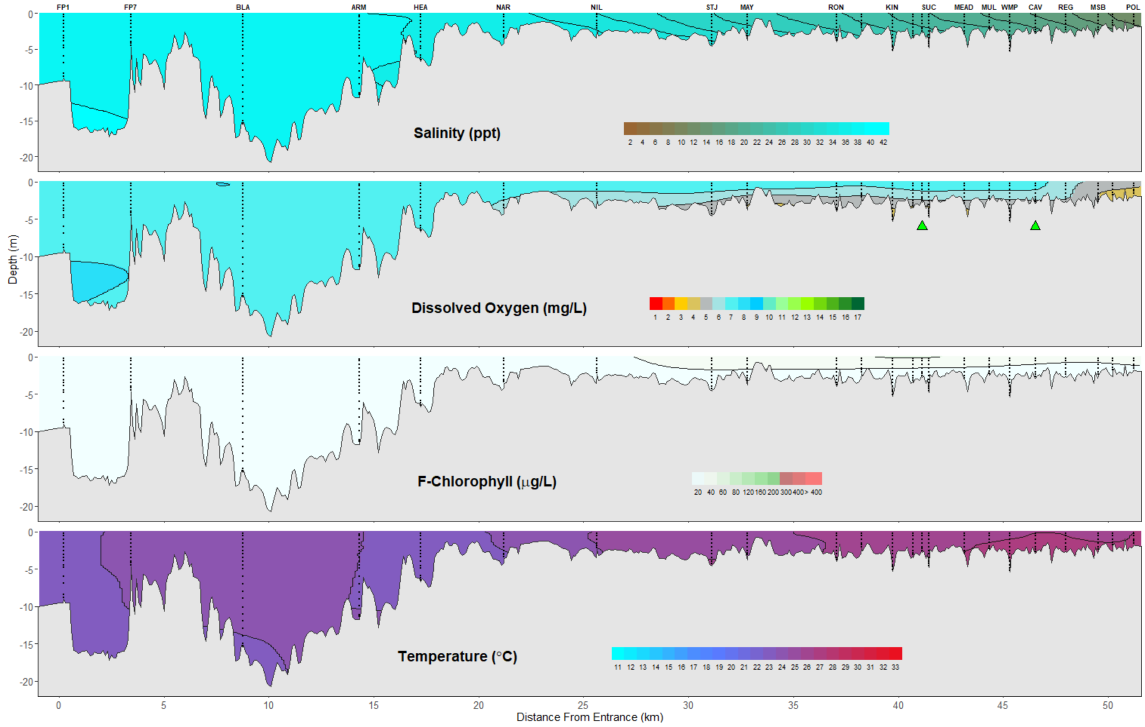
4th January 2021



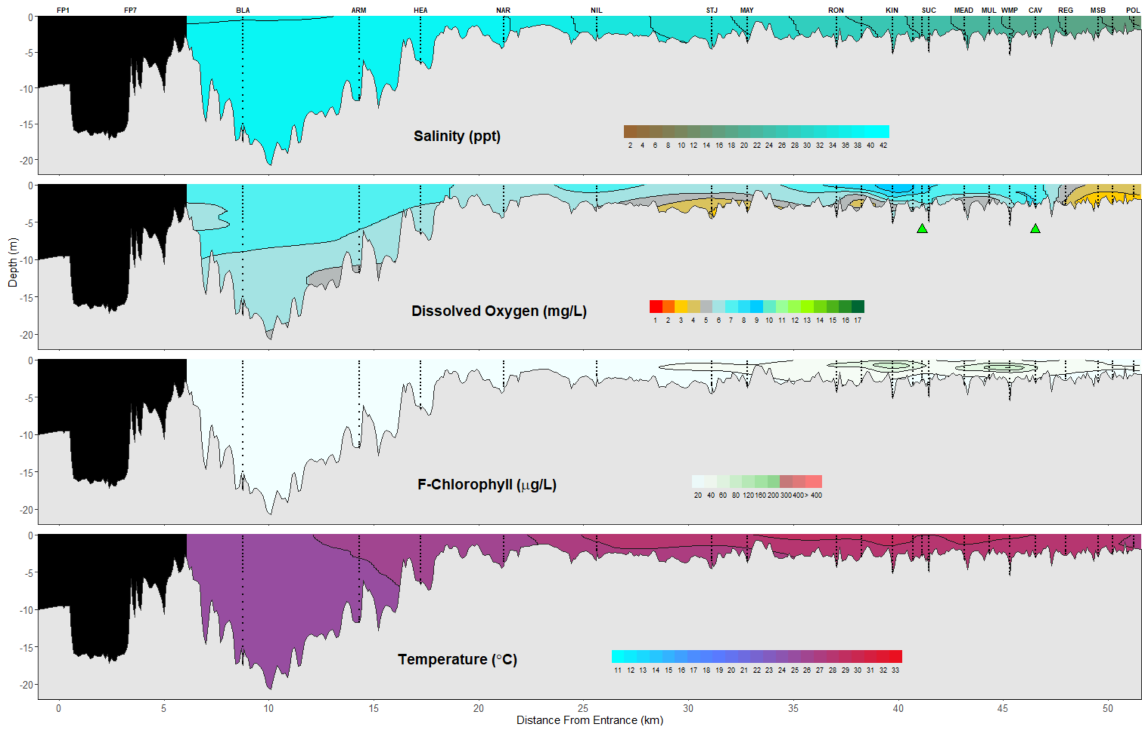
11th January 2021



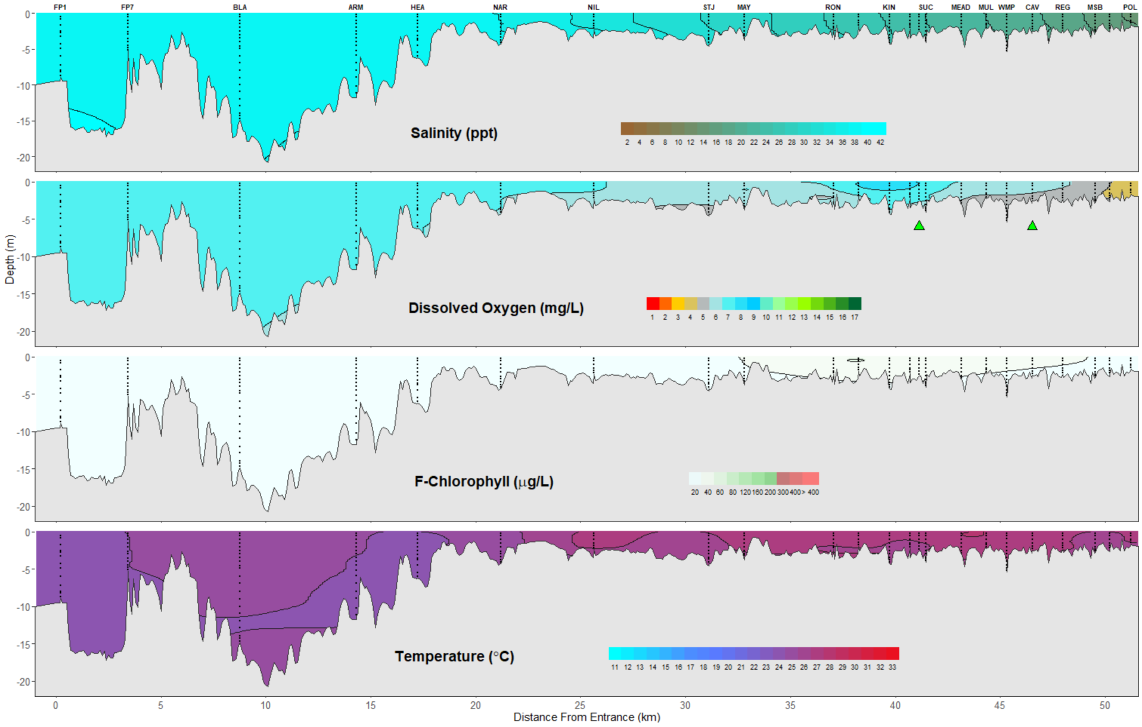
18th January 2021



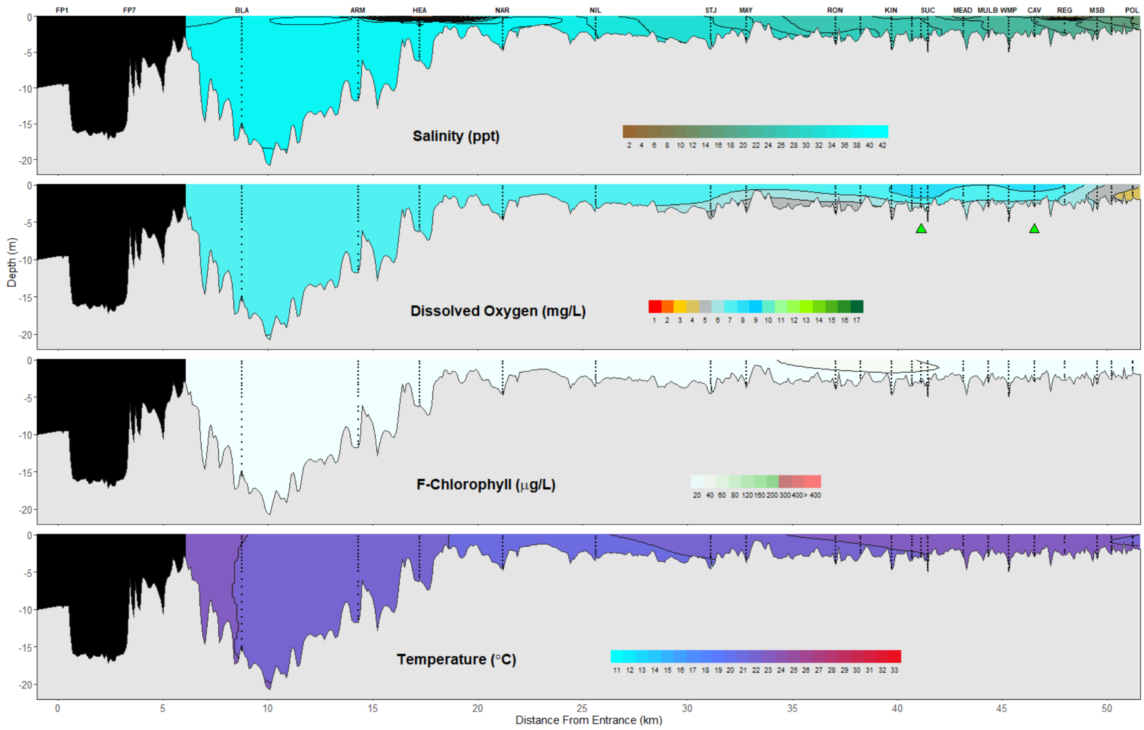
25th January 2021



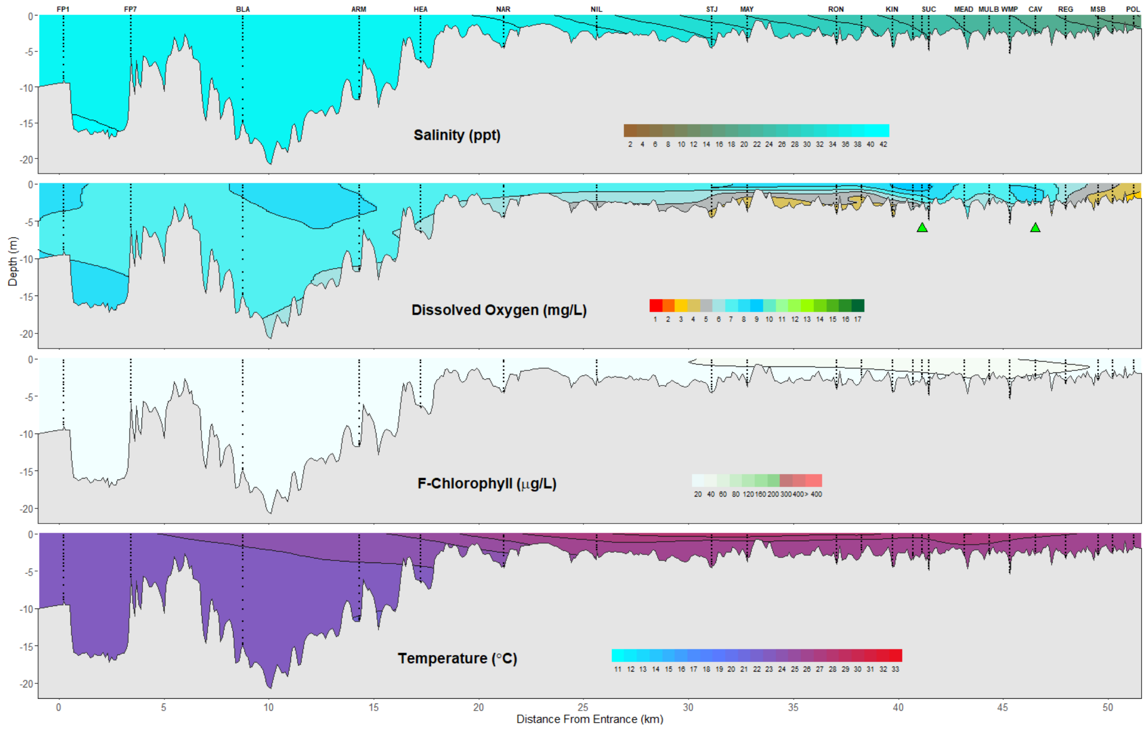
1st February 2021



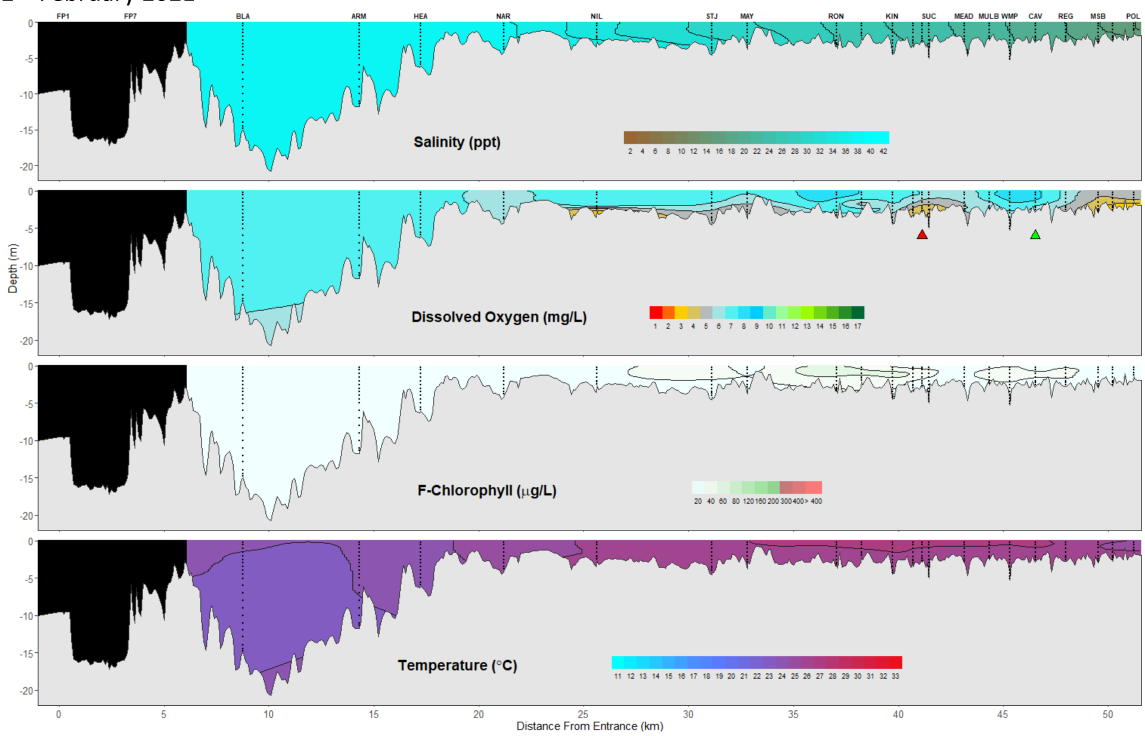
8th February 2021



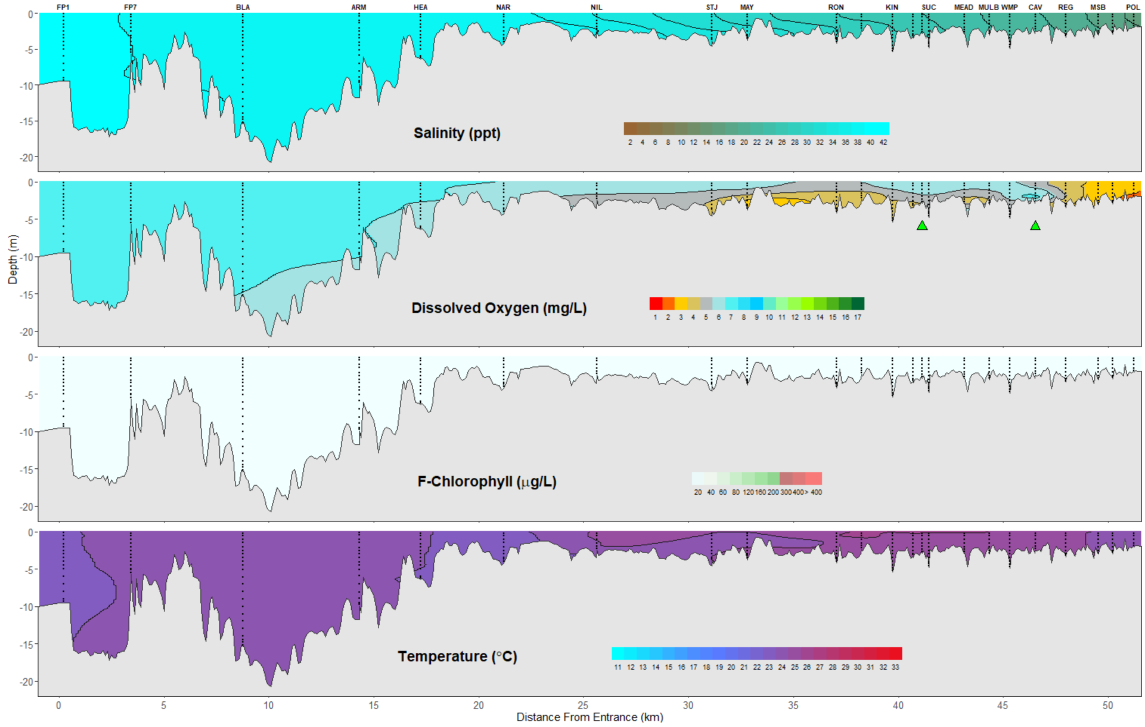
15th February 2021



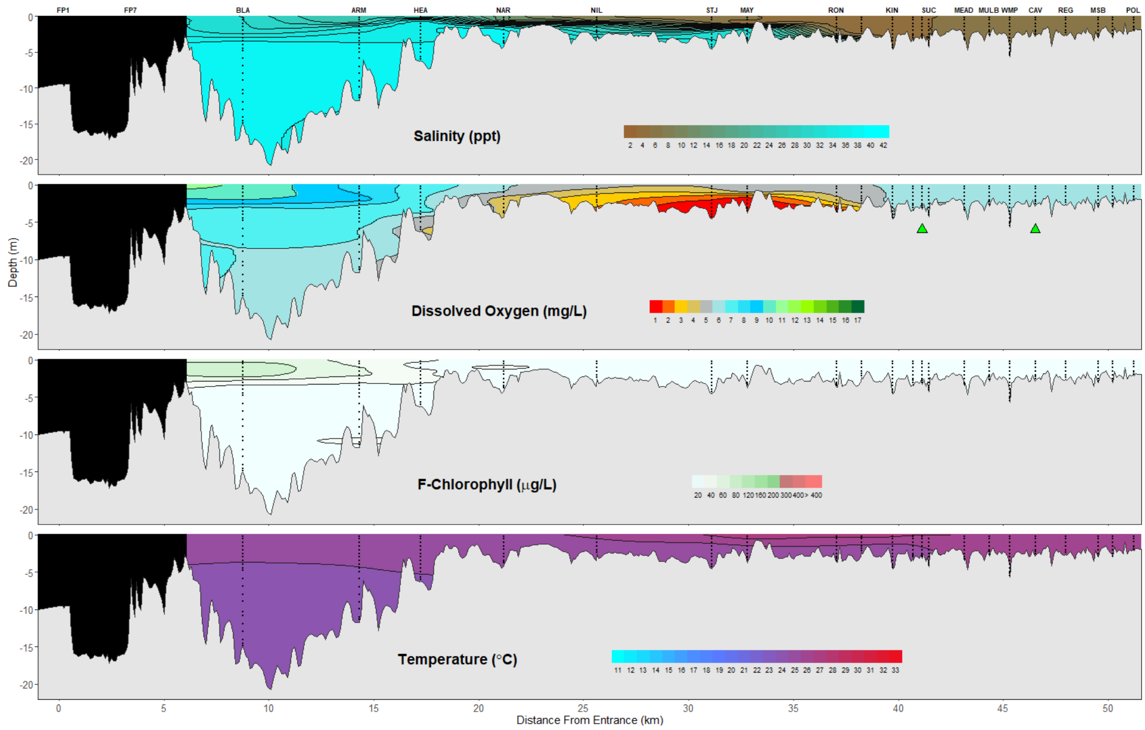
22nd February 2021



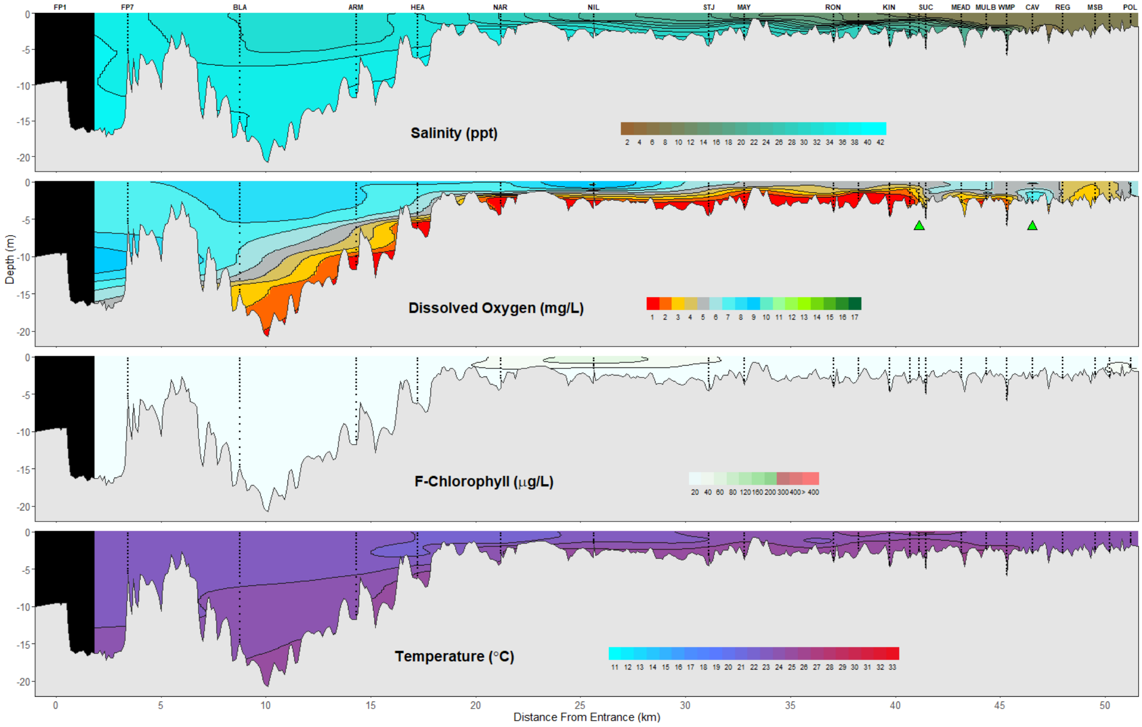
2nd March 2021



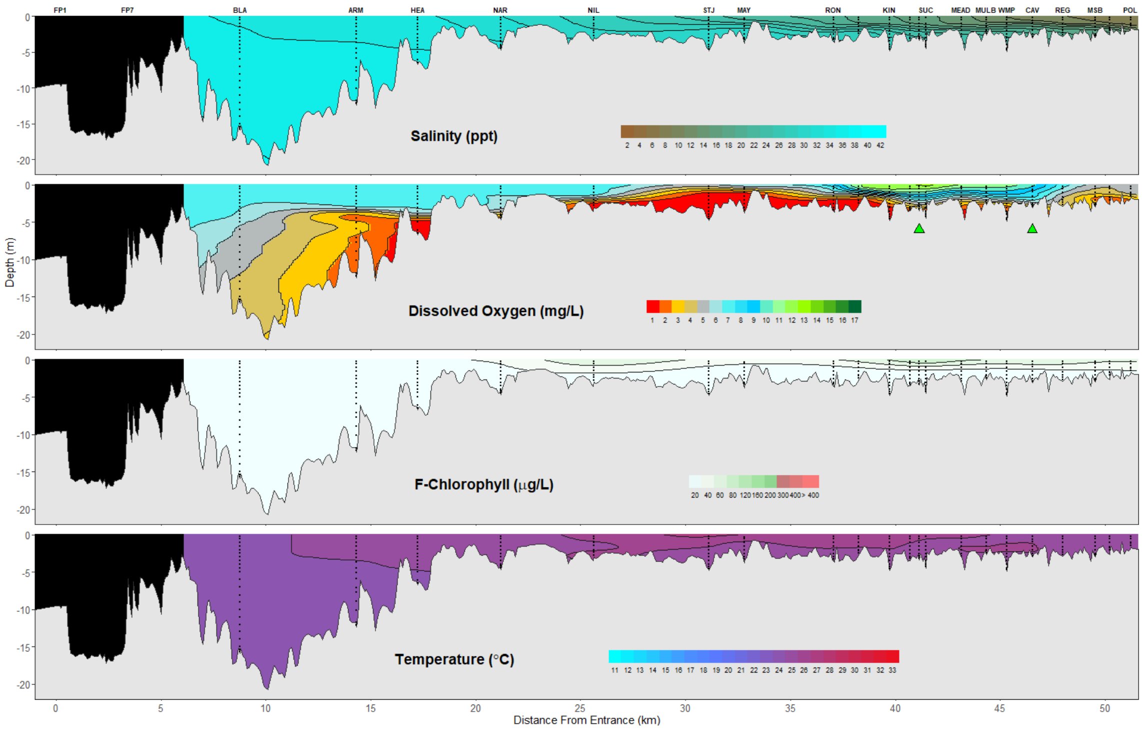
8th March 2021



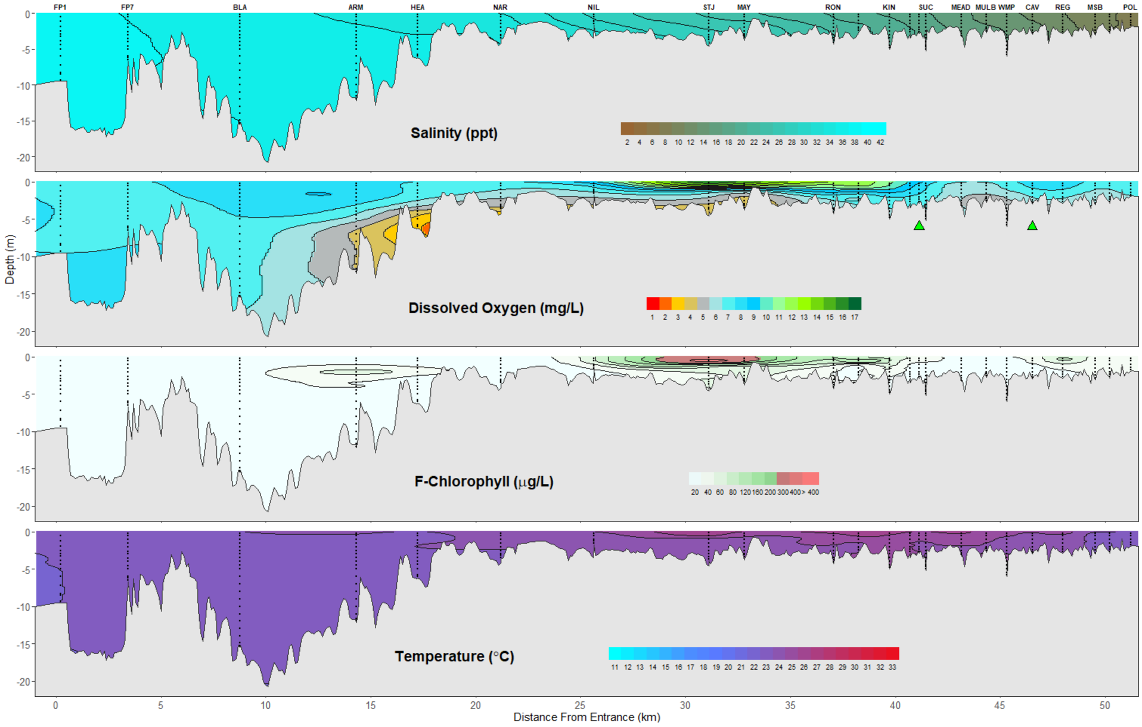
15th March 2021



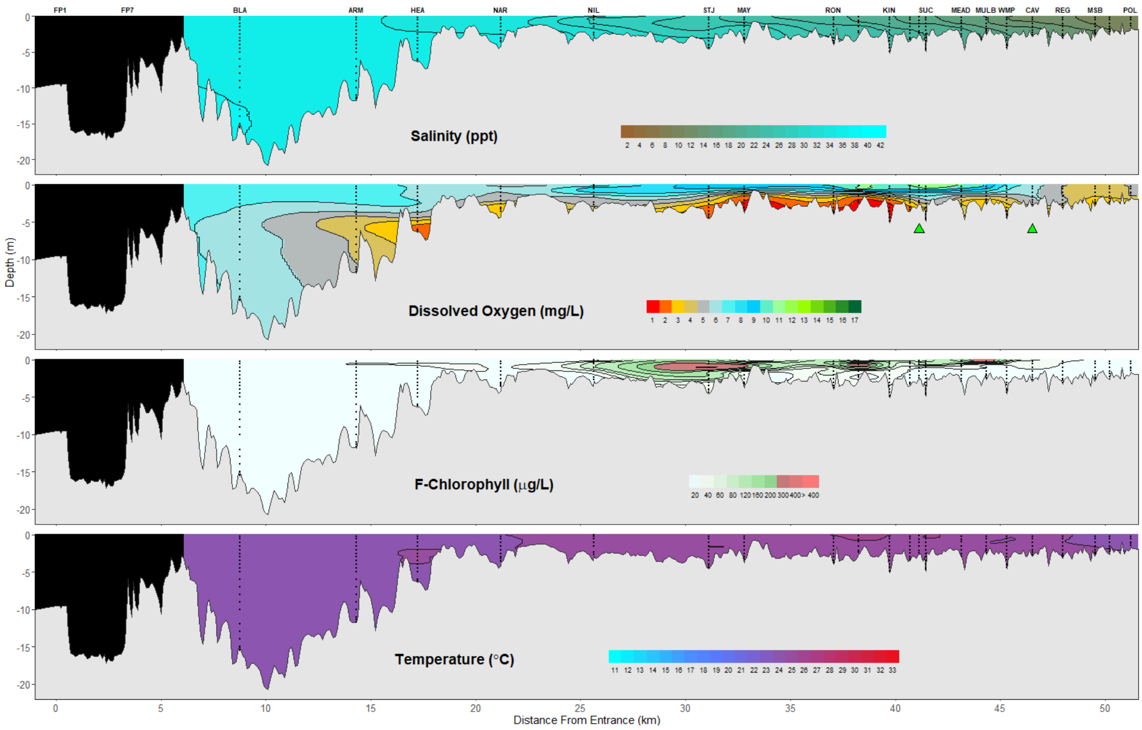
22nd March 2021



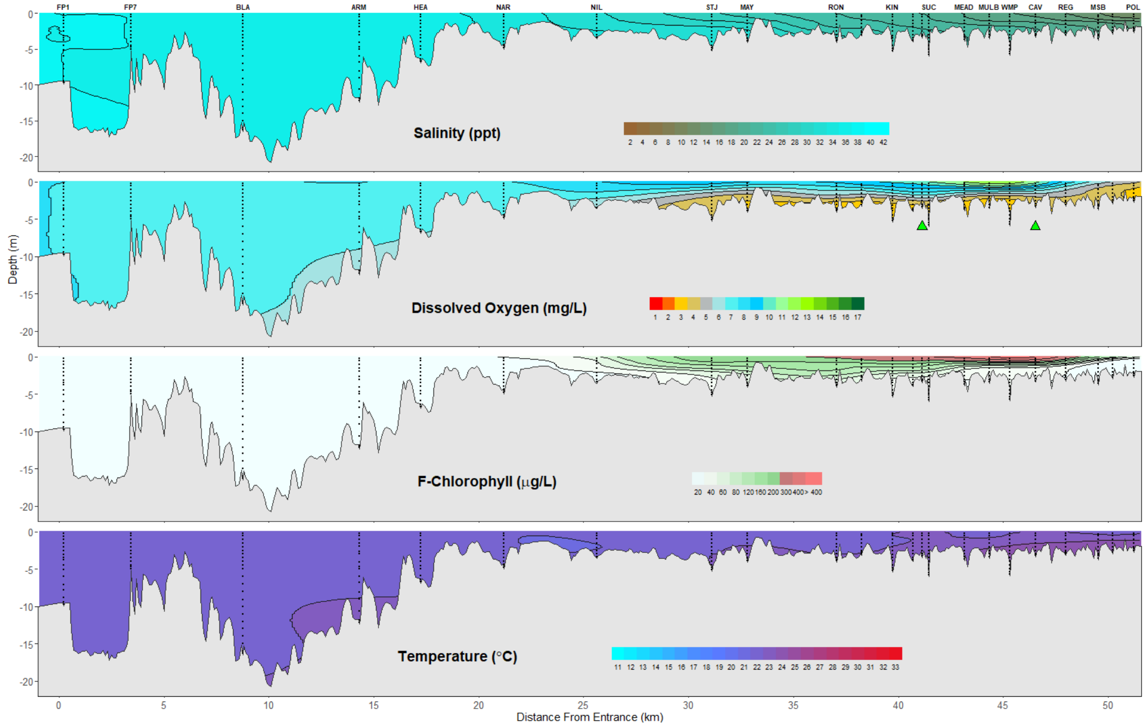
29th March 2021



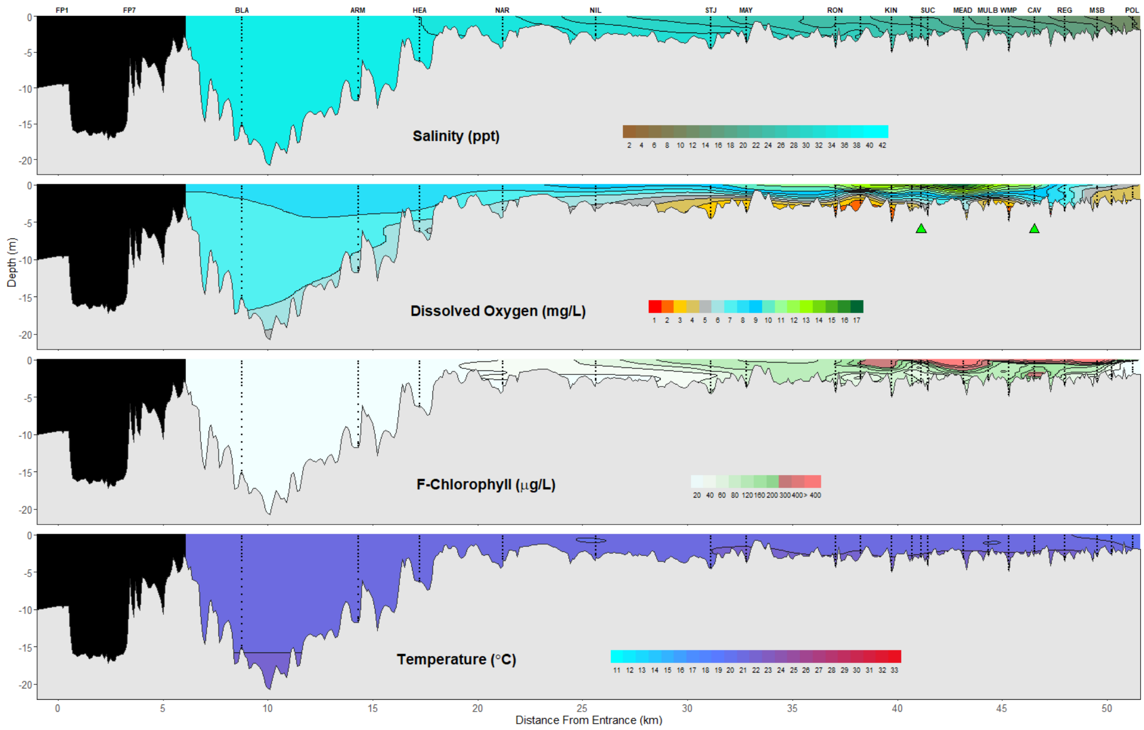
6th April 2021



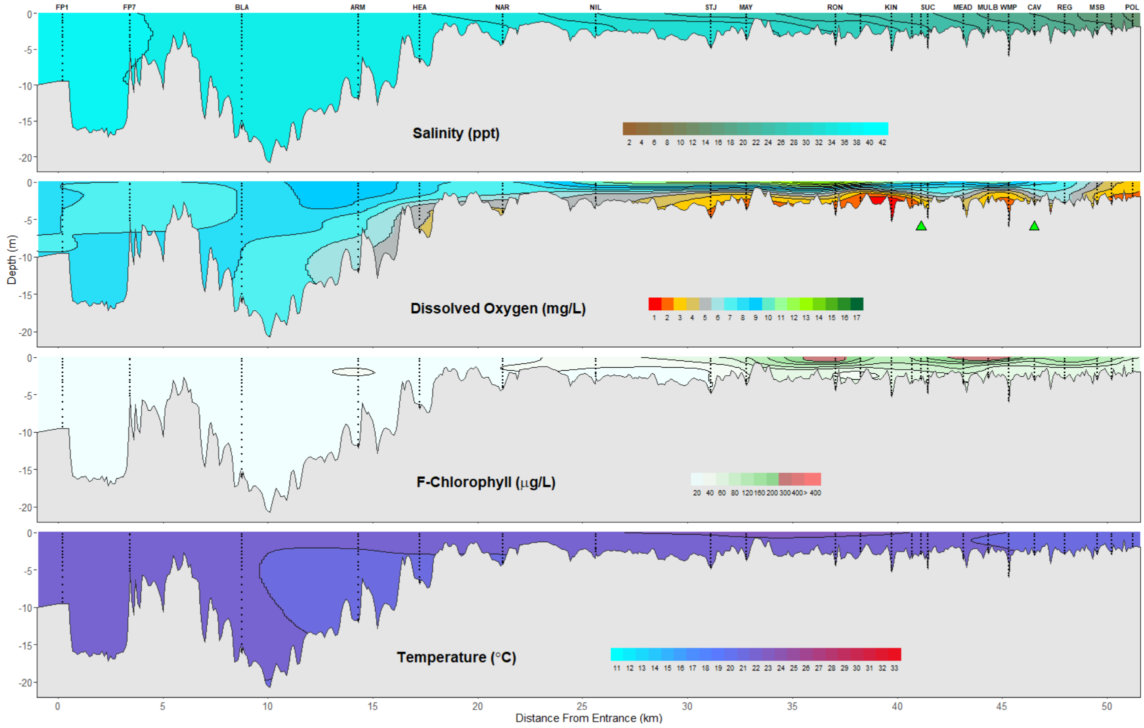
12th April 2021



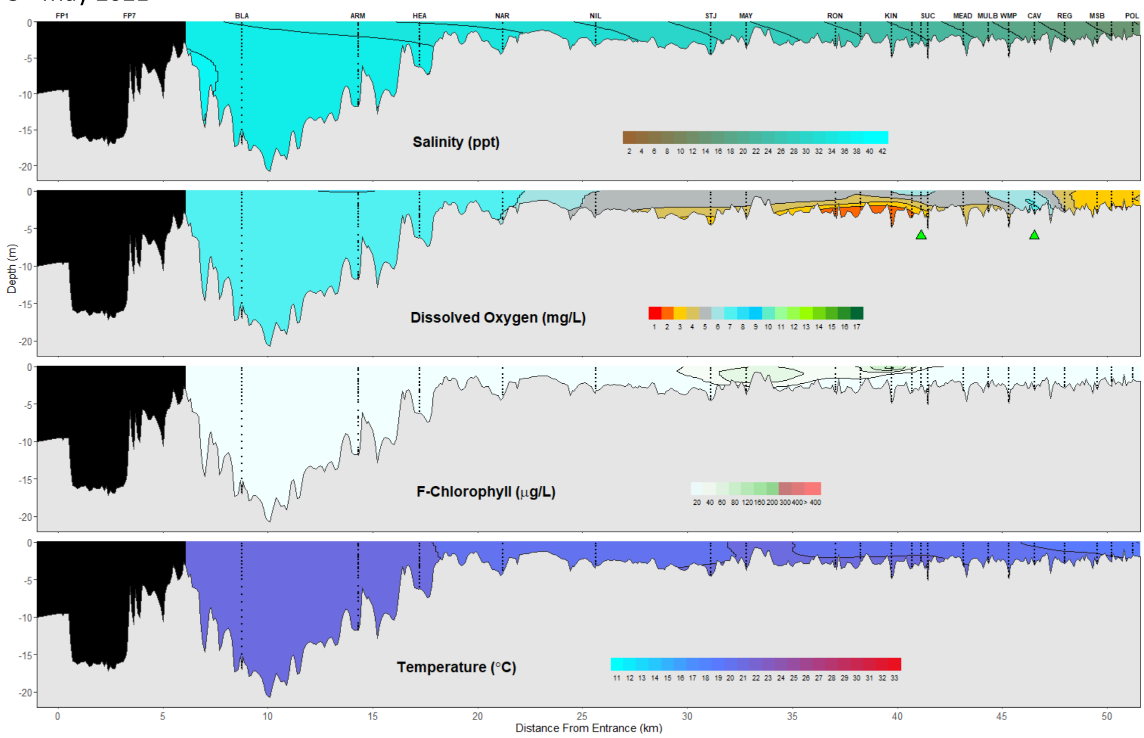
19th April 2021



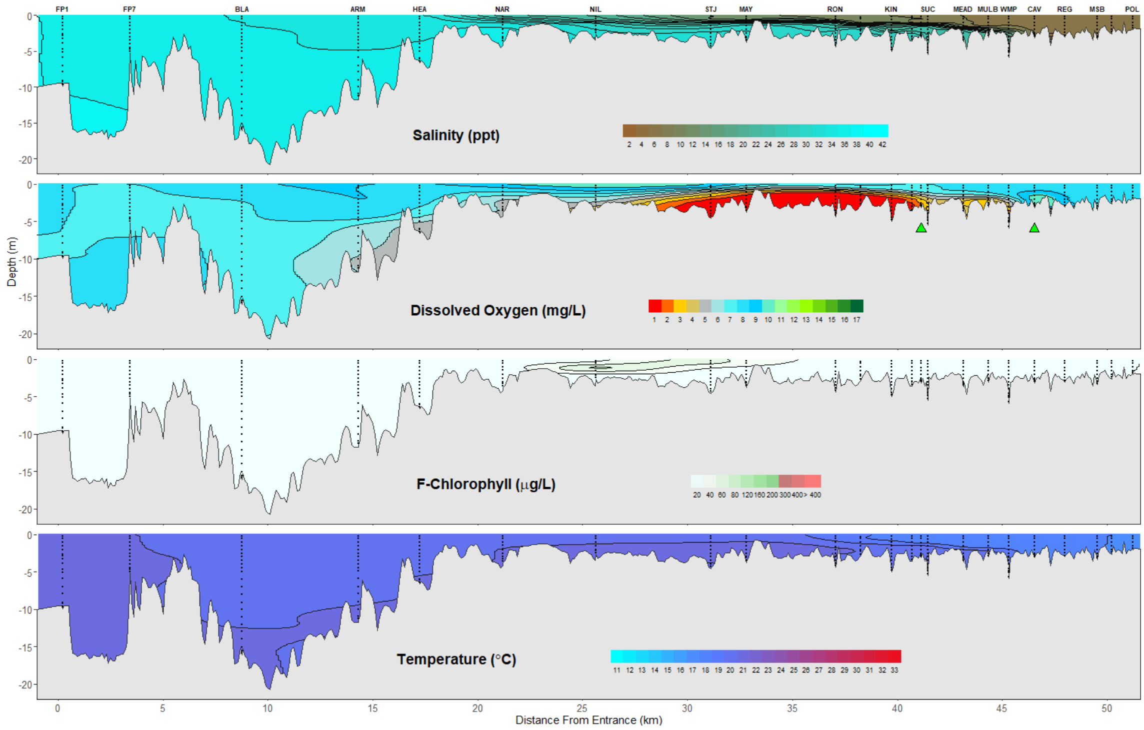
27th April 2021



3rd May 2021

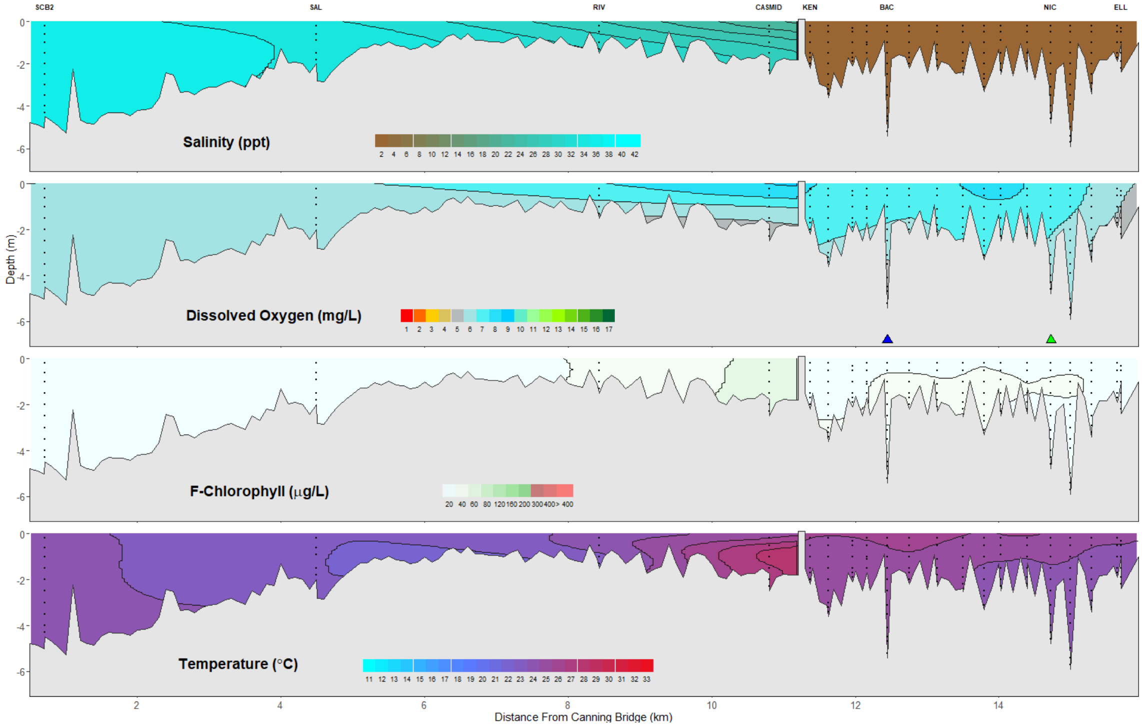


11th May 2021

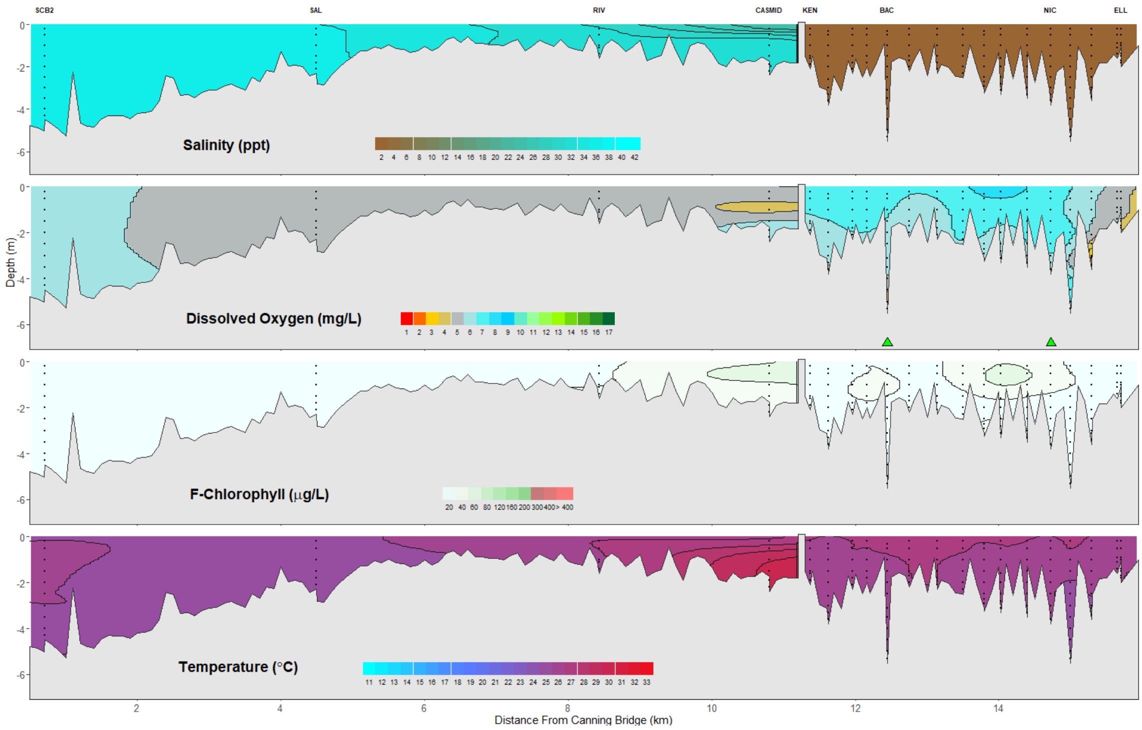


CE zone in summer through autumn 2021

5th January 2021



12th January 2021



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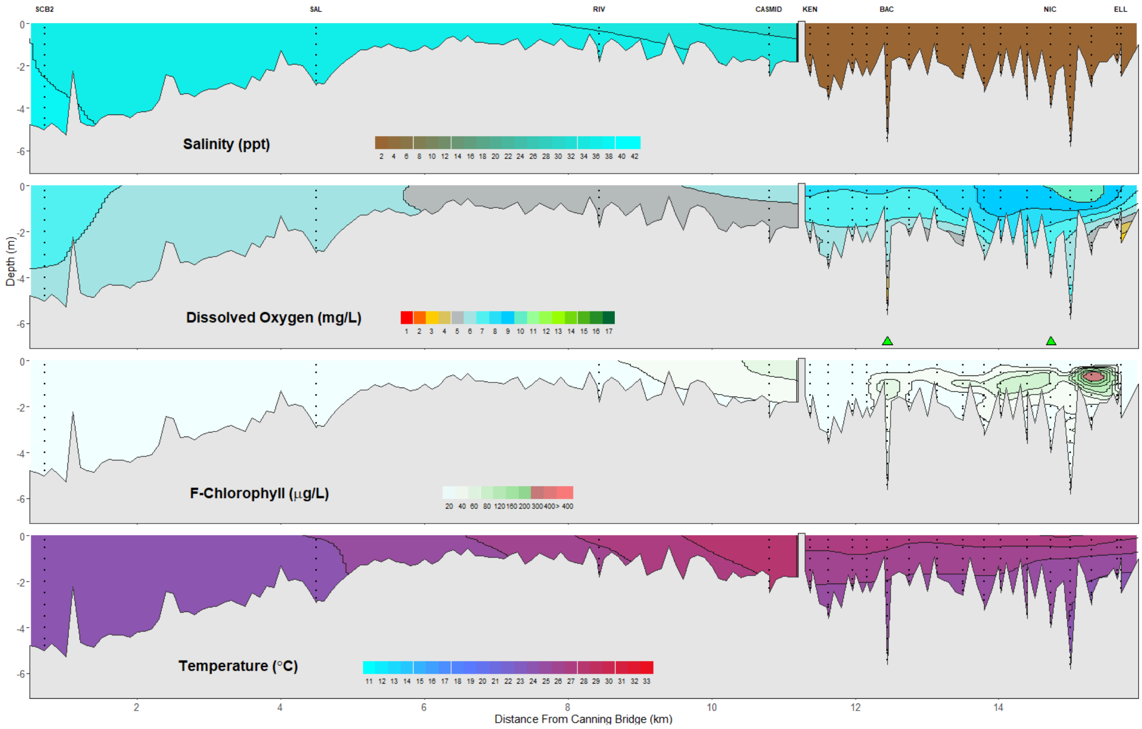

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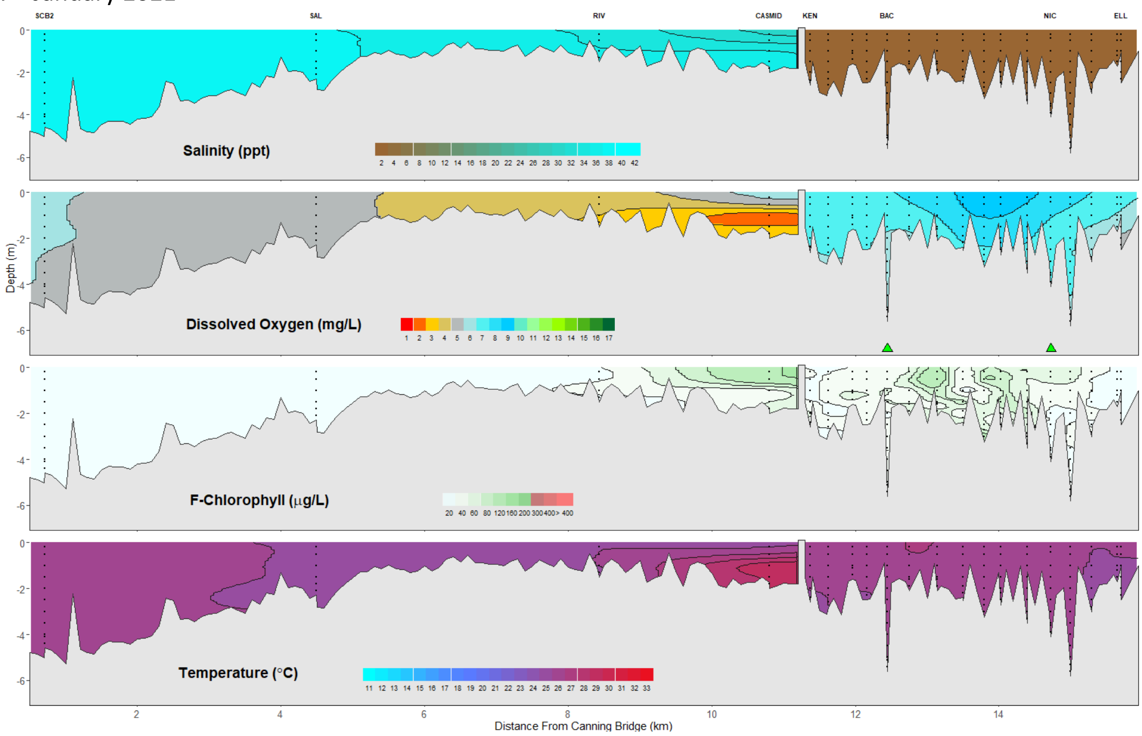
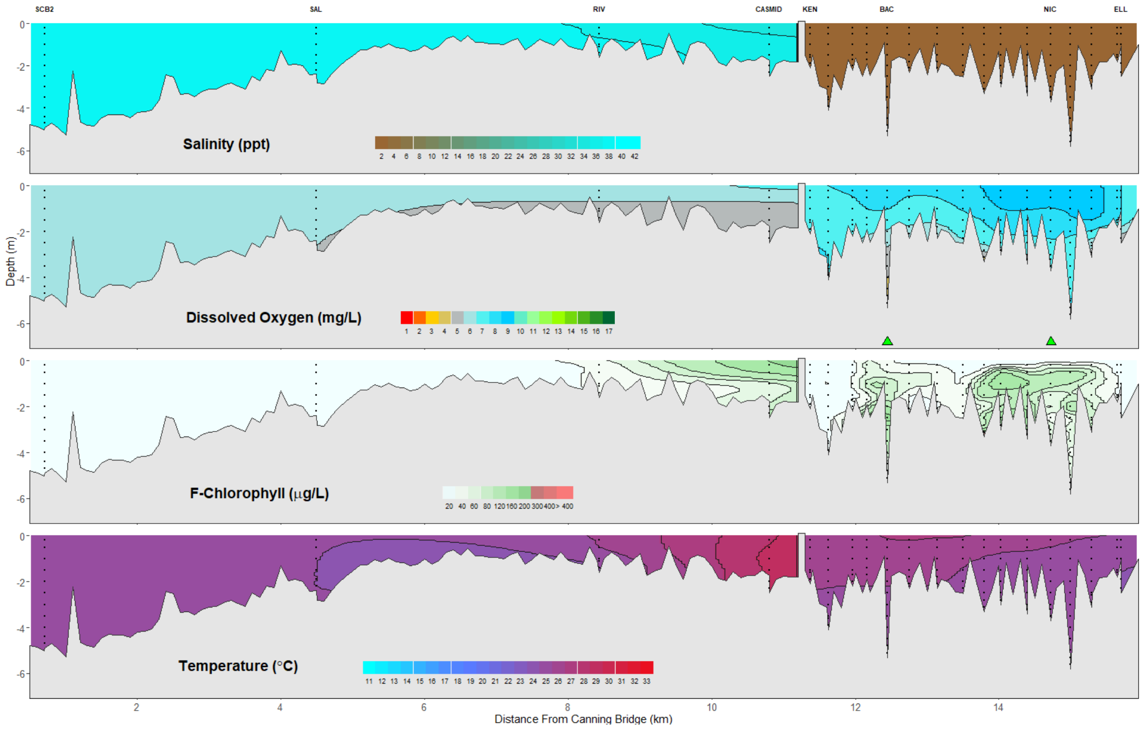
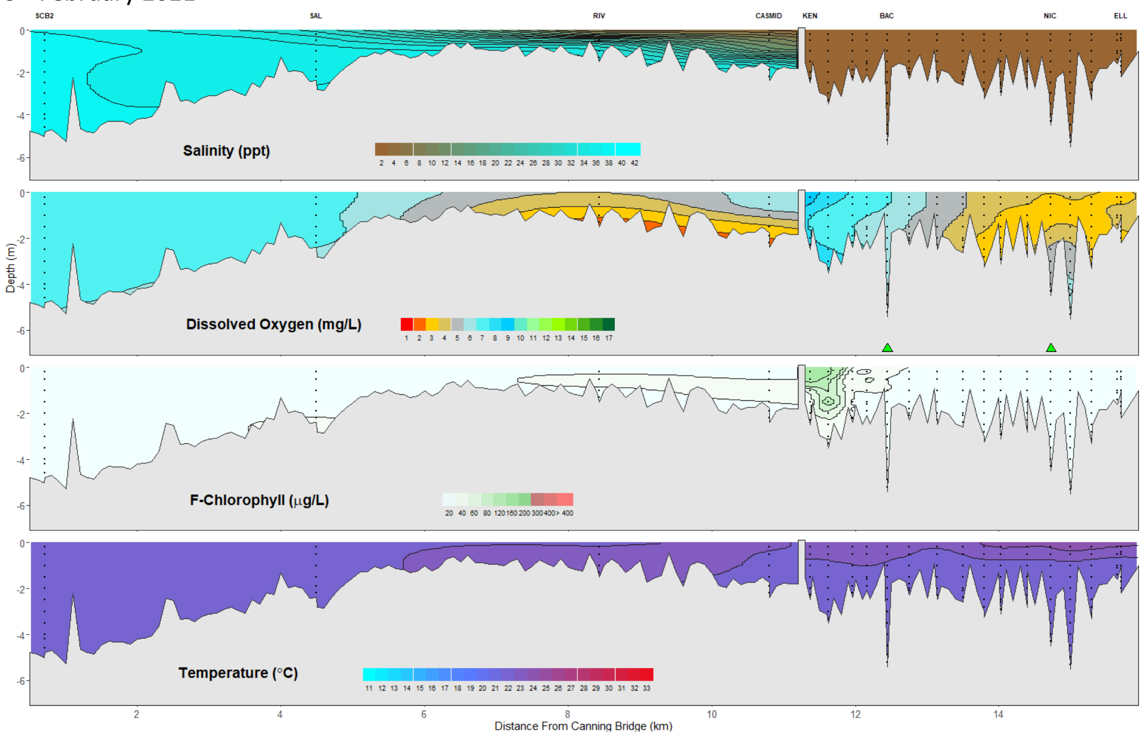


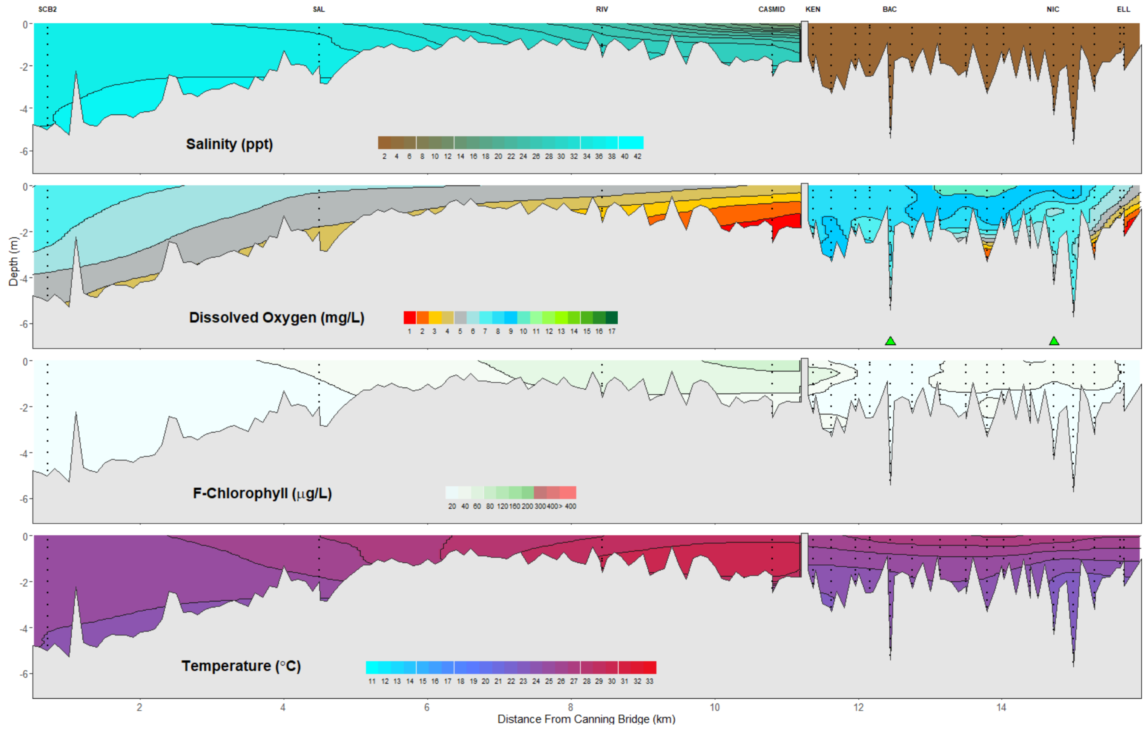
2nd February 2021



9th February 2021



16th February 2021



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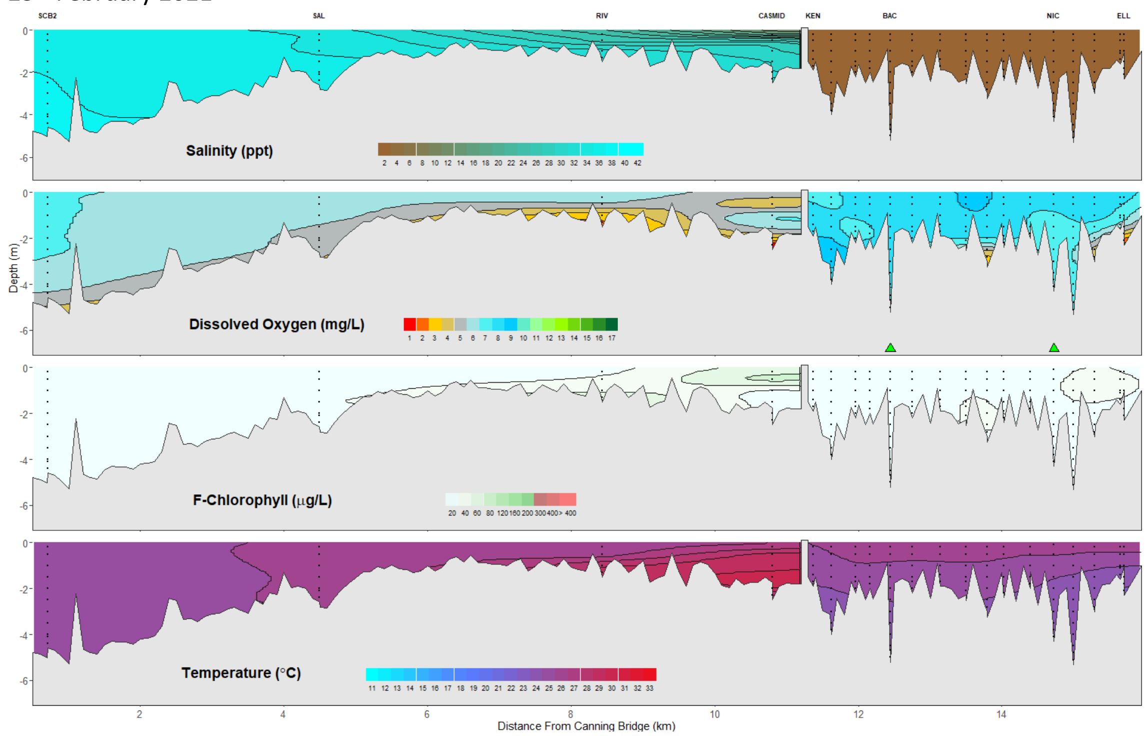
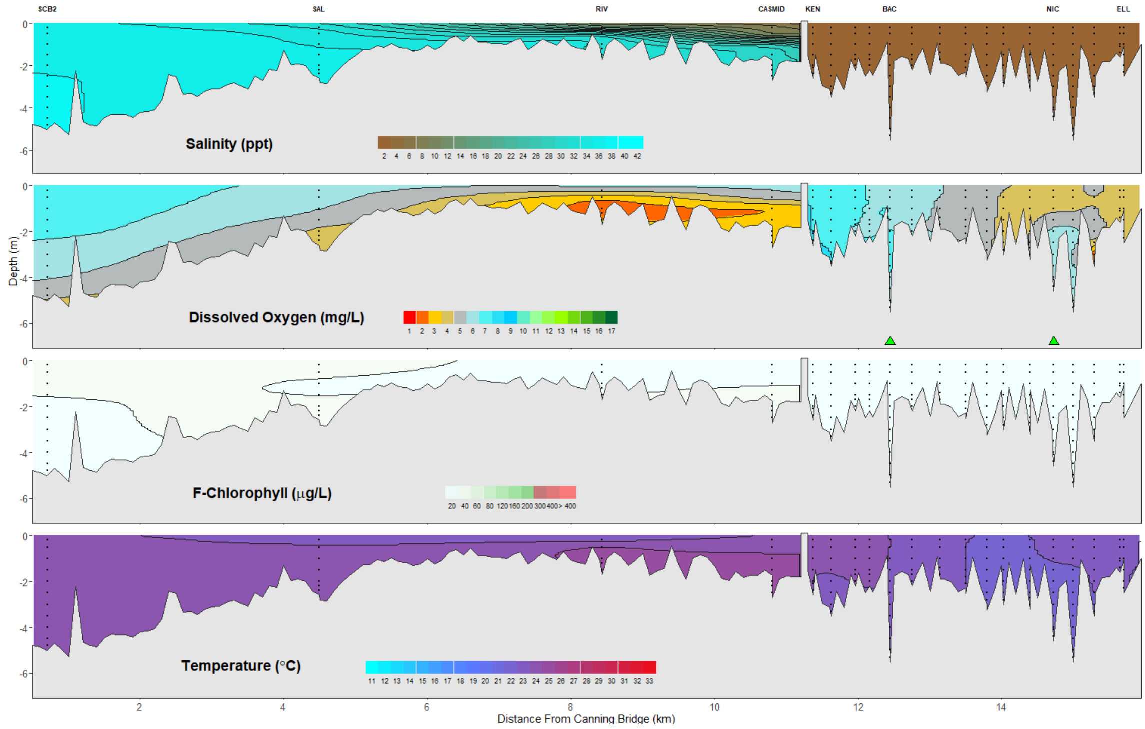


3rd March 2021



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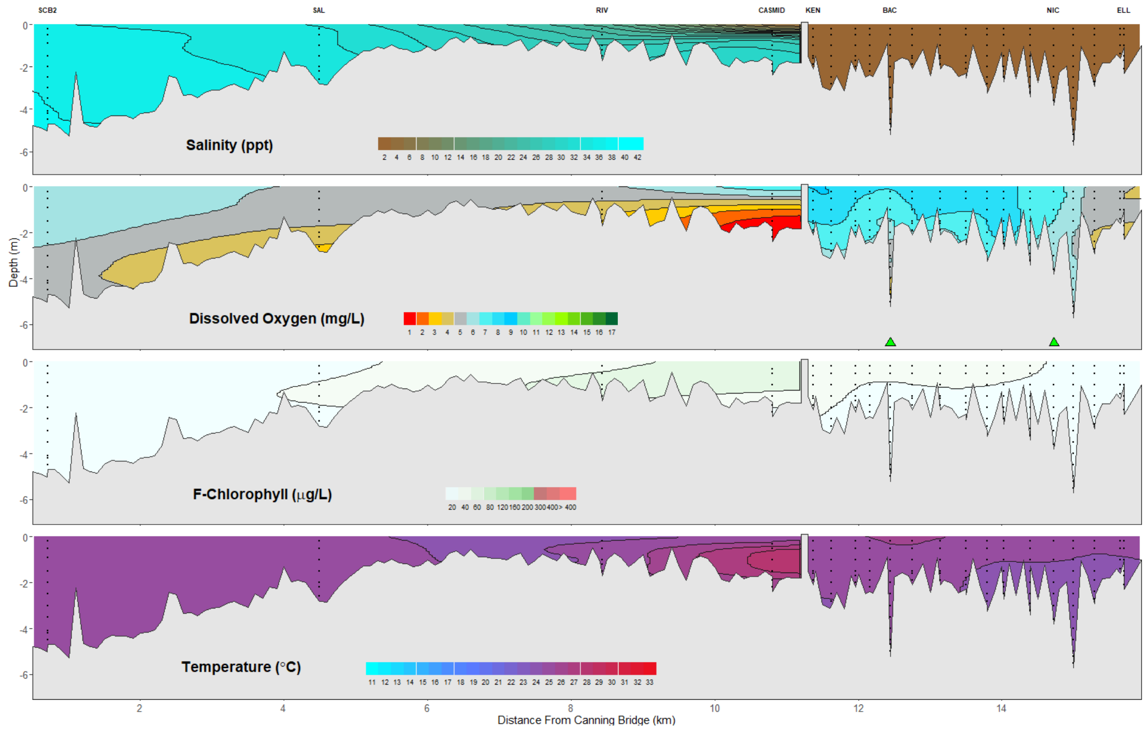

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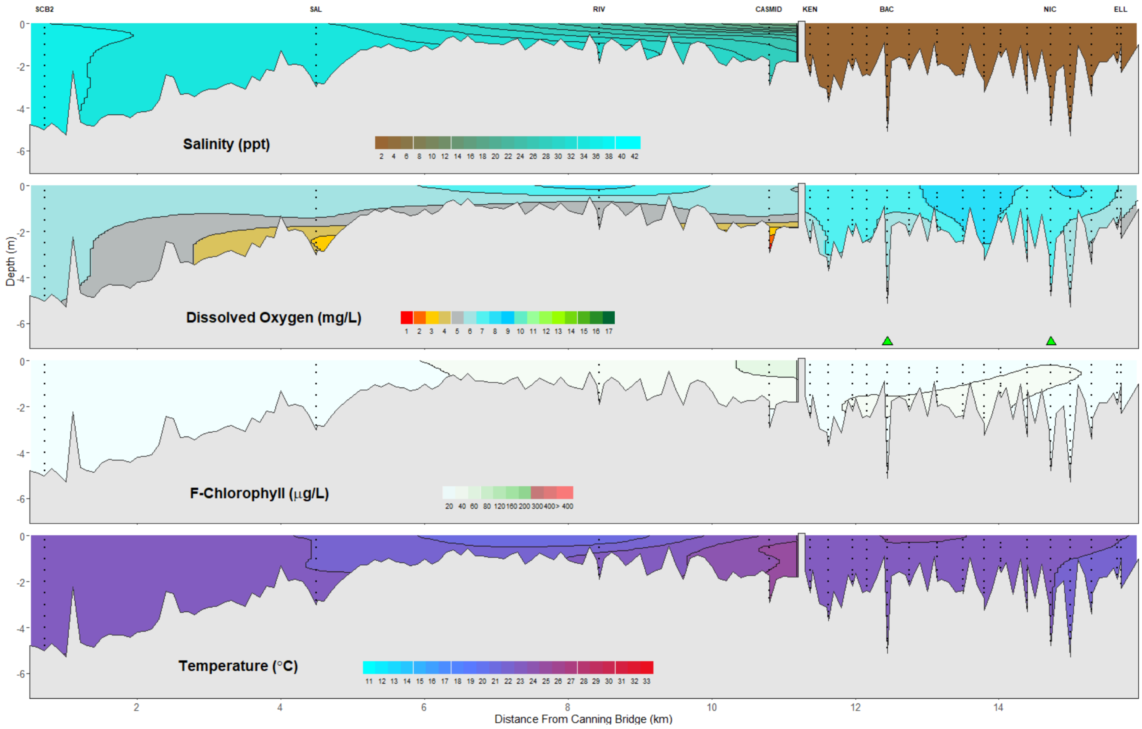

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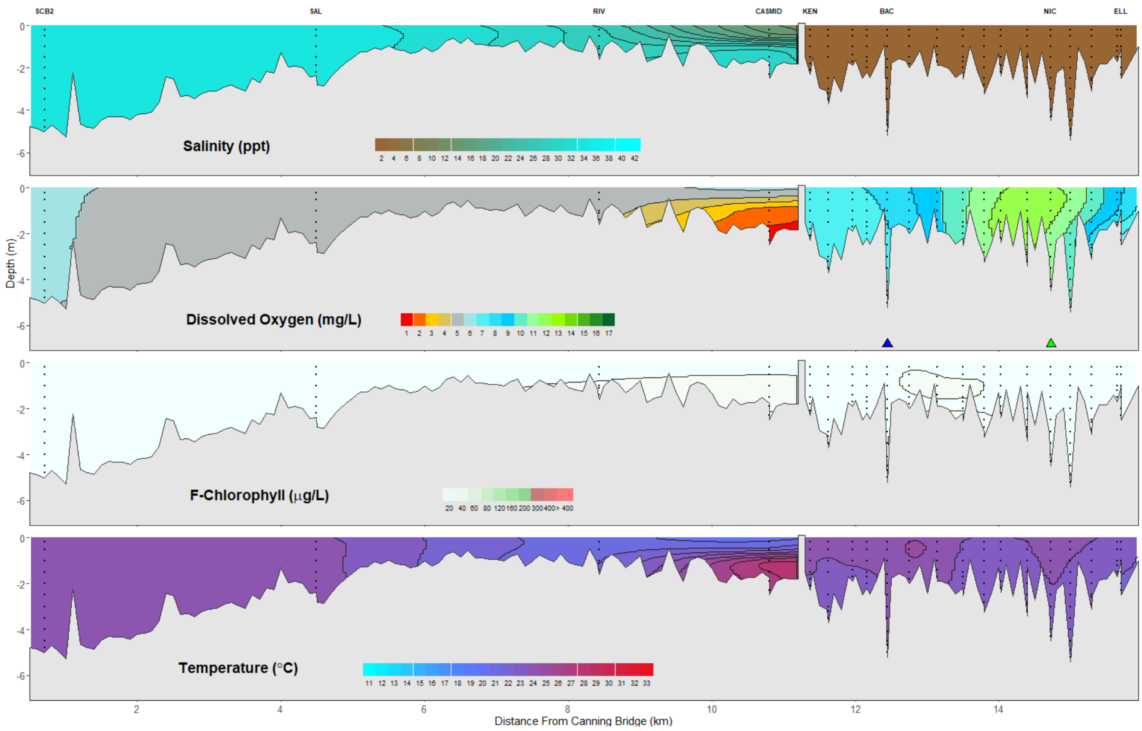
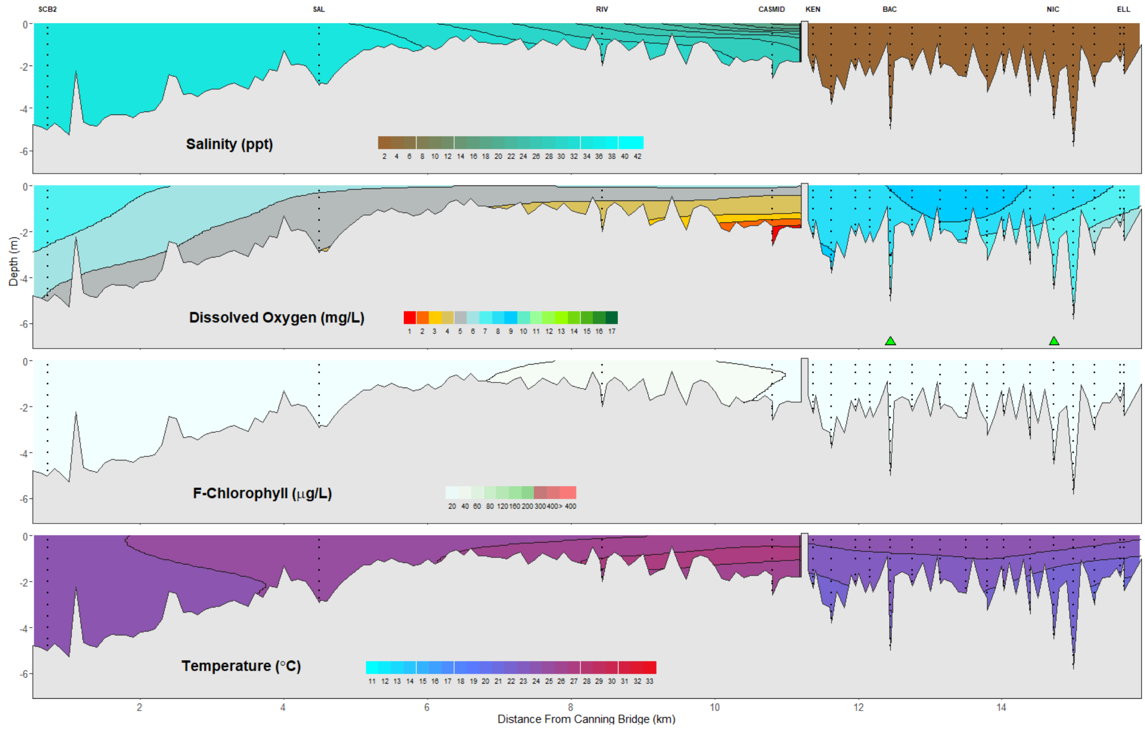
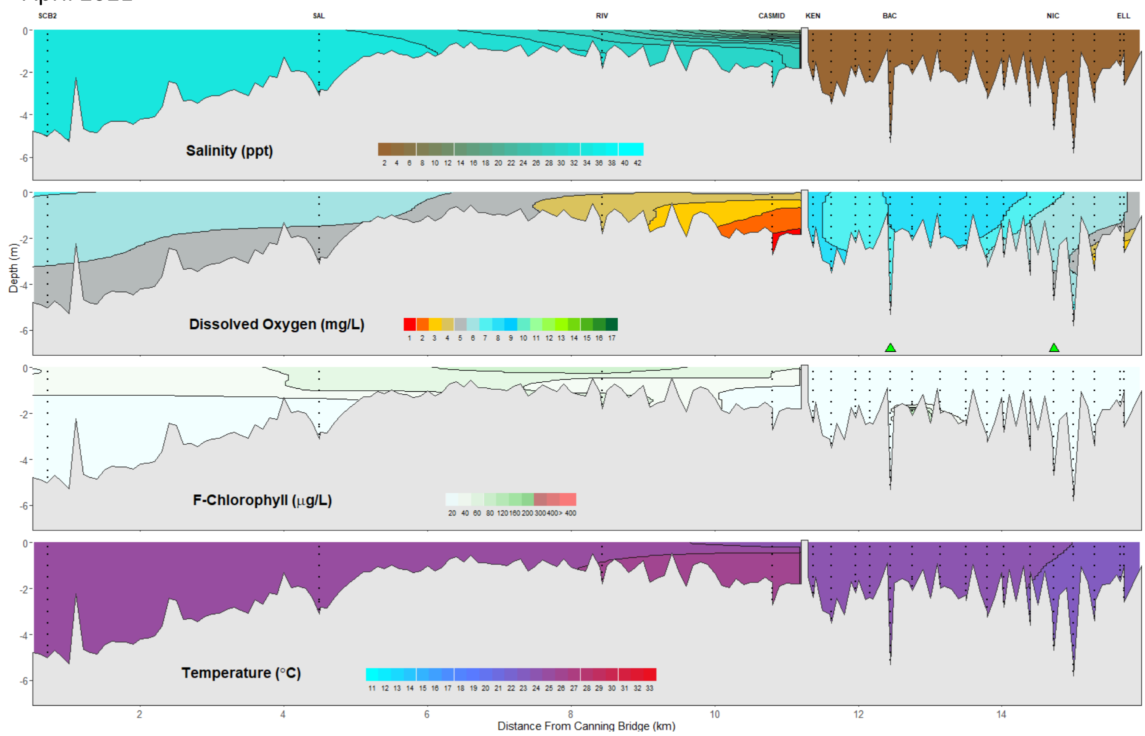


30th March 2021



7th April 2021



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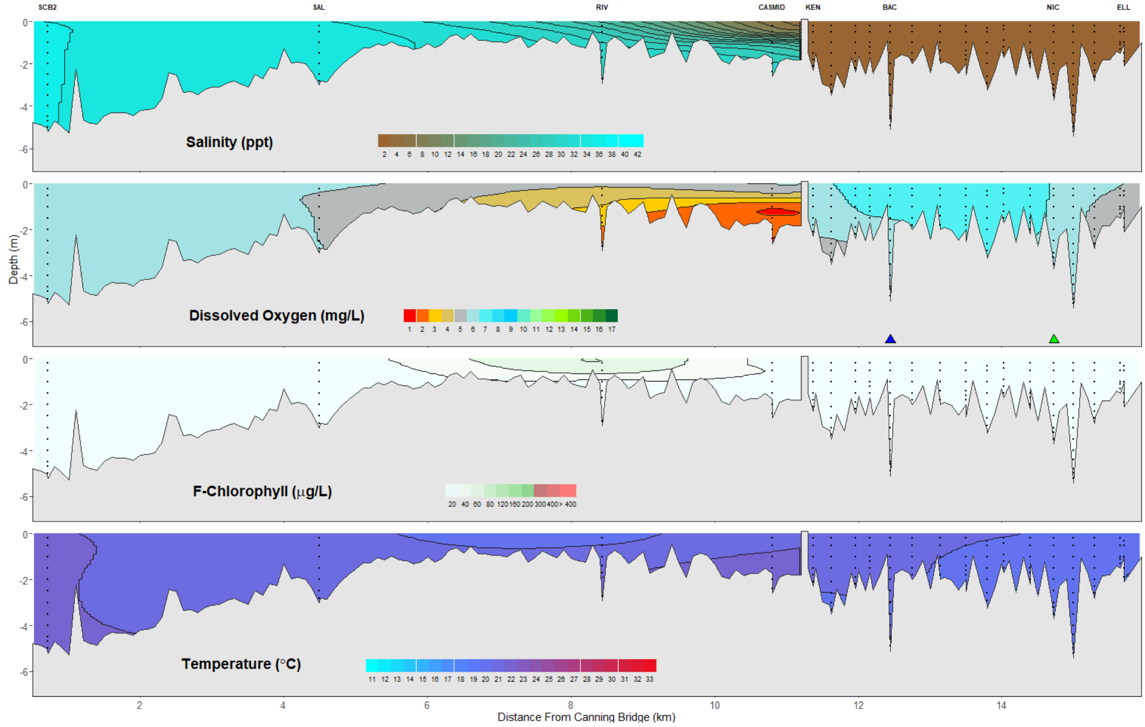
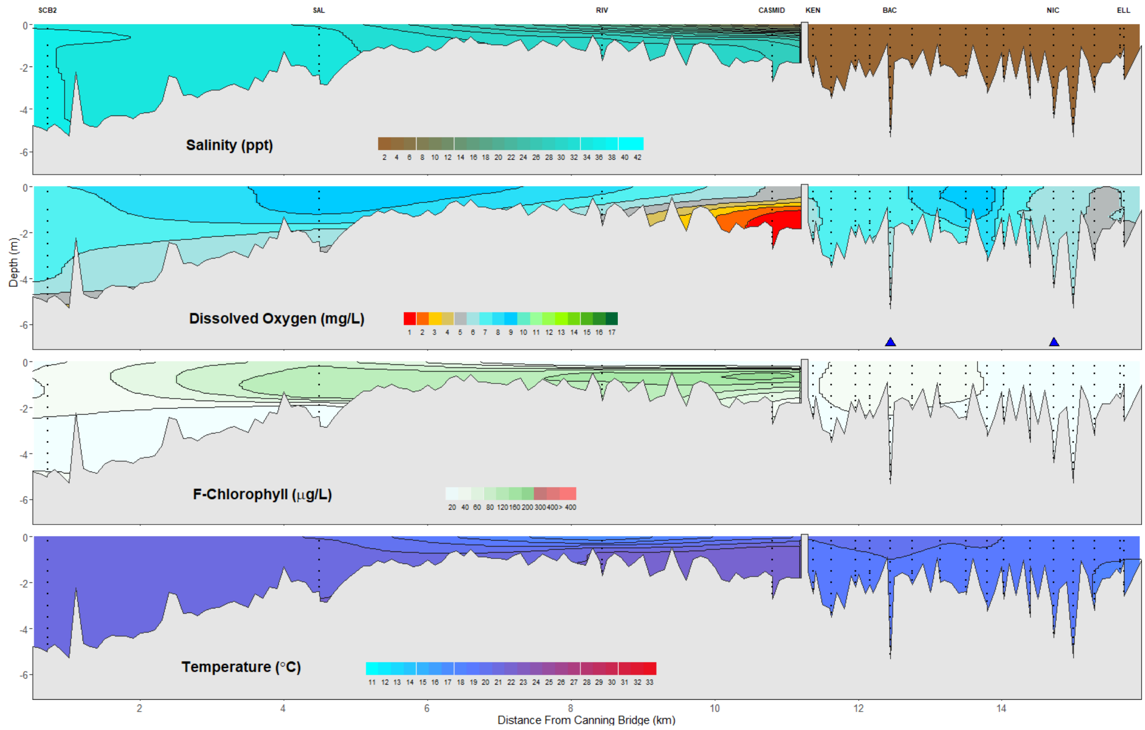
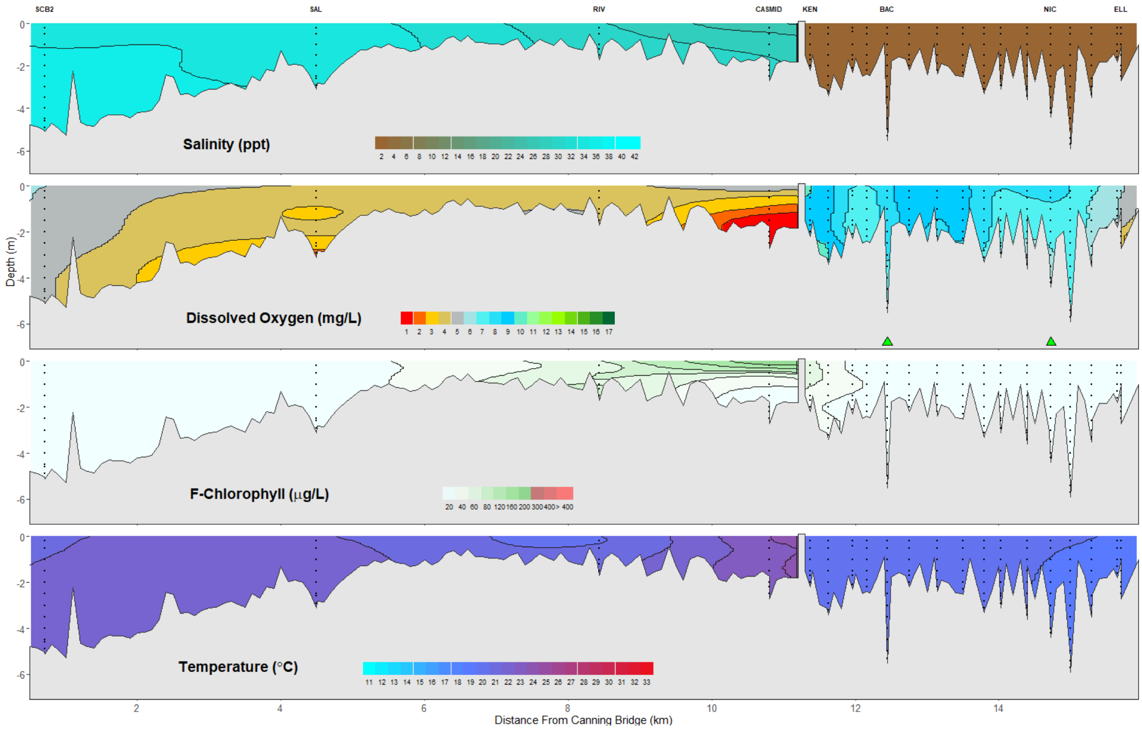


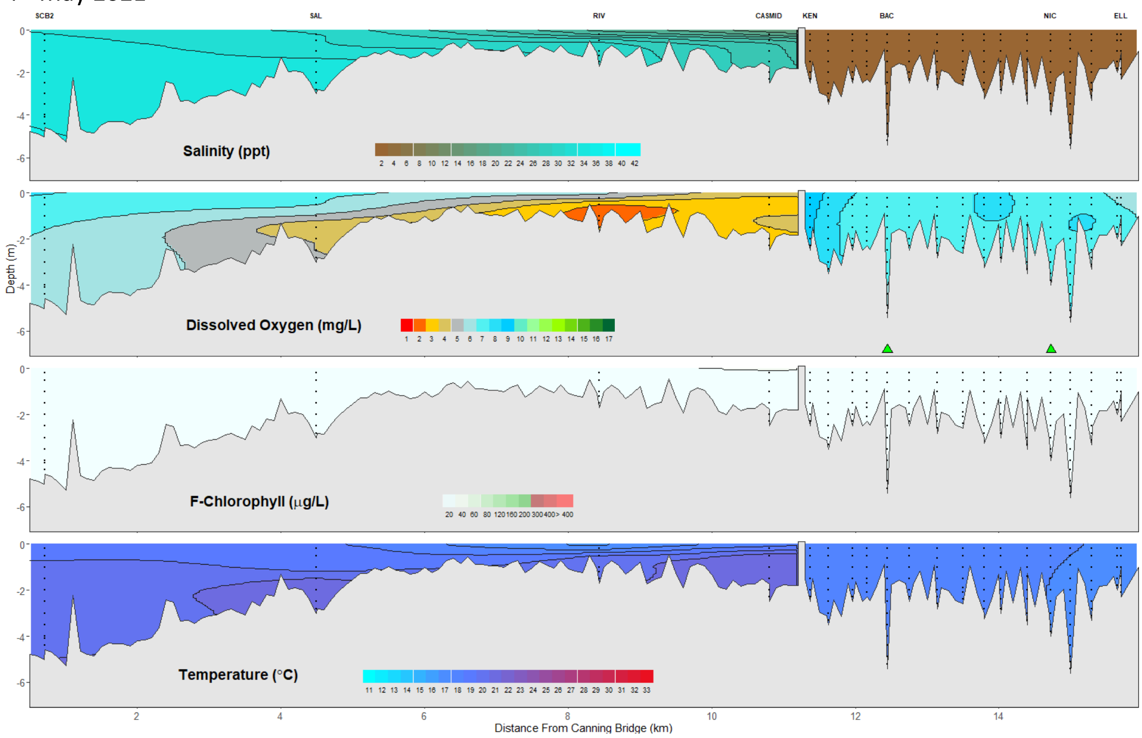
20th April 2021



28th April 2021



4th May 2021



12th May 2021