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Department of **Water and Environmental Regulation**

Department of **Primary Industries and Regional Development**

REGIONAL ESTUARIES INITIATIVE

Estuary Condition Report: Peel-Harvey 2016/17

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Cover photograph: Peel-Harvey estuary (Ashley Ramsey, 2017)

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Contents

Figures

Tables

1. Summary

This 2016-17 annual condition assessment of the Peel-Harvey estuary is based on the Regional Estuaries Initiative (REI) estuary monitoring program. The monitoring program includes fortnightly sampling of salinity, temperature, oxygen, chlorophyll, phytoplankton and monthly nutrient variables at 12 sites in the main estuary basins and the estuarine reaches of the Murray and Serpentine rivers. This condition assessment has been determined for the 12 months from the start of the REI program: that is, October 2016 to September 2017.

Overall, the main basins of the Peel-Harvey estuary had reasonable water quality free from persistent eutrophic symptoms. All mean nutrient concentrations were generally below the relevant guidelines. In contrast, the estuarine parts of the Murray and Serpentine rivers showed significant eutrophication, each river system displaying different but distinctive eutrophic symptoms. These included high algal activity, harmful algal blooms, low dissolved oxygen and fish kills.

The estuary was divided into five reporting zones; the condition of each is summarised below.

Dawesville

The Dawesville zone contains two estuary sites closest to the Dawesville Channel, and is the most marine-influenced zone. Dawesville had the best water quality (with marine salinities), was well-oxygenated, and had low nutrient concentrations and low phytoplankton activity throughout the year.

Peel basin

In the Peel basin, mean salinities were slightly below marine levels, given it received flow from the Murray and Serpentine rivers. The waters were well-oxygenated and had good water clarity. Nutrients and chlorophyll concentrations were mostly below relevant guidelines, except after a significant summer rainfall event in February 2017 which delivered high loads of nitrogen, primarily from the Murray River. This event resulted in elevated phytoplankton activity in the Peel basin and a significant fish kill extended from the Murray River into the Peel Inlet.

The phytoplankton flora was dominated by diatoms and cryptophytes. Harmful species were relatively few in number and generally in low cell densities.

Harvey basin

The Harvey basin had salinities slightly above marine levels, indicating the tendency towards hypersalinity in summer and autumn due to low freshwater inputs and summer evaporation. Waters were well-oxygenated and had good clarity for light penetration. Nutrients and chlorophyll concentrations were mostly below relevant guidelines.

Phytoplankton composition was dominated by cryptophytes, diatoms and dinoflagellates. Several harmful species were detected, mostly at low densities. The harmful dinoflagellate

species *Dinophysis acuminata* was observed throughout the year, with concentrations above guidelines for shellfish harvesting – particularly at the southern-most site (these were of a similar magnitude to those observed in the Murray).

D. acuminata is associated with diarrhoeic shellfish poisoning of humans who consume contaminated shellfish. The guideline value for *D. acuminata* is one cell per millilitre (mL^{-1}) and this was persistently equalled or exceeded.

Murray River – estuarine reach

The lower reaches of the Murray River had persistent salinity stratification with poor oxygen status in the bottom waters. Also recorded in the Murray were six harmful species of phytoplankton comprising mostly dinoflagellates and diatoms.

Four fish kills occurred in the Murray River; these were associated with catchment inflows, stratification, low oxygen and – in three of the four events – high densities of *Karlodinium* (a harmful dinophyte). The atypical flood event in February 2017 was a precursor to the worst of the four fish kill events in the Murray River during the monitoring period. On average, fish kills in the Murray have occurred once a year during the past 15 years, so the four observed during the monitoring period represented a relatively high frequency.

The possible causes of the February 2017 flood fish kill event include an abrupt change in salinity and/or pH, high organic loads causing low oxygen conditions, or toxins that came in from the catchment.

Serpentine River – estuarine reach

The Serpentine River, which is shallower and has less flow than the Murray, tended to be longitudinally stratified, having extreme ranges of salinity from fresh to hypersaline at the end of summer. The highest nutrient concentrations, chlorophyll *a* concentrations and phytoplankton cell densities were observed here. The Serpentine was one of the most eutrophic zones of all the REI monitored estuaries for the monitoring period. Harmful algae were present in all estuary zones, however the greatest cell densities and number of harmful species were observed in the Serpentine. The Serpentine had 18 harmful algae species, predominantly cyanophytes (blue-green microalgae/bacteria).

While the Peel and Harvey basins are considered to have relatively good water quality, there is a risk to estuary health from high rainfall/flood events, when high organic loads and poor quality brackish waters are transferred from the river systems to the estuary basins. This creates the potential for harmful algal blooms, fish/fauna deaths and smothering of seagrass. The February 2017 rainfall event, for example, caused fish kills and was likely responsible for the subsequent *Karlodinium* bloom.

The 2016-17 results of the estuary monitoring program underpin the importance of a continued commitment to actions already underway in the Peel-Harvey catchments, such as use of soil amendments in agricultural catchments, clay trials for agricultural drains, stream restoration and fencing, improved dairy effluent management, and drainage works for better water quality outcomes.

2. Introduction

The Regional Estuaries Initiative (REI) has funded a comprehensive water quality monitoring program in the Peel-Harvey estuary and its catchment since October 2016. This program is a continuation of water quality monitoring that has been conducted since 2000. Before then, monitoring was undertaken at similar sites but at variable frequencies since the 1970s.

The monitoring program is designed to describe the estuary's condition, primarily in terms of water quality variables as an indicator of overall estuary health. The water quality monitoring program provides human and environmental health alerts if potentially toxic phytoplankton are detected at elevated levels and informs the management of fish kill events.

Long-term continuous monitoring is also used to assess the effectiveness of management actions, and/or the impact of both natural variability and anthropogenic changes, such as climate change and significant land use changes. Both an estuary and a catchment model are being developed for the Peel-Harvey system; real monitoring data is essential for model validation.

The purpose of this annual estuary condition report, the first since the inception of the REI monitoring program, is to describe the water quality condition of the Peel-Harvey estuary for the period 1 October 2016 to 30 September 2017.

It is one of a series of reports for REI estuaries (the Peel-Harvey, Leschenault, Hardy Inlet, Wilson Inlet and Oyster Harbour). It is anticipated that condition reports for all estuaries will be produced annually during the REI program. The Vasse-Wonnerup estuary's condition will be reported through the Revitalising Geographe Waterways Program.

Catchment flows and nutrient loads have long been recognised as negatively impacting the health of the Peel-Harvey estuary. A phosphorus reduction target of 50% was first introduced through the Environmental Protection Peel Inlet-Harvey Estuary Policy 1992 (EPA 1992).

The REI includes a complementary catchment monitoring program. The most recent catchment nutrient reports (for the 2016 calendar year) are available online at rei.dwer.wa.gov.au/estuary/peel-harvey-estuary/publications. These show that catchment concentrations of phosphorus are still in the high to very high category for most subcatchments. The 2017 calendar year nutrient reports will be available in 2019.

The Peel-Harvey estuary is the largest and most complex estuarine system in the South West. It forms a key part of the Peel-Yalgorup wetland system, which in 1990 was listed as a Wetland of International Importance under the Ramsar Convention (Ramsar 2017). The wetland system is an important area for waterbirds and waders, regularly supporting more than 20 000 individuals. The system also supports a regionally important estuarine fishery and is used extensively for recreational purposes, particularly boating, fishing and crabbing.

The Peel-Harvey catchment has an area of approximately 11 940 km^2 compared with an estuary area of 134 km^2 (*Figure 1).*

The Serpentine and Murray rivers flow from the north and east to the Peel Inlet and the Harvey River flows from the south-east to the southern part of the Harvey Estuary.

Figure 1 Peel-Harvey and other catchment boundaries (hydrological) for estuaries of the Regional Estuaries Initiative.

About 55% of the catchment has been cleared since European settlement in 1830. Numerous drainage systems were built to prevent flooding of farmland and combat increased flows due to catchment clearing. Land use categories have been detailed based on 2015 spatial data and aerial photography, and then validated by peer review (Hennig, *pers. comm*). On the Swan coastal plain, the region which has most influence on the estuary, the dominant land uses were identified as native vegetation (42%) and cattle for beef (41%) (Kelsey et al. 2011).

The Peel-Harvey estuary has a long history of eutrophication. It suffered ecological collapse in the 1970s-80s due to nutrient enrichment. Extensive and persistent blooms of *Nodularia spumigena* (a toxic cyanophyte) in the Harvey Estuary and macroalgal blooms of *Cladophora* and *Chaetomorpha* in the Peel Inlet (McComb & Lukatelich 1995) destroyed the estuary's social and environmental values in the late 1980s and early 1990s. The social and environmental history has been well-documented (Bradby 1997).

Part of the solution to these problems was to increase marine exchange in the estuary by construction of the Dawesville Channel in 1994. The channel dramatically improved the water quality in the main estuary basins through increased ocean water exchange, however significant actions to address the catchment nutrient loads were not undertaken.

The estuary is again suffering from pressures that threaten the natural values of and lifestyles in the region. In response to the increasing threats to the ecological, social and cultural values of the wetlands and in accordance with Australia's international and national commitments to managing Ramsar-listed wetlands, a management plan has been developed by the Peel-Harvey Catchment Council (PHCC 2017) to:

- work towards protecting and/or restoring the ecological character of the Peel-Yalgorup system
- promote the wise use of wetlands in the system by fostering the roles and responsibilities of local stewards.

In addition, an estuary protection plan is being developed in parallel with an update to the most recent water quality improvement plan (WQIP(EPA 2008). The WQIP will detail actions to improve the health of the estuarine ecosystem from a catchment perspective.

The REI applies a collaborative approach to improve water quality in the Peel-Harvey estuary through on-ground action and innovative science. Specifically it will:

- in partnership with the Department of Primary Industries and Regional Development, the Peel-Harvey Catchment Council (PHCC) and farmers, reduce the nutrient runoff from farms while supporting farm productivity
- in partnership with the PHCC and the Water Corporation, build drainage infrastructure to capture phosphorus and possibly extend the growing season for farmers
- trial new materials to treat soil, water and drains
- update modelling to evaluate potential estuary management actions
- monitor water quality condition for four years, augmenting the frequency of our usual monitoring, setting a baseline from which to gauge the effectiveness of investment in catchment actions.

3. Measuring estuary condition

Estuary condition is typically measured by a suite of biological, chemical and physical indicators.

The major current threats to the condition of estuaries in the South West of Western Australia are eutrophication due to excessive nutrient inputs, and reduced flushing by freshwater inflows due to climate change.

Eutrophication is a deterioration of water quality indicated by symptoms such as overgrowth of aquatic plants, macroalgae and/or phytoplankton and their subsequent decomposition, leading to anoxia (an absence or deficiency of oxygen). These effects can contribute to fish deaths and even an ecosystem shift from a healthy macrophyte/ seagrass-dominated system to a less desirable nuisance macroalgae/ phytoplankton-dominated system (Figure 2).

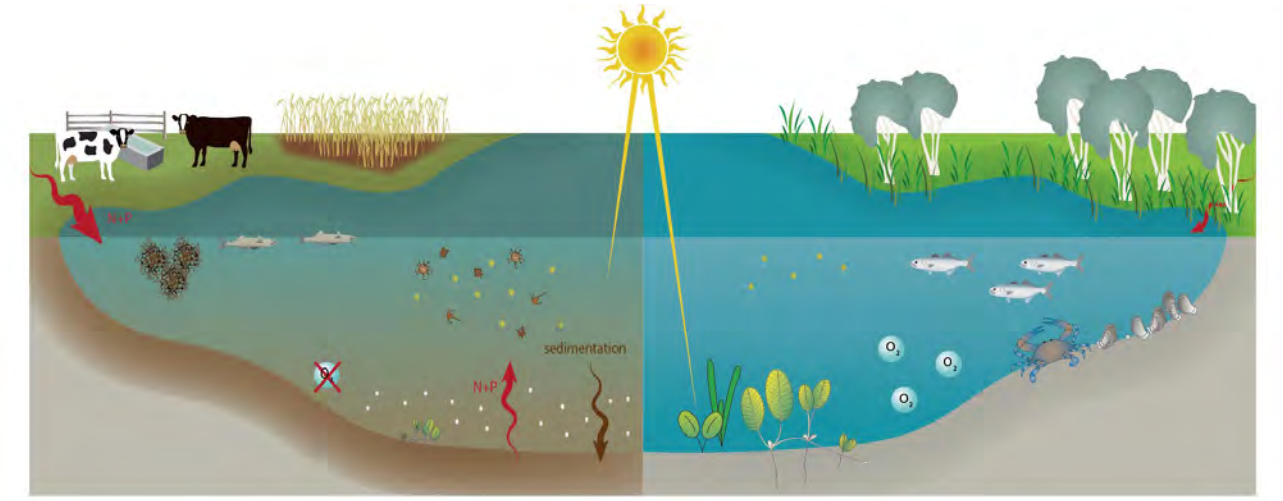


Figure 2 Conditions in a healthy (right) and unhealthy (left) estuary.

One of the goals in measuring the condition or water quality status of an estuary is to describe the extent to which a system is eutrophic.

Throughout the world a number of consistent indicators are routinely monitored for this purpose. The REI monitoring program measures a similar set of water quality indicators, and these include the following variables:

- salinity, dissolved oxygen, temperature, pH and turbidity at 0.5 to 1 m intervals in vertical profile
- Secchi depth
- nitrogen and phosphorus as both total concentrations and their bioavailable components
- chlorophyll *a*
- phytoplankton cell densities and their taxonomic group and species identification.

Data are presented as raw data and as means of surface water samples and bottom water samples, at each site for each zone of the estuarine system. Means are also compared with relevant guideline values.

The Peel-Harvey estuary has had resource condition targets set through the WQIP (EPA 2008) and Limits of Acceptable Change (LACs) through condition assessments, as dictated by the Ramsar Convention obligations. A comprehensive condition statement for the Peel Yalgorup system was prepared as part of the *Strategic impact assessment of the Perth Peel region* (DPC 2015). The 2015 statement reported on the broader ecosystem aspects of estuary condition in addition to water quality; for example, invertebrates, fish, birds and fringing vegetation, some of which were identified as information gaps. The current REI monitoring program assessment is focused on the physical, chemical and phytoplankton aspects of water quality as one indicator of estuary condition.

The ANZECC and ARMCANZ water quality guidelines are also used for assessing condition: these are derived from biological and ecological effects data and through the use of reference data. If data exceed the guideline values then this is considered a trigger for further investigations or management actions: both of which are underway in the Peel-Harvey estuary. For indicators where condition targets or guidelines have not been set, we have used the ANZECC and ARMCANZ guideline default values as reference points to compare data between different zones of the estuary and, in some cases, between seasons. For each analyte the data are plotted against the default guideline value for comparison and not as a pass or fail test. Where relevant, data are also compared against EPA (2008) WQIP targets.

4. The monitoring program

The water quality monitoring program measures a suite of physical, nutrient and phytoplankton variables on a fortnightly or monthly basis from sites in the main basins, as well as in the estuarine parts of the Murray and Serpentine rivers (Figure 3 and Table 1). Due to similarities in the water quality data and hydrological influences, sites are grouped into five reporting zones: Harvey, Dawesville, Peel, Murray River and Serpentine River. Although the Dawesville sites are located in both the Peel and Harvey basins, they are largely influenced by the ocean exchange through the Dawesville Channel. For this reason they are grouped together, as it allows comparison of the most marine-influenced zone with the estuarine and lower river zones.

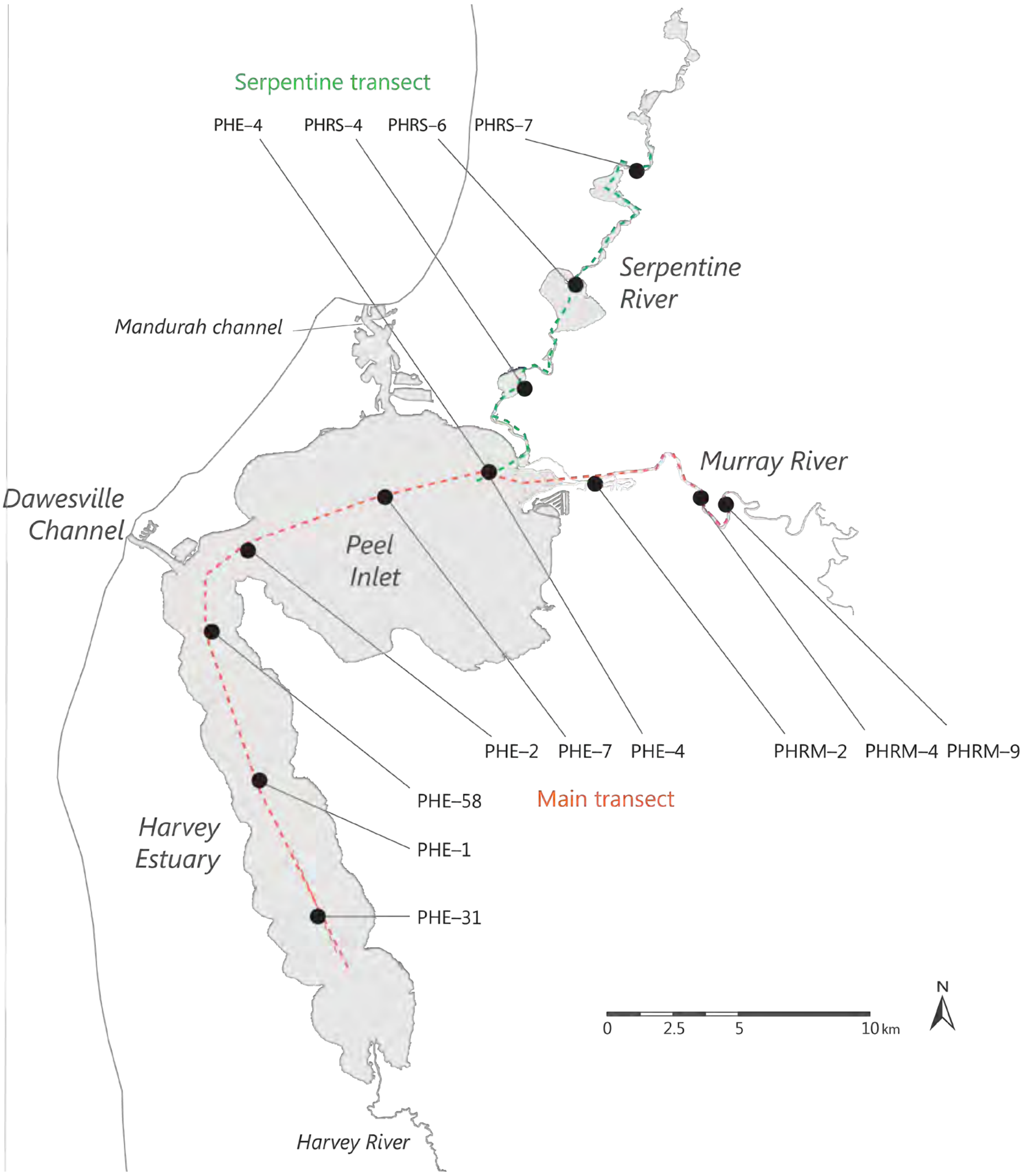


Figure 3 Peel-Harvey estuary site map with sampling locations. The transect lines are relevant to the physical profiles shown in Section 5.7 and in Appendix B.

Table 1 Peel-Harvey estuary sampling regime

Code	AWRC ref.	Easting	Northing	Max depth	Dist. from mouth	Salinity, DO, temperature, pH, Secchi	Chlorophyll		Phyto-plankton	TN, NO_x, NH_3/NH4, TP, FRP	
		metres	metres	metres	km	Vertical profile	Surface	Int	Int	Surface	Bottom
Harvey Estuary											
PHE-1	6131321	375969.8	6383055	1–3	8.6	f	f	f	f	m	m
PHE-31	6131322	377708.8	6377884	1.5–3	14	f	f	f	f	m	m
Dawesville											
PHE-58	6131323	374387.8	6388576	1.5–3.5	2.8	f	f	f	f	m	m
PHE-2	6140029	375329.8	6391875	1.5–3.5	2.5	f	f	f	f	m	m
Peel Inlet											
PHE-7	6140031	379242.8	6393234	1.5–3	6.6	f	f	f	f	m	m
PHE-4	6140030	383127.8	6395061	1–3.5	10.9	f	f	f	f	m	m
Murray River											
PHRM-2	6142624	386384.8	6394324	1.8–5.5	14.4	f	f	f	f	m	m
PHRM-4	6142625	390105.9	6393899	2.5–5.5	19.2	f	f	f	f	m	m
PHRM-9	6142855	390581	6394024	2.5–4.5	22.1	f	f	f	f	m	m
Serpentine River											
PHRS-4	6142627	384315.8	6398669	1–3.5	16.7	f	f	f	f	m	m
PHRS-6	6142953	385995.8	6402376	1	21.9	f	f		f*	m	
PHRS-7	6142629	388164.9	6406598	1	28.7	f	f		f*	m	

DO = dissolved oxygen, TN = total nitrogen, NO_x = nitrate+nitrite, NH_3/NH_4 = ammonium, TP = total phosphorus, FRP= filterable reactive phosphorus, Int = integrated, f = fortnightly, m = monthly, surface ~0.3 metres, bottom = 0.5 metres above sediment, max depth is a range due to variations in bottom topography and water level change seasonally and over the tidal cycle. *Phytoplankton monitoring at Serpentine sites S-6 and S-7 are surface grab samples as the water is too shallow for an integrated sample.

5. Physical-chemical dynamics

5.1 Salinity

Salinity measurements indicate the relative influence of marine exchange and freshwater inflows. Seawater is typically 35 parts per thousand (ppt) and pure freshwater is 0 ppt. When salinities increase above 35 ppt it means that the rate of evaporation is greater than the exchange and flushing dynamics, which would maintain salinities from 0 to 35 ppt.

Annual mean salinities for the Harvey and Peel basins – 34 to 37 ppt – were close to marine salinity (Figure 4). This illustrates the dominance of marine exchange via the Dawesville Channel compared with riverine inflows.

The Peel Inlet surface and bottom annual means were slightly lower than the Harvey Estuary, as the Peel receives more freshwater flow from the Murray and Serpentine rivers. The Murray River salinity annual means were 13 ppt in the surface and 25 ppt in the bottom waters. This difference highlights that this zone was stratified for extensive periods except for around two months in winter and in February after an atypical high rainfall event. At these times surface and bottom waters were less than 5 ppt (see Appendix C).

The Serpentine River annual means were also brackish – about 20 ppt – however there was large variation: standard deviations were a similar order of magnitude to the means (Figure 4). The high variability in means is because these sites were less than 5 ppt salinity in winter and hypersaline in late summer – up to 71 ppt (Serpentine River site S-7) (Appendix C).

The Serpentine sites also differed to the Murray sites in that they were generally unstratified. This is because sites S-6 and S-7 are very shallow (<1 m) and freshwater inflows are relatively small.

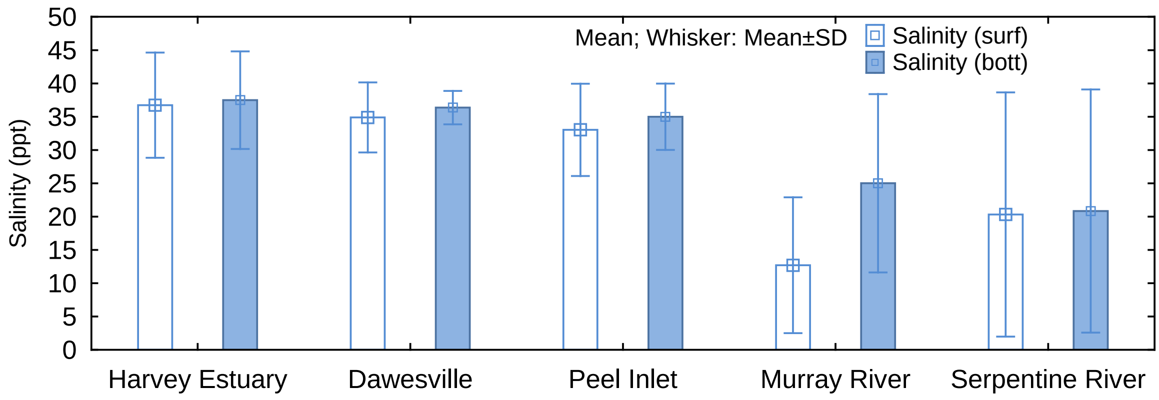


Figure 4 Zone mean and standard deviation of salinity in surface and bottom waters.

5.2 Oxygen

Oxygen is as vital to animals in water as to those on land. It is a key water quality indicator which reflects ecosystem health. Oxygen concentrations below 4.8 milligrams per litre (mg L^{-1}) are stressful to fish and below 2 mg L^{-1} can be lethal. Low oxygen conditions in bottom waters also negatively affect water quality by enabling release of sediment-bound nutrients. This, in turn, can lead to excessive algal growth.

Annual mean dissolved oxygen concentrations for the Harvey and Peel in surface and bottom waters were about 7 mg L^{-1} throughout the monitoring period (Figure 5). Bottom water oxygen in these basins was always above 5 mg L^{-1}.

The Murray River annual means showed the greatest variation between surface and bottom waters – 7.9 to 4.2 mg L^{-1} respectively – once again reflecting the stratification. Strong stratification inhibits the potential for wind mixing, which oxygenates the water column. Note also that the variation around the mean was considerable for the Murray bottom water sites and frequent episodes of anoxia or hypoxia were observed (see Appendix C).

For the two Murray sites (M-4 and M-9) furthest upstream, bottom water oxygen was below 5 mg L^{-1} in about 70% of samples and below 2 mg L^{-1} in about 45% of samples.

In the Serpentine River the annual means were about 6 mg L^{-1}, in surface and bottom waters (Figure 5). There was, however, large variation in the range from 2 to 10 mg L^{-1} (Appendix C).

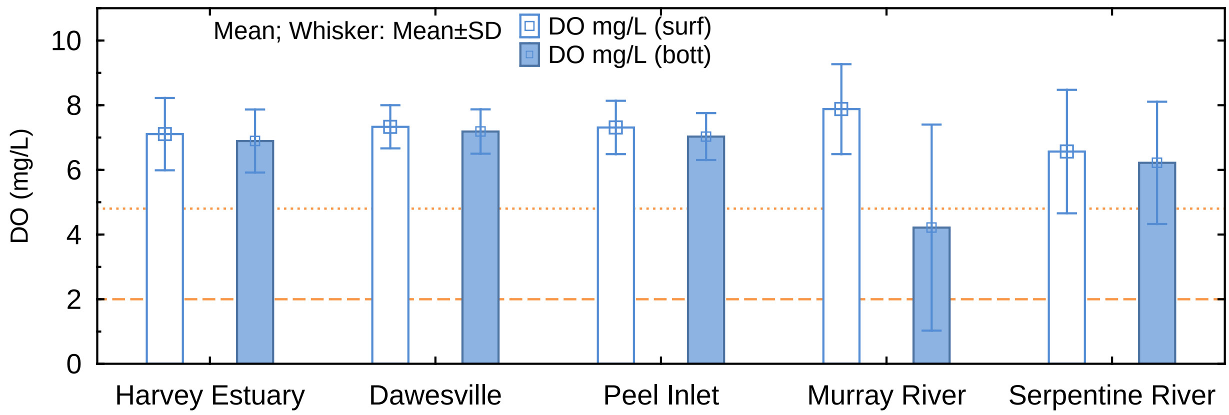


Figure 5 Zone mean and standard deviation of dissolved oxygen (DO) in surface and bottom waters (orange lines = guideline values).

5.3 Temperature

Temperature varies temporally, in response to the daily and seasonal solar radiation patterns, and spatially, due to different water sources – marine or freshwater inflows and depth.

Annual mean temperatures in both surface and bottom waters were around 18.5 degrees celsius (°C) in the Harvey Estuary, 19°C in the Peel Inlet, 19.5°C in the Serpentine River and 20.4°C in the Murray River (Figure).

Temperatures followed a consistent seasonal pattern, ranging from the high 20s in summer and autumn to winter lows of 10 to 12°C (see Appendix C).

In general there was little evidence of temperature stratification, however on a few occasions bottom temperatures were slightly higher (1 to 2°C) than surface temperatures, particularly in the late autumn months in the Murray River, with fewer instances in the Serpentine River. This was associated with stratified conditions where the surface layer was likely to be cooler due to lower air temperatures, especially at night.

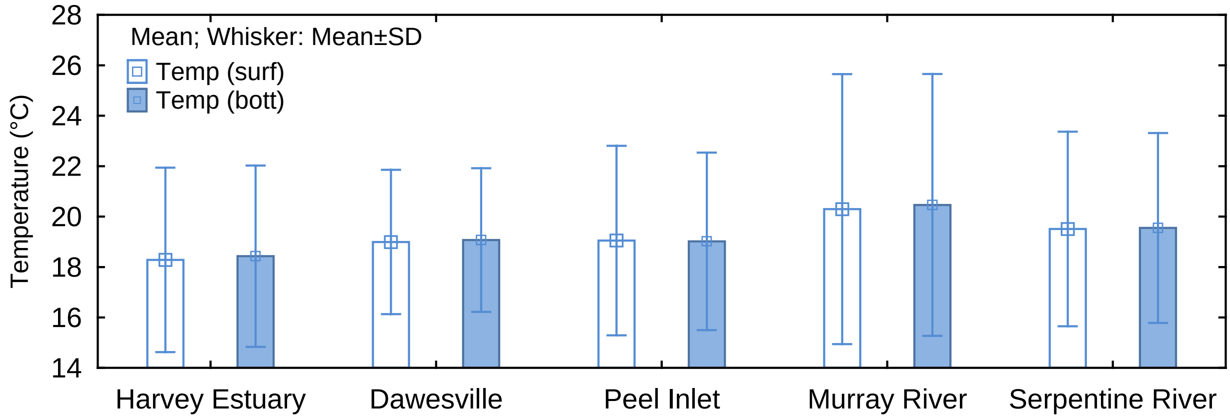


Figure 6 Zone mean and standard deviation of temperature in surface and bottom waters.

5.4 Acidity

The scale of acidity (pH) in estuarine waters is influenced by input from the catchment and by biological and chemical processes in the water column and at the sediment/water interface. During photosynthesis (e.g. algal blooms) carbon dioxide is removed from the water, which increases the pH. The pH in river waters tends to be lower.

Annual pH means ranged from 7.5 to 8.4 in the Harvey and Peel, which is within the ANZECC default trigger values for South West estuaries of 7.5 to 8.5 (Figure 7).

In the Murray River, pH means were 7.6 to 7.7, with greater variation in the bottom waters; that is, 6.9 to 8.3 (Figure 7 and Appendix C).

Serpentine River annual means were higher – 8 to 8.2 – but with considerable variation, being 6 to 10 pH units (Figure 7 and Appendix C). These means are higher than the ANZECC upper limit for pH in South West lowland rivers, which is 6.5 to 8 pH units (ANZECC 2000).

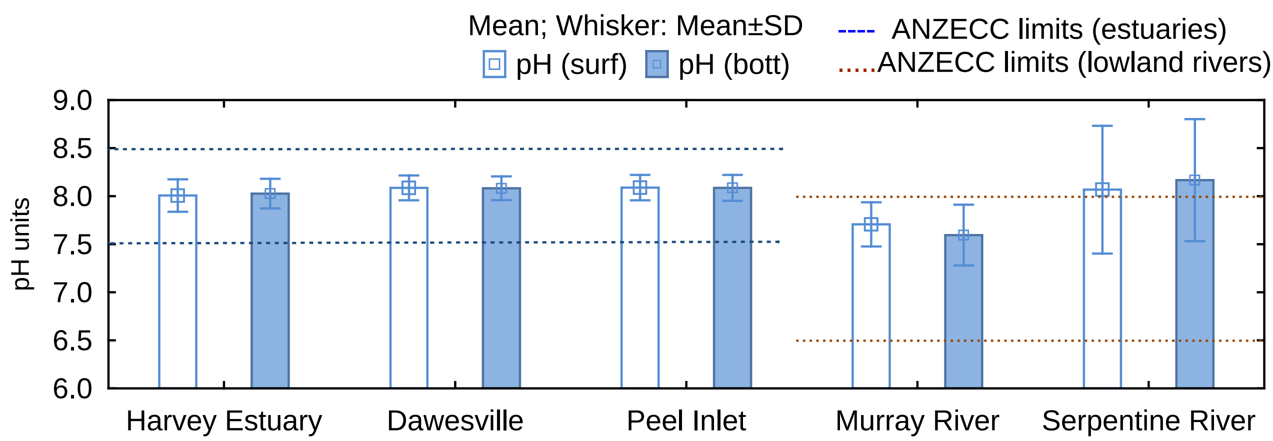


Figure 7 Zone mean and standard deviation of pH in surface and bottom waters.

5.5 Turbidity

Turbidity means for the Harvey Estuary and Peel Inlet were 1.8 to 2 nephelometric turbidity units (NTU) (Figure 8). Turbidity was higher in the river systems, with means of 4 and 7 NTU for the Murray surface and bottom respectively and 6.5 and 7 NTU for the Serpentine surface and bottom respectively. The large variation in Murray River data was due to one sampling event; hence the data do not necessarily represent conditions throughout the year.

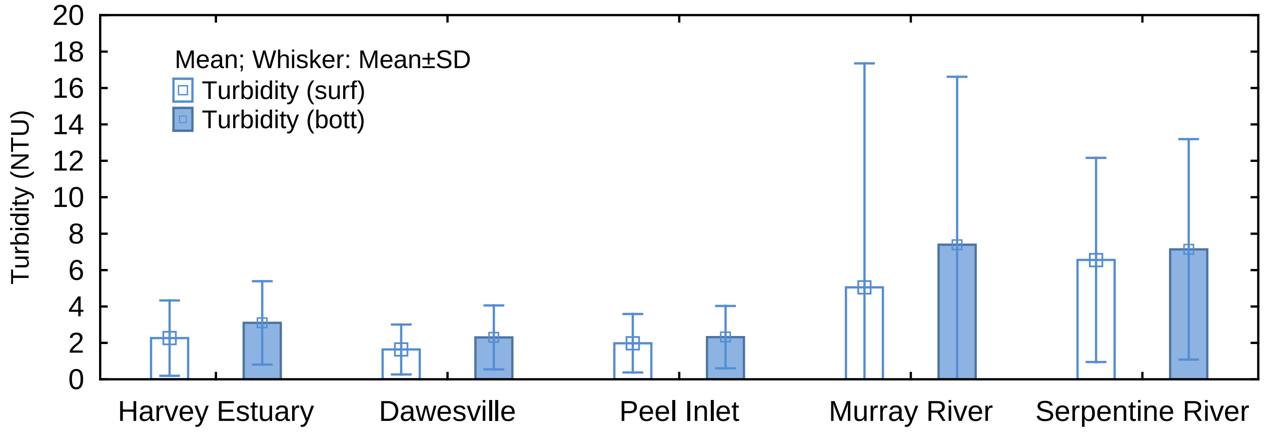


Figure 8 Zone mean and standard deviation of turbidity in surface and bottom waters.

5.6 Water clarity

Water clarity is the degree to which light penetrates the water column. Secchi depth is a universal and simple estimate of light penetration. In estuaries – from an ecosystem point of view – the focus is on whether or not light can reach the benthic layer for growth of seagrass and benthic microalgae. From a recreational and amenity point of view, clear waters are also preferable.

The annual mean Secchi depths for each zone are plotted in reference to the average of the maximum depth for each zone (*Figure 9*).

The Dawesville sites had the best water clarity of all the sites: mean Secchi depth of 2 m, 80% of the water column (*Figure 9*). The Harvey and Peel had Secchi depth means of 1.5 m and 1.7 m respectively, which corresponded to about 85% of the depth.

In contrast, the Murray and Serpentine rivers had means of 1.3 m and 0.7 m respectively, some 34% of the water depth (*Figure 9*), indicating substantially reduced light penetration in the lower river reaches.

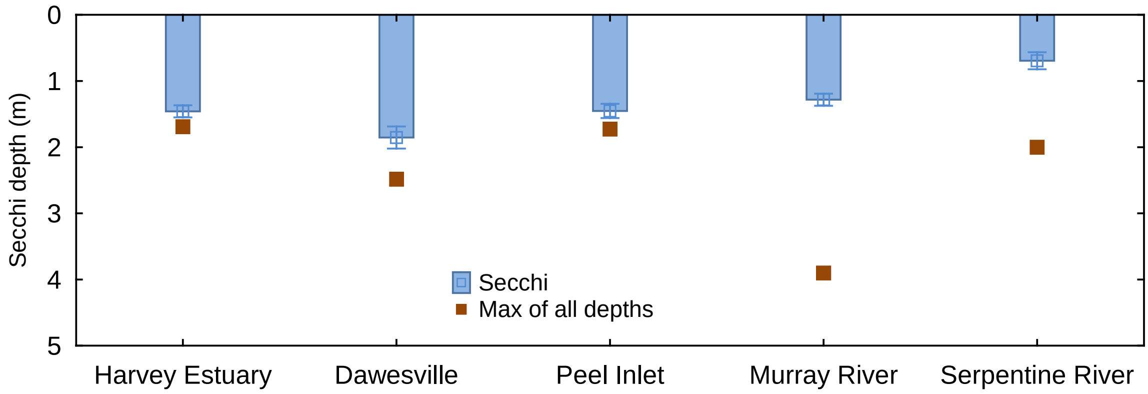


Figure 9 Zone means and standard deviations of Secchi depth and bottom depths. Zero on the y-axis represents the water surface (NB. S-6 and S-7 are shallower than S-4).

5.7 Hydrodynamics

The full vertical profile of physical data is visualised as contour plots; these show a vertical slice through the estuary along a transect for each sampling event (Figures 10 to 13).

At each site, data are measured at 0.5 m intervals vertically through the water column (dots on the contour plots). Contours are determined by interpolating between data points using *SURFER®$_{v13}$* (Golden Software, LLC). The contour lines join points of equal concentration.

The contour plot of **salinity** shows the relative influence of ocean exchange and river flow and whether or not these two inputs are well-mixed to give a uniform salinity at a site, or form layers of water with different densities (stratified).

The denser marine water will tend to sit below freshwater inflows unless there is a source of energy mixing them. Mixing occurs from wind energy at the surface, and/or from high flow velocities, which cause shear and turbulence at the interface of the layers.

The **oxygen** contour plot shows the amount of oxygen dissolved in the water at the time of sampling.

When the waters are well-mixed, shown as uniform salinity, oxygen concentrations tend to be above 6 mg L^{-1} and provide healthy conditions for aquatic fauna. When phytoplankton (microscopic algae) bloom, often in the surface layer, oxygen concentrations may exceed 10 mg L^{-1}. This is plenty of oxygen for fish but still potentially harmful: they can suffer from gas bubble disease or high densities of algal cells can block their gills.

When the water is stratified, shown by horizontal contour lines of salinity, the oxygen in the bottom layer is rapidly consumed by organic breakdown – leading to anoxic or hypoxic conditions.

The full set of contour plots for the monitoring period in the Peel-Harvey estuary and the estuarine lower river reaches show the hydrodynamic conditions for each fortnightly sampling event (see Appendix B).

The range of hydrodynamic conditions are illustrated by the summer and winter contour plots and by the 22 February 2017 plot, which shows an unusual summer inflow event.

The summer profile (3 January 2017) shows a marine (36 to 37 ppt), fully mixed and well-oxygenated (7 to 8 mg L^{-1}) water column in the Peel and Harvey estuaries (Figure 10).

The lower Murray River was stratified from brackish to marine salinities, associated with vertically stratified oxygen concentrations ranging from 8 mg L^{-1} to less than 1 m gL^{-1} in bottom waters (Figure 10). In the Serpentine there was a strong longitudinal gradient from the shallow and uppermost PHRS-7 to downstream sites, which had marine salinities. Note that the Serpentine River was hypersaline by the end of summer, with salinities up to 71 ppt (Appendix C).

Maximum temperatures were observed in the Murray River, around 29ºC (Figure 10).

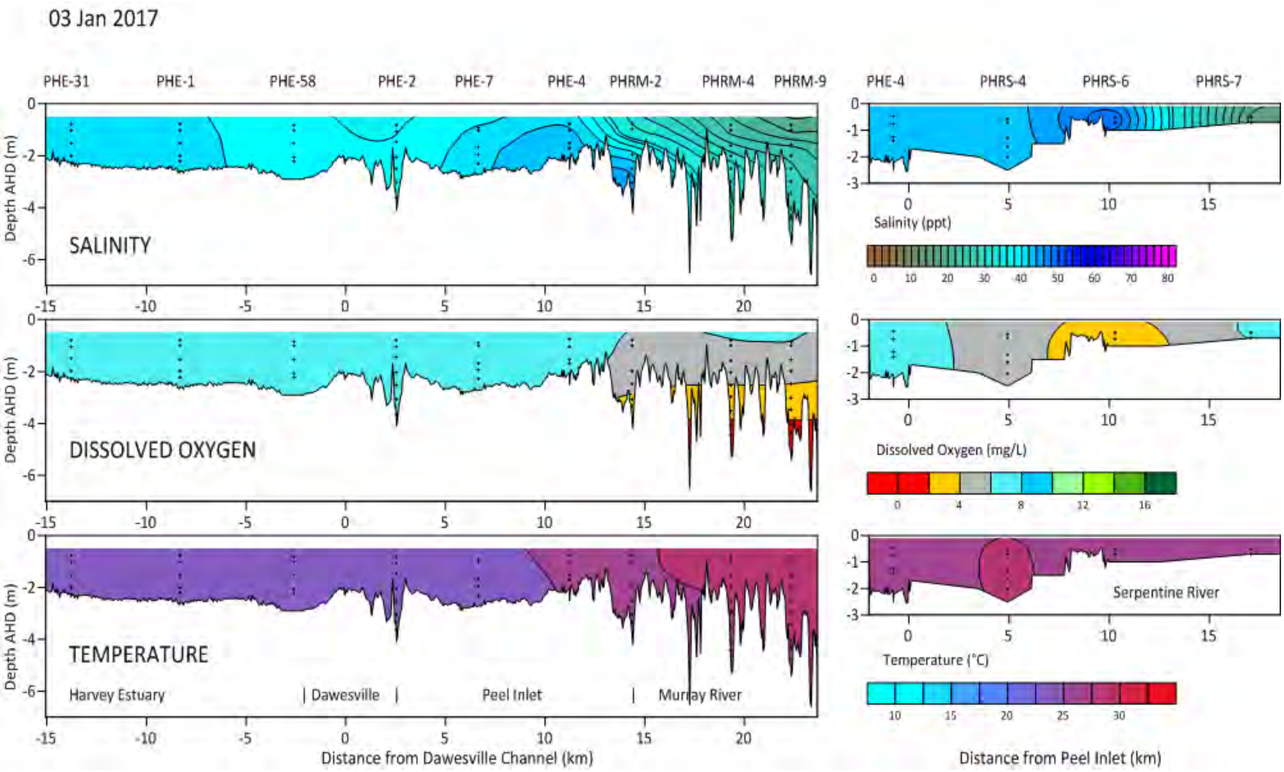


Figure 10 Summer salinity, dissolved oxygen and temperature contour plots, 3 January 2017.

February is typically a low-rainfall month in South West Western Australia; however, in early 2017 an active monsoon trough and several tropical lows over the state's north contributed to persistent and at times very heavy rainfall in late January and early February in the South West. For the 24 hours to 9 am on 10 February 2017, Dwellingup recorded 111 mm of rain, five times higher than the February average of 21.8 mm (BOM 2017).

The February 2017 rainfall event in the Murray and Serpentine river catchments resulted in freshwater flows, which flushed saline water from sites PHRM-4 and PHRM-9, and created strongly stratified conditions in the lower Murray at site PHRM-2 (Figure 11).

Even with this freshwater inflow, the oxygen status of the Murray and Serpentine rivers was moderate compared with the winter oxygen concentrations, which were above 8 mg L^{-1} (Figure 11). This suggests that despite the freshwater inflows, there was considerable oxygen demand – most likely attributable to the high organic matter load brought with the catchment inflows, as well as accumulated organic matter in the sediments, and warm seasonal temperatures.

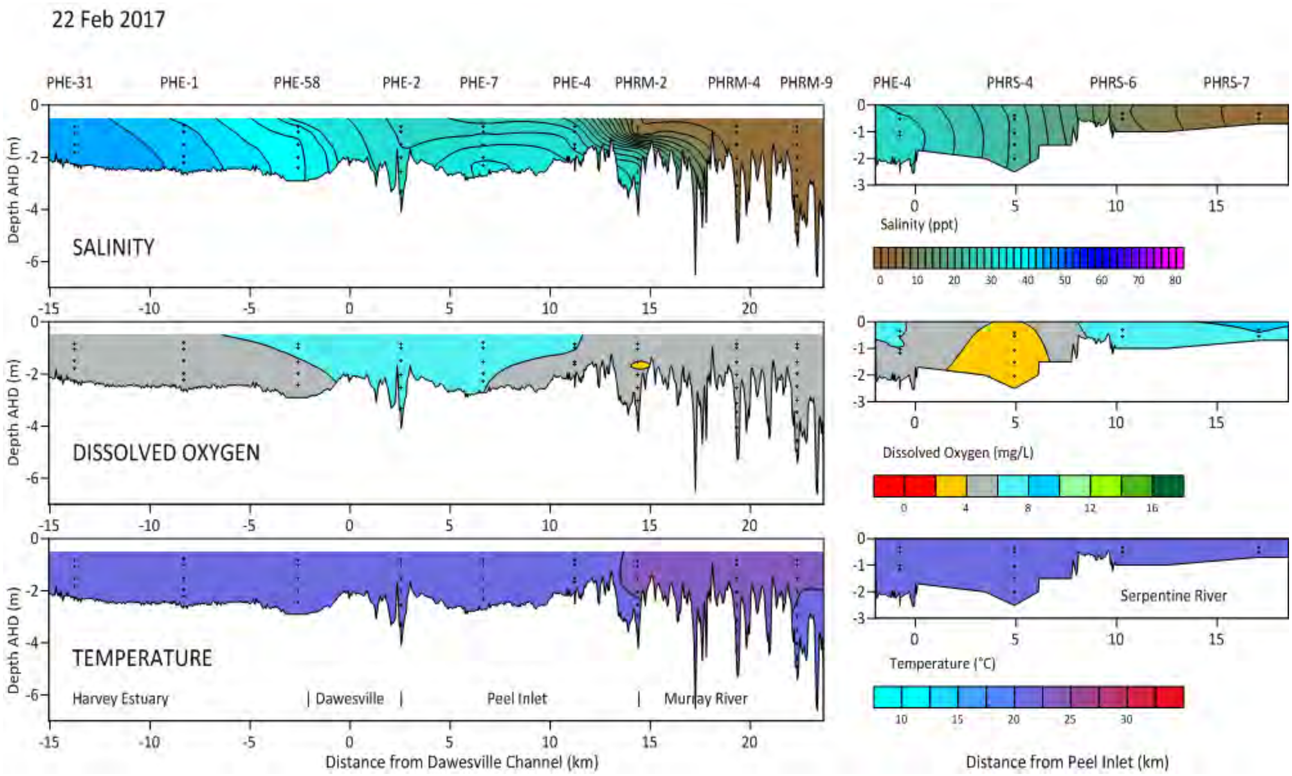


Figure 11 Salinity, dissolved oxygen and temperature contour plots, 22 February 2017.

Two weeks later (Figure 12), the length of the lower Murray was stratified and oxygen concentrations below 2 mg L^{-1} were observed in the bottom waters.

Concurrently the temperature across the rivers and estuary increased from 24°C to around 27 to 28°C.

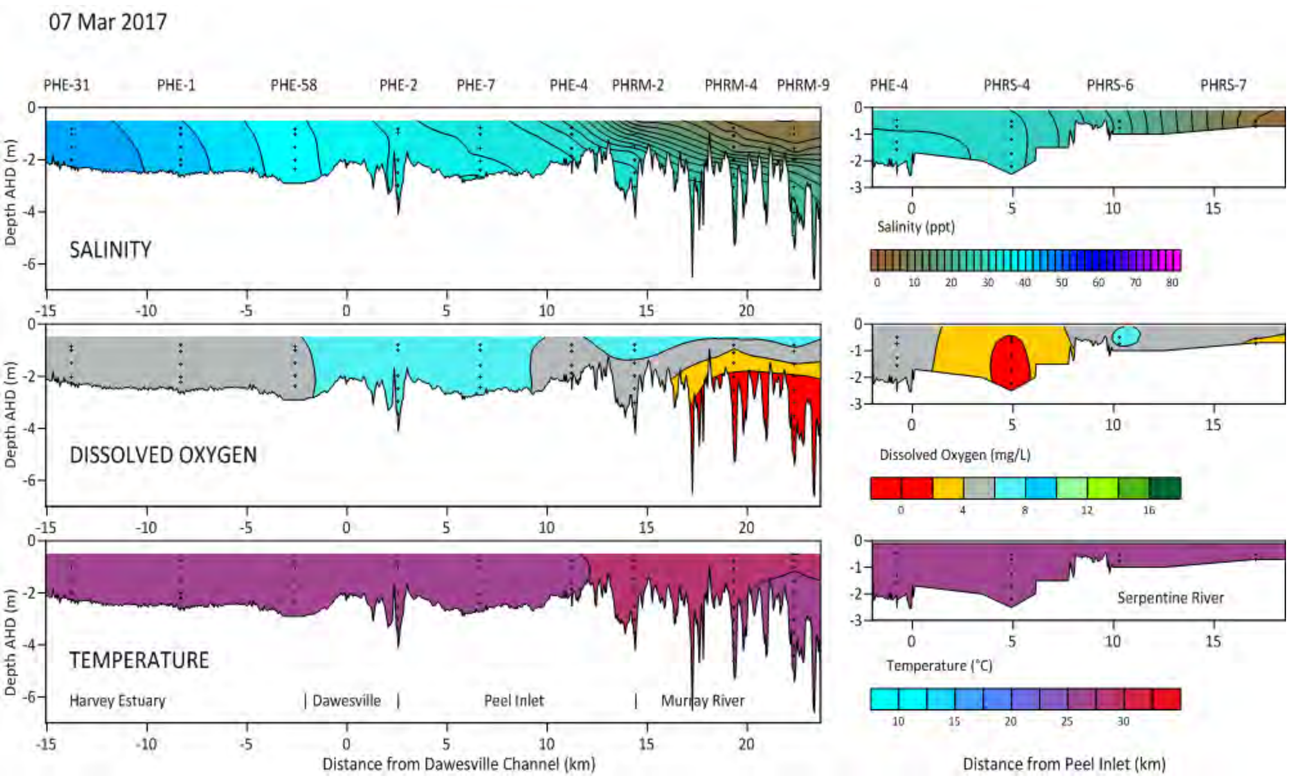


Figure 12 Late summer salinity, dissolved oxygen and temperature contour plots, 2 March 2017

In late July 2017, the typical winter rainfall/flow patterns established: this resulted in a fresh homogeneous water column of about 3 to 4 ppt in the Murray River and from less than 1 ppt to 3.5 ppt in the Serpentine (Figure 13).

Corresponding oxygen concentrations were above 8 mg L^{-1} in the Murray but still moderately low for fresh, well-mixed waters in the Serpentine, ranging from 5 to 7 mg L^{-1} (Figure 13).

Temperatures were cooler, from 14 to 16ºC (Figure 13).

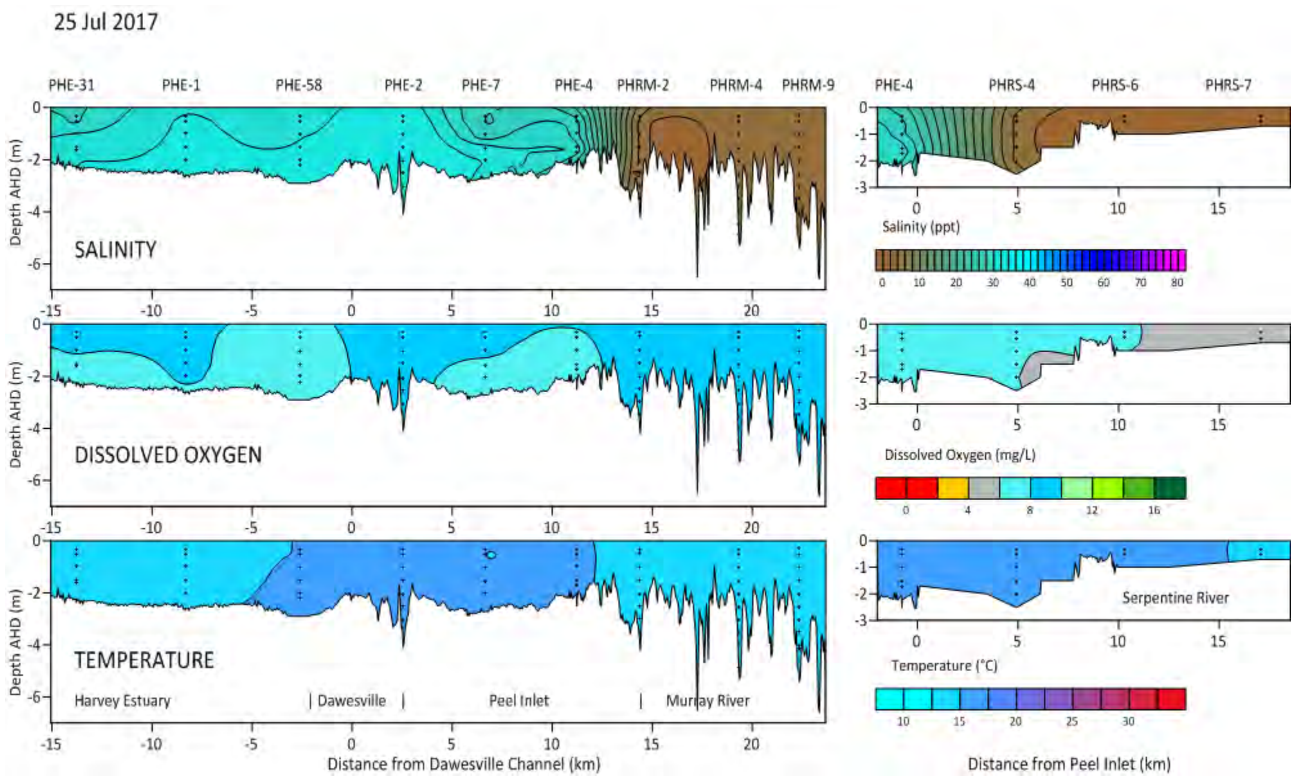


Figure 13 Winter salinity, dissolved oxygen and temperature contour plots, 25 July 2017.

6. Nutrients and chlorophyll *a*

Eutrophication is caused by the excessive nutrient enrichment of a waterbody, leading to rapid and undesirable algal growth and decomposition. Both nutrient and chlorophyll *a* concentrations in water are key indicators of the eutrophic status of a waterway. Chlorophyll *a*, a plant pigment, is used to estimate the concentration of microalgae in water. The key nutrients of concern in estuary management are nitrogen and phosphorus: these occur in different chemical forms and include both dissolved and undissolved fractions.

6.1 Nitrogen

Annual mean total nitrogen (TN) concentrations for the Harvey Estuary and Peel Inlet were below the ANZECC guideline for South West estuaries (Figure 14). The time series plots show two episodes of TN above the ANZECC guideline in February and September 2017 (Appendix C).

Murray River means were below the ANZECC guideline for lowland rivers; however, Serpentine River means in both surface and bottom waters were above the lowland river ANZECC guideline (Figure 14). Surface TN at the Serpentine River sites were frequently two to three times the ANZECC guideline in spring, summer and autumn (Appendix C).

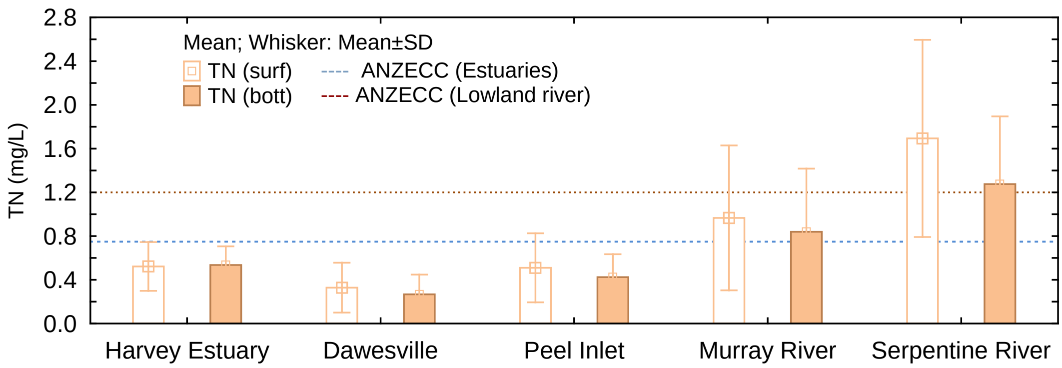


Figure 14 Zone mean and standard deviation of total nitrogen (TN) in surface and bottom waters.

Peel and Harvey nitrate plus nitrite (NOx) means were below the ANZECC guideline for estuaries, but the Murray River surface means were above the ANZECC guideline for lowland rivers (Figure 15). High NOx concentrations were about five to six times the ANZECC guideline in the Peel Inlet and Murray River in February after the atypical rainfall event – evidence that the Murray catchment is a high NOx source during times of flow.

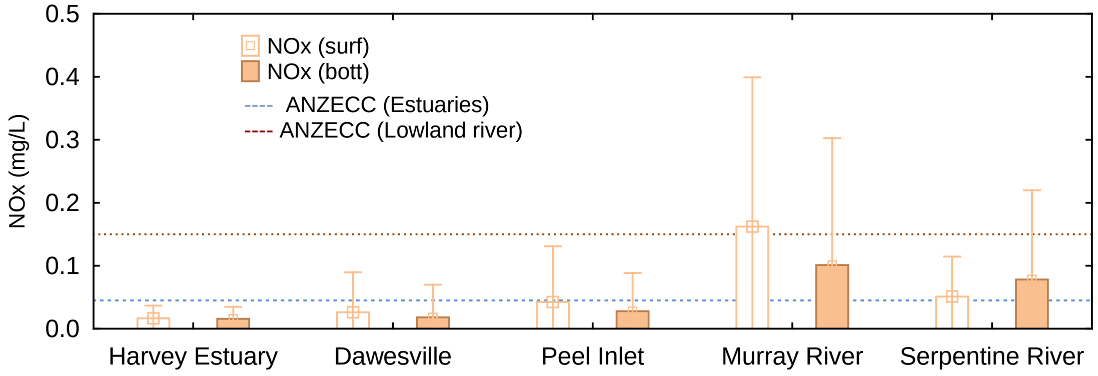


Figure 15 *Zone mean and standard deviation of nitrate+nitrite (NOx) in surface and bottom waters.*

Mean ammonium concentrations for the Peel Inlet and Harvey Estuary were below the ANZECC guideline for estuaries (Figure 16). However, the bottom water mean for the Serpentine River (0.098 mg L^{-1}) was above the ANZECC guideline for lowland rivers (0.08 mg L^{-1}) (Figure 16).

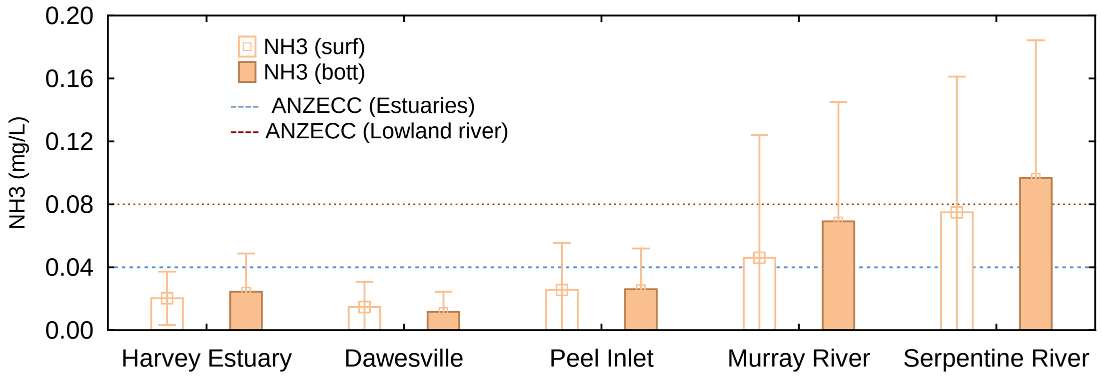


Figure 16 *Zone mean and standard deviation of ammonium (NH_3/NH_4) in surface and bottom waters.*

Total organic nitrogen (TorgN) means followed similar patterns to TN as it was the dominant nitrogen component in all samples. The waters of the Serpentine River had the highest TorgN mean, with large variation – particularly in the surface waters (Figure *17*).

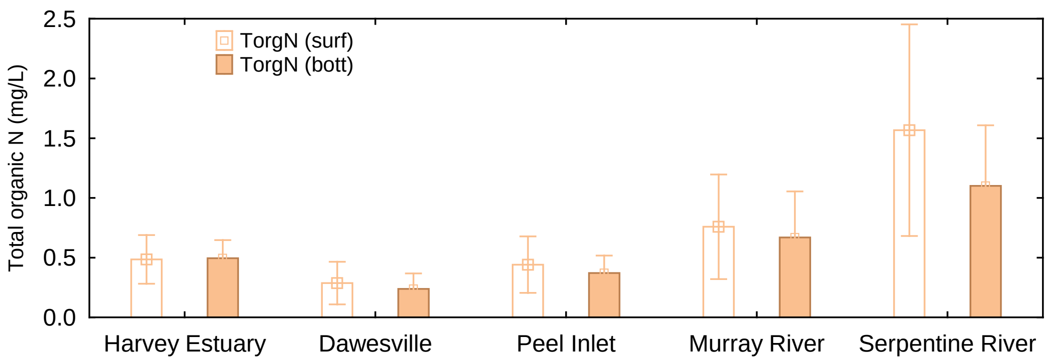


Figure 17 *Zone mean and standard deviation of total organic nitrogen (TorgN) in surface and bottom waters.*

6.2 Phosphorus

The total phosphorus (TP) mean for the Serpentine River (surface) was equal to the EPA target, 0.1 mg L^{-1} (Figure 18). Bottom phosphorus means and Murray River means were below the EPA target.

For the estuary main basins, all means were below the relevant ANZECC guideline.

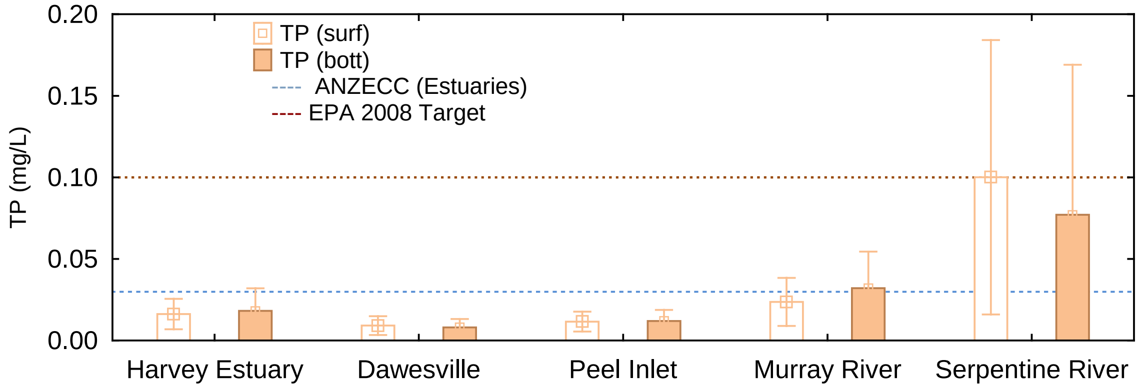


Figure 18 Zone mean and standard deviation of total phosphorus (TP) in surface and bottom waters.

Filterable reactive phosphorus (FRP) means for the Harvey and Peel were below the ANZECC guideline.

Murray River FRP means were at or slightly above the ANZECC guideline for estuaries (Figure *19*). However, the Serpentine River means were significantly higher but still below the guideline for lowland rivers (Figure *19*).

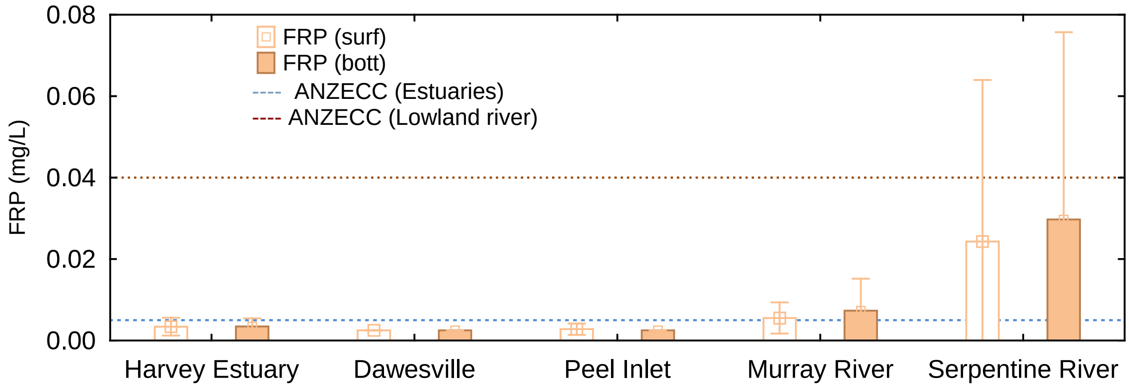


Figure 19 *Zone mean and standard deviation of filterable reactive phosphorus (FRP) in surface and bottom waters.*

6.3 Chlorophyll *a*

Surface chlorophyll *a* seasonal means for the Harvey, Dawesville and Peel zones ranged from 0.6 to 2 μg L^{-1} – all below the ANZECC guideline for South West estuaries (*Figure 20*). Dawesville chlorophyll *a* concentrations were consistently low in all seasons.

The Murray River means ranged from 3.3 µg L^{-1} in spring to 12.6 µg L^{-1} in autumn, and the Serpentine means ranged from 2.8 µg L^{-1} in winter to 28.1 µgL^{-1} in autumn. The maxima in autumn followed the February 2017 rainfall event and might not be indicative of an annual pattern.

Murray River chlorophyll *a* means were below the EPA target (10 µg L^{-1}) in winter and spring; in autumn the mean exceeded the EPA target. In the Serpentine, chlorophyll *a* means exceeded the EPA target in spring, summer and autumn (*Figure 20*).

The Serpentine River is the most productive zone in terms of algal activity. Note that substantial variation occurred during the autumn peak algal activity in the Serpentine, as indicated by the large standard deviation. The chlorophyll *a* maximum for the Serpentine River was 180 µg L^{-1} in March 2017.

The peak in algal activity in the Murray and Serpentine rivers followed the unusual February rainfall event. In the Serpentine this event resulted in a rapid reduction in salinity – from hypersaline (~60 ppt) to fresh/brackish (3 to 29 ppt) – and additional organic nutrients coming into the river. This event also coincided with maximum water temperatures of up to 27ºC.

There was also a significant reduction in salinity in the Murray River at this time, and a sharp elevation in NO_x.

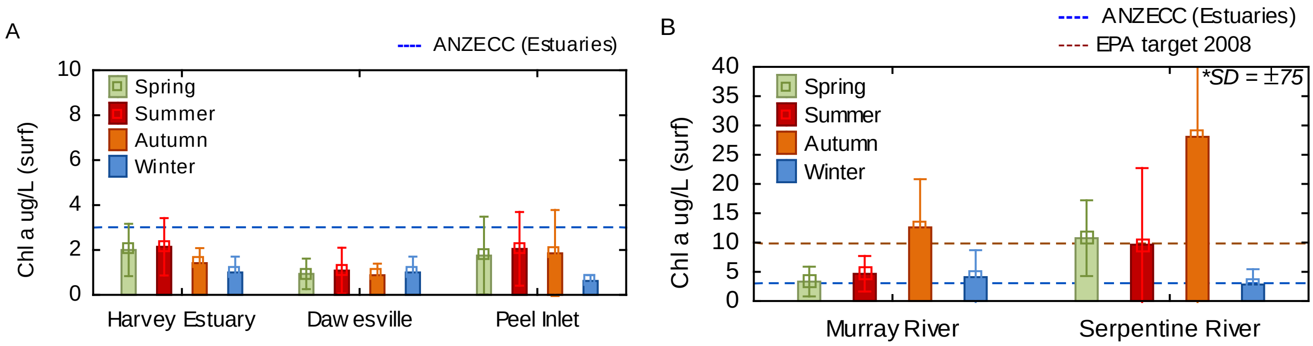


Figure 20 *Seasonal means and standard deviations of surface chlorophyll* a *in the (A) main basins and (B) lower rivers estuarine zones.*

A review of historical chlorophyll *a* data in Western Australian estuarine waters by the former Department of Fisheries (Pearce *et al.* 2000) for the same estuary sites summarised observed chlorophyll *a* means before and after the Dawesville cut (Table 2). These show that spring and summer means in both the Peel and Harvey (>50 µg L^{-1}) reflected extreme eutrophic conditions before the Dawesville cut , while dramatic reductions in chlorophyll *a* were observed in the early post-cut years. The 2016–17 chlorophyll *a* means were below or at the low end of the post-cut range of means in spring to autumn and the winter means were well below the post-cut means. These results highlight the success of the Dawesville Channel in terms of reducing eutrophic symptoms in the main estuary basins.

While the same historical data does not exist for the Murray and Serpentine estuary reaches, it is interesting to note that pre-cut peaks in the Peel and Harvey were in spring and summer; in contrast, the current peak chlorophyll *a* means in 2017 were observed in the Murray and Serpentine in autumn (Table 2). In part this may have been due to the unseasonal February rainfall event.

Table 2 Seasonal chlorophyll a *means (µg L^{-1}) compared with means pre and post the Dawesville Channel.*

		Spring	Summer	Autumn	Winter
Harvey	2016–17	1.6	1.7	1.2	0.9
	post-cut[1]	1.7–5.8	2.5–6.8	1.5–5.5	2.3–9.0
	pre-cut[2]	85–102	66–80	2.7–4.8	8.4–11
Peel	2016–17	1.5	1.8	1.6	0.8
	post-cut	2.1–3.3	2.4–4.0	1.1–2.8	2.8–6.0
	pre-cut	53–103	24–30	1.5–2.3	4.7–7.2
Murray	2016–17	3.3	4.7	12.6	4.1
Serpentine	2016–17	10.8	9.6	28.1	2.8

[1] Post-cut range of means from July 1994 to April 1997 (summarised by Pearce *et al*. 2000)
[2] Pre-cut range means from July 1991 to August 1993 (summarised by Pearce *et al.* 2000)

7. Phytoplankton

Phytoplankton are microscopic single-celled algae and form the base of the food web in aquatic ecosystems. They contain chlorophyll, photosynthesise, and globally play an important role in capturing carbon from carbon dioxide in the atmosphere.

Taxonomically, phytoplankton are divided into a number of groups which have similar characteristics and genetic connections. When an ecosystem is unbalanced, phytoplankton populations can grow exponentially and/or the relative group composition can change. As a broad generalisation, dominance by the diatom group tends to indicate good water quality or ecosystem health. Dominance by the dinophyta or cyanophyta groups is a signal of poor water quality and less desirable for a healthy and diverse food web. Certain species can produce toxins which are harmful to aquatic organisms, birds and/or humans.

In the Peel-Harvey, the phytoplankton groups and species distributions showed quite distinctive spatial patterns in the estuary basins and the lower river reaches.

Total phytoplankton densities in the Harvey Estuary reached a maximum of 4500 cells per mL at site PHE-31 in spring (Figure 21). A secondary peak in January 2017 at site 31 was dominated by *Rhizosolenia* (diatom). The spring 2017 maxima at sites 1 and 31 were dominated by cryptophyte species.

The Dawesville sites had the lowest peak cell densities: 3350 cells per mL at site PHE-2. These were mostly diatoms.

Peak phytoplankton densities in the Peel Inlet were up to 10 000 cells per mL in the mid-basin site (PHE-7), where diatoms (*Skeletonema*) were dominant (Figure 21). This rapid increase in cell densities from <300 cells per mL in the preceding fortnight was a response to the atypical February rainfall event that brought high concentrations of nitrate and ammonium to the Peel basin.

Generally cell densities at PHE-4, closest to the river inputs, had more peaks than PHE-7, ranging from 1000 to 7000 cells per mL.

The Murray River peaks in May 2017 were *Karlodinium* (dinophyte) and *Skeletonema* (diatom) co-dominant. Total densities typically ranged from 1000 to 40 000 cells per mL.

Serpentine River cell densities were significantly higher than other regions. The maximum at site PHRS-7 was 3 500 000 cells per mL, dominated by cyanobacteria species (see Appendix D for all phytoplankton cell densities). Note that due to the shallow nature of site PHRS-6 and PHRS-7, the sampling method for phytoplankton was a surface grab sample rather than an integrated tube sample. As such, the data are indicative and not directly comparable with the other Serpentine site (PHRS-4) or other sites in the Peel-Harvey and Murray River zones. At site PHRS-4, all phytoplankton group densities were significantly lower than the upstream Serpentine sites. Total phytoplankton densities were orders of magnitude lower: maximum of 58 000 cells per mL.

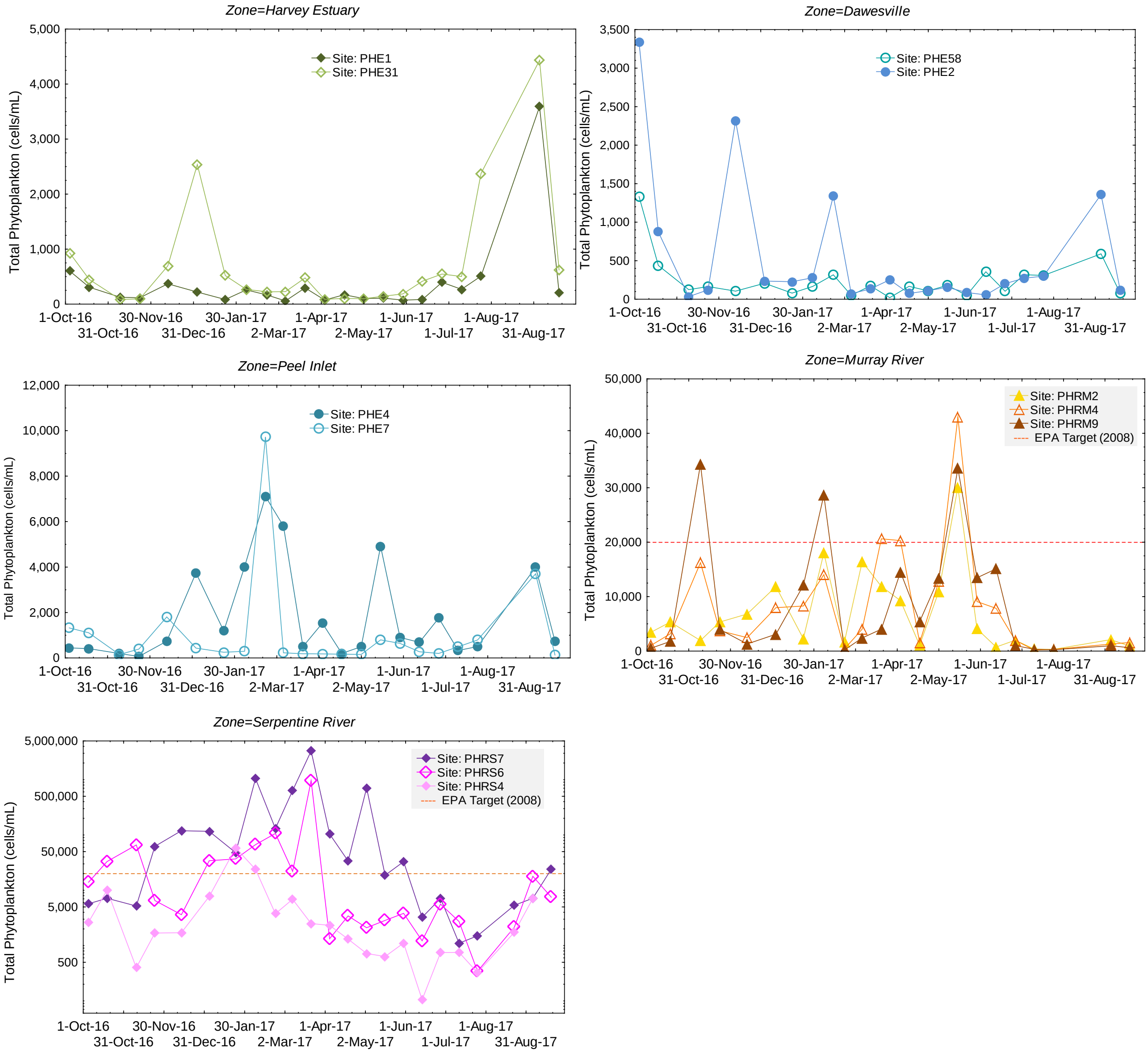


Figure 21 Total phytoplankton time series for all sites grouped by zone. Note the Serpentine data are on a logarithmic scale.

The relative abundance of phytoplankton groups during the 12-month monitoring period showed a similar pattern at the Harvey Estuary, Dawesville and Peel Inlet sites with diatoms and cryptophytes co-dominant (Figure 22). Dinoflagellates tended to be dominant or co-dominant in autumn in the Harvey Estuary. On a couple of occasions haptophytes were co-dominant in the mid Peel basin, at site PHE-7 (Figure 22).

Group composition patterns in the Murray and Serpentine rivers were very different. In the Murray, diatoms and dinophytes were the dominant groups, with dinophytes dominant in autumn, especially at site PHRM-9 (Figure 23).

The Serpentine River sites were diatom/cryptophyte-, chlorophyte- and sometimes cyanophyte-dominant in summer, autumn and spring 2017 (Figure 23). Cyanophyte-dominated sampling events – about 25 per cent of samples – occurred at the most upstream site, PHRS-7 (Figure 23).

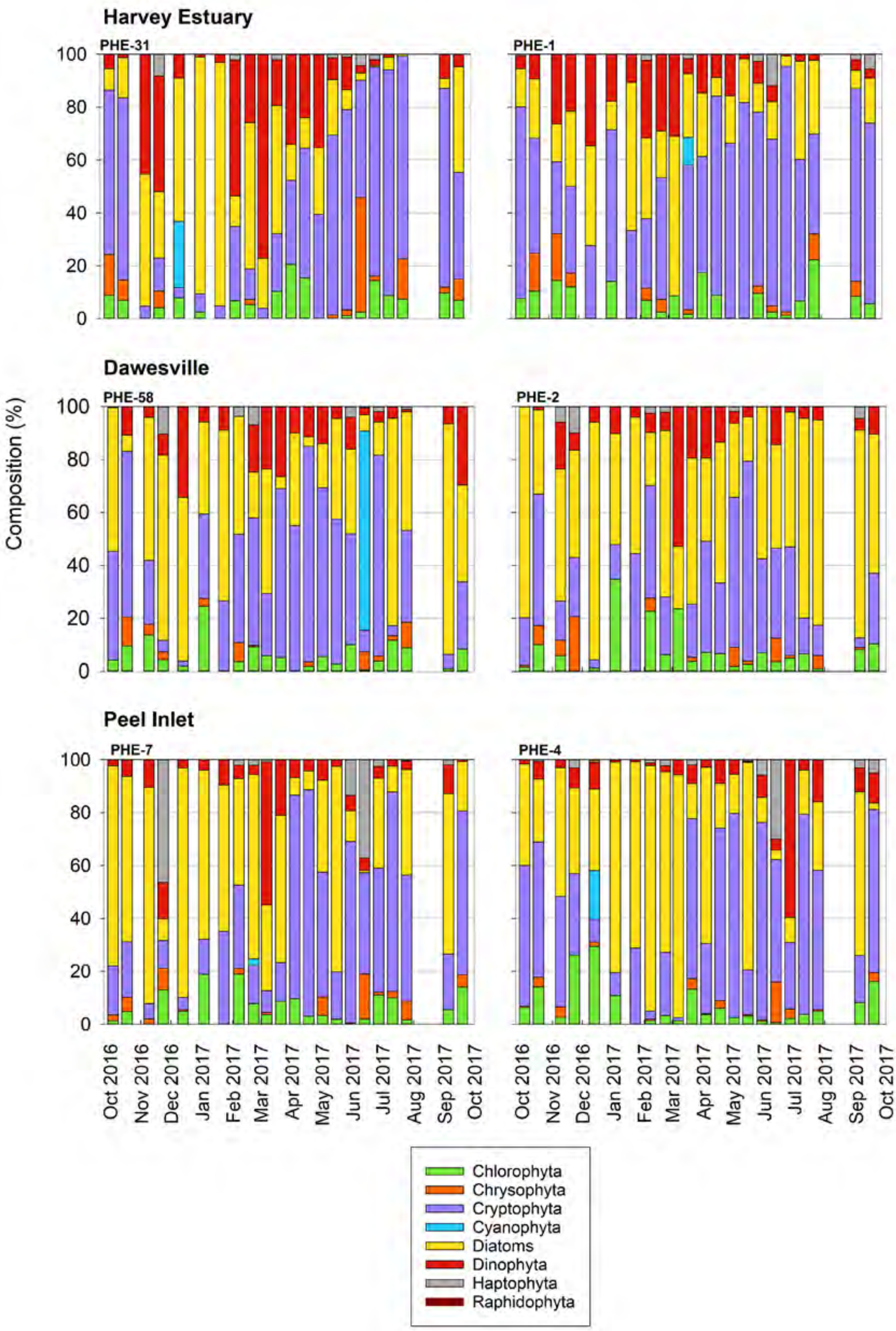


Figure 22 Phytoplankton group percent composition for the Harvey Estuary, Dawesville and Peel Inlet sites.

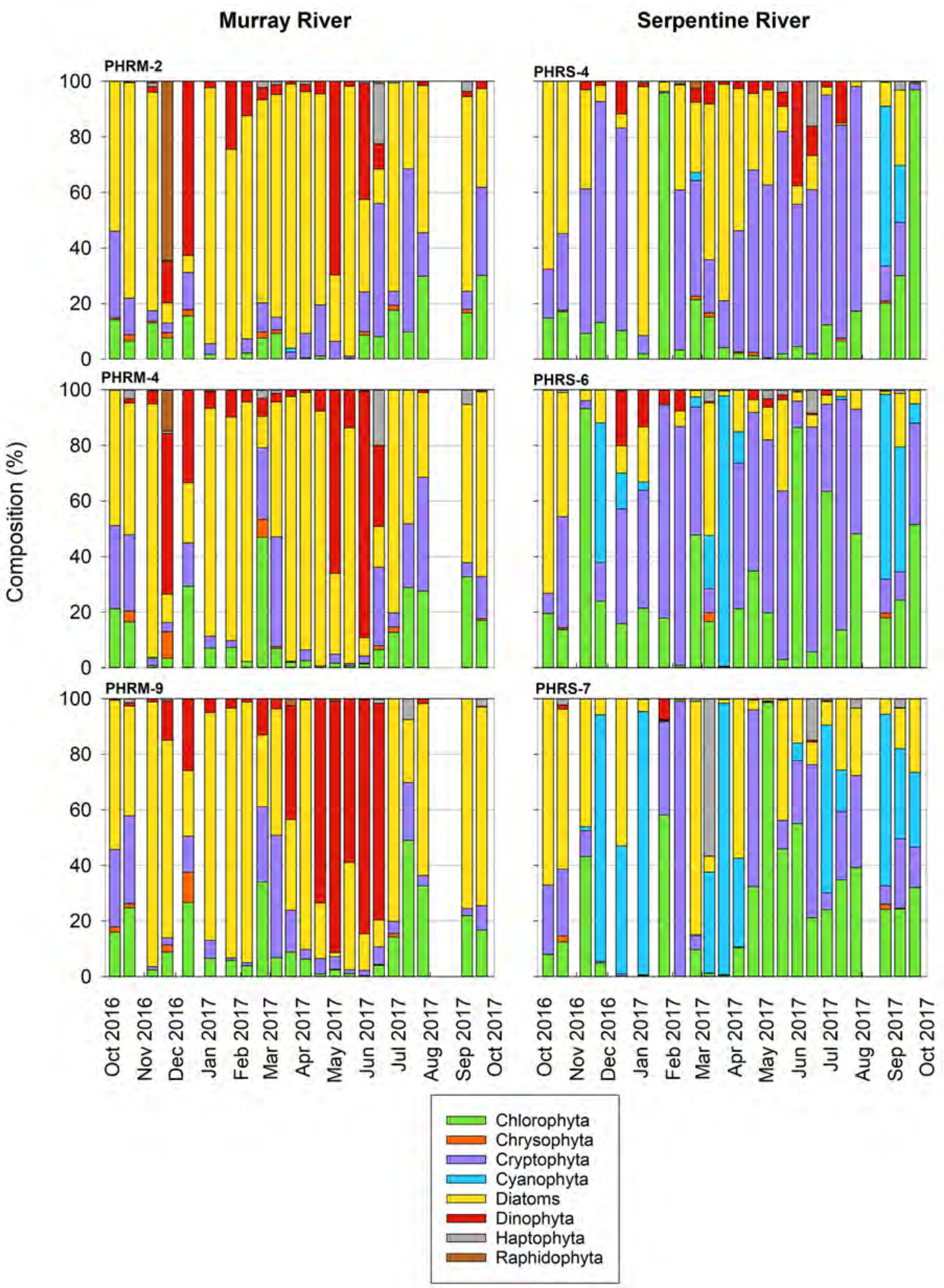


Figure 23 Phytoplankton group percent composition for sites at the Murray and Serpentine rivers.

7.1 Harmful algal species

A total of 26 potentially harmful microalgae genera were identified during the 2016–17 monitoring period. Nineteen of these were identified to species level, representing five major taxonomic groups – cyanophytes, diatoms, dinophytes, haptophytes and raphidophytes.

Cyanophyta

The global expansion of cyanobacterial harmful algal blooms (cyanoHABs) due to climate change and anthropogenic nutrients is a recognised threat to the ecology and social values of inland and coastal waters (Paerl *et al.* 2015). The cyanoHAB *Nodularia spumigena* was prolific in the Harvey Estuary in the 1980s and early 1990s before the Dawesville cut. At that time, summer *Nodularia* blooms were a typical feature, driven by freshwater inflows and sediment phosphorus sources (McComb & Lukatelich 1995).

The current monitoring shows that cyanoHABs were dominant in the Serpentine River; numerous notable harmful cyanophyte species were observed in excess of 500 000 cells per mL (Figure *24*). The previously dominant *Nodularia spumigena* – absent from the Harvey, Peel and the lower Murray samples – was present in the two upper Serpentine sites, mostly in summer.

A total of eight cyanoHAB species (and 10 genera) were identified in the Serpentine River, some at very high cell densities, >500 000 cells per mL (Table 3). In the Serpentine, the cyanophytes were dominant about 20% of the time. The genera with greatest densities were *Aphanizomenon, Anabaena, Psuedoanabaena* and *Planktolyngbya*.

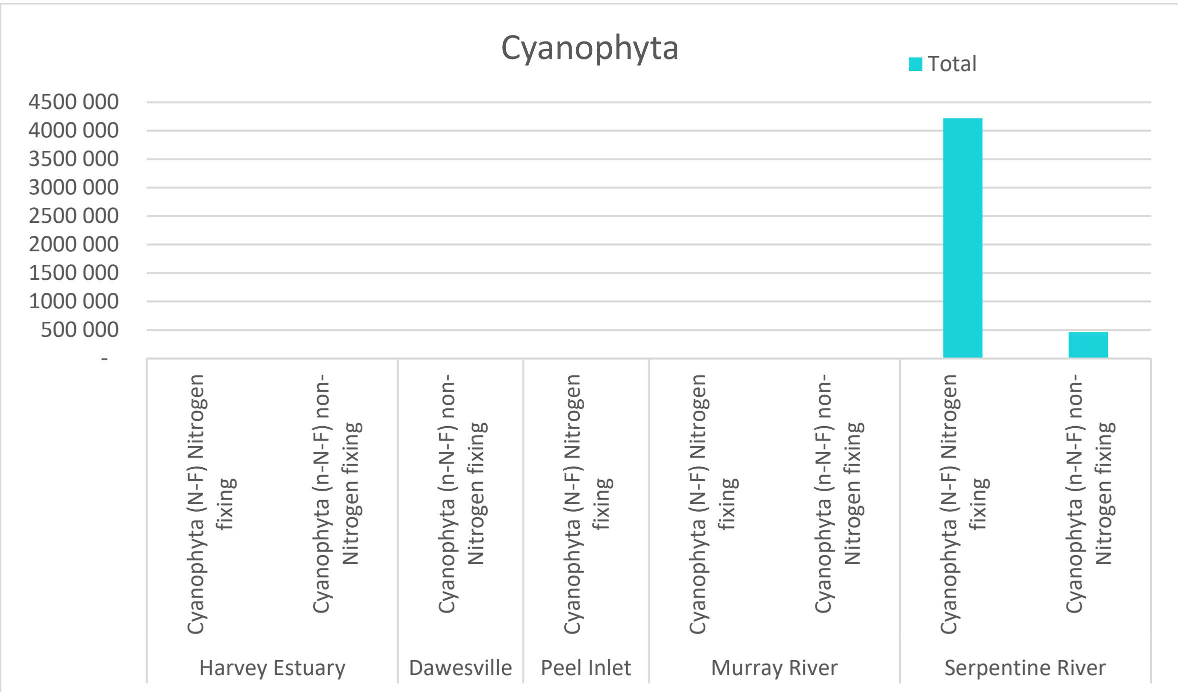


Figure 24 *Sum of cell densities (cells per mL) of harmful phytoplankton of the cyanophyta (nitrogen fixing) and cyanophyta (non-nitrogen fixing) groups in the five main estuary zones.*

Table 3   Sum of cell densities of harmful cyanophyta species in the Serpentine River.

Cyanophyta	Sum of species density cells/ml
Serpentine River	**4 684 322**
Cyanophyta (nitrogen fixing)	**4 222 677**
Anabaena aphanizomenioides	554
Anabaena circinalis	2583
Anabaena **spp.**	100 062
Anabaenopsis arnoldii	22
Anabaenopsis spp.	784
Cylindrospermopsis raciborskii	5684
Nodularia spp.	21 135
Nodularia spumigena	5296
Planktolyngbya minor	3 586 005
Pseudanabaena limnetica	426 556
Pseudanabaena spp.	73 996
Cyanophyta (non-nitrogen fixing)	**461 645**
Aphanizomenon ovalisporum	30 047
Aphanizomenon spp.	427 476
Aphanocapsa spp.	12
Merismopedia spp.	4090
Microcystis spp.	20
Grand total	**4 684 322**

Diatoms

Only one harmful diatom genus was identified: *Psuedonitzschia.* This phytoplankton predominantly occurred at the Dawesville sites at relatively low cell densities and very low densities in the Peel and Harvey zones (Figure 25 and Table 4).

Pseudonitzschia is a marine planktonic diatom genus capable of producing the neurotoxin domoic acid (DA), which causes amnesic shellfish poisoning in humans.

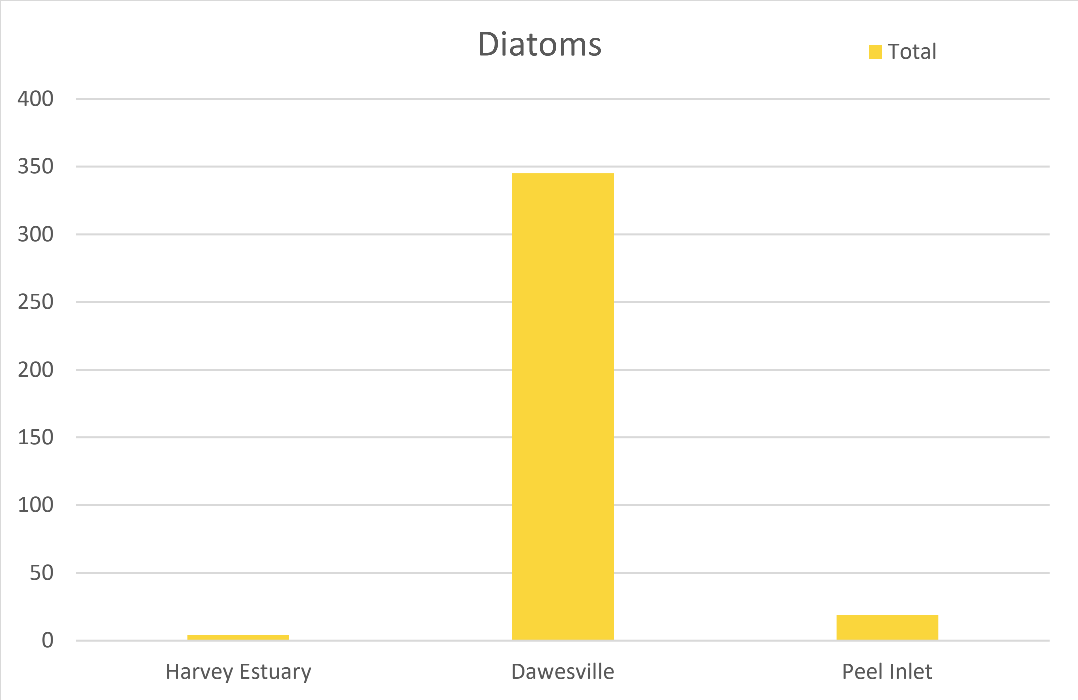


Figure 25 *Sum of cell densities (cells per mL) of harmful diatoms in the three estuary zones.*

Table 4 *Sum of cell densities of harmful diatom species in the three estuary zones.*

Diatoms	Sum of species density cells/mL
Harvey Estuary	4
Pseudonitzschia spp.	4
Dawesville	345
Pseudonitzschia spp.	345
Peel Inlet	19
Pseudonitzschia spp.	19
Grand total	368

Dinophyta

Harmful dinophyta species were concentrated in the Murray River with 95 000 cells per mL, predominantly *Karlodinium* spp., reported during the monitoring period (Figure 26 and Table 5).

Karlodinium is known to produce karlotoxins and has been implicated in numerous fish kill events. Elevated cell densities of *Karlodinium* spp. were observed, mostly in the Murray River and in association with the fish kill events of May and June 2017 (see Section 9).

Maximum *Karlodinium* cell densities from 5000 to 18 000 cells per mL were recorded in the Murray River sites from 2 May 2017 to 16 June 2017 (Figure 28). Interestingly, these observations coincided with fish kill events; however, the cell densities were relatively low compared with other *Karlodinium* blooms such as the Swan River estuary blooms of 2003 and 2004, which recorded maxima of 93 000 cells m L^{-1}. Note that the Swan River had a higher sampling frequency – weekly monitoring with additional response sampling events associated with the *Karlodinium* bloom, and so the peak density in the Murray River might not have been measured.

Karlodinium were also observed at low cell densities: <50 cells m L^{-1} in the main estuary basins and Serpentine River during the monitoring period (Figure 28).

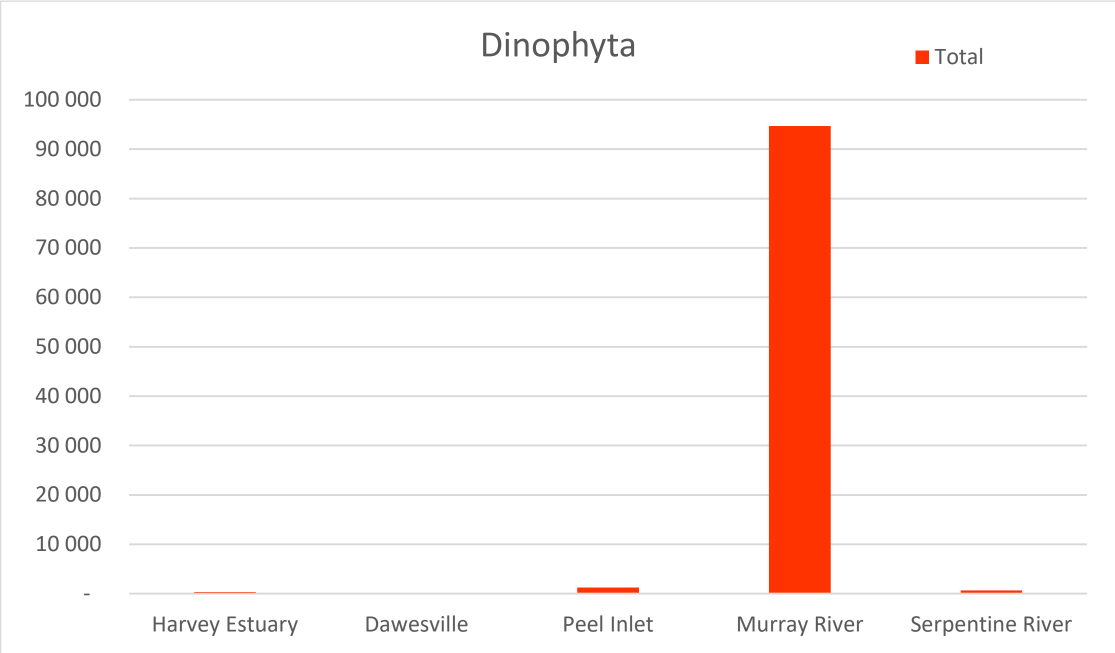


Figure 26 Sum of cell densities (cells per mL) of harmful phytoplankton of the dinophyta group in the five main estuary zones.

Table 5 Sum of cell densities of harmful dinophyta species in all estuary zones.

Zone/species	Sum of species density cells/ml	Zone/species	Sum of species density cells/ml
Harvey Estuary	**353**	**Murray River**	**94 679**
Alexandrium minutum	3	Alexandrium spp.	3
Alexandrium spp.	5	Dinophysis acuminata	94
Dinophysis acuminata	140	Karlodinium spp.	92 865
Gonyaulax spinifera	4	Pfiesteria spp.	18
Karenia spp.	1	Prorocentrum minimum	1 699
Karlodinium spp.	55	**Serpentine River**	**652**
Prorocentrum minimum	43	Alexandrium spp.	9
Prorocentrum rhathymum	102	Amphidinium carterae	34
Dawesville	**18**	Dinophysis acuminata	38
Alexandrium minutum	2	Gonyaulax spinifera	10
Dinophysis acuminata	3	Karlodinium spp.	426
Karenia papilionacea	0	Prorocentrum minimum	125
Karlodinium spp.	13	Prorocentrum rhathymum	2
Phalacroma rotundatum	0	Prorocentrum spp.	8
Peel Inlet	**1 259**		
Alexandrium spp.	1		
Amphidinium carterae	1		
Dinophysis acuminata	34		
Gonyaulax spinifera	5		
Karlodinium spp.	1 000		
Prorocentrum minimum	218		
Grand total			**96 961**

Dinophysis acuminata is associated with diarrheic shellfish poisoning (DSP), a globally significant human health syndrome. It is mixotrophic and growth is promoted by nitrogen loading.

Although few in number compared with other dinophytes such as *Karlodinium*, *D. acuminata* has a guideline of one cell mL^{-1} for aquaculture sites (WASQAP 2016). *D. acuminata* exceeded this guideline multiple times throughout the current monitoring period and in all zones, with cell densities ranging from 1 to 18 cells mL^{-1} (Figure 27).

The higher densities were observed in the uppermost Harvey Estuary site, the middle Murray River site and the Peel Inlet site closest to the Murray and Serpentine rivers (Figure 27). Seasonally, the highest densities were observed in autumn; previous reports recorded the higher densities in the Peel in spring (EPA 2008).

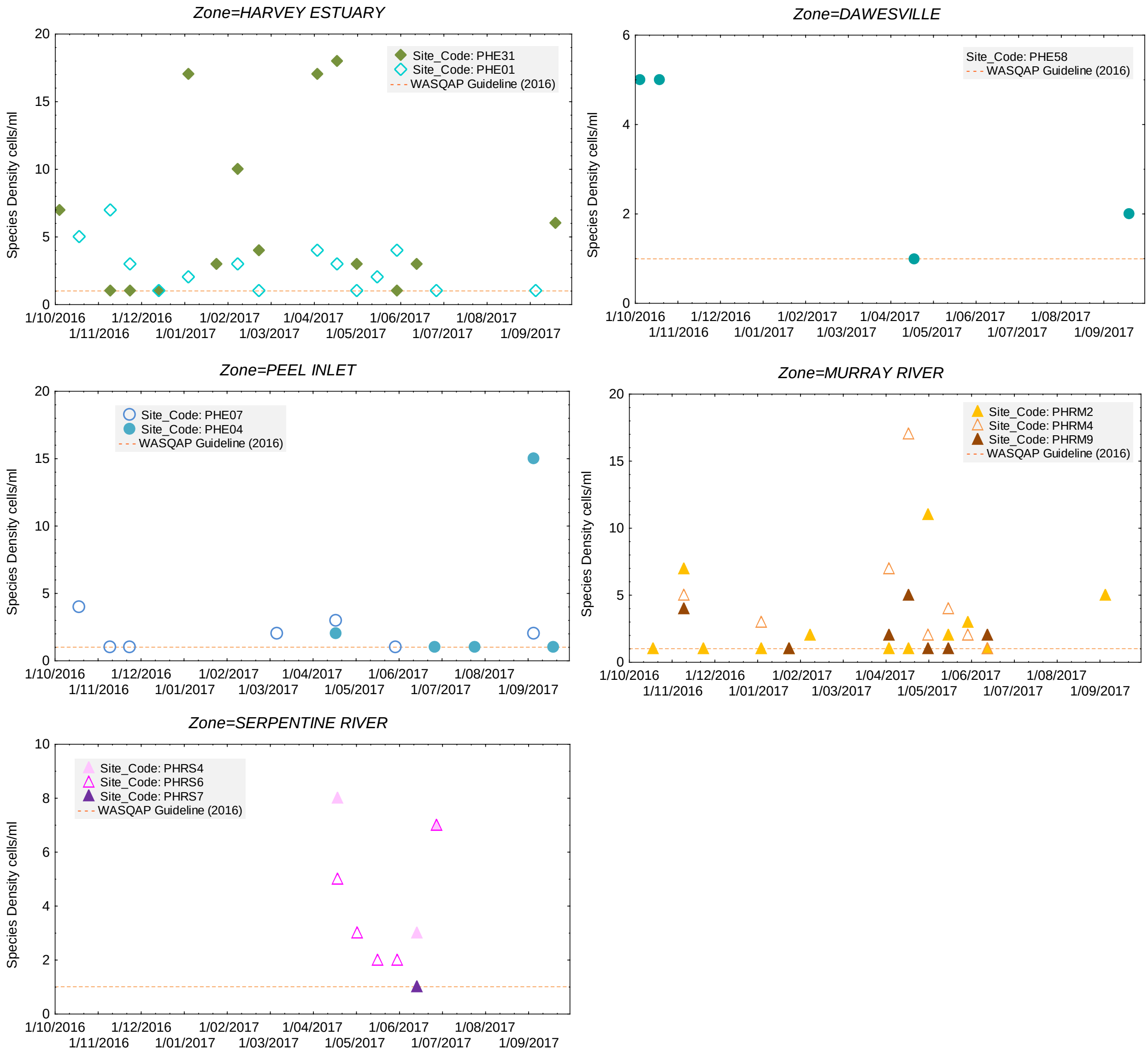


Figure 27 Dinophysis acuminata *cell densities time series for all monitoring sites grouped by zone, compared with the WASQAP 2016 reference guideline.*

Karlodinium was present in the estuary in November 2016, predominantly in the Murray River at cell densities in the hundreds of cells per mL (Figure 28). Increased cell densities were observed in April in the uppermost Murray River site and by May, densities peaked at about 10 000 to 19 000 cells per mL (Figure 28).

This period of growth occurred in the two to three months following the February rain event inflows, whereby the Murray River became strongly stratified, oxygen concentrations were below 2 mg L^{-1} in the bottom waters, and high concentrations of organic nitrogen and ammonium were observed.

By late June, the more typical seasonal winter inflows flushed the Murray River with low salinity waters, eliminating the stratification and the *Karlodinium* bloom. The bloom was transported by flows to the Peel Inlet (PHE-04), where a peak density of 959 cells per mL also at the end of June was recorded (Figure 28).

Subsequent sampling events recorded only one observation of *Karlodinium*: 6 cells per mL in the Harvey Estuary, at the site closest to the Dawesville channel, namely PHE-58.

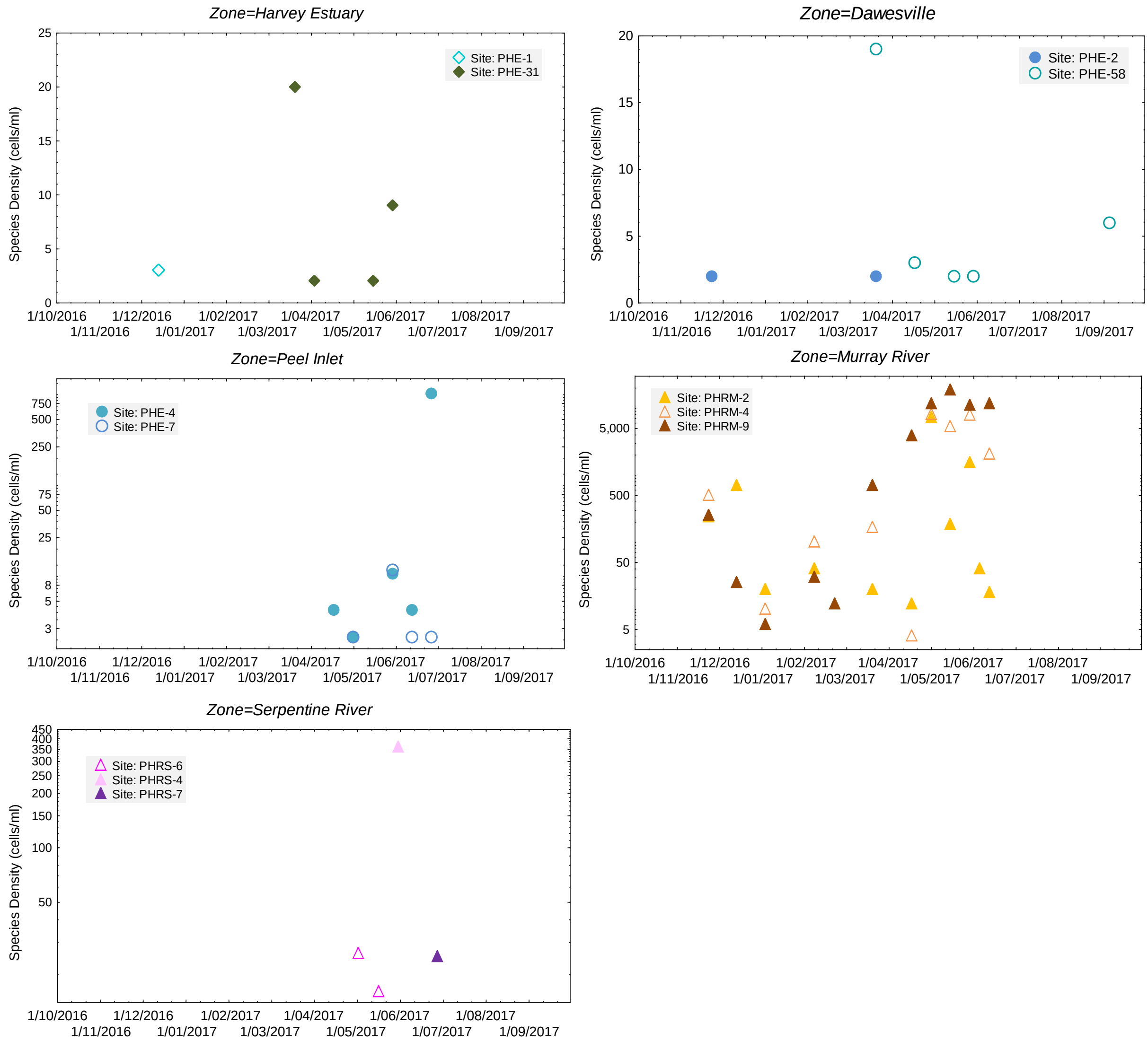


Figure 28 Karlodinium *species cell densities for all monitoring sites.*

Haptophyta

The total sum of cell densities of harmful haptophytes exceeded 350 000 cells/mL in the Serpentine River (Figure 29 and Table 6).

Haptophytes, also known as prymnesiophytes, are characterised by the presence of a haptonema (a filamentous, microtubule-supported appendage). They play a globally significant role in the conversion of dissolved carbon dioxide (CO_2) to calcium carbonate ($CaCO_3$) in the marine environment (Taylor et al. 2009). Harmful haptophytes have been responsible for fish kills in other parts of the world, typically at cell densities >50 000 cells per mL (Burkholder 2009). They also have an impact on food webs in estuaries.

In the Peel-Harvey system, high haptophyte numbers (>350 000 cells per mL) were recorded on one sampling event only: 8 March 2017 at Serpentine River site PHRS-7. Otherwise, haptophytes were generally present in all zones throughout the year, in low numbers (see Appendix D).

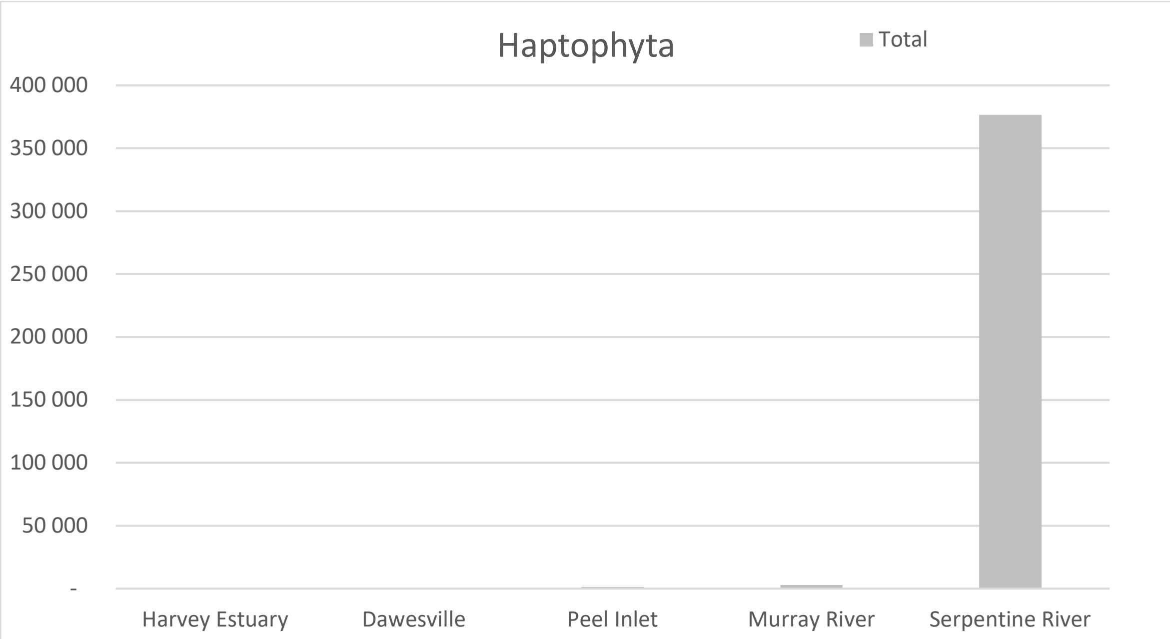


Figure 29 Sum of cell densities (cells per mL) of harmful phytoplankton of the haptophyta group in the five main estuary zones.

Table 6 Sum of cell densities of harmful haptophyta species in the five estuary zones.

Zone/species		Sum of species density cells/ml
Harvey Estuary		**217**
	Haptophyte spp.	217
Dawesville		**71**
	Haptophyte spp.	71
Peel Inlet		**1 395**
	Chrysochromulina spp.	6
	Haptophyte spp.	1 389
Murray River		**2 914**
	Chrysochromulina spp.	35
	Haptophyte spp.	2 879
Serpentine River		**376 607**
	Chrysochromulina spp.	14 631
	Haptophyte spp.	361 976
Grand total		**381 204**

Raphidophyta

Raphidophytes are typically large-celled, marine and freshwater unicellular algae. Marine species often form large blooms in coastal waters known as red tides and have caused disruption to fish farms, such as off the Japanese coast. The highest total cell densities of harmful raphidophytes were observed in the Murray River (Figure 30).

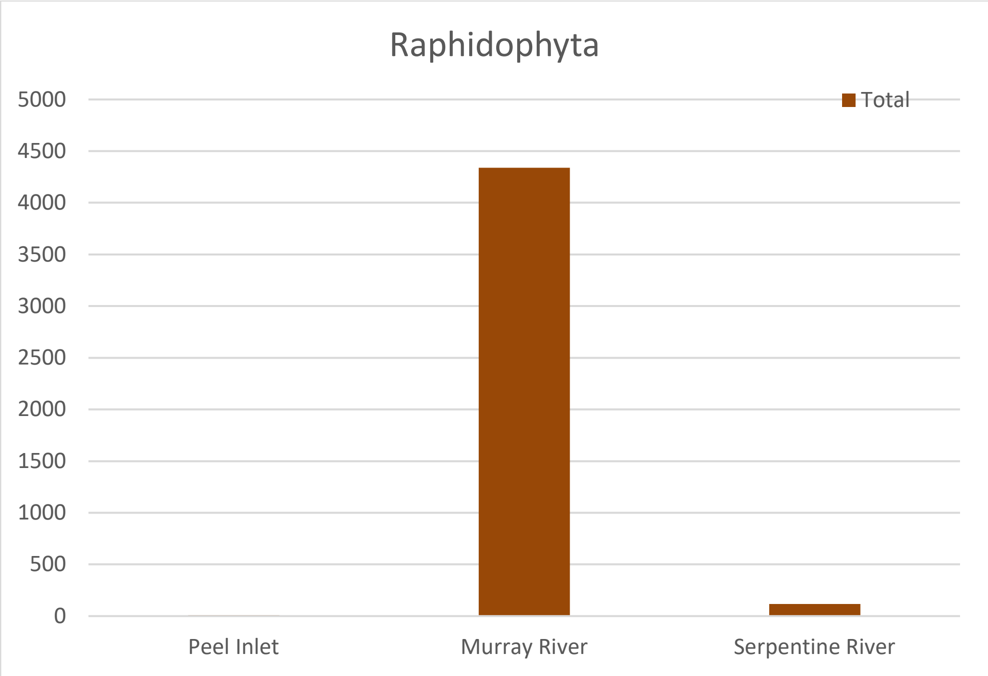


Figure 30 Sum of cell densities of harmful phytoplankton of the raphidophyta group in the Peel Inlet, and Murray and Serpentine rivers.

Heterosigma akashiwo was the dominant harmful raphidophyte species in the Murray River (Table 7). *H. akashiwo* is known as a cause of fish kills in the Pacific Northwest region (e.g. Puget Sound) and Japan. Cell densities around 500 to 750 cells per mL are known to cause mortalities (NOAA 2007). *H. akashiwo* is frequently found in association with fish farms and eutrophication events.

Table 7 Sum of cell densities of harmful raphidophyta species in the Murray River.

Raphidophyta	Sum of species density cells/ml
Murray River	
Raphidophyta	4 339
Chattonella marina	4
Fibrocapsa japonica	2
Heterosigma akashiwo	4 333
Grand total	4 339

H. akashiwo was observed on a few occasions, mostly in the Murray River and dominated by a single event, on 23 November 2016. On this day cell densities were 3383 and 555 cells per mL at Murray River sites, 2 and 4, respectively (*Figure 31*).

H. akashiwo is known to bloom during late spring and at times of vertical stratification in Puget Sound (NOAA 2007). For the current monitoring program, peak *H. akashiwo* in the Murray River was also associated with strong vertical stratification, but in summer.

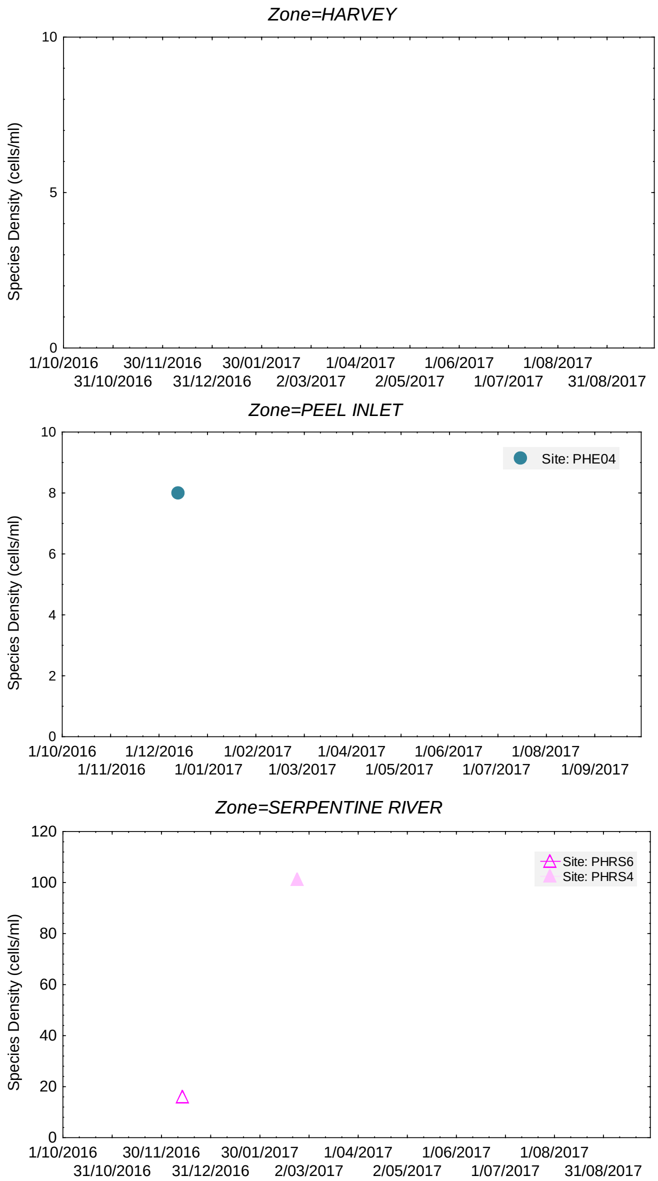


Figure 31 Heterosigma akashiwo species cell densities for all monitoring sites.

The dominant harmful groups and species for each zone are summarised in Table 8.

Table 8 Harmful algae – groups and species

Indicator	Harvey Estuary	Dawesville	Peel Inlet	Murray River	Serpentine River
Dominant groups	Cryptophytes Diatoms Dinophytes	Diatoms	Diatoms Cryptophytes Dinophytes	Diatoms Dinophytes Cryptophytes	Diatoms Chlorophytes Cyanophytes
HABs – #species	2	1	2	6	18
HABS – group (species)	Diatoms (*Psuedonitzschia* spp.) Dinophyta (*Dinophysis acuminata*)	Diatoms (*Psuedonitzschia* spp.)	Diatoms (*Psuedonitzschia* spp.) Dinophyta (*Dinophysis acuminata*)	Dinophyta (*Karlodinium* spp.) Raphidophyte (*Heterosigma akashiwo*)	Cyanophytes (*Planktolyngbya, Anabaena, Aphinizomenon, Nodularia*) Haptophytes

8. Seagrass and macroalgae

A substantial loss of the seagrasses *Halophila* and *Ruppia*, at the same time as a proliferation of the macroalgae *Cladophora montagneana,* occurred in the Peel-Harvey estuary the late 1960s due to eutrophication.

Since opening of the Dawesville Channel, seagrass and macroalgal abundance has expanded in parts of the Peel-Harvey estuary, particularly near the Dawesville Channel where there is good exchange with marine waters and good light penetration.

The latest reported seagrass survey in 2009 showed the expansion of seagrass in the Peel and Harvey basins and particularly near the Dawesville Channel area (Pedretti *et al.* 2011). *Zostera* was the dominant species in terms of biomass. *Ruppia* was dominant by biomass in the Peel. *Halophila* biomass was small in comparison, however it did cover a substantial area of the Peel central basin.

More recent surveys have been undertaken by Murdoch University but these have not yet been published (at the time of printing this report). The 2009 seagrass maps are presented here for reference (Figure 32).

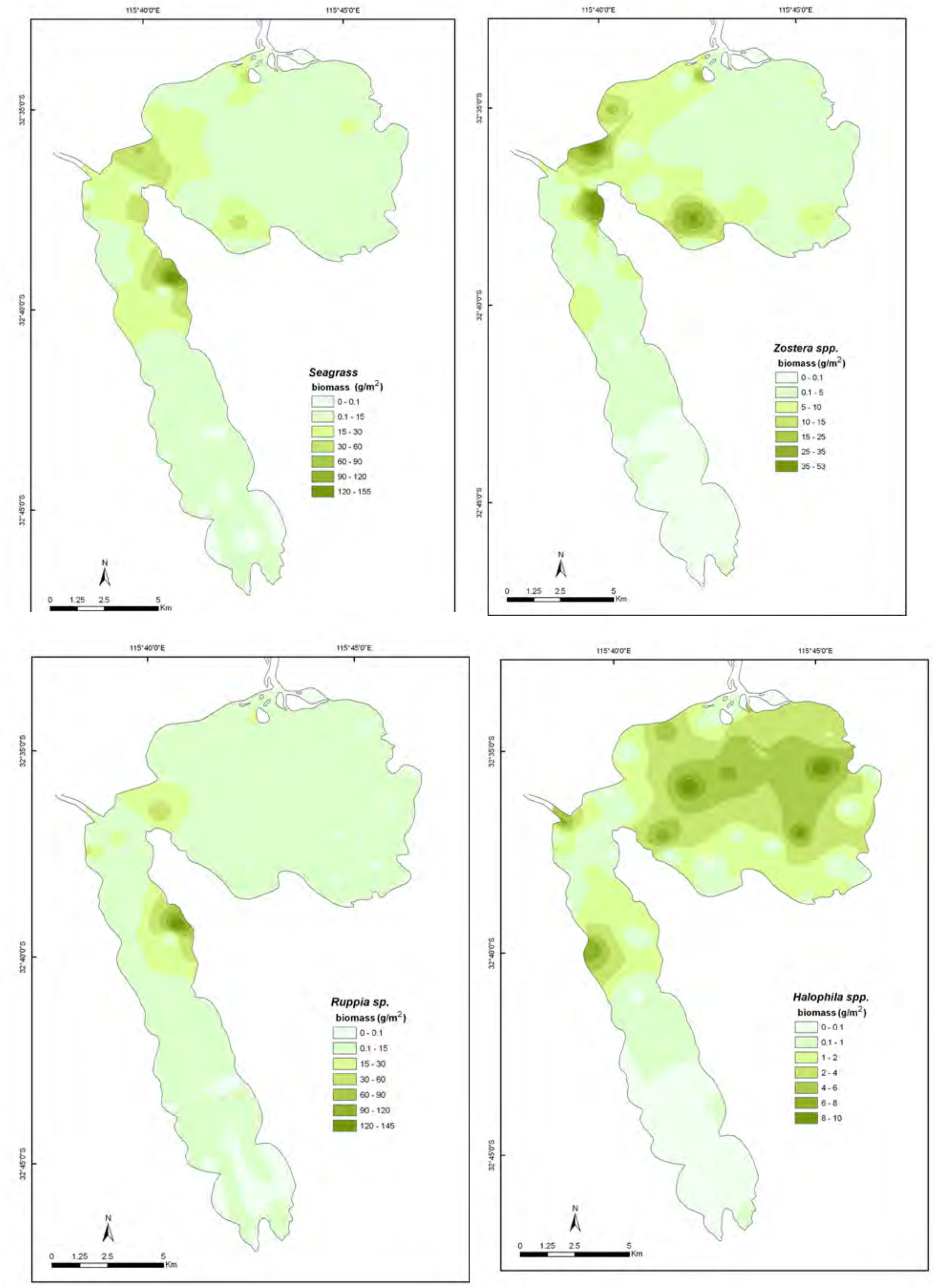


Figure 32 Mean distribution of total seagrass, Zostera, Ruppia *and* Halophila *biomass in November/December 2009 (Pedretti et al. 2011).*

9. Events

During the October 2016 to October 2017 monitoring period four fish kills occurred in the Peel-Harvey estuary (Figure 33).

Three of these were localised in the lower Murray River and one extended over a larger area including the Murray, Serpentine and Peel Inlet.

Figure 33 Fish kill events in the Peel-Harvey estuary system in 2017.

The largest fish kill on February 13–19 occurred after the large rainfall event on February 10, as discussed in Section 5.7.

Historically, on average one fish kill per year has occurred in the Murray River, so the four fish kills for 2017 are considered higher than usual.

10. Conclusions and recommendations

The Peel-Harvey estuarine system is the largest and one of the most complex estuaries in the South West. It comprises four spatial zones: the Peel basin, Harvey basin, lower Serpentine River and lower Murray River. The Peel and Harvey sites closest to the Dawesville Channel were grouped as a separate zone, as these two sites are the most marine-influenced. All five zones tend to have distinct differences in terms of water quality indicators and phytoplankton dynamics.

The hypereutrophic status of the main Peel-Harvey basins in the 1980s has been ameliorated by the construction of the Dawesville Channel, as was intended. From the recent monitoring data (2016–17), these two basins were shown to have a relatively low incidence of eutrophic symptoms. The Peel and Harvey basins were generally of marine salinity, well-oxygenated and with good water clarity. Some harmful species were observed in low numbers.

In contrast, the data show that the lower Serpentine and Murray rivers are hypereutrophic. The deeper Murray River is characterised by persistent stratification and low to anoxic dissolved oxygen concentrations in the bottom layer. Nutrient and chlorophyll concentrations frequently exceeded the relevant guidelines. Phytoplankton densities were high, dominated by diatoms, dinophyta and cryptophyta. Many potentially harmful species were observed, in particular *Karlodinium* spp*.* (dinophyta) and *Heterosigma akashiwo* (raphidophyta). *Dinophysis acuminata* (dinophyta) was also regularly observed at concentrations above what is deemed safe for commercial shellfish harvesting. Four fish kills were observed in the Murray River, one of which extended to the Peel and Serpentine River. The worst fish kill event followed an atypical high rainfall event in February 2017.

The Serpentine River had a high degree of variability in its salinity regime, both horizontally and temporally, ranging from fresh to hypersaline. The Serpentine also had the highest concentrations of nutrients and chlorophyll *a* concentrations, frequently exceeding the relevant guidelines. The worst chlorophyll concentrations were observed in the Serpentine in autumn (mean 28.1±75 μgL^{-1}) and these concentrations were equivalent to those observed in the Peel, pre-cut, in summer. The dominant phytoplankton group was cyanophyta, within which there were numerous harmful species at high cell densities.

The 2008 Peel-Harvey estuary WQIP specified a set of resource condition indicators and targets (EPA 2008). The current monitoring data are compared against these targets (Table 9). An updated WQIP is being developed and these resource condition targets are likely to change.

In the Peel-Harvey estuary basins, phosphorus and chlorophyll concentrations met the designated targets in 2016–17. However, 90% of dissolved oxygen concentrations were outside the target range of 70 to 80%. The target range is quite restrictive and we would recommend using concentration targets in $mg\ L^{-1}$ rather than percent saturation, as done for the lower river estuarine zones. The target of ‘no increase in distribution, density and toxicity of toxic algae’ is difficult to quantify and requires longer-term trend analysis to determine. Toxicity is not routinely measured. However, the data clearly show the distribution of harmful species persists in the Serpentine and Murray rivers at high cell densities. The Peel and Harvey basins also had a number of harmful dinophytes present, especially a persistent presence of *Dinophysis acuminata* in the Harvey Estuary.

Table 9 The 2016–17 water quality indicators compared against resource condition targets.

Region	Objective	Resource condition		2016–17	Target met?
		Indicator	Target[3]		
Lower estuarine Serpentine and Murray rivers	Reduce nutrients to reduce phytoplankton blooms	Phosphorous (winter median)	<0.1 mg L^{-1}	0.043	Yes
	Reduce toxic algal blooms	Phytoplankton - cell counts	<20 000 cells mL^{-1}	88% of samples	Mostly
		Phytoplankton - number of blooms	Reduce blooms and eliminate nuisance and toxic algal blooms	Cyanobacteria blooms frequent in Serpentine; *Karlodinium*, *Heterosigma akashiwo* in Murray	No
		Chlorophyll *a* (median)	<10 µg L^{-1}	6 µgL^{-1}	Yes
	Reduce spatial extent and frequency of hypoxia/anoxia events	Dissolved oxygen (surface and in bottom when surface achieved)	>5 mg L^{-1}	MRsurf 4% <5 MRbott 63% <5 SRsurf 25% <5 SRbott 29% <5	No
	Reduce number and extent of fish kills	Fish kill events	zero	4	No
Peel Inlet Harvey Estuary	Reduce nutrients to reduce phytoplankton blooms	Phosphorus (P) load	75 tonnes pa		
		P concentration (long term)	<30 µg L^{-1}	12 µg L^{-1}	Yes
	Phytoplankton at acceptable levels	Chlorophyll a (long term)	<3 µg L^{-1}	1 µg L^{-1} (10% samples exceeded 3)	Yes
		Dissolved oxygen	70–80% saturation	90% outside range 70–80%	No
	Minimise toxic algae e.g. *Lyngbya*	Toxic algae	No increase in distribution, density, toxicity	*Lyngbya* (not monitored) *Dinophysis acuminata* regularly present above guideline esp. in Harvey Estuary	Unknown

Water quality indicators for the lower river reaches reflect very poor water quality status, which is likely to have a significant impact on the ecosystem integrity of these reaches. While the Peel and Harvey basins have relatively good water quality, the risk is that atypical rain/flood events will deliver high organic loads and poor quality brackish waters from the river systems to the estuary basin. This creates the potential for harmful algal blooms, fish/fauna deaths and smothering of seagrass. The February 2017 rainfall event was an example of this situation, which caused fish kills and was likely responsible for the subsequent *Karlodinium* bloom.

[3] Resource condition targets (EPA 2008)

Paradoxically, in the drying climate scenario with its predicted overall reduced freshwater inflows, the estuarine zones are likely to face increased salinisation through evaporation. Hypersaline conditions also cause changes to the region's flora and fauna. Hypersalinity was observed in the Harvey Estuary, Peel Inlet and Serpentine River – particularly in summer.

The 2016–17 monitoring results demonstrate hyper-eutrophication of the lower reaches of the Serpentine and Murray rivers and their potential to adversely impact the broader Peel and Harvey basins. This, combined with increasing pressures – climate change impacts, population growth and agricultural intensification – highlights that large-scale catchment management of nutrient inflows to the estuary must be the focus of management efforts.

Climate-driven reductions in streamflows, increased temperatures and atypical storm events represent risks to sustaining the improved water quality conditions observed in the Peel and Harvey main basins post-Dawesville channel construction.

REI trials such as the Punrak drain clay dosing to bind phosphorus, application of soil amendments, and widespread uptake of non-soluble phosphate fertilisers are all critical future technologies. A long-term commitment to such activities is needed to promote the efficient use and retention of nutrients within the catchment for the purpose for which they were intended.

Management, upgrading and transformation of urban and agricultural drains to more sophisticated living streams would also contribute to maintaining, and restoring to their full potential, the Peel-Harvey's social, economic and environmental values.

With respect to the REI estuary monitoring program, the sampling regime is considered adequate to assess estuary condition from a water quality point-of-view, with the exception of monthly nutrient and chlorophyll data. The following recommendation is made to adjust the monitoring program as follows:

- Increase the frequency of nutrient monitoring from monthly to fortnightly (all other indicators are monitored fortnightly). Fortnightly monitoring of nutrients will provide better data for model development and for assessing the impact of catchment pressures and/or management actions.

Shortened forms

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment Conservation Council
BOM	Bureau of Meteorology
CO_2	Carbon dioxide
DO	Dissolved oxygen
DPC	Department of Premier and Cabinet
DSP	Diarrhoeic shellfish poisoning
DWER	Department of Water and Environmental Regulation
EPA	Environmental Protection Authority
FRP	Filterable reactive phosphorus
kL	Kilolitres
km^2	Square kilometres
$m^3 s^{-1}$	Cubic metres per second
$mg L^{-1}$	Milligrams per litre
$m L^{-1}$	Millilitre
NH_3/NH_4	Ammonia/ammonium
NOx	Nitrate + nitrite
NSP	Neurologic shellfish poisoning
NTU	Nephelometric turbidity units
pH	Measure of acidity or alkalinity in water and sediments
PHCC	Peel-Harvey Catchment Committee
ppt	Parts per thousand
REI	Regional Estuaries Initiative
Secchi	Secchi depth
TN	Total nitrogen
TP	Total phosphorus
$\mu g L^{-1}$	Micrograms per litre
WASQAP	Western Australian Shellfish Quality Assurance Program

Glossary

Acidity	The level of acid in water.
Ammonium	An important source of nitrogen to plants, particularly in low oxygen environments. Ammonium is a waste product of animals and enters waters either directly or as urea. It is a particularly important source of nutrients to phytoplankton.
Anoxic	A total decline in dissolved oxygen in the water column.
Anthropogenic	Caused by human beings.
ANZECC guidelines	Guidelines published by the Australian and New Zealand Environment Conservation Council for ecological and recreational water quality in marine and freshwater environments. It is a framework for conserving ambient water quality in rivers, estuaries, lakes and marine waters.
ANZECC guideline values	The ANZECC guideline values are intended to provide government, industry, consultants and community groups with a framework to maintain ambient water quality in rivers, lakes, estuaries and marine waters. The core concept is to manage water quality to protect environmental values. These values may include protection of aquatic ecosystems, drinking water, primary and secondary recreation, visual amenity, and agricultural water for irrigation, livestock and growing aquatic foods.
Aquatic macrophytes	Aquatic plants that can be seen with the naked eye, and grow submerged, emergent or floating within marine, estuarine and riverine environments, e.g. seagrasses.
Benthic	Relating to or occurring at the sea, estuary or lake bottom.
Catchment	The area of land that collects precipitation and drains via streams and rivers into estuaries and/or the ocean.
Chlorophyll	A plant pigment essential in photosynthesis. Chlorophyll *a*, *b*, and *c* are different forms of chlorophyll which absorb different wave lengths of light.
Chlorophytes	A group of algae characterised by green chloroplasts. They include unicellular phytoplankton and large leaf macroalgae.
Contaminant	A substance that has the potential to present a risk of harm to human or environmental health.
Cryptophytes	A group of phytoplankton, typically small in size with two flagella and without a skeleton (or shell).
Cyanobacteria	Also known as blue-green algae, these are a photosynthetic bacteria that occur as single cells or as colonies (which can form filaments). Some species are nitrogen-fixing, converting nitrogen from the air to form ammonia and nitrates/nitrites.
Diatom	Microscopic one-celled or colonic algae of the class Bacillaophycae, having cell walls of silica consisting of two interlocking symmetrical valves.
Dinoflagellate	Chiefly protozoans characteristically having two flagella and sculptured shell or pellicle that is formed from plates of cellulose deposited in membrane vesicles. They are one of the chief constituents of plankton. They include bioluminescent forms and forms that produce ‘red tides’.

Enumerated	To determine the number of.
Epiphytes	A plant that grows on another plant but is not parasitic.
Estuary	Partially enclosed coastal body of water, having an open connection with the ocean, where freshwater from inland is mixed with saltwater from the sea.
Eutrophication	Eutrophication is a deterioration of water quality caused by the excessive input of nutrients. It leads to overgrowth of aquatic plants, macroalgae and/or phytoplankton, and the ultimate decomposition of this plant growth leads to anoxia.
Filterable reactive phosphorus	Filterable reactive phosphorus is a bioavailable form of phosphorus that promotes phytoplankton growth.
Hydrodynamics	The flow and movement of water.
Hydrological cycle	Describes the cycle of water on and in the earth and atmosphere.
Hypereutrophic	Aquatic environments with excessive concentrations of nitrogen and phosphorus.
Hypoxic	Low in oxygen.
Inorganic dissolved nutrients	These include nitrate/nitrite, ammonium and soluble phosphate and are in forms most readily available to plants.
Invertebrates	An animal without a backbone, includes shellfish, worms.
Macroalgae	Photosynthetic plant-like organisms that can be seen with the naked eye. Macroalgae may be divided into the groupings: reds (rhodophytes), greens (chlorophytes), browns (phaeophytes) and blue-greens (cyanophytes). These divisions are primarily based on pigments in their tissues, which are also usually evident in their appearance.
Macrophyte	Rooted aquatic plants.
Mixotrophic	Deriving food from different sources, such as by photosynthesis or by feeding on other plants or animals. Usually in reference to phytoplankton.
Nitrate/nitrite	A dissolved inorganic form of nitrogen. Often used in fertilisers and the source of nutrients in catchment runoff. It is also a byproduct of septic systems which can leach into groundwater.
Nutrient analytes	Chemical constituents of nutrient forms such as nitrogen and phosphorus.
Nutrients	Nutrients (nitrogen and phosphorus) are chemicals that are important for plants to survive and grow; however, water quality is reduced by excess nutrients entering waterways.
Nutrient load	The amount of nutrient being deposited into the estuary. Calculated as median annual nutrient concentration x annual total flow volume.
Organic loading	The amount of organic matter or sediment being deposited into a specific area.
Organic matter	The collection of carbon-based compounds aquatic and terrestrial environments.
Pathogens	An infectious organism which can cause disease.

pH	pH is a measure of the relative acidity or alkalinity of water. It reflects the concentrations of hydrogen (H+) and hydroxide ions (OH-) in a water sample. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasingly basic solutions.
Photosynthesis	The biological process of plants which captures light energy and carbon dioxide and creates chemical energy for plant growth and metabolic processes.
Phytoplankton	Microscopic plants, usually single-celled.
Point source	An identifiable source of a substance, usually a contaminant, such as industrial discharges.
Salinity	The concentration of salt in water.
Seagrass wrack	Collection of dead or decaying seagrass leaves, usually on shorelines and associated with the odour of decomposition.
Sediment	Loose particles of sand, clay, silt and other substances that settle at the bottom of a body of water. Sediment can be derived from the erosion of soil or from the decomposition of plants and animals.
Stratification	The forming of water layers based on differences in salinity, oxygen or temperature.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape. In an estuary it also refers to the upper layer of the water column.
Taxonomically analysed	Identified as a taxonomic group.
Total nitrogen	The sum of all forms of nitrogen found in the water column. This includes particulate and dissolved forms of an inorganic and organic nature.
Total phosphorus	The sum of all forms of phosphorus found in the water column. This includes particulate and dissolved forms of an inorganic and organic nature.
Toxicity	The degree to which a substance or combination of substances is able to damage an exposed organism.
Tributaries	A river, stream or creek which flows into another larger river.
Turbidity	Opaqueness of water due to suspended particles in the water causing a reduction in the transmission of light. The units of measurement are NTU (nephelometric turbidity units).

Appendices

Appendix A: Water quality indicators – methods

Table 10 summarises the suite of nutrient analytes programmed for the Peel-Harvey estuary.

Nitrogen and phosphorus are nutrients critical for phytoplankton and higher plant growth and are thus routinely measured in estuaries. Total nitrogen and total phosphorous include all forms of nitrogen and phosphorus (particulate and dissolved, organic and inorganic), and are measured to determine the total nutrients in the estuary.

Dissolved forms of nitrogen and phosphorous such as ammonium, nitrate/nitrite and filterable phosphate are also measured. Dissolved nutrients are readily bioavailable to plants and phytoplankton for growth.

Also included in Table 1 are the limits of reporting (LOR) and the Australian and New Zealand Environment Conservation Council (ANZECC) Guideline concentration for each analyte (ANZECC & ARMCANZ 2000).

- The 'limit of reporting' or **reporting limit** means the concentration (or amount) of analyte that can be reported by a laboratory.
- The **ANZECC guideline values** are intended to provide government, industry, consultants and community groups with a framework to maintain ambient water quality in rivers, lakes, estuaries and marine waters. The core concept is to manage water quality to protect environmental values. These values may include protection of aquatic ecosystems, drinking water, primary and secondary recreation, visual amenity, and agricultural water for irrigation, livestock and growing aquatic foods.

The limit of reporting for each analyte should be equal or more sensitive than the guideline value in order to demonstrate the performance of any management measures to improve water quality (reduce nutrient inputs) in the receiving waterway.

Table 11 summarises the analysis methods for nutrients and biological parameters measured.

Table 10 *Nutrient suite and sampling rationale*

LOR is limit of reporting for an analyte determined by the analytical method and laboratory used for analysis.

Parameter	Description and sampling rationale	Limit of reporting (LOR) and ANZECC guideline
Total nitrogen (TN)	TN includes all forms of nitrogen (particulate and dissolved), such as nitrate, nitrite, ammonia, and organic nitrogen. Measured to determine total nutrients (nitrogen) in the estuary.	**ANZECC guideline** 0.75 mgL^{-1} **LOR** 0.025 mgL^{-1}
Total oxidised nitrogen **(NO_x-N), or Nitrate (NO_3^-) + Nitrite (NO_2^-)**	NO_x-N (TON) is the sum of the nitrate (NO_3^-) and nitrite (NO_2^-) nitrogen concentrations in mg/L nitrogen. Nitrate and nitrite species can be determined separately. This is a dissolved form of nitrogen, readily available to phytoplankton and higher plants for growth. Surface NO_x can be a good indicator of nutrient/fertiliser inputs from the catchment, often closely related to flow volume.	**ANZECC guideline** 0.045 mgL^{-1} **LOR** 0.01 mgL^{-1}
Ammonium nitrogen **(NH_3-N/NH_4-N)**	Ammonium and ammonia species are determined using the same analytical method. Analytically they are the same species. At pH 5-8, the species exists predominantly as ammonium (NH_4^+). This is a dissolved form of nitrogen, readily available to phytoplankton and higher plants for growth.	**ANZECC guideline** 0.04 mgL^{-1} **LOR** 0.01 mgL^{-1}
Total phosphorus (TP)	TP includes all forms of phosphorus, organic and inorganic in particle or detritus, or in the bodies of aquatic organisms. Phosphorus occurs in natural waters and in wastewaters predominantly as phosphates (PO_4^{3-},pyro-, meta-, and other polyphosphates), and as organically bound phosphates. Measured to determine total phosphorus in the estuary.	**ANZECC guideline** 0.03 mgL^{-1} **LOR** 0.005 mgL^{-1}
Filterable reactive phosphorus (FRP)	Filterable reactive phosphorus (FRP) describes the dissolved phosphates. This is a dissolved form of phosphorus, readily available to phytoplankton and higher plants for growth.	**ANZECC guideline** 0.005 mgL^{-1} **LOR** 0.005 mgL^{-1}

Table 11 *Analysis method for nutrients and chlorophyll*

Parameter	Analysis method
Total nitrogen (TN)	The sample is mixed with potassium persulfate and sodium hydroxide and heated to 120°C for 30 minutes in an autoclave. The nitrogenous compounds in the sample are oxidised to nitrate. Total nitrogen is determined by analysing the nitrate in the digestate. Measurements are performed using the auto analyser. Persulphate digestion method 4500-N C (APHA 1998), and the cadmium reduction method 4500-NO3- F (APHA 1998).
Total oxidised nitrogen **(NO_x-N), or Nitrate (NO_3^-) + Nitrite (NO_2^-)**	The method is based on the cadmium reduction method. The sample is passed through a column containing granulated copper-cadmium to reduce the nitrate to nitrite. The nitrite that was originally present and the reduced nitrate is determined by diazotizing with sulphanilamide and coupling with α-napthylenediamine dihydrochloride to form a highly coloured azo dye which is measured at 540 nm. Nitrite (NO_2-N) is determined using the same method omitting the copper-cadmium column. Nitrate (NO_3-N) is obtained by subtracting the nitrite result from the total organic nitrogen result. Cadmium reduction method 4500-NO3- F (APHA 1998).
Ammonium nitrogen **(NH_3-N/NH_4-N)**	The method is based on a modified Berthelot reaction. Alkaline phenol and hypochlorite react with ammonia to form indophenol blue. The blue colour is intensified with sodium nitroprusside. The absorption is measured photometrically at 630 nm. Phenate method 4500-NH3 G (APHA 1998).
Total phosphorous (TP)	The sample is mixed with potassium persulfate and sodium hydroxide and heated to 120°C for 30 minutes in an autoclave. The phosphorus compounds in the sample are oxidised to ortho-phosphate. Measurements are performed using the auto analyser. Persulphate digestion method 4500-P B.5 (APHA 1998), and Ascorbic Acid Colorimetric method 4500-P E (APHA 1998).
Filterable reactive phosphorus (FRP)	Ascorbic Acid Colorimetric method 4500-P (APHA 2017)
Chlorophyll (includes Chl a, b, c and Pheaeophytin)	Plankton from water is isolated by filtration and the pigments are extracted using aqueous acetone. The concentration of chlorophyll *a*, *b*, *c* and pheophtyin *a* in the extract is determined by measuring the optical density at compound specific wavelengths using a UV VIS spectrophotometer. Method: 10200 H(2) (APHA 1998).

Table *12* summarises the biological measures of water quality for the Peel-Harvey estuary.

Phytoplankton are a natural component of the estuarine ecology. Most species are favourable but some are harmful because they are either toxin-producing or able to cause mechanical damage to other organisms.

Phytoplankton numbers can quickly increase in response to nutrient inputs. Phytoplankton densities (cell counts) and identifications (community composition) provide valuable information on phytoplankton population dynamics in the estuary.

Chlorophyll *a* is a pigment found in plant cells and is measured as a surrogate indicator of phytoplankton abundance and biomass (productivity).

Table 12 *Biological indicator (phytoplankton) sampling and rationale*

Parameter	Description and relevance	Unit/ Guideline
Phytoplankton	Phytoplankton are microscopic algae which can be used as an indicator of water quality. Different species of phytoplankton may develop blooms causing discolouration, odours, anoxic or toxic conditions.	**Units**: cells mL^{-1}
Chlorophyll (a, b, c and phaeophytin)	Chlorophyll a, b, c are pigments found in plants. It absorbs sunlight and converts it to sugar during photosynthesis. Chlorophyll a concentrations are an indicator of phytoplankton abundance and biomass. Phaeophytin is a common chlorophyll degradation product.	**ANZECC guideline** 3 μgL^{-1} (Chl *a*) **LOR** 1 μgL^{-1}

Table *13* summarises the physicochemical data collected from water column profiling in the Peel-Harvey estuary.

Profile data help us monitor natural phenomena such as stratification, river flows and tidal intrusion.

Table 13 *Physicochemical variables collected at each site*

Parameter	Description and relevance	Limit of reporting (LOR) and ANZECC guideline where available
Salinity and conductivity	Salinity is the mass fractions of salts in the water column expressed as PSU (practical salinity units) which are based on water temperature and conductivity measurements. Salinity used to be expressed in parts per thousand (ppt). For oceanic seawater, ppt and PSU are very close. Salinity varies horizontally and vertically in the estuary and gives a measure of water movement and stratification.	Measured in the field using a calibrated EXO2 sonde **Units**: ppt and mS/cm

Parameter	Description and relevance	Limit of reporting (LOR) and ANZECC guideline where available
	Electrical conductivity (EC) measures a substance's ability to conduct an electric current. EC is to be measured and recorded *temperature compensated*. EC units are expressed in micro-siemens/cm (µS/cm) or milli-siemens (mS/cm) at 25°C 1000 EC = 1000 µS/cm = 640 ppm = 1 dS/m	
Temperature	Water temperature is a measure of heat content. Temperature is a vital indicator of the water column's ability to support growth and aquatic life. Water temperature regulates various biochemical reaction rates that influence water quality and also influence oxygen availability in the water column.	Measured in the field using a calibrated EXO2 sonde **Units**: °C
Dissolved oxygen (DO)	Dissolved oxygen is the amount of gaseous oxygen (O_2) dissolved in the water. Dissolved oxygen is a good measure of the estuary's ability to support life. Values below 4 mg/L are considered unhealthy. Values below 2 mg/L can result in fish deaths.	Measured in the field using a calibrated Exo2 sonde **Units**: mg/L and % saturation **ANZECC guideline** 90-110% saturation
pH	pH is a measure of acidity or alkalinity of water on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). The pH of marine waters is close to 8.2, whereas most natural fresh waters have pH values in the range from 6.5 to 8.0.	Measured in the field using a calibrated Exo2 sonde **ANZECC guideline** 7.5–8.5
Turbidity	Turbidity is a measure of water clarity or murkiness. It is an estimate of the degree to which light is scattered and absorbed by molecules and particles. Turbidity is caused by suspended matter such as clay and silt (suspended sediment) and detritus and organisms (such as phytoplankton and zooplankton)	Measured *in situ* using a calibrated Exo2 sonde **Units:** Nephelometric turbidity units (NTU) **ANZECC guideline** 1–2 NTU

The measurements described in Table *14* inform on the field conditions at the time of monitoring.

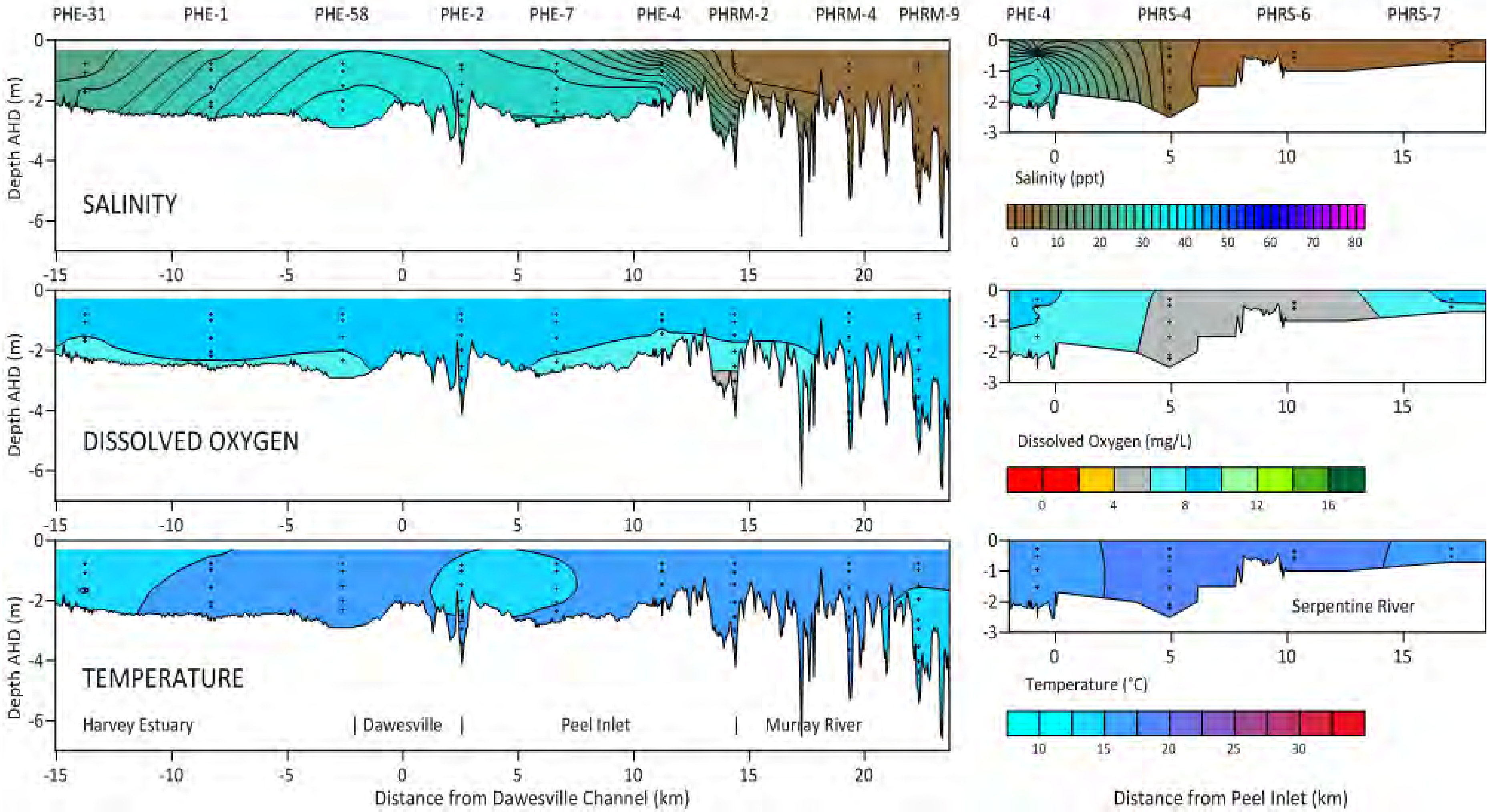
These are documented on *field observation forms* and can be used to inform on any inconsistencies or peculiarities in the physical data collected at a particular site or on a particular day.

Table 14 *Other field observations*

Parameter	Description and relevance	Unit where applicable
Secchi depth	Secchi depth is a measure of water transparency, providing an estimate of turbidity, measured using a Secchi disk.	Measured in the field using a 30 cm diameter Secchi disk. **Units**: m
Wind speed and wind direction	Wind speed and direction may be useful for interpretation of water quality results as wind can influence waves, water mixing and aeration, location of scums etc.	Measured in the field using an anemometer and compass (or observed). **Units**: knots and degrees
Flow or tide code	Ebbing, flooding or stationary tide is useful for interpretation of water quality results.	http://www.transport.wa.gov.au/imarine/tide-predictions.asp
Cloud cover	An estimate of the percentage of sky covered by cloud may be useful for interpretation of water quality results.	Observed in the field. **Units**: %

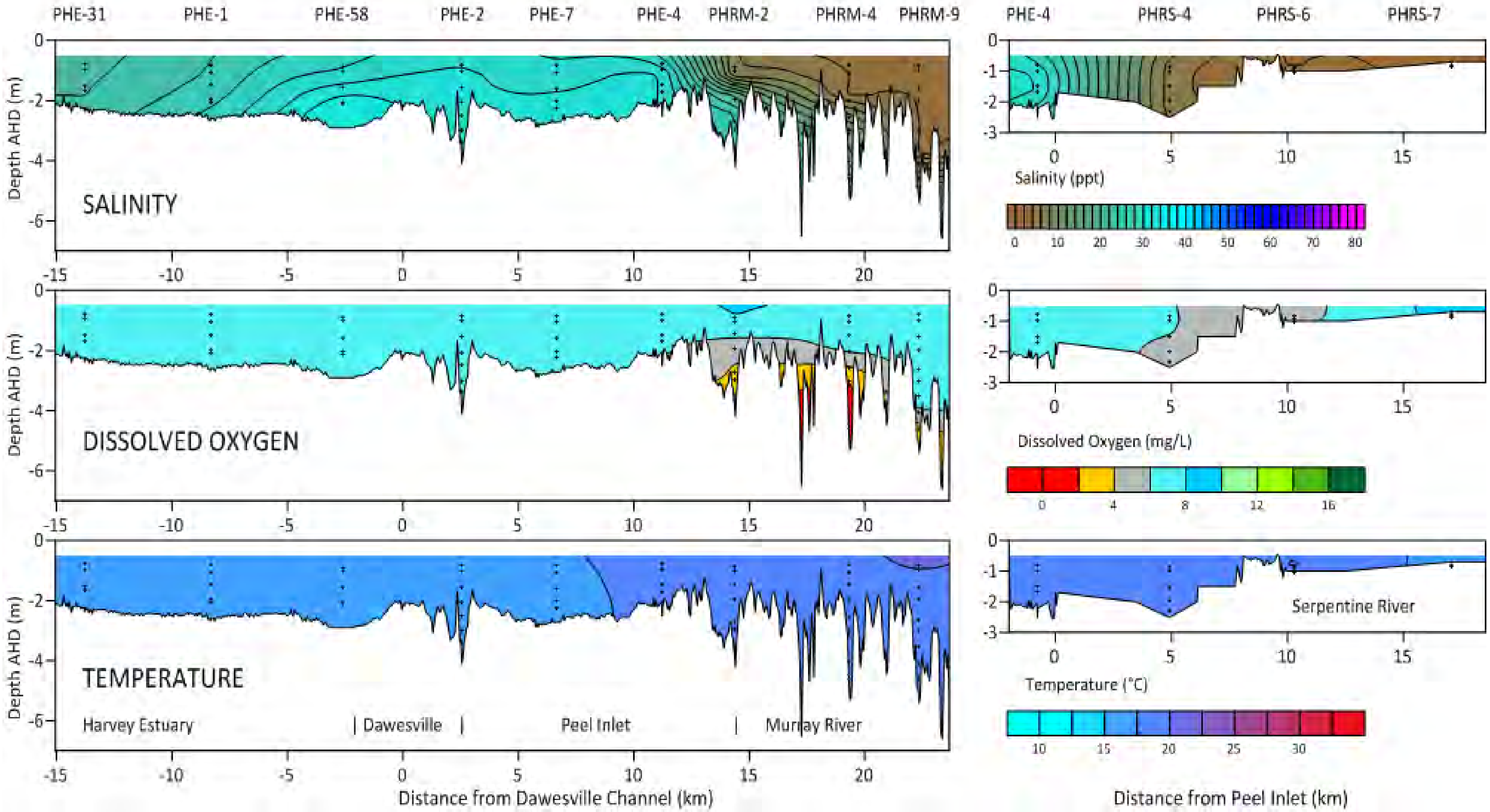
Appendix B: Surfer profiles

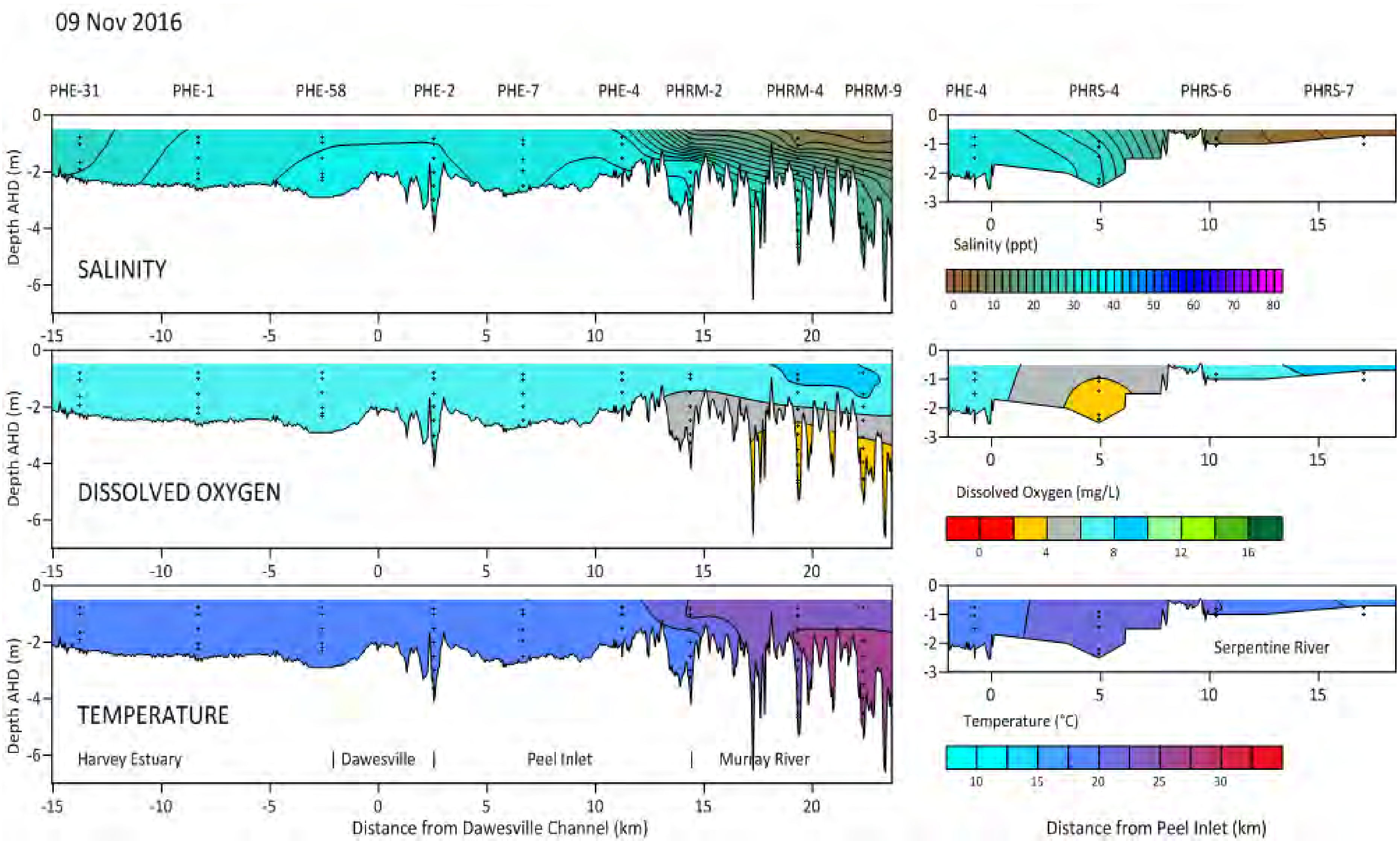
04 Oct 2016



PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
PHE-4
PHRS-4
PHRS-6
PHRS-7
Salinity (ppt)
Dissolved Oxygen (mg/L)
Serpentine River
Temperature (°C)
Distance from Peel Inlet (km)

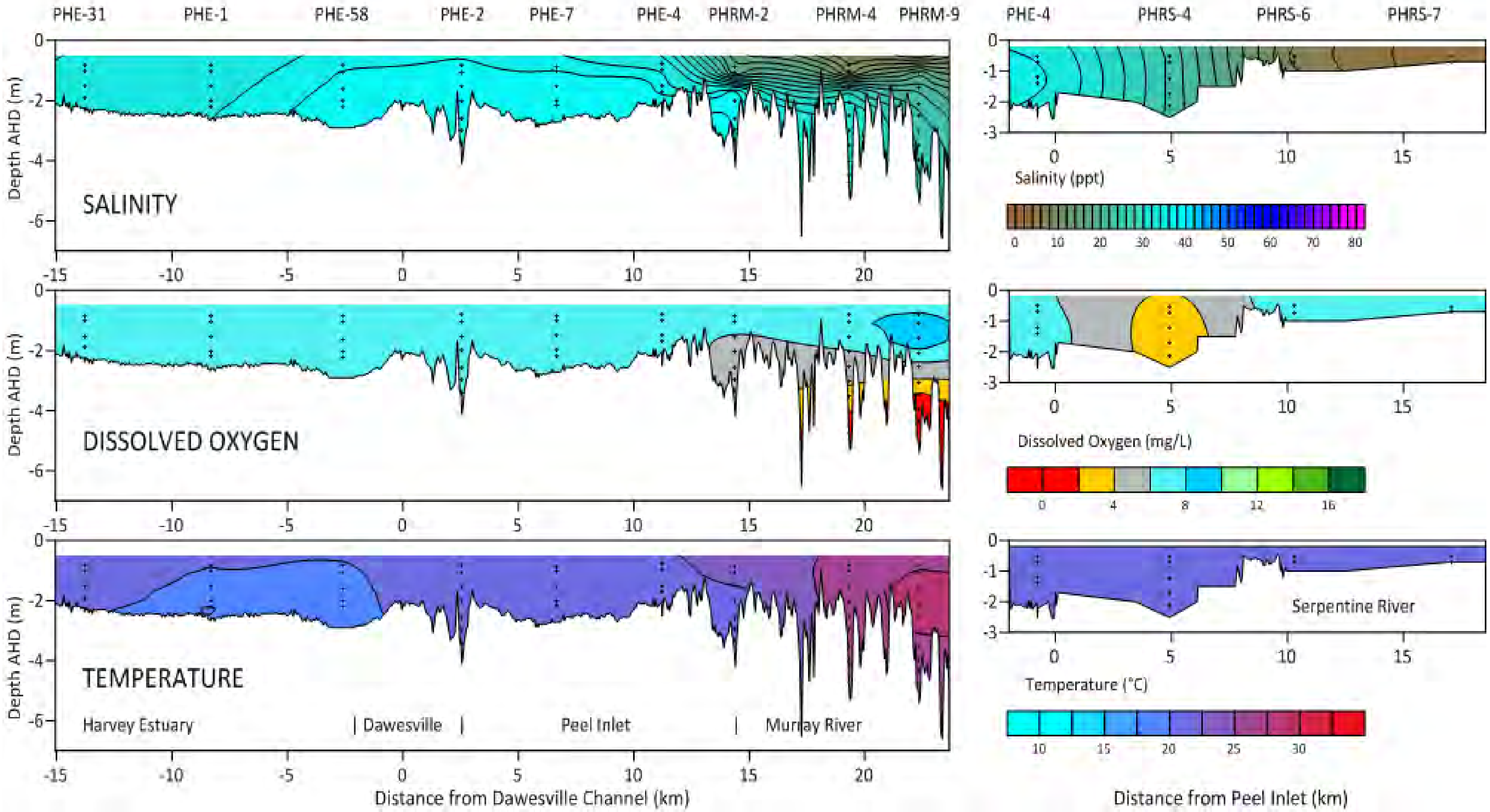
18 Oct 2016


PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Distance from Peel Inlet (km)



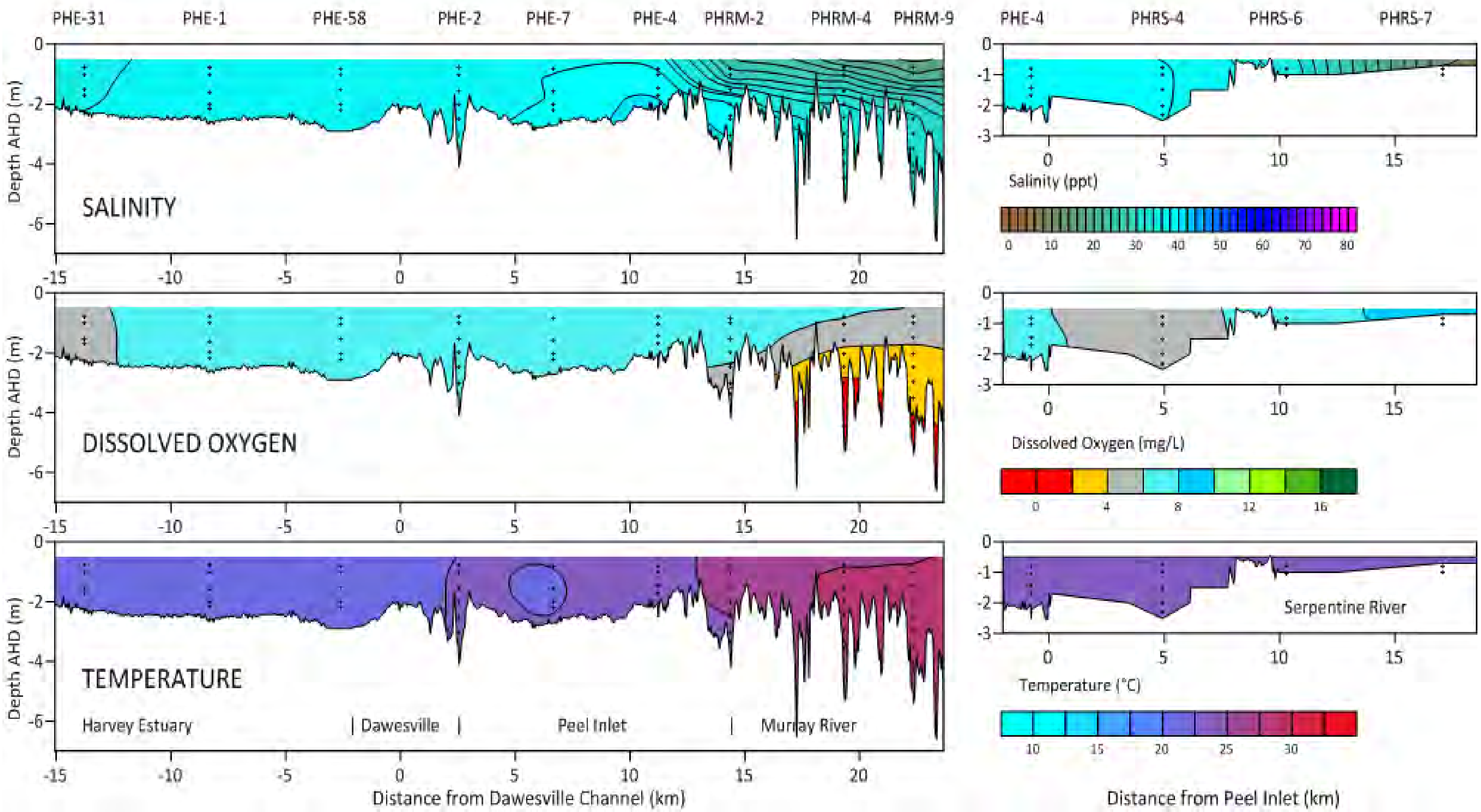
09 Nov 2016
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

23 Nov 2016

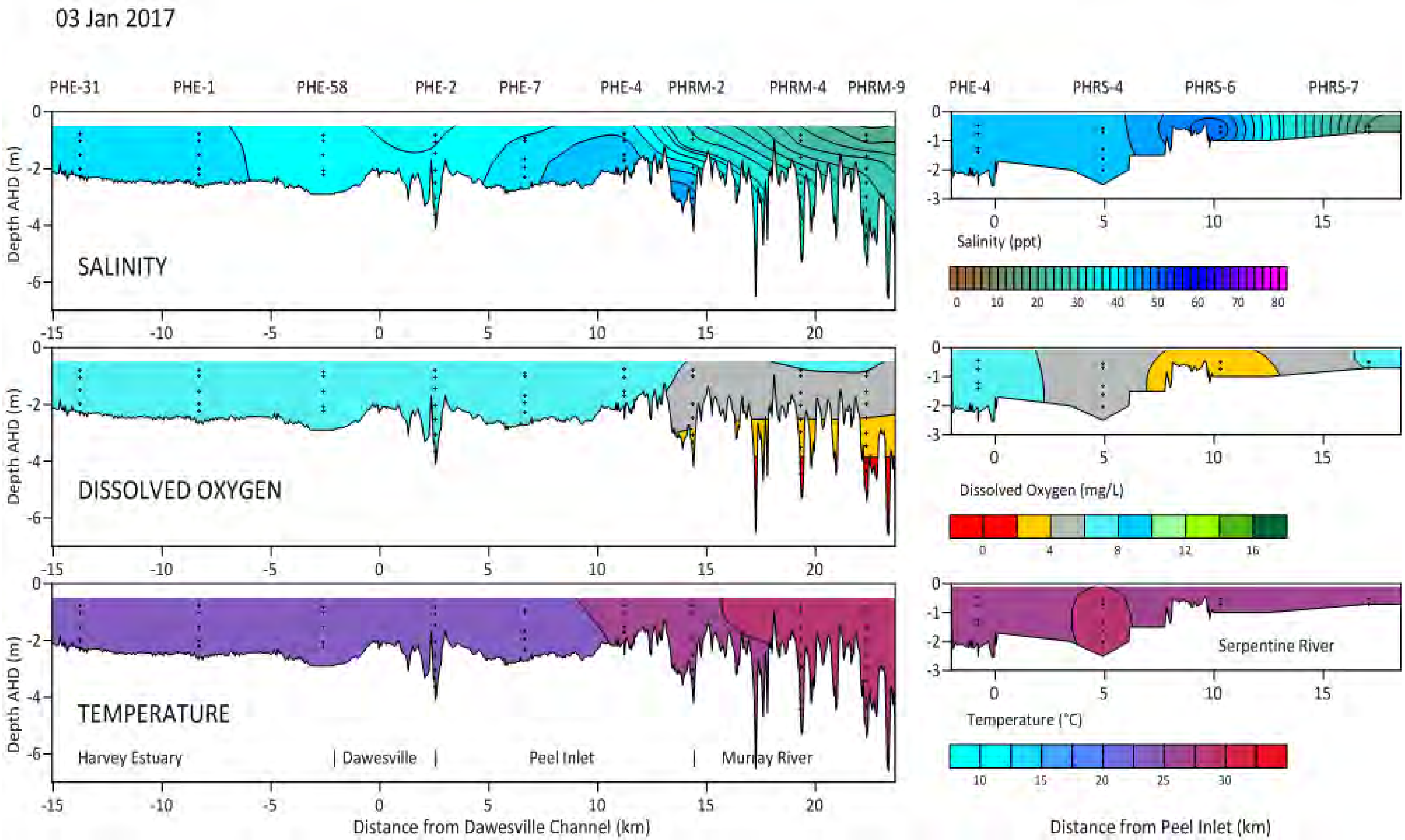


PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

13 Dec 2016

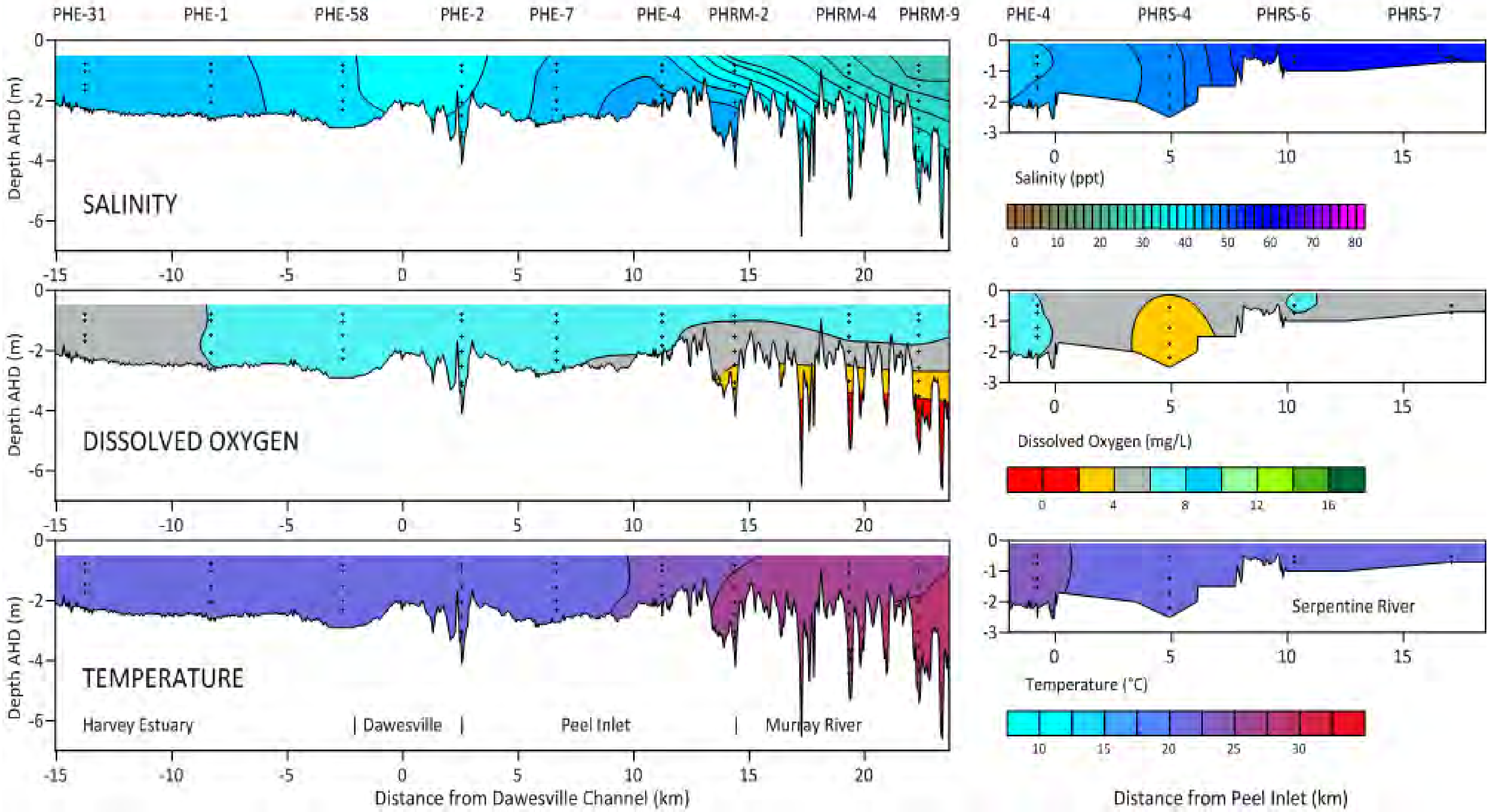


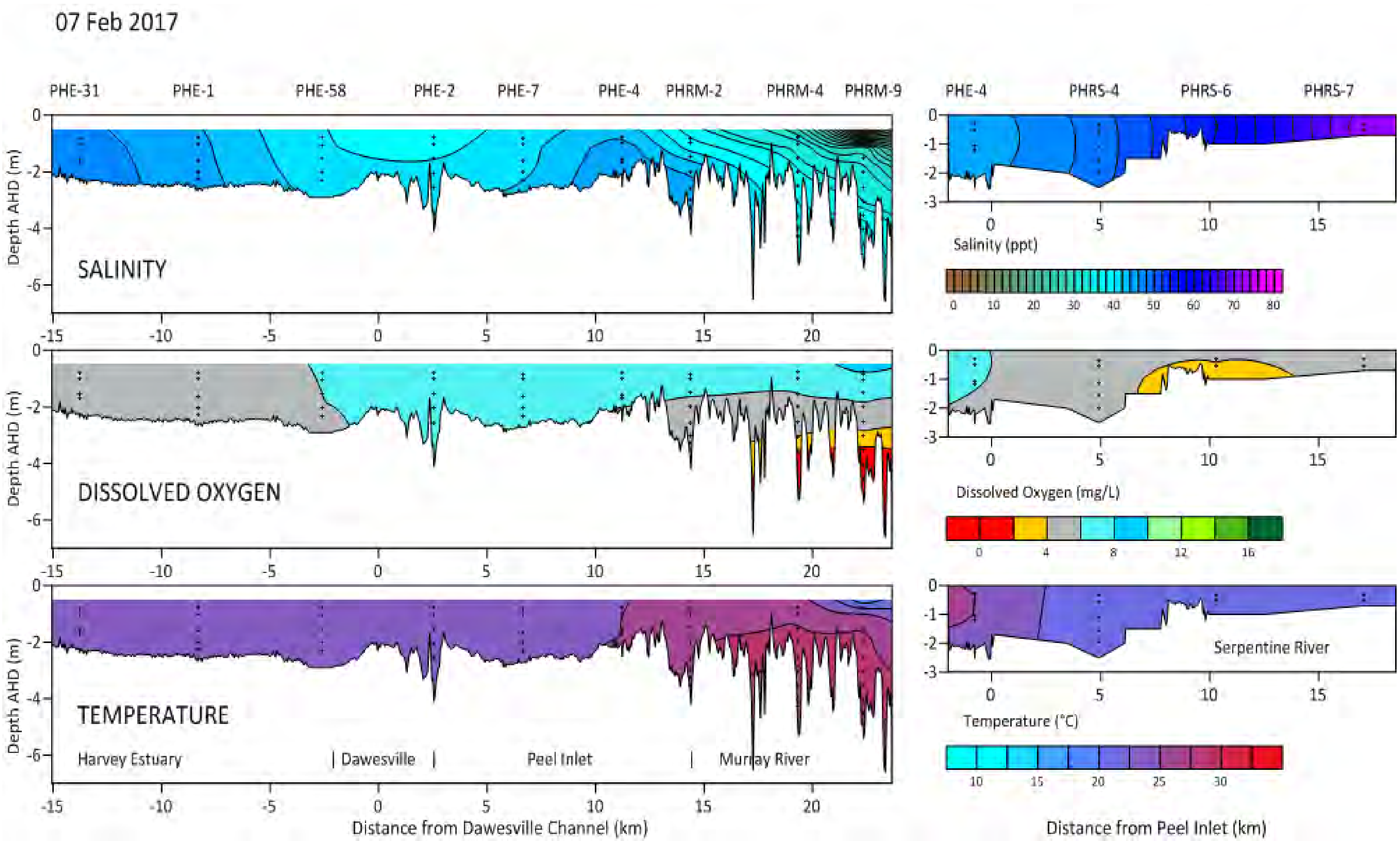
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

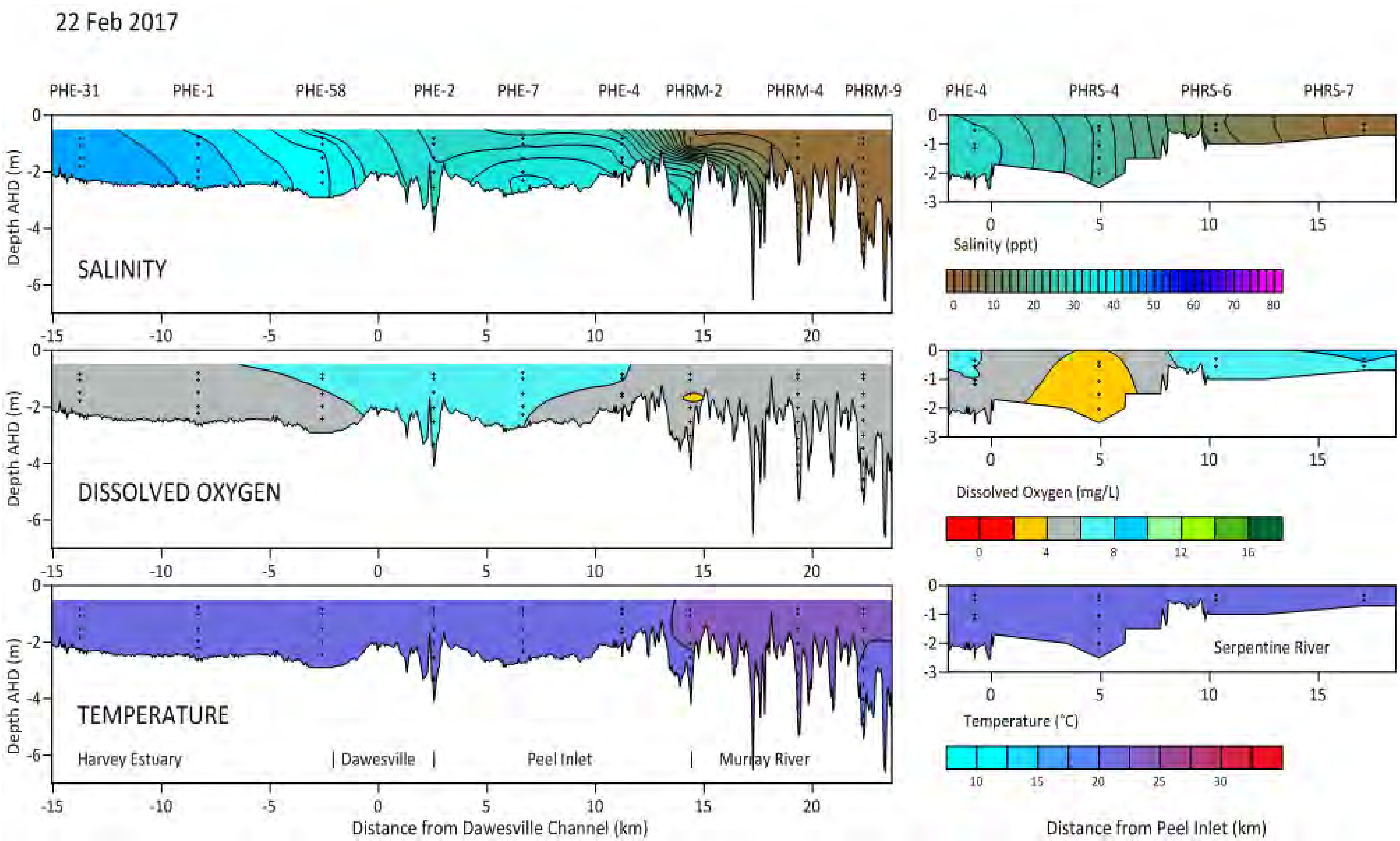


03 Jan 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

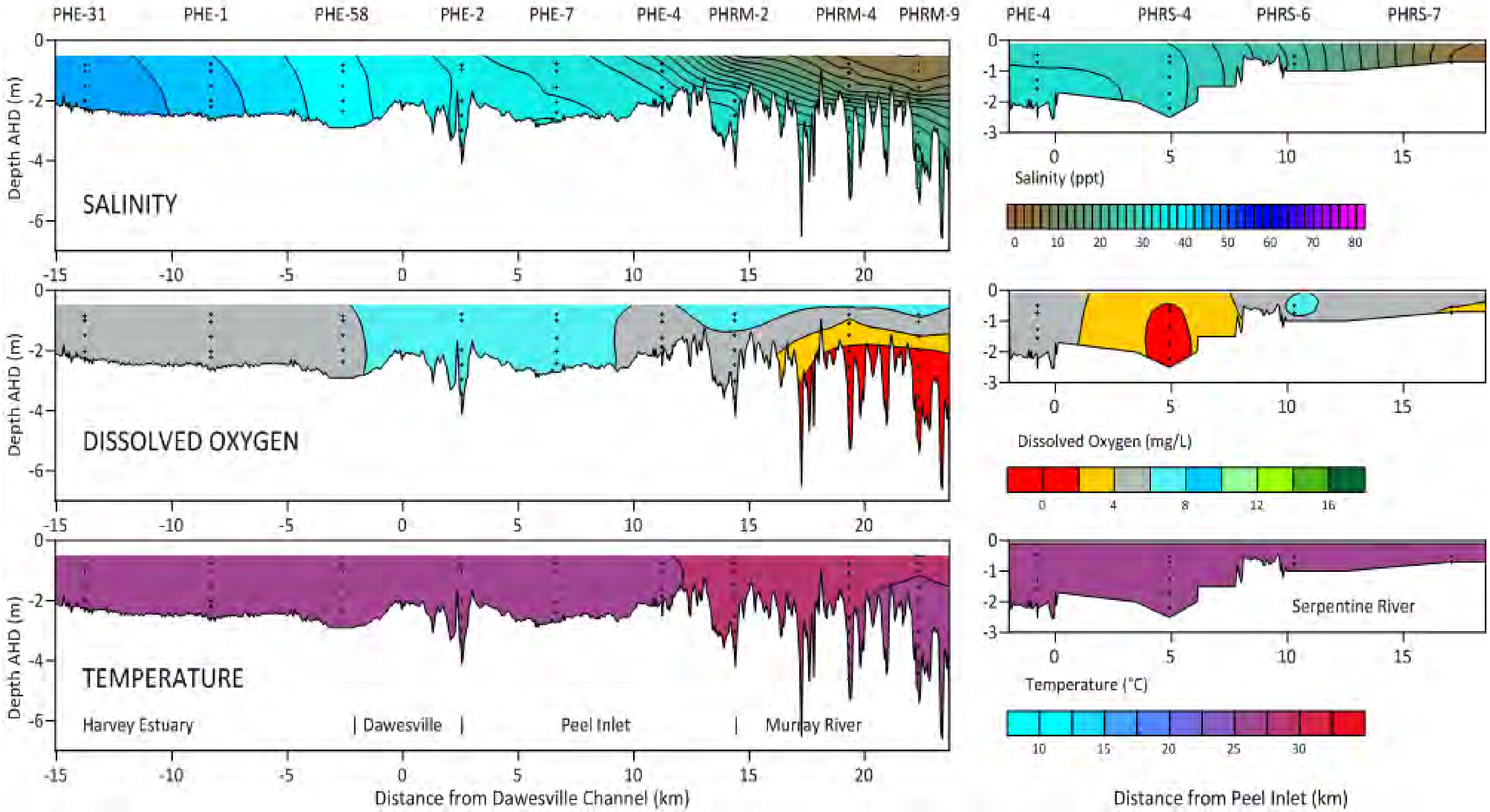
23 Jan 2017


PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Depth AHD (m)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

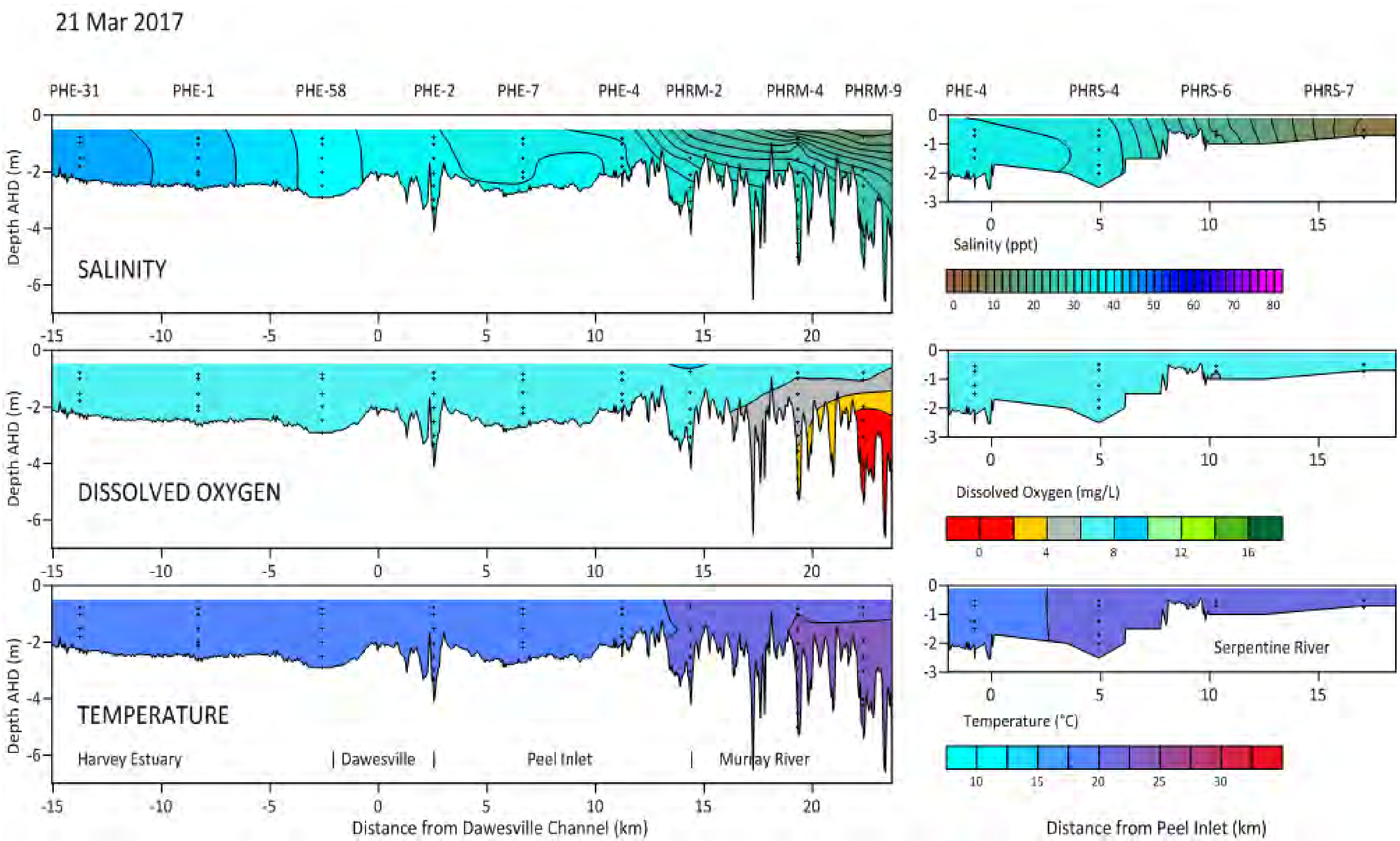

07 Feb 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)


22 Feb 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

07 Mar 2017

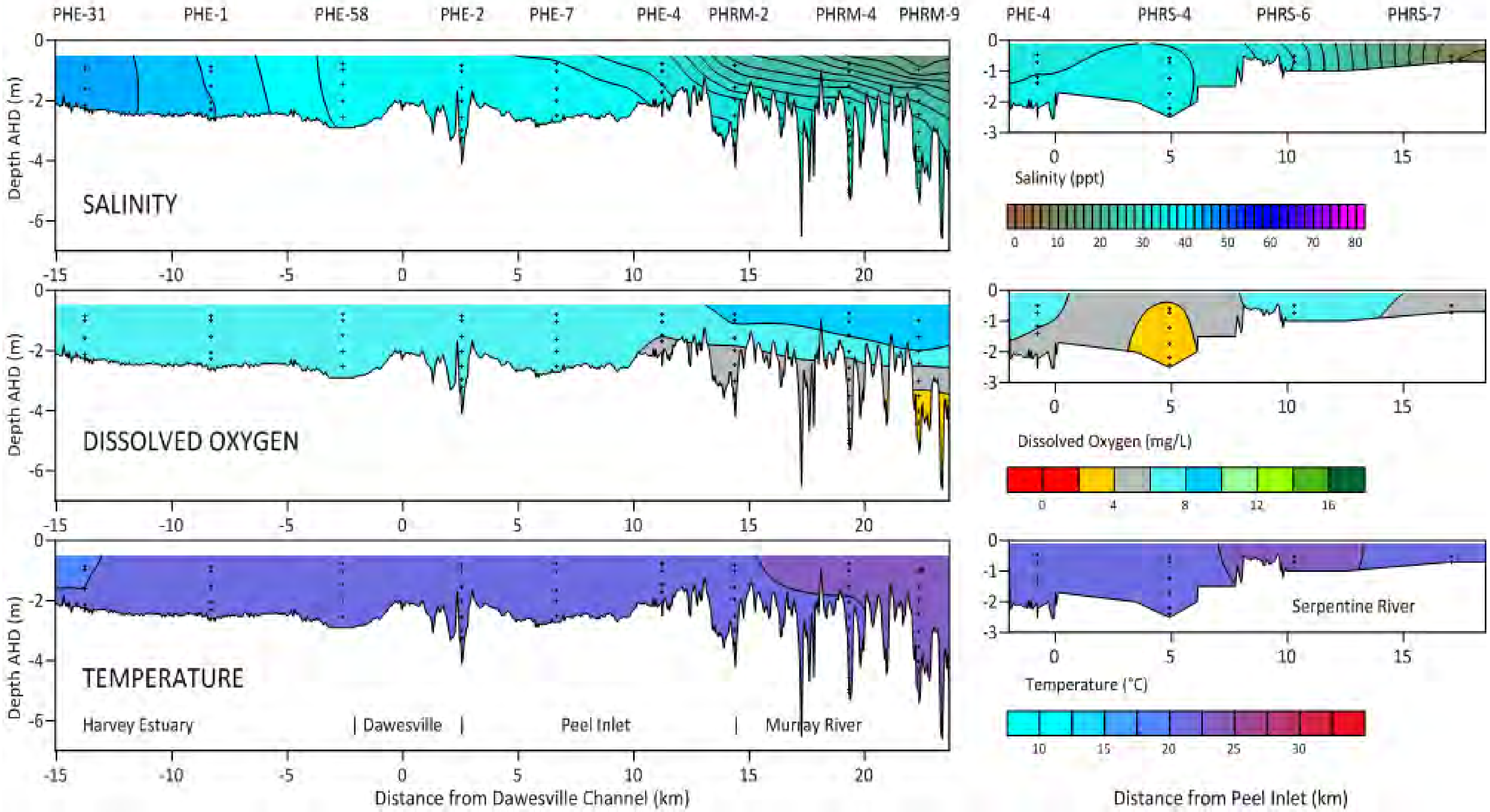


PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

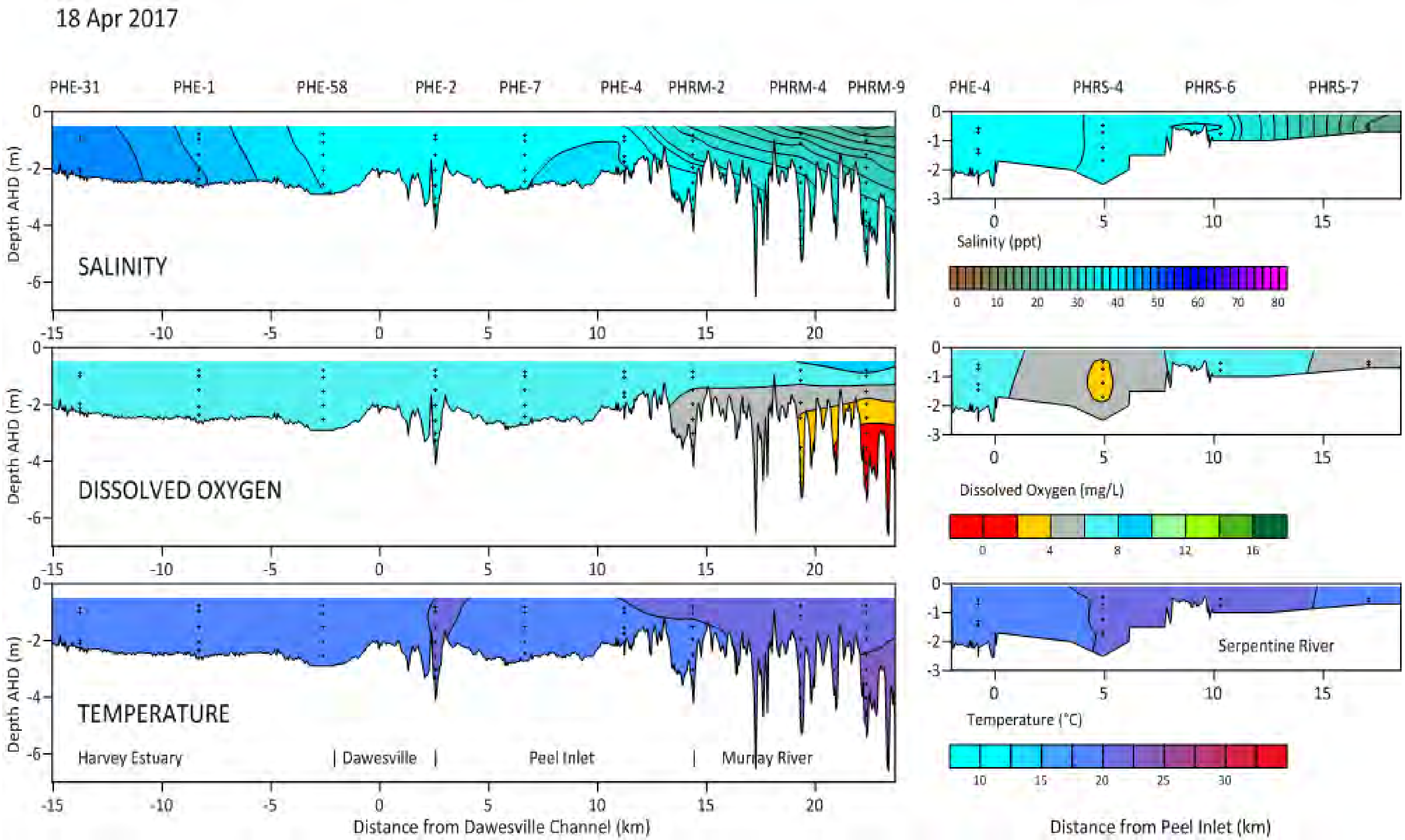


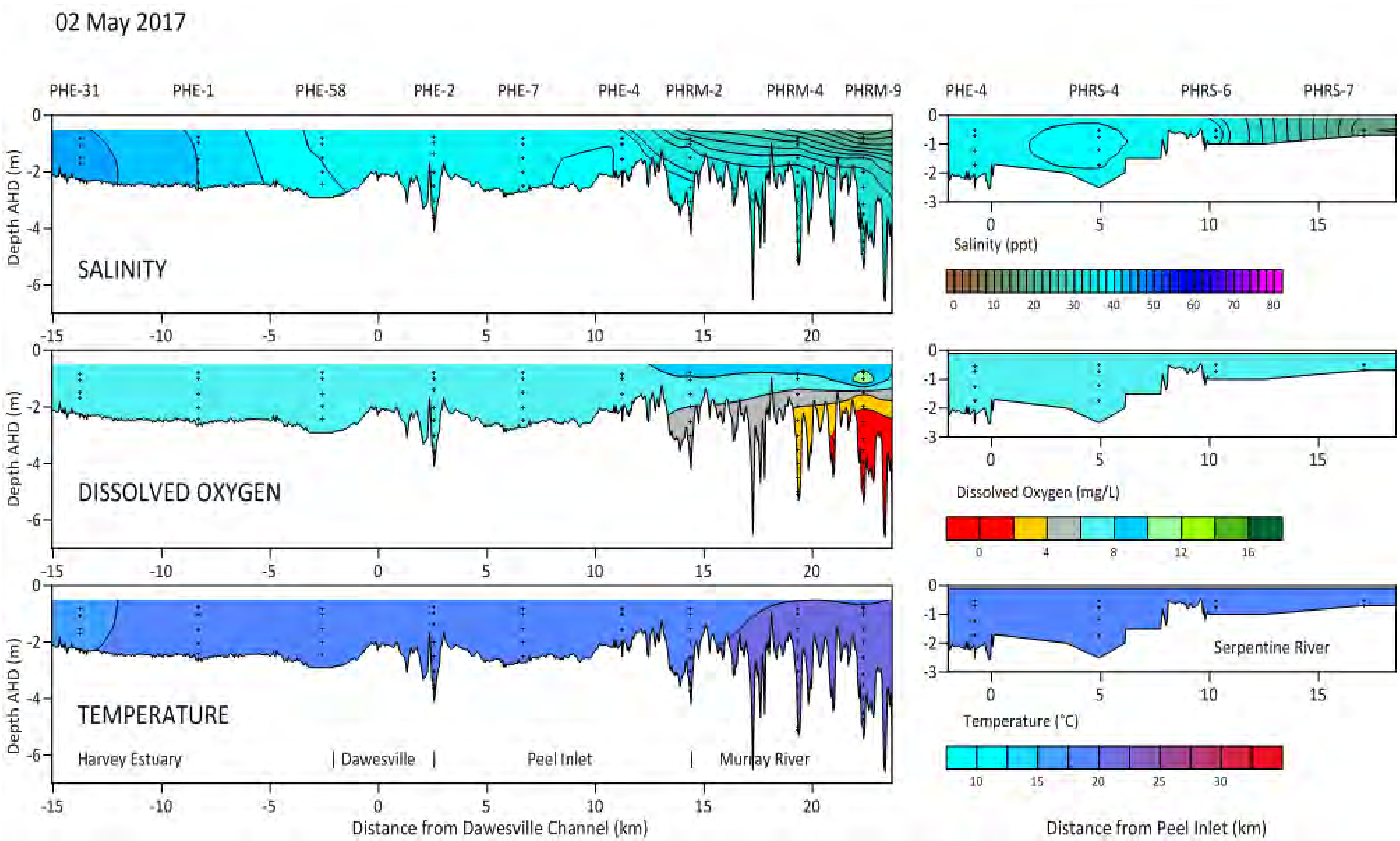
21 Mar 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

04 Apr 2017



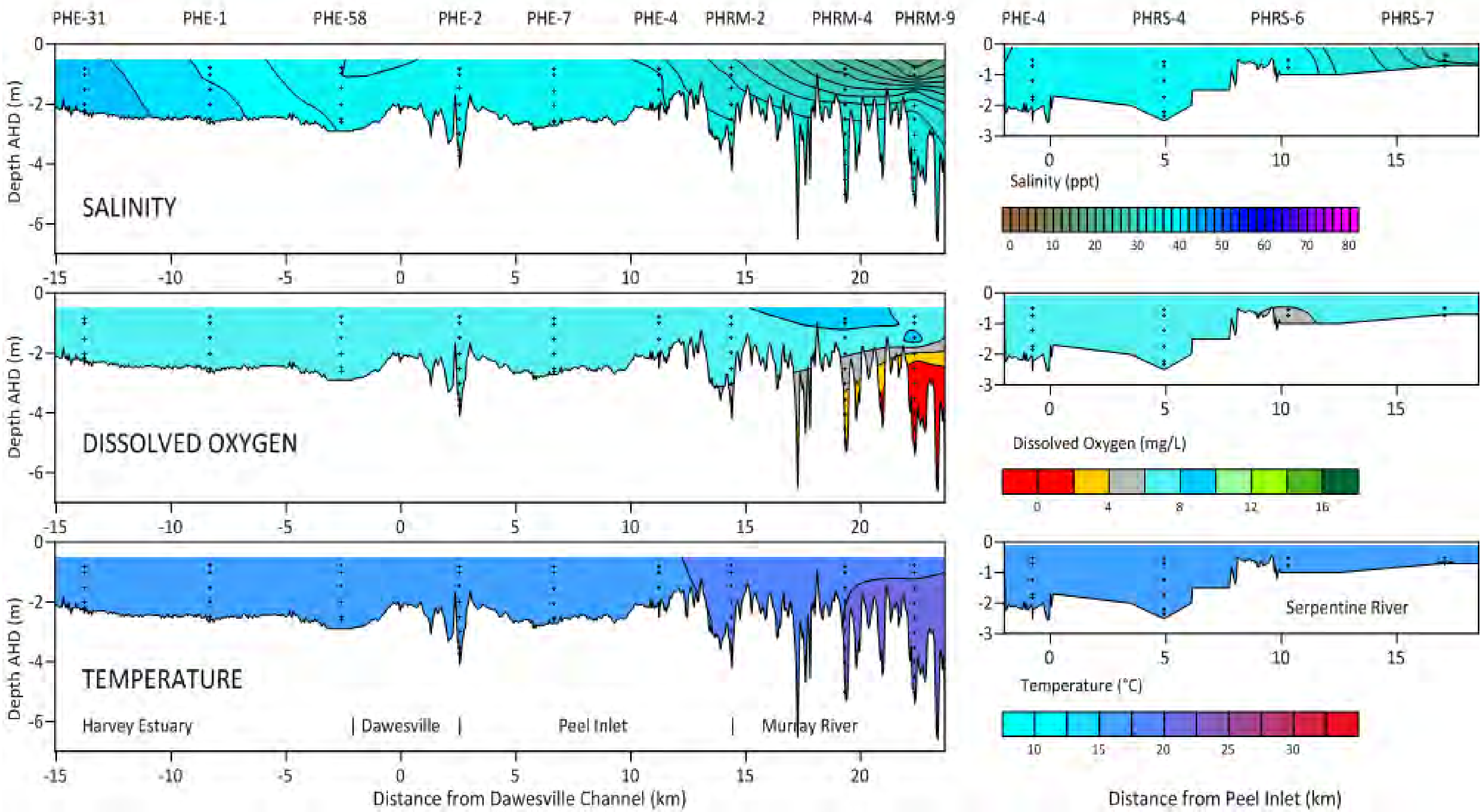
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)


18 Apr 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

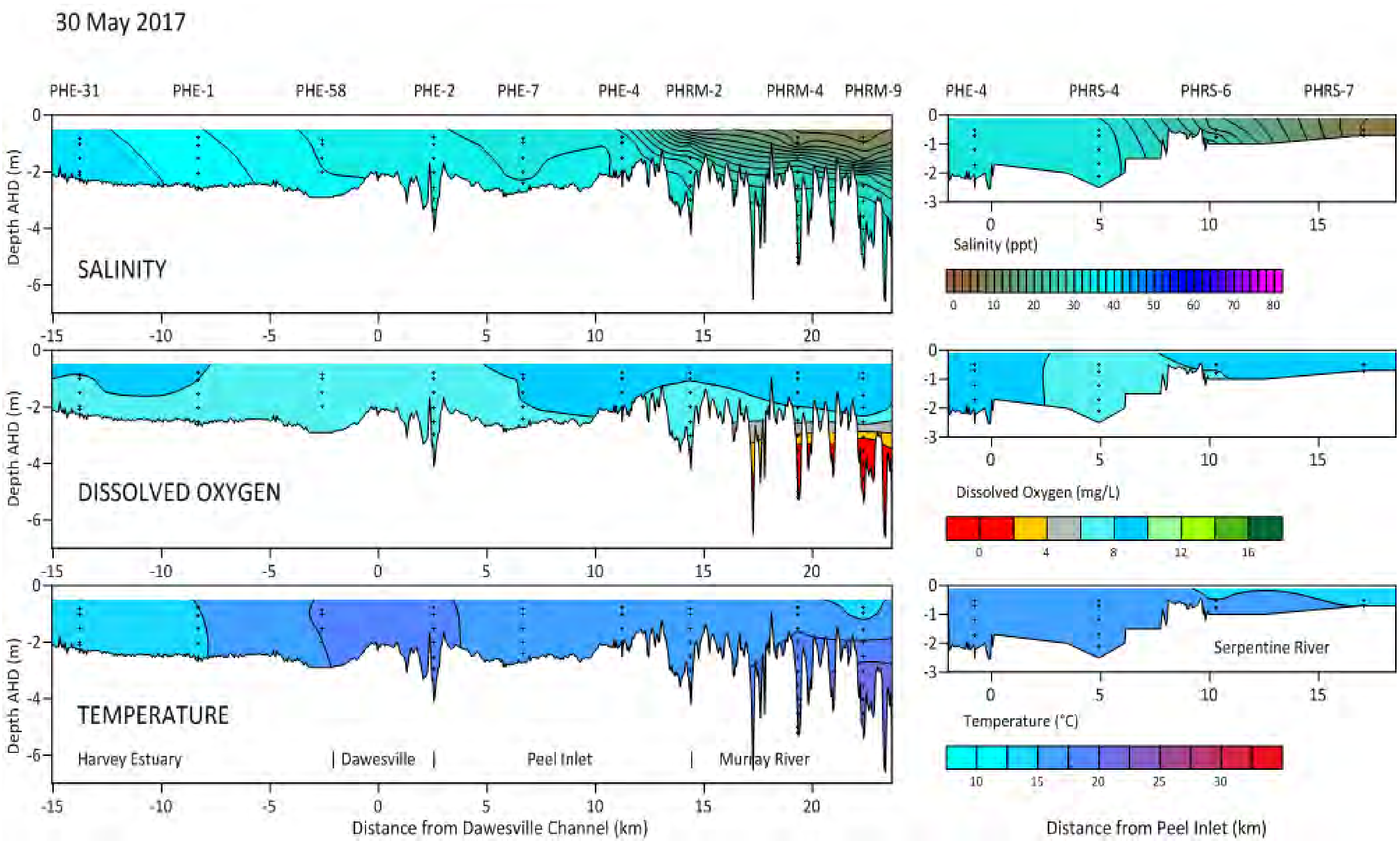


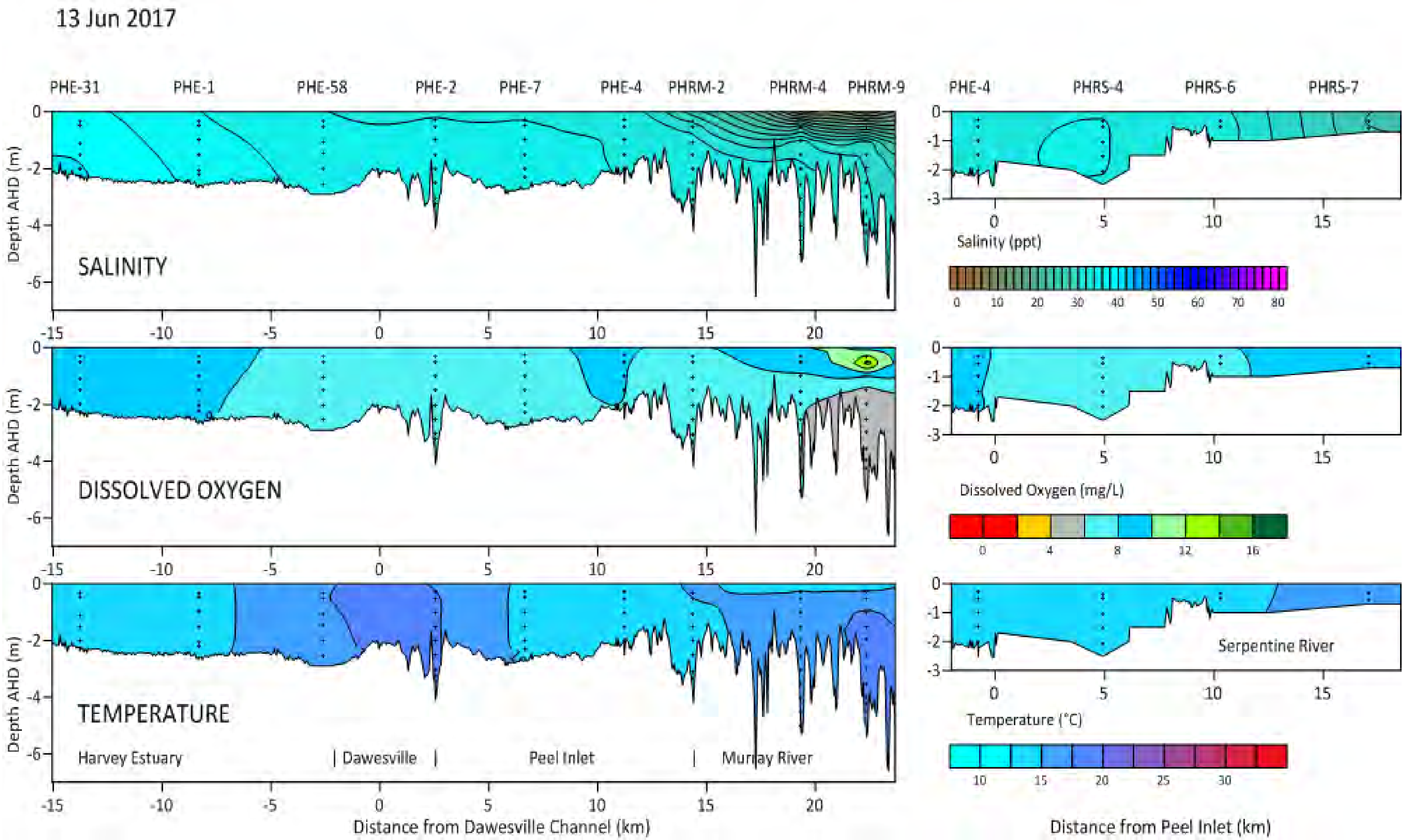
02 May 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

16 May 2017



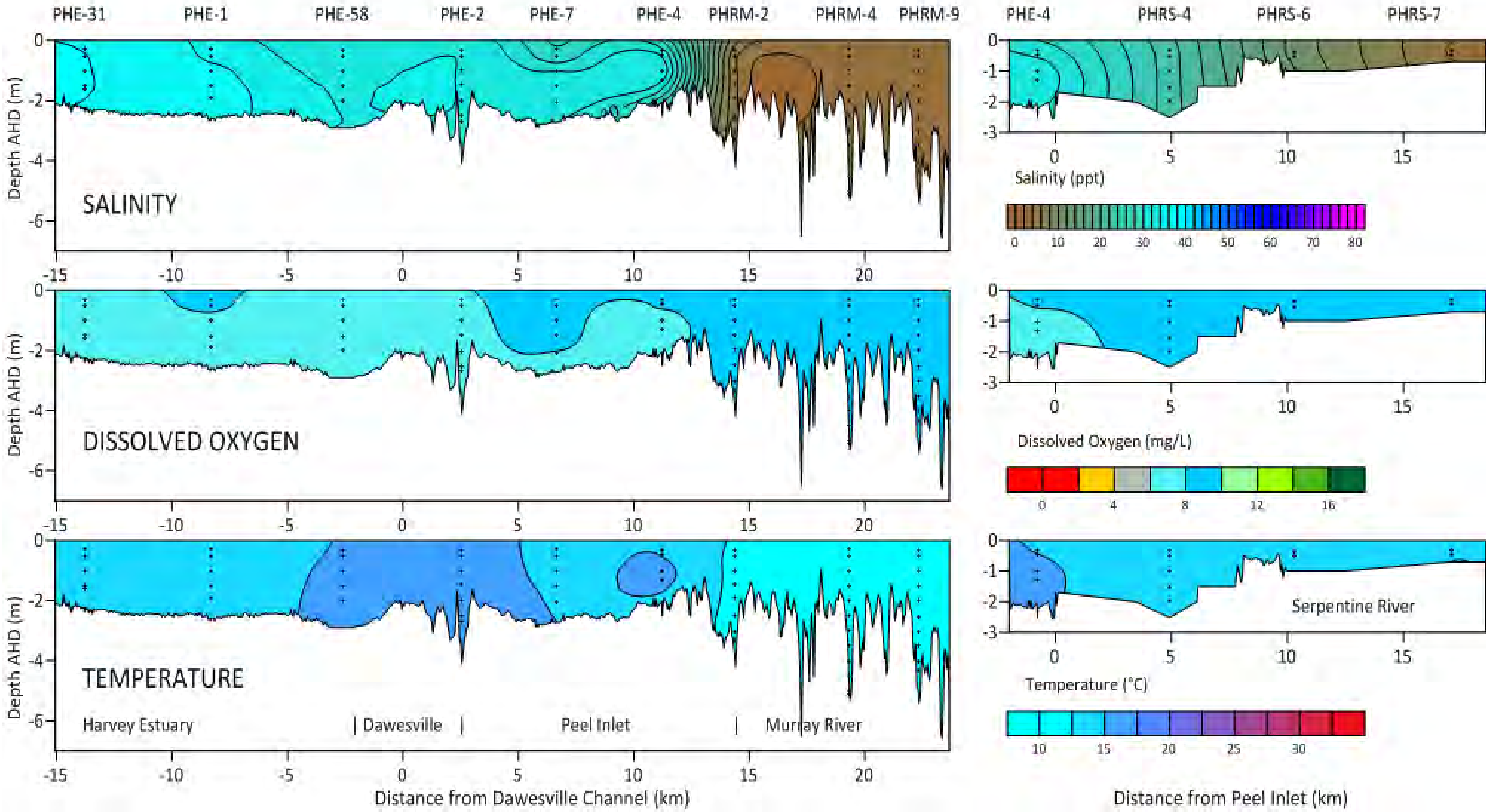
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)


30 May 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)



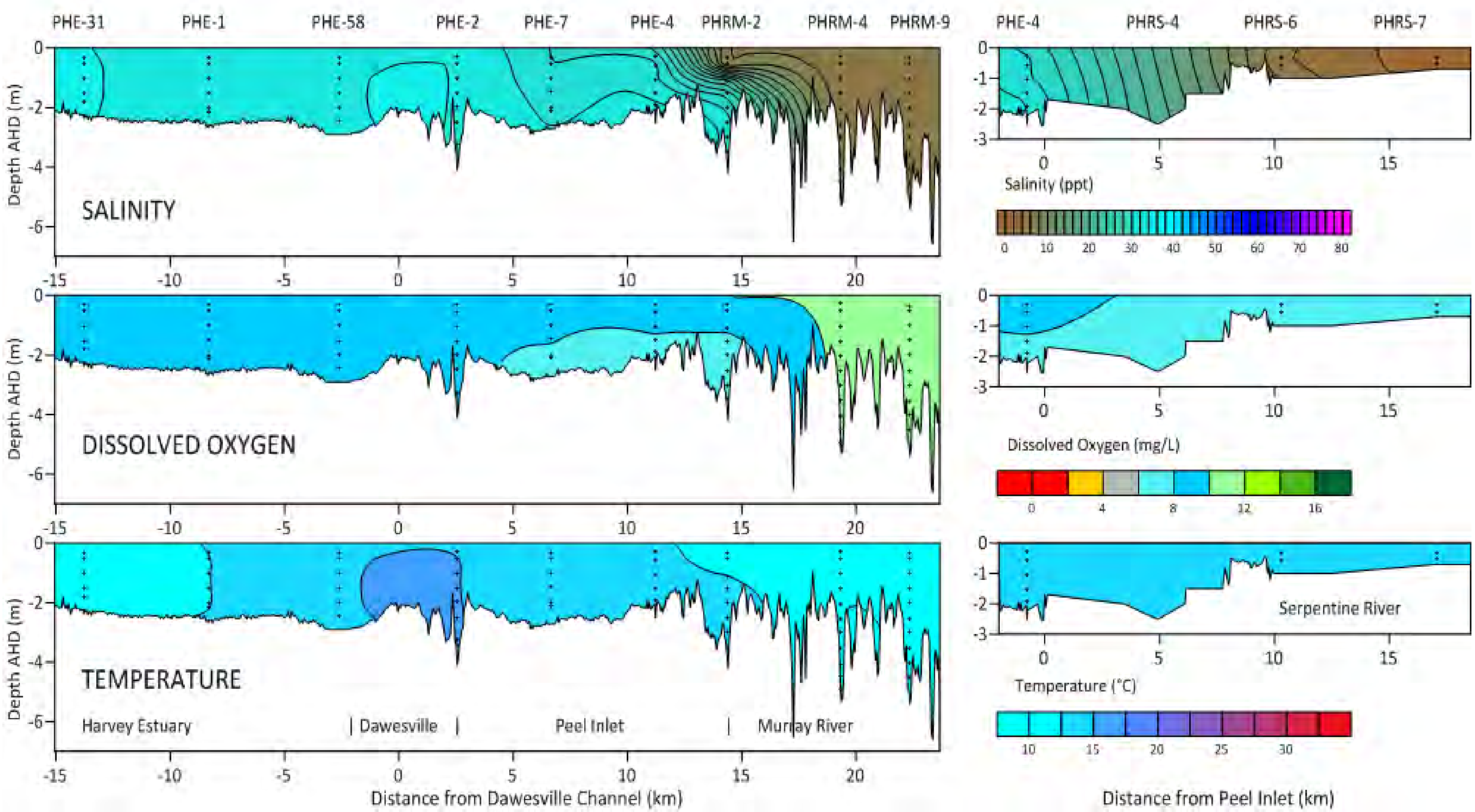
13 Jun 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

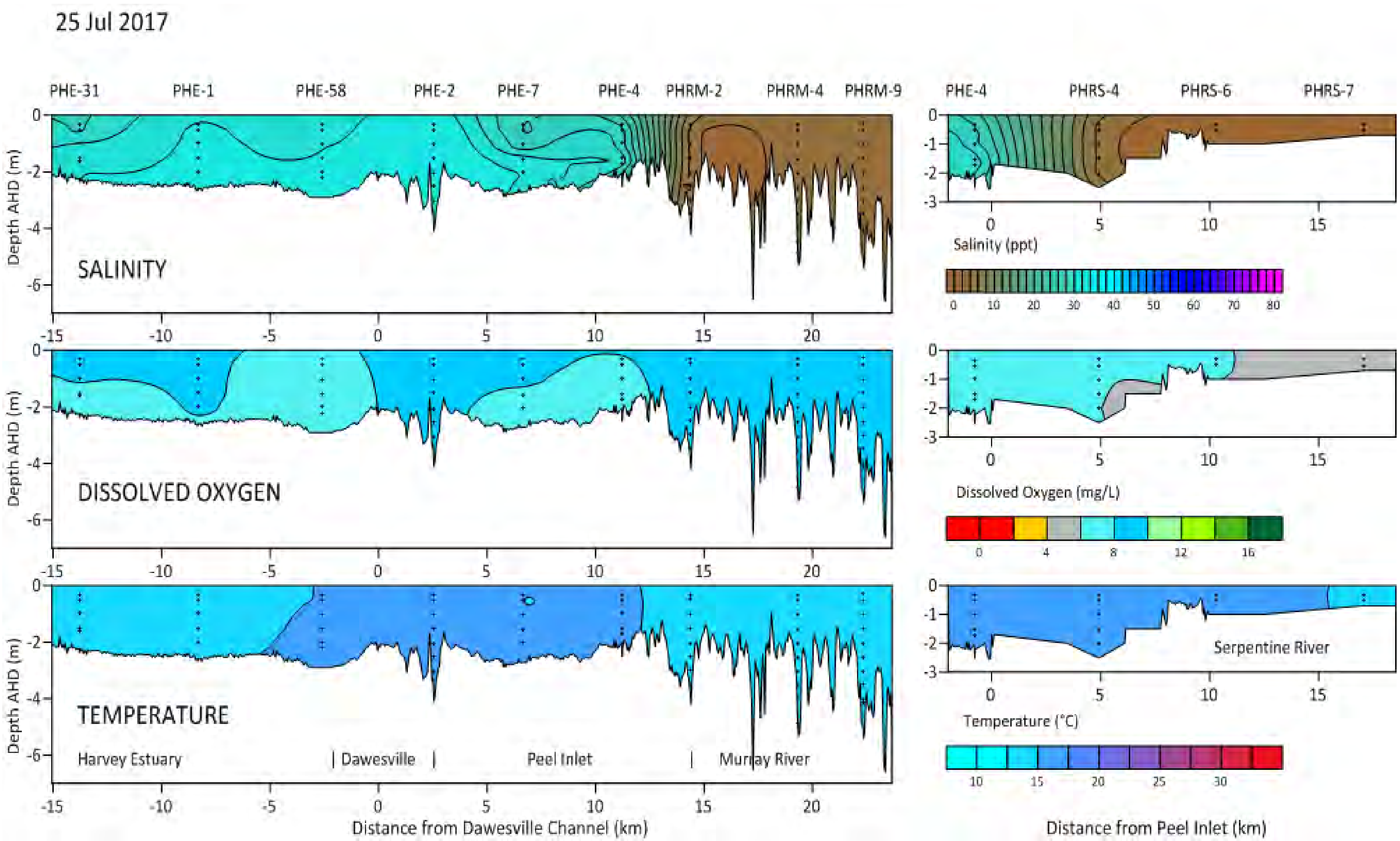
27 Jun 2017



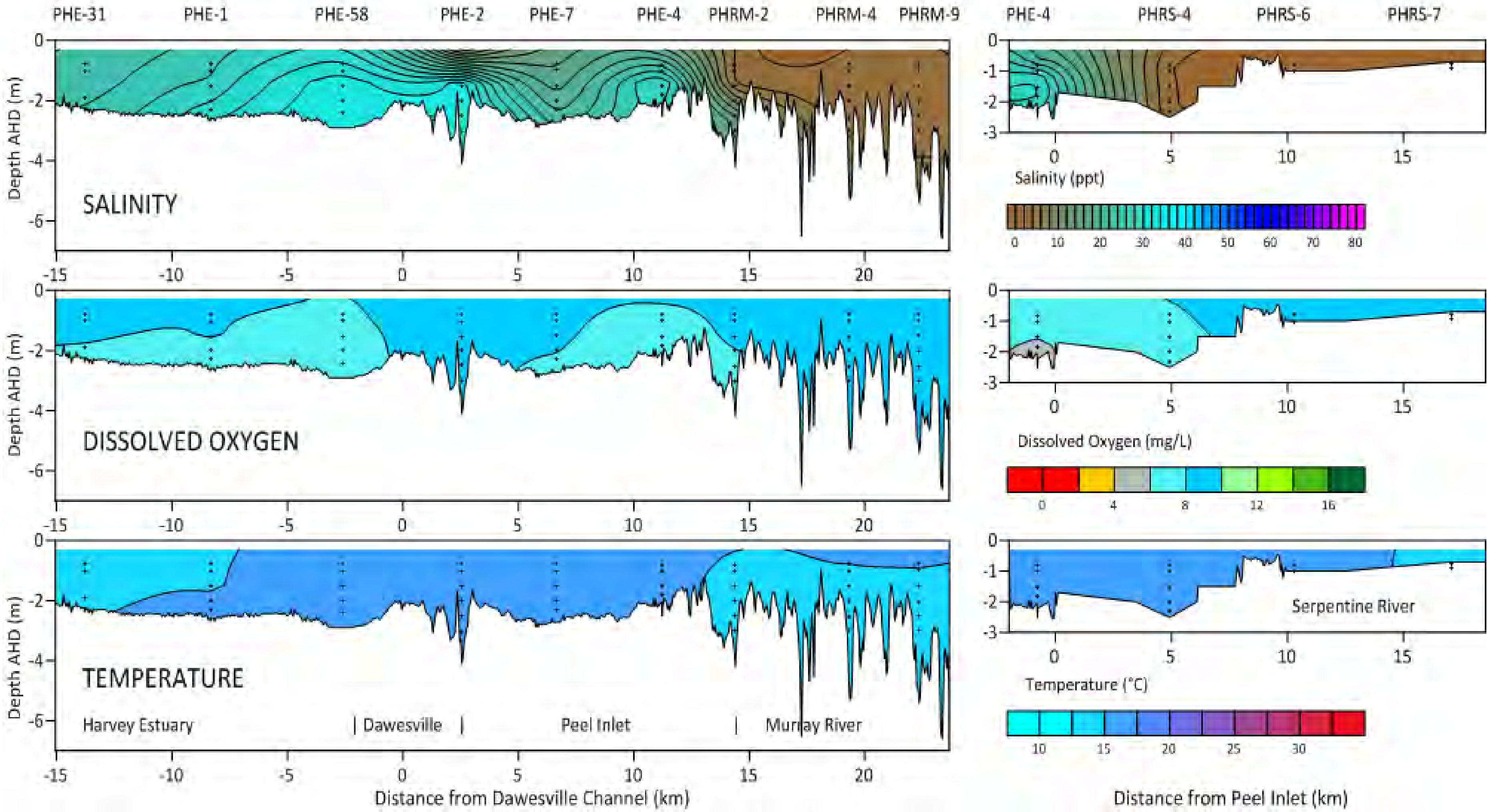
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

11 Jul 2017

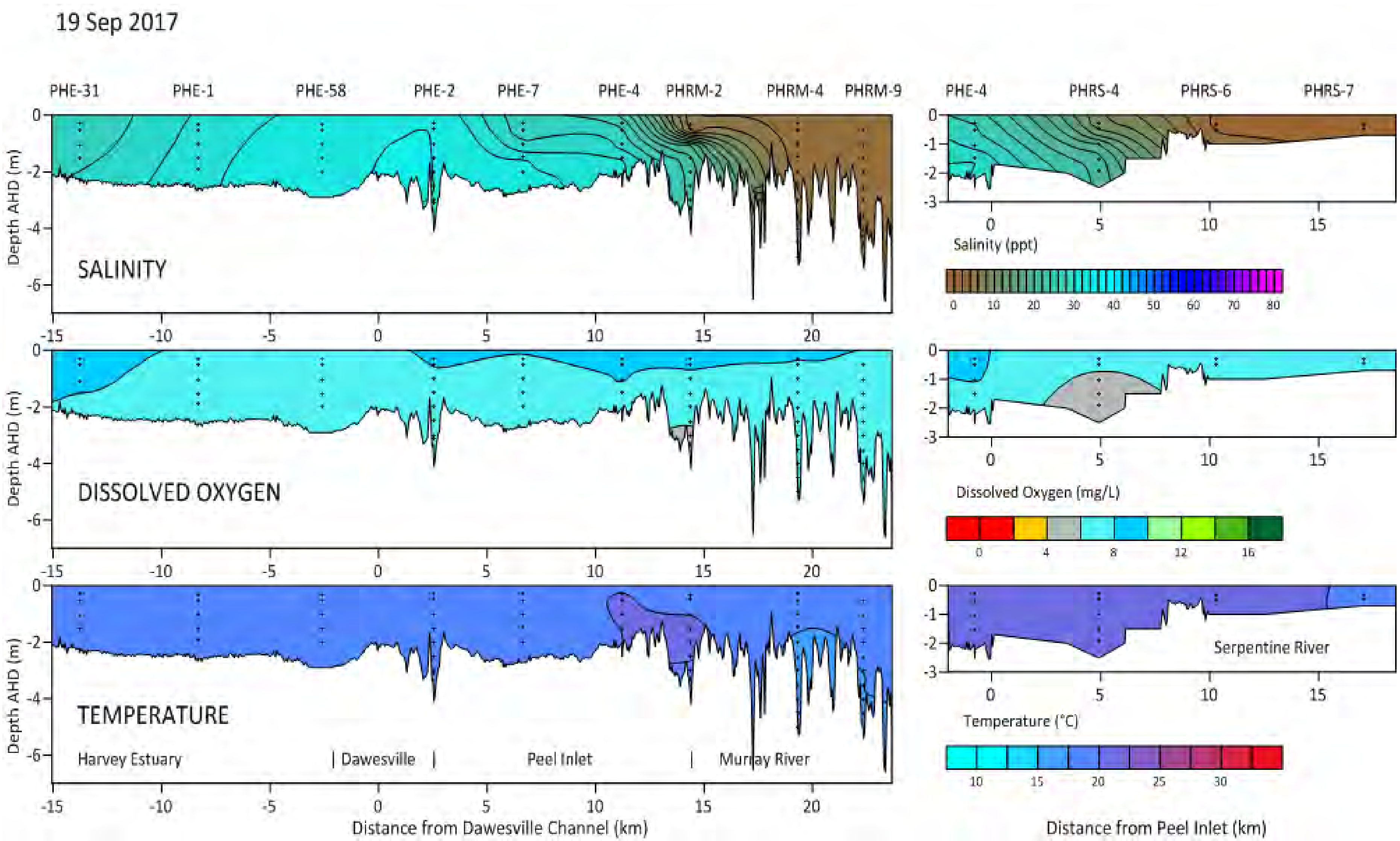

PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Depth AHD (m)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)


25 Jul 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

05 Sep 2017



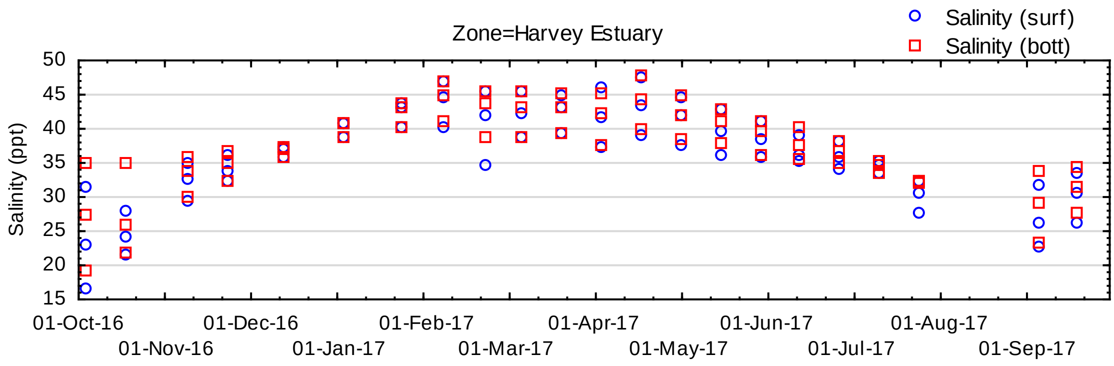
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
SALINITY
DISSOLVED OXYGEN
TEMPERATURE
Depth AHD (m)
Salinity (ppt)
Dissolved Oxygen (mg/L)
Temperature (°C)
Serpentine River
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

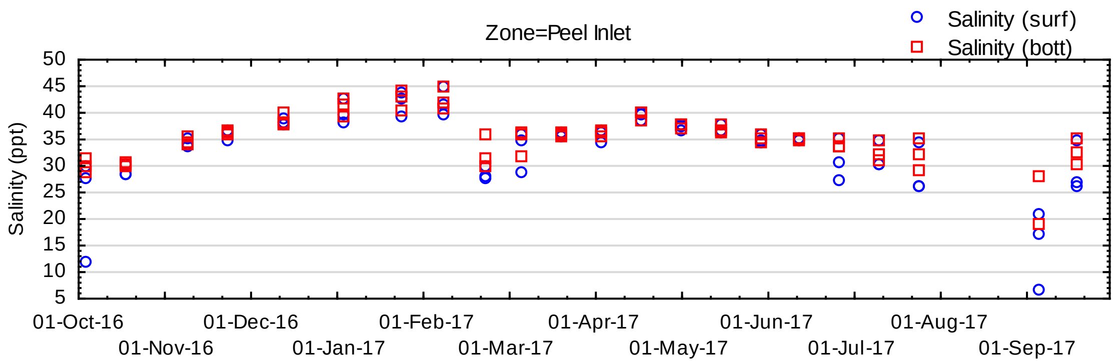


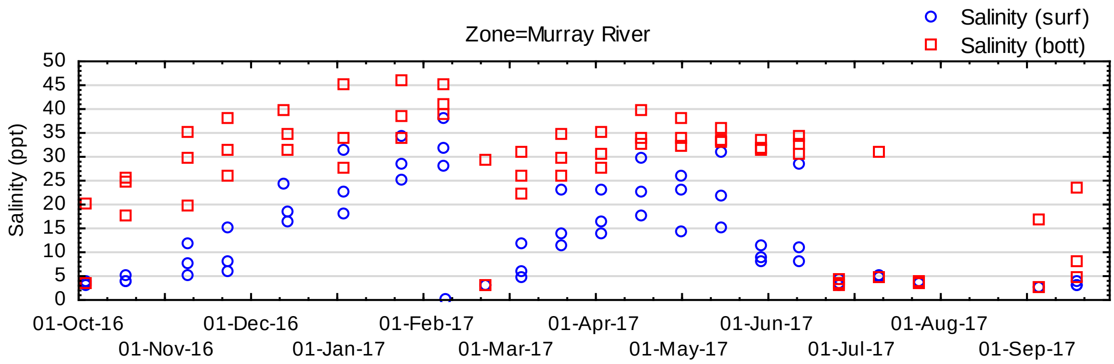
19 Sep 2017
PHE-31
PHE-1
PHE-58
PHE-2
PHE-7
PHE-4
PHRM-2
PHRM-4
PHRM-9
PHE-4
PHRS-4
PHRS-6
PHRS-7
Depth AHD (m)
SALINITY
Salinity (ppt)
DISSOLVED OXYGEN
Dissolved Oxygen (mg/L)
TEMPERATURE
Temperature (°C)
Harvey Estuary
Dawesville
Peel Inlet
Murray River
Serpentine River
Distance from Dawesville Channel (km)
Distance from Peel Inlet (km)

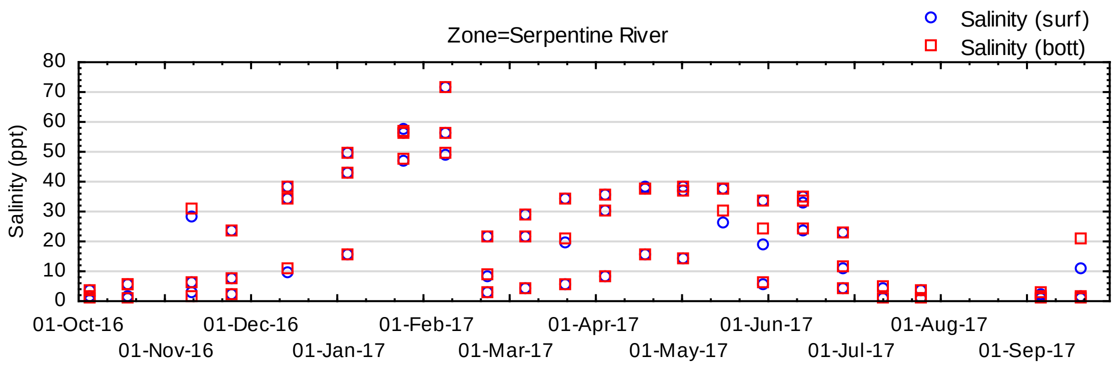
Appendix C: Water quality indicators time series

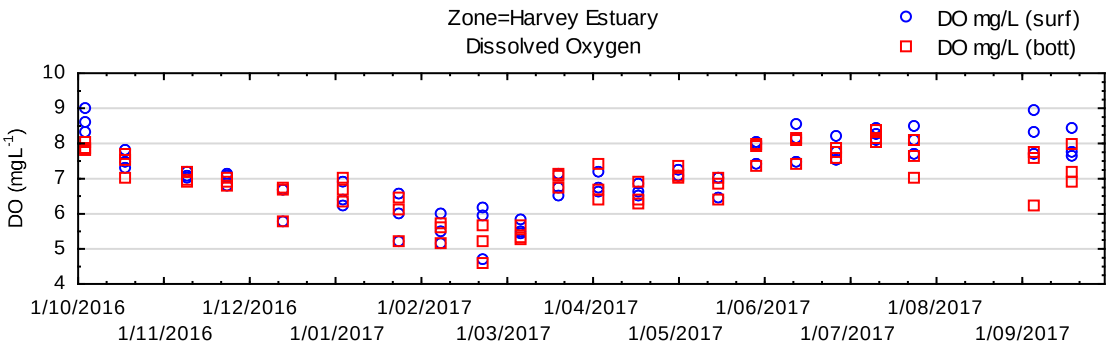
Note: Concentrations measured at or below the limit of reporting (LOR) (Appendix A) are displayed as 0.5 × LOR.

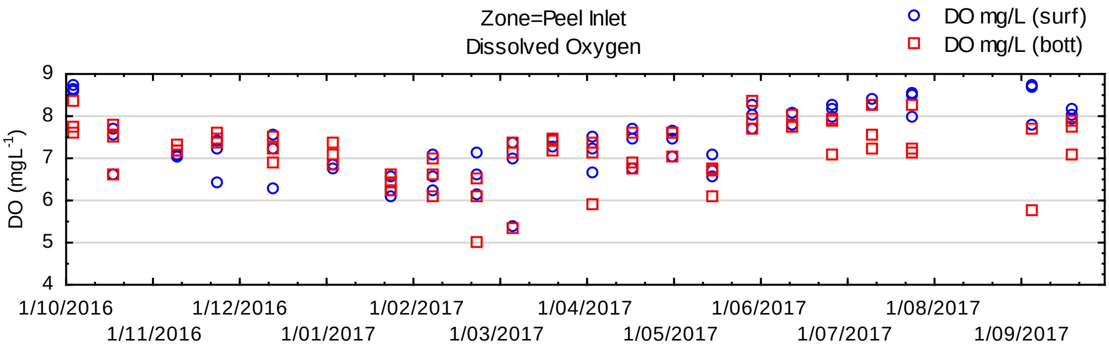


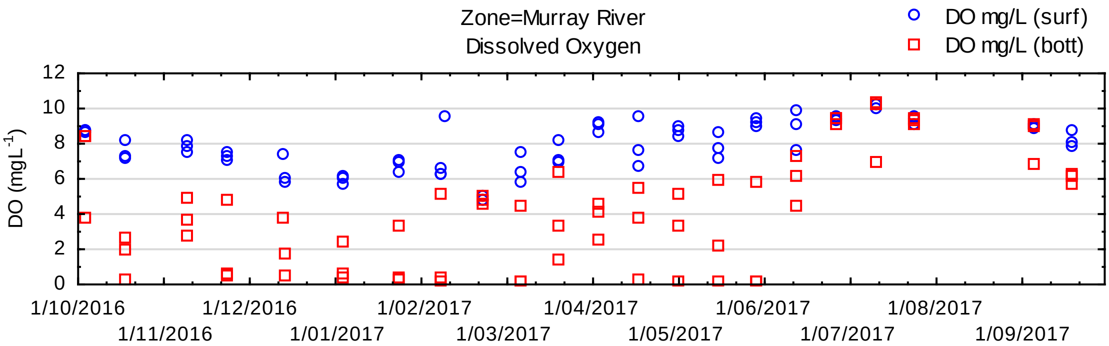


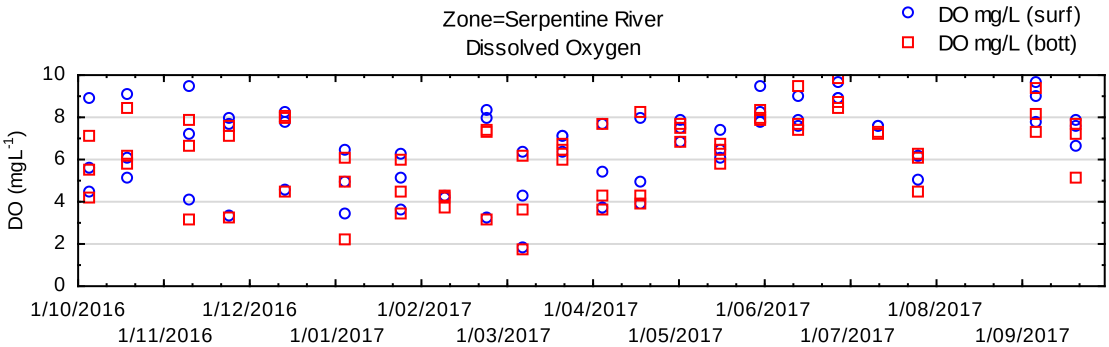


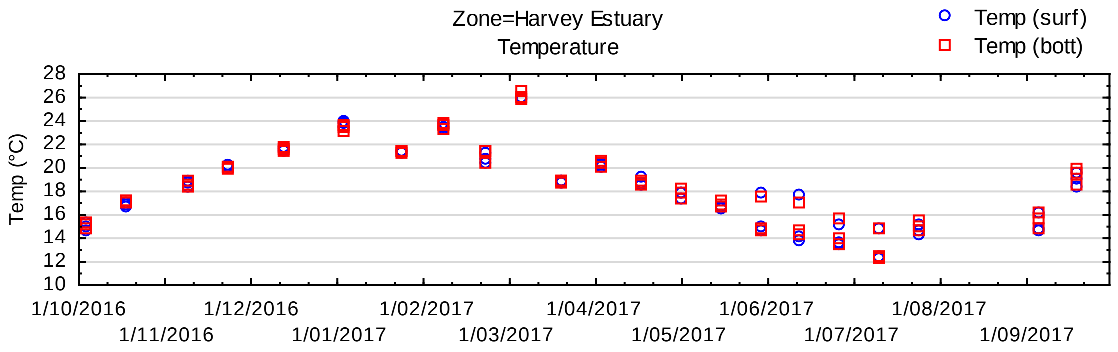


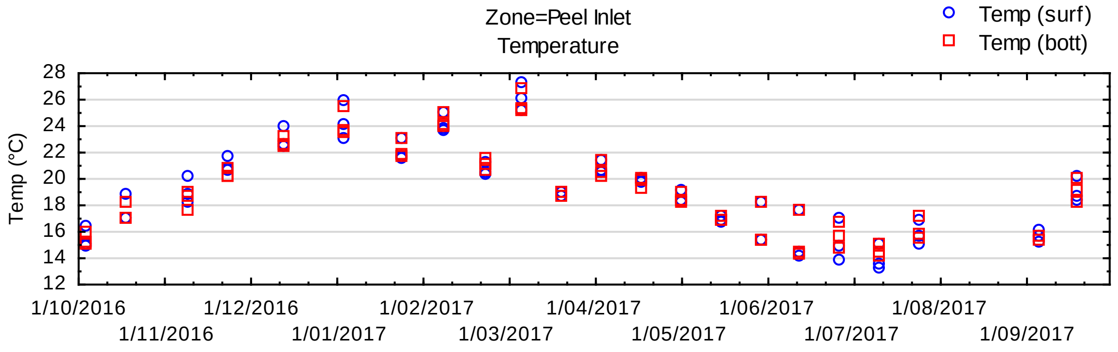

Zone=Harvey Estuary
Dissolved Oxygen
DO mg/L (surf)
DO mg/L (bott)
DO (mgL-1)
10
9
8
7
6
5
4
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

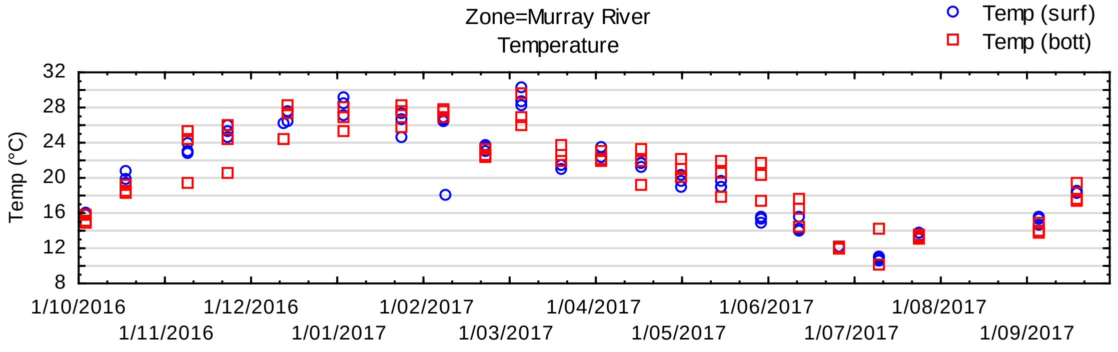

Zone=Peel Inlet
Dissolved Oxygen
DO mg/L (surf)
DO mg/L (bott)
DO (mgL-1)
9
8
7
6
5
4
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

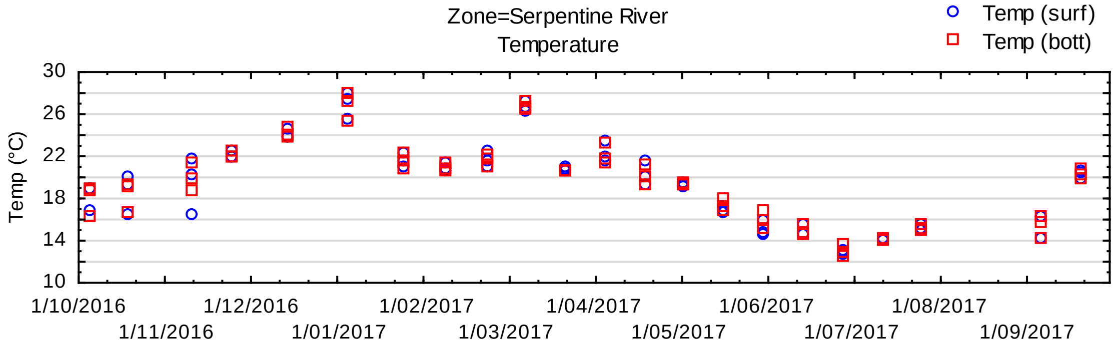

Zone=Murray River
Dissolved Oxygen
DO mg/L (surf)
DO mg/L (bott)
DO (mgL-1)
12
10
8
6
4
2
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

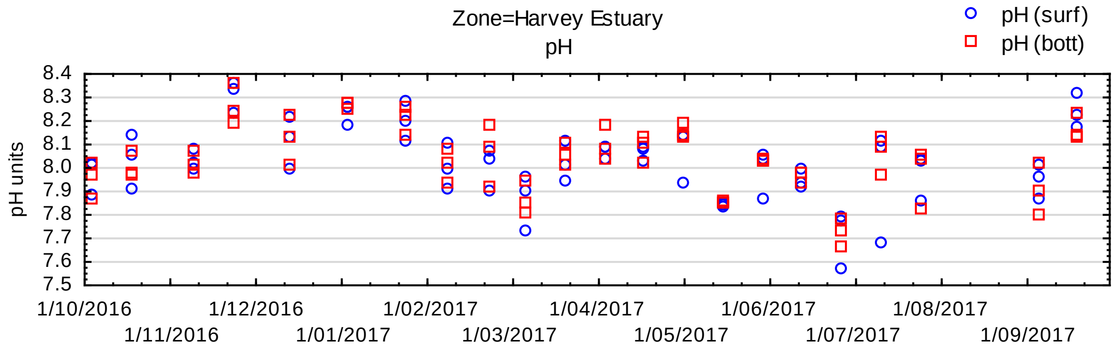

Zone=Serpentine River
Dissolved Oxygen
DO mg/L (surf)
DO mg/L (bott)
DO (mgL-1)
10
8
6
4
2
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

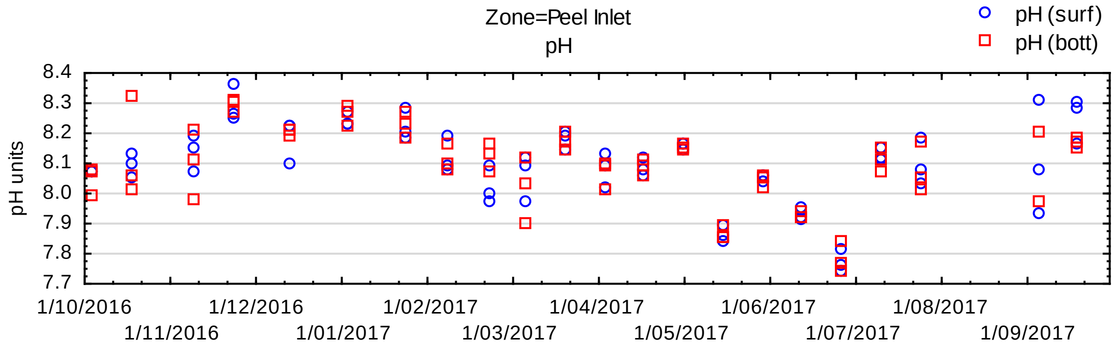

Zone=Harvey Estuary
Temperature
Temp (surf)
Temp (bott)
Temp (°C)
28
26
24
22
20
18
16
14
12
10
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

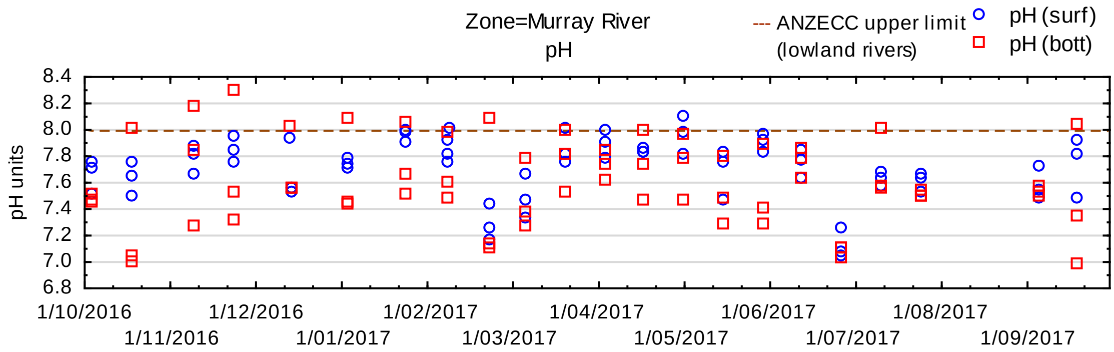

Zone=Peel Inlet
Temperature
Temp (surf)
Temp (bott)
Temp (°C)
28
26
24
22
20
18
16
14
12
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

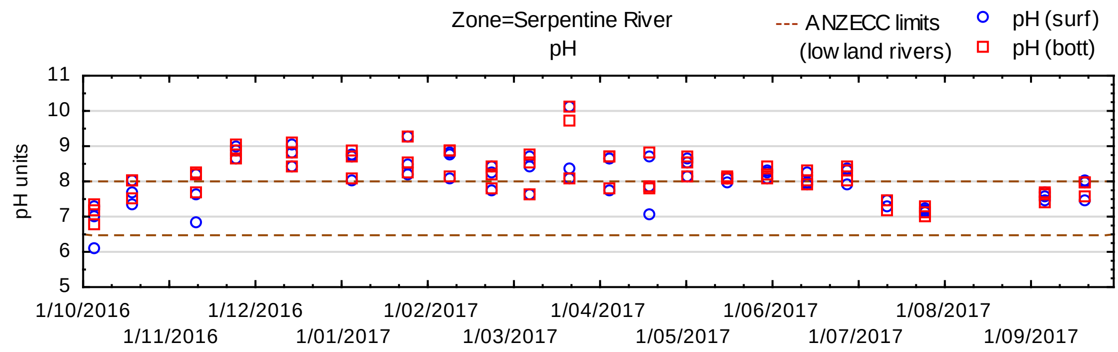

Zone=Murray River
Temperature
Temp (surf)
Temp (bott)
Temp (°C)
32
28
24
20
16
12
8
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

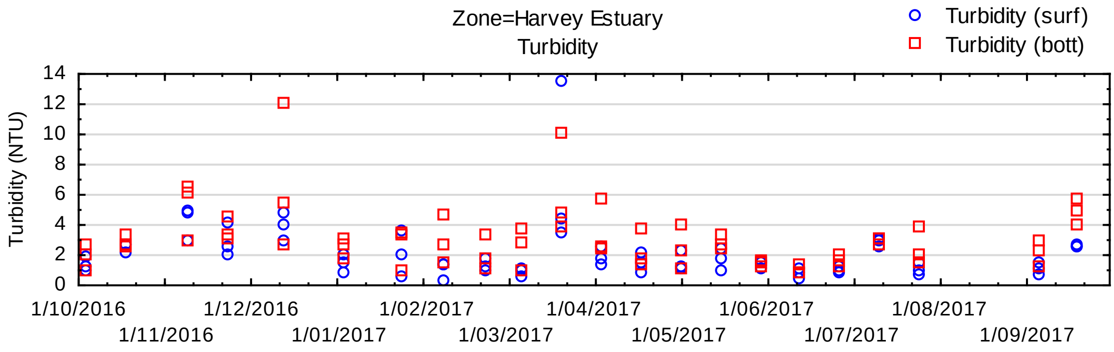

Zone=Serpentine River
Temperature
Temp (surf)
Temp (bott)
Temp (°C)
30
26
22
18
14
10
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

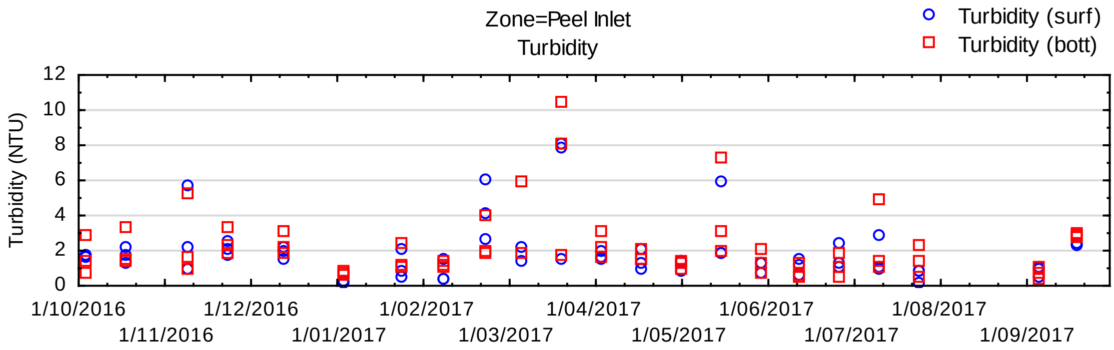

Zone=Harvey Estuary
pH
pH (surf)
pH (bott)
pH units
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

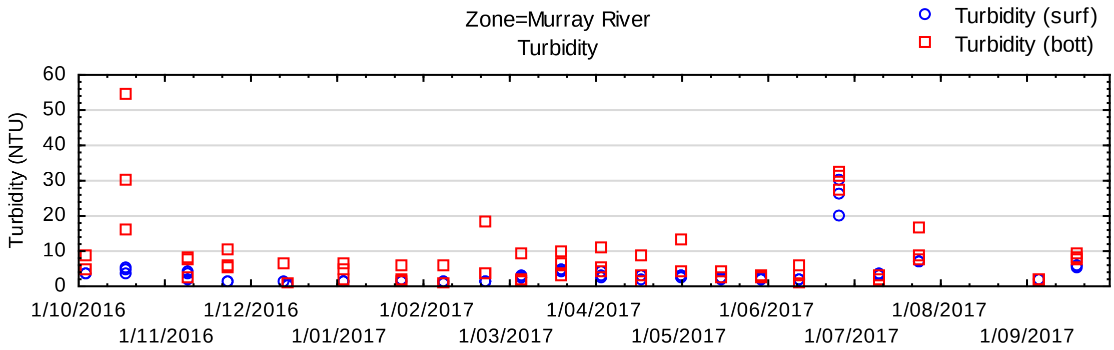

Zone=Peel Inlet
pH
pH (surf)
pH (bott)
pH units
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

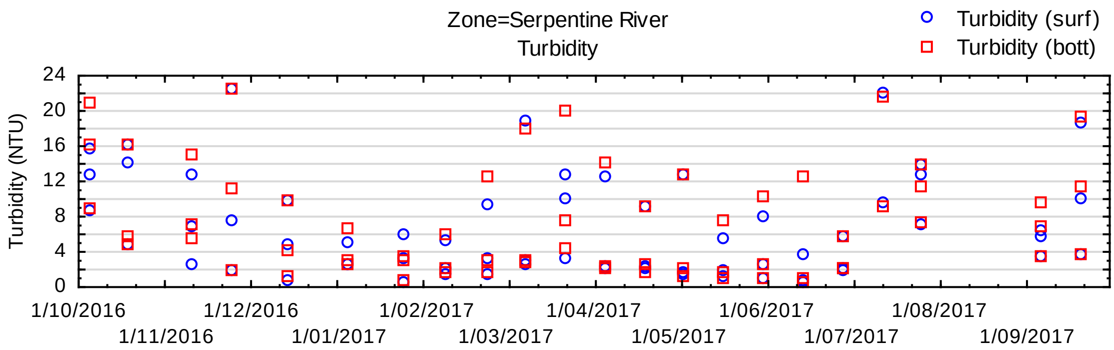

Zone=Murray River
pH
--- ANZECC upper limit
(lowland rivers)
pH (surf)
pH (bott)
pH units
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

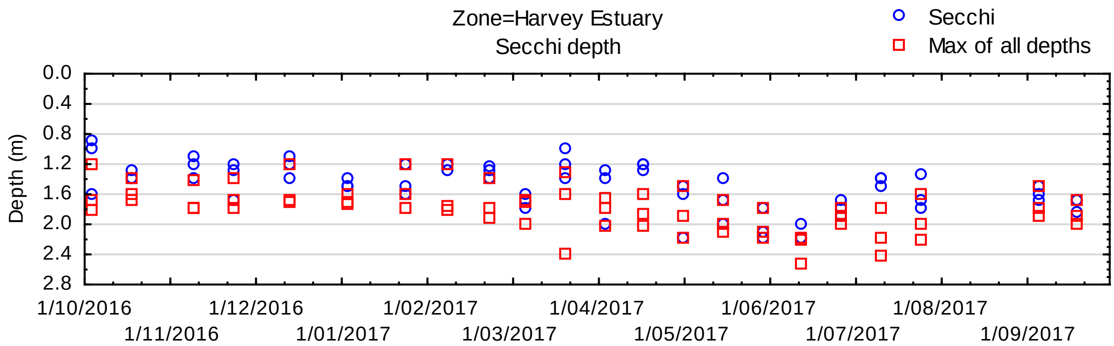

Zone=Serpentine River
pH
--- ANZECC limits
(low land rivers)
pH (surf)
pH (bott)
pH units
11
10
9
8
7
6
5
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

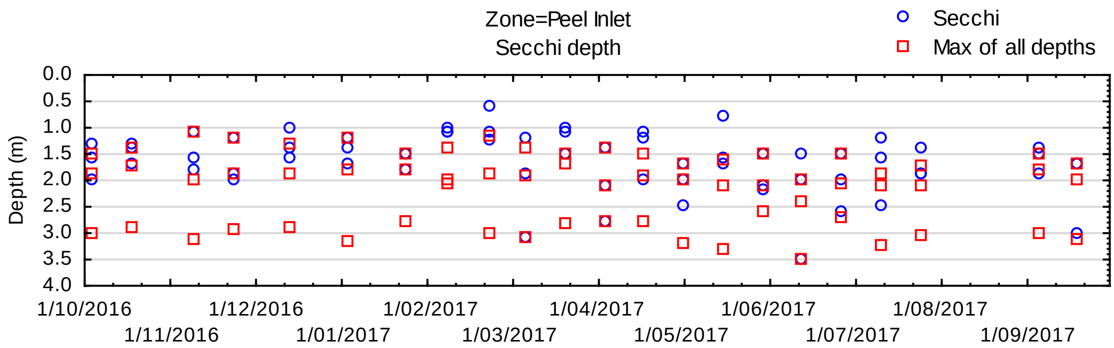

Zone=Harvey Estuary
Turbidity
Turbidity (surf)
Turbidity (bott)
Turbidity (NTU)
14
12
10
8
6
4
2
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

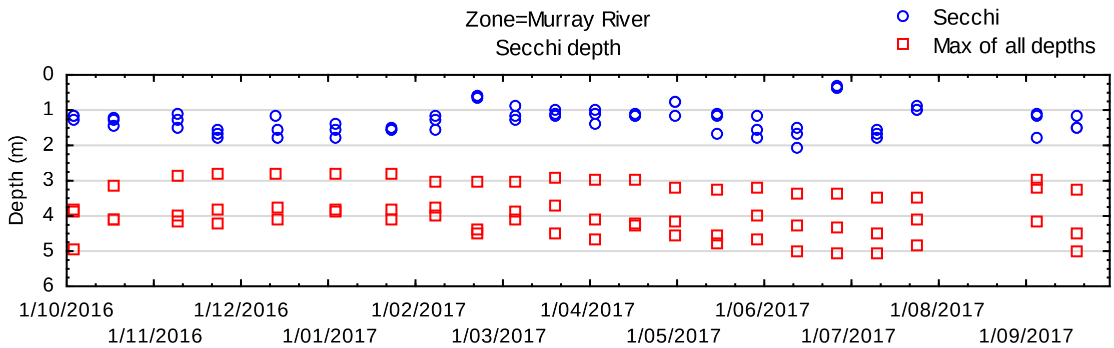

Zone=Peel Inlet
Turbidity
Turbidity (surf)
Turbidity (bott)
Turbidity (NTU)
12
10
8
6
4
2
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

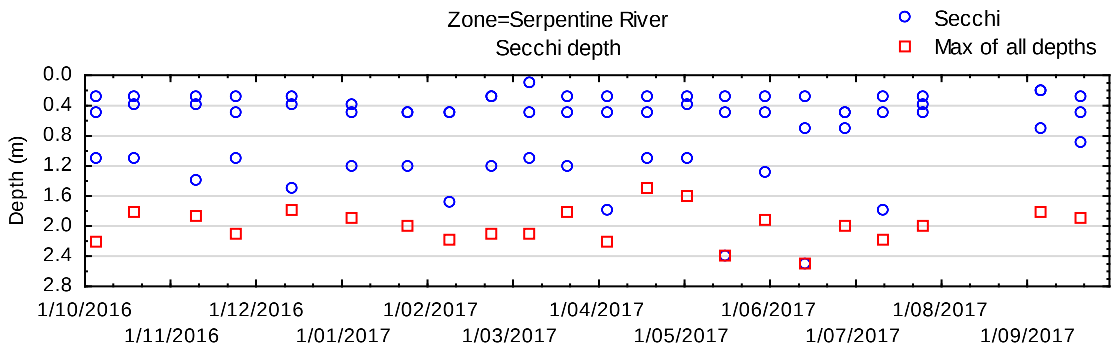

Zone=Murray River
Turbidity
Turbidity (surf)
Turbidity (bott)
Turbidity (NTU)
60
50
40
30
20
10
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

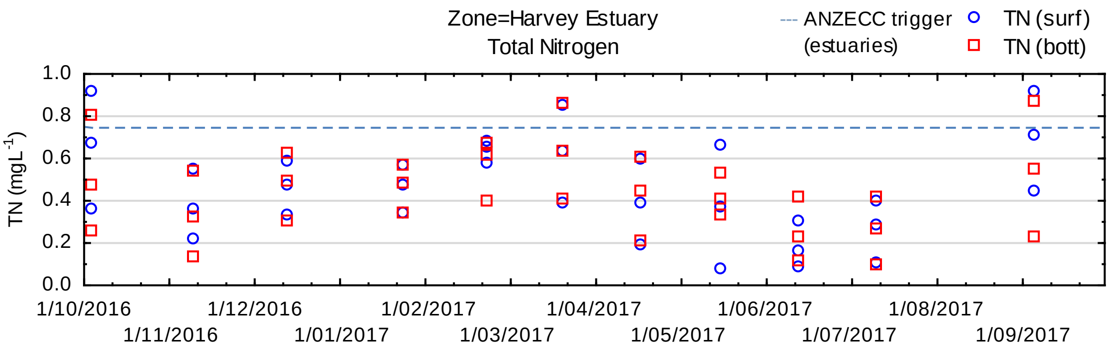

Zone=Serpentine River
Turbidity
Turbidity (surf)
Turbidity (bott)
Turbidity (NTU)
24
20
16
12
8
4
0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

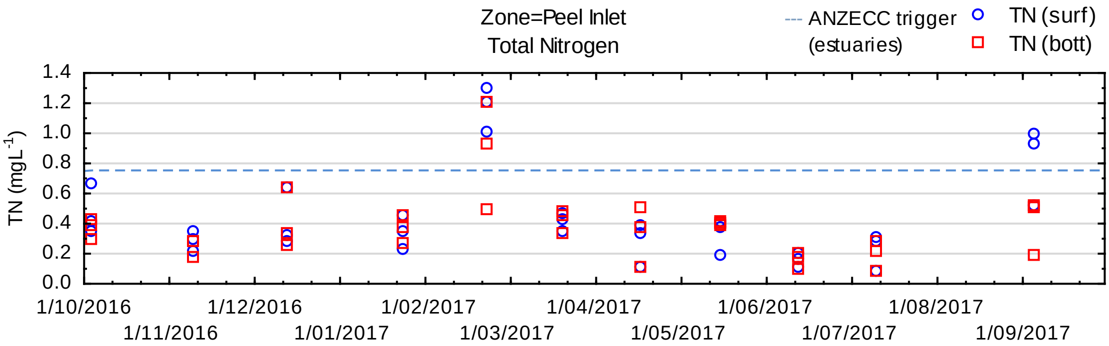

Zone=Harvey Estuary
Secchi depth
Secchi
Max of all depths
Depth (m)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

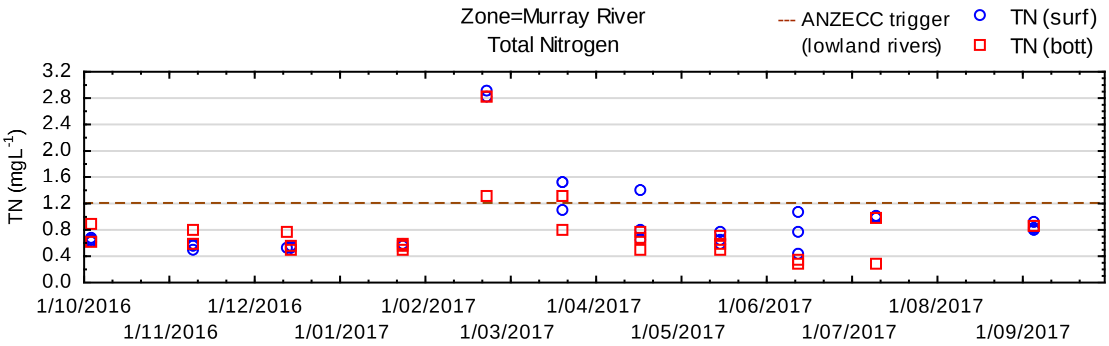

Zone=Peel Inlet
Secchi depth
Secchi
Max of all depths
Depth (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

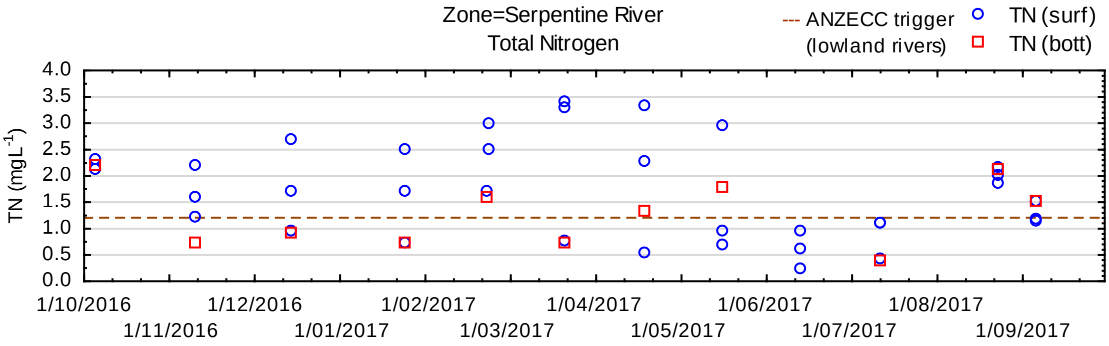

Zone=Murray River
Secchi depth
Secchi
Max of all depths
Depth (m)
0
1
2
3
4
5
6
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

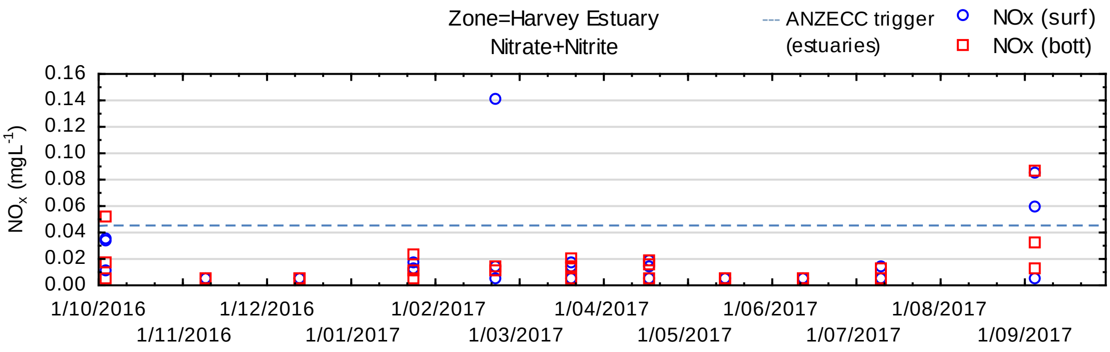

Zone=Serpentine River
Secchi depth
Secchi
Max of all depths
Depth (m)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

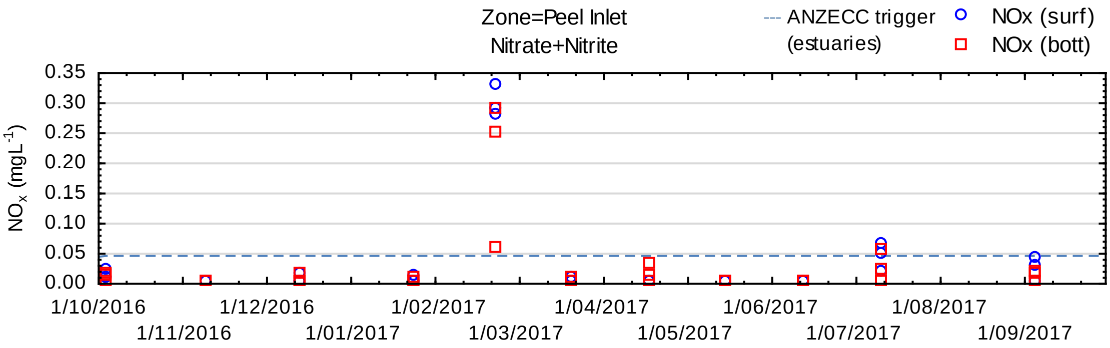

Zone=Harvey Estuary
Total Nitrogen
ANZECC trigger (estuaries)
TN (surf)
TN (bott)
TN (mgL-1)
1.0
0.8
0.6
0.4
0.2
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

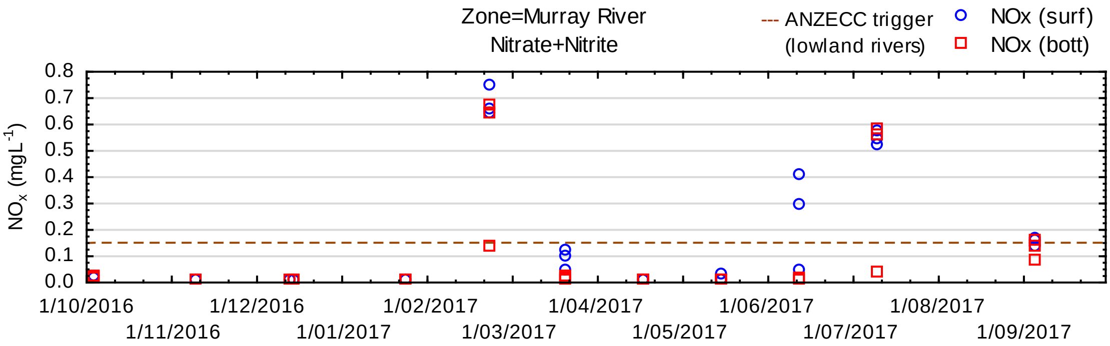

Zone=Peel Inlet
Total Nitrogen
ANZECC trigger (estuaries)
TN (surf)
TN (bott)
TN (mgL-1)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

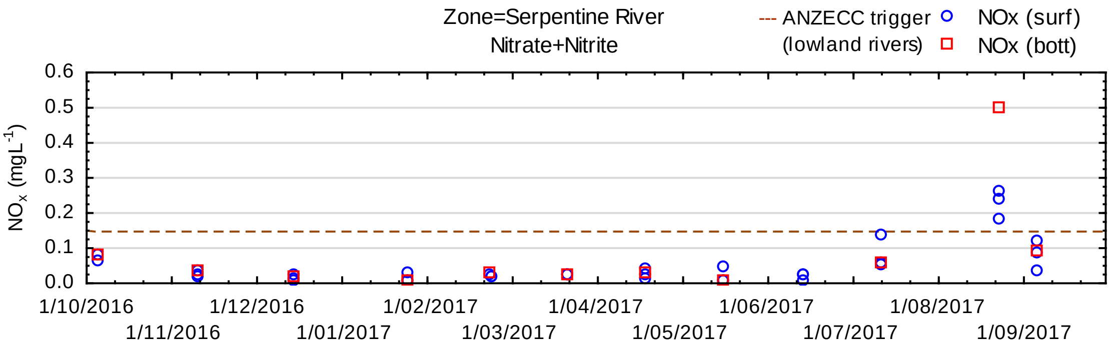

Zone=Murray River
Total Nitrogen
ANZECC trigger (lowland rivers)
TN (surf)
TN (bott)
TN (mgL-1)
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

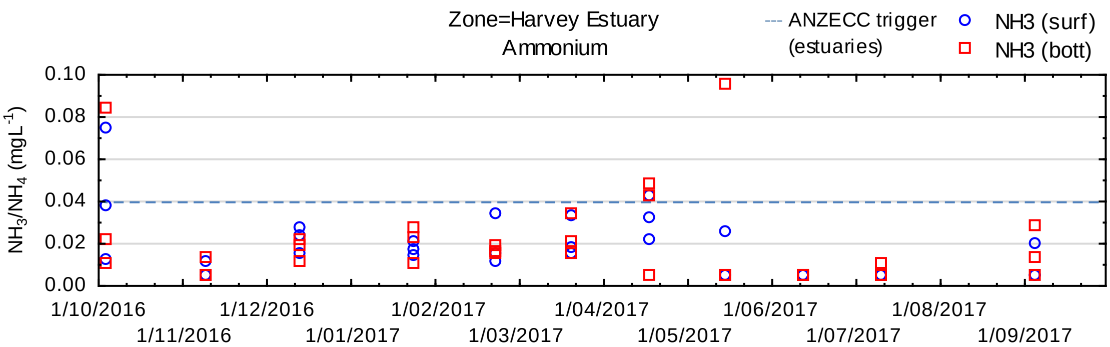

Zone=Serpentine River
Total Nitrogen
ANZECC trigger (lowland rivers)
TN (surf)
TN (bott)
TN (mgL-1)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

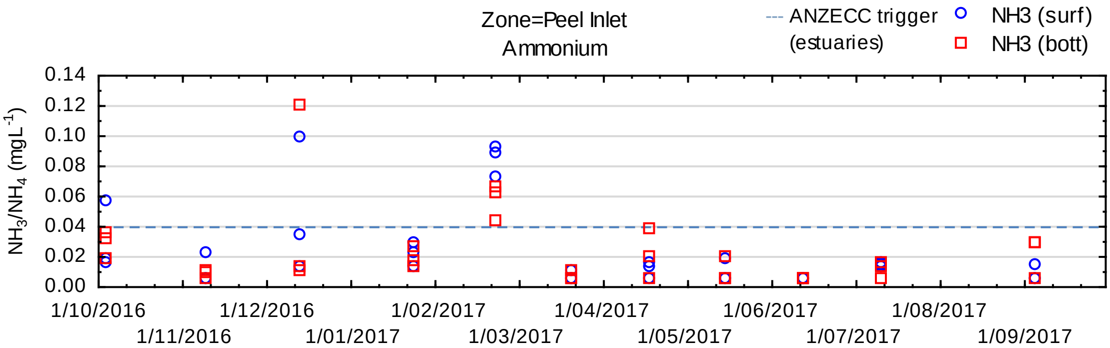

Zone=Harvey Estuary
Nitrate+Nitrite
ANZECC trigger (estuaries)
NOx (surf)
NOx (bott)
NO_x (mgL^{-1})
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

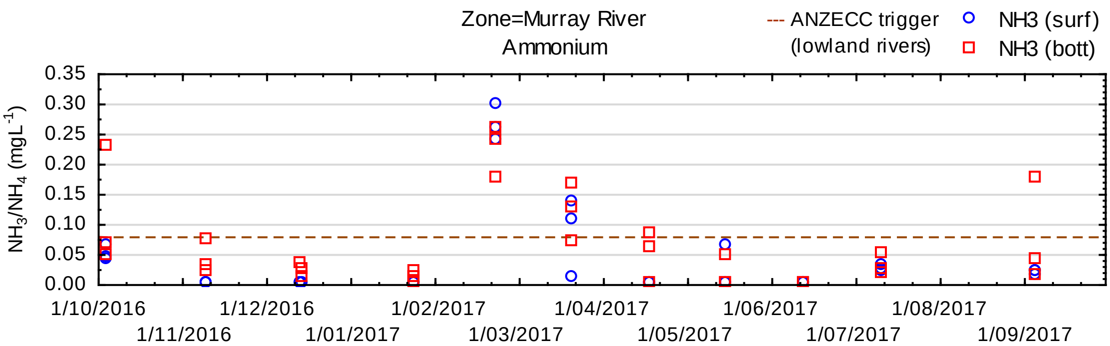

Zone=Peel Inlet
Nitrate+Nitrite
ANZECC trigger (estuaries)
NOx (surf)
NOx (bott)
NO_x (mgL^{-1})
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

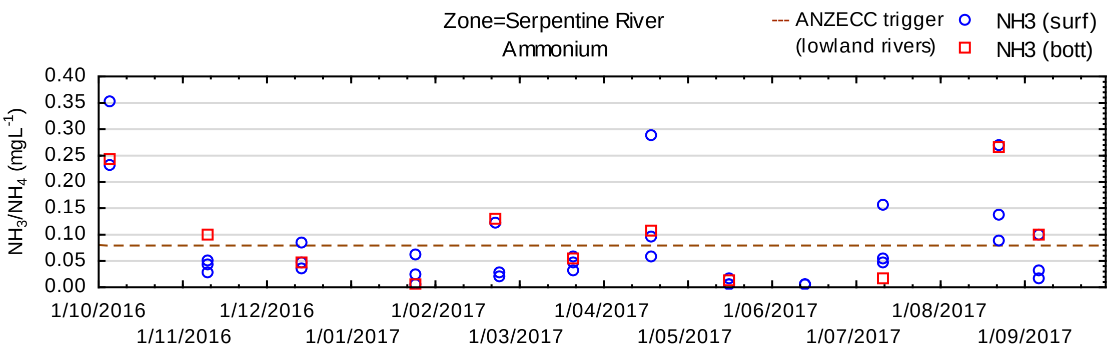

Zone=Murray River
Nitrate+Nitrite
ANZECC trigger (lowland rivers)
NOx (surf)
NOx (bott)
NO_x (mgL^{-1})
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

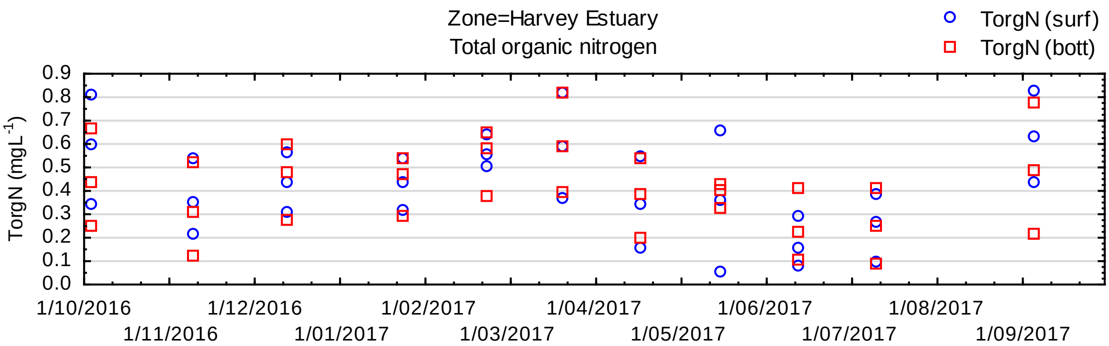

Zone=Serpentine River
Nitrate+Nitrite
ANZECC trigger (lowland rivers)
NOx (surf)
NOx (bott)
NO_x (mgL^{-1})
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

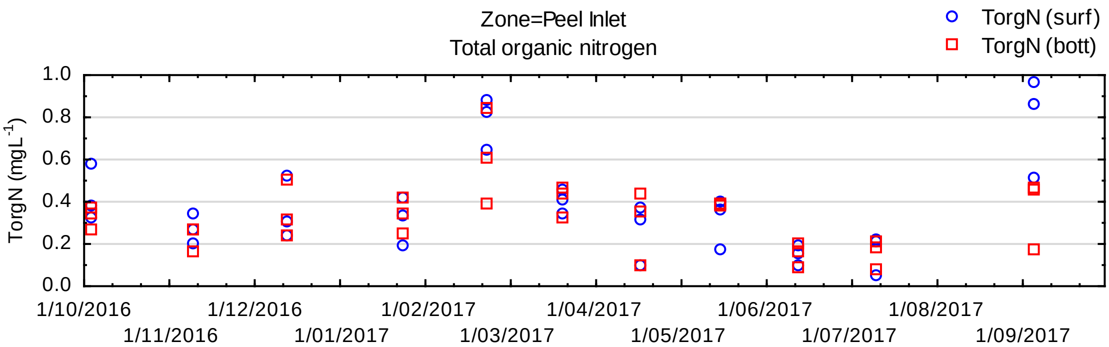

Zone=Harvey Estuary
Ammonium
ANZECC trigger (estuaries)
NH3 (surf)
NH3 (bott)
NH_3/NH_4 (mgL^{-1})
0.10
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

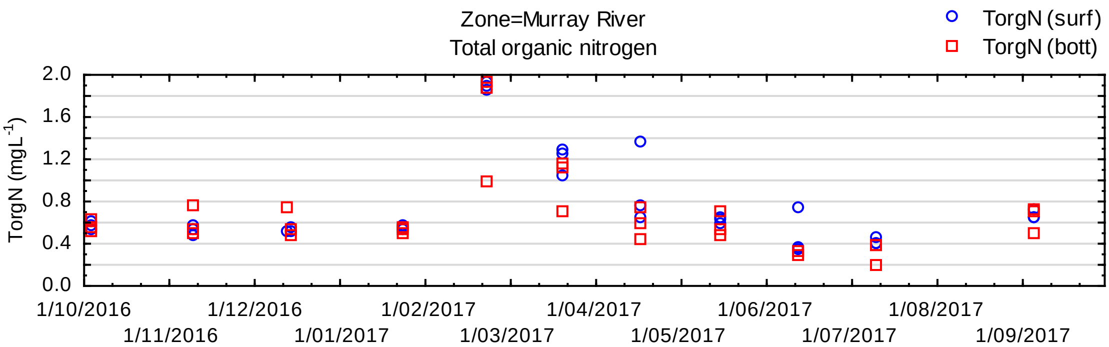

Zone=Peel Inlet
Ammonium
ANZECC trigger (estuaries)
NH3 (surf)
NH3 (bott)
NH_3/NH_4 (mgL^{-1})
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

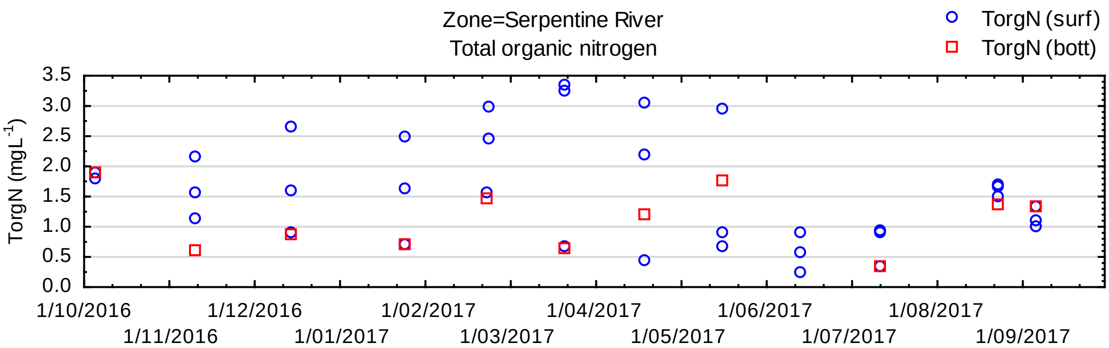

Zone=Murray River
Ammonium
ANZECC trigger (lowland rivers)
NH3 (surf)
NH3 (bott)
NH_3/NH_4 (mgL^{-1})
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

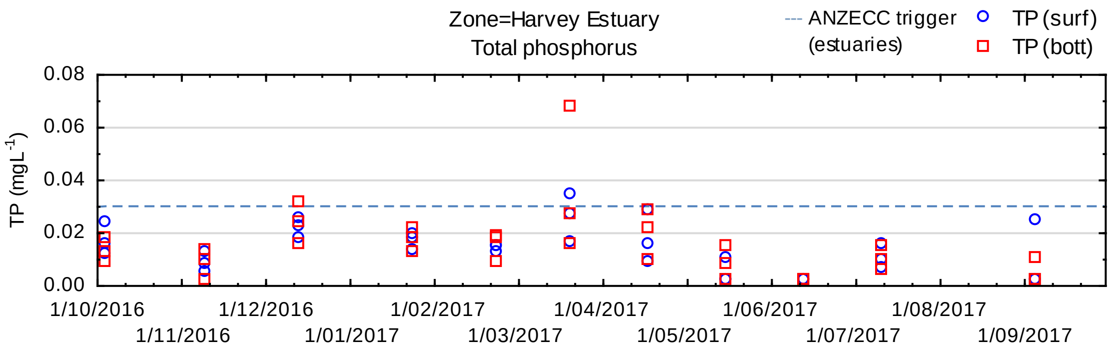

Zone=Serpentine River
Ammonium
ANZECC trigger (lowland rivers)
NH3 (surf)
NH3 (bott)
NH_3/NH_4 (mgL^{-1})
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

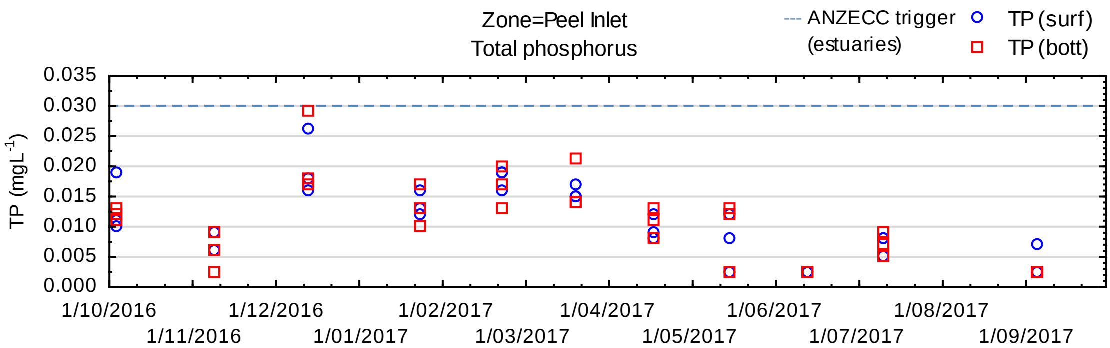

Zone=Harvey Estuary
Total organic nitrogen
TorgN (surf)
TorgN (bott)
TorgN (mgL-1)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

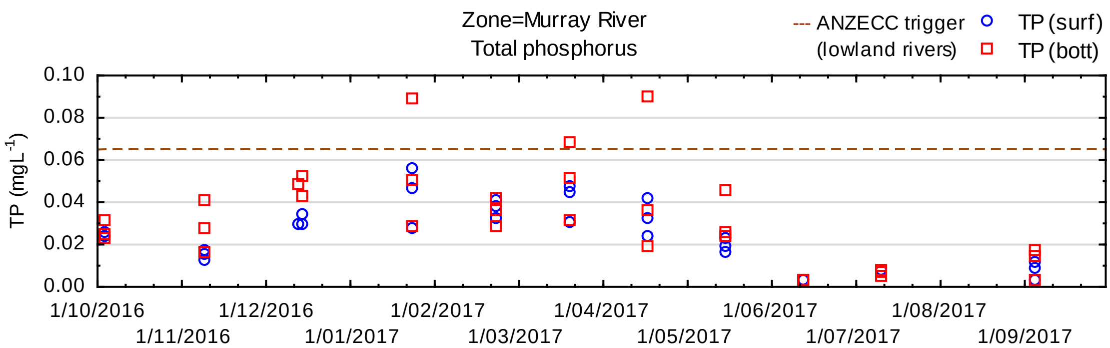

Zone=Peel Inlet
Total organic nitrogen
TorgN (surf)
TorgN (bott)
TorgN (mgL-1)
1.0
0.8
0.6
0.4
0.2
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

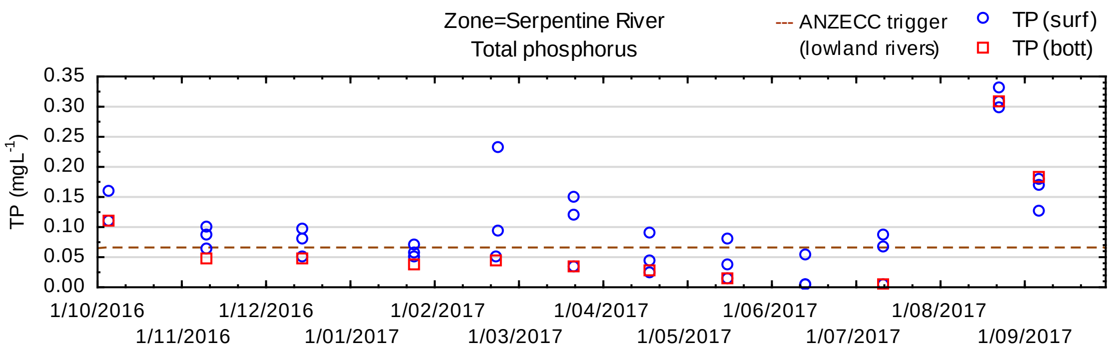

Zone=Murray River
Total organic nitrogen
TorgN (surf)
TorgN (bott)
TorgN (mgL-1)
2.0
1.6
1.2
0.8
0.4
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

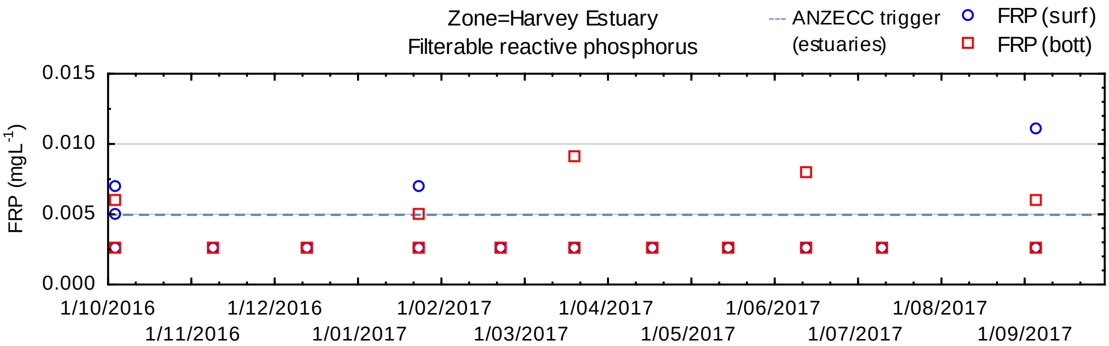

Zone=Serpentine River
Total organic nitrogen
TorgN (surf)
TorgN (bott)
TorgN (mgL-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017


Zone=Harvey Estuary
Total phosphorus
--- ANZECC trigger (estuaries)
TP (surf)
TP (bott)
TP (mgL-1)
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

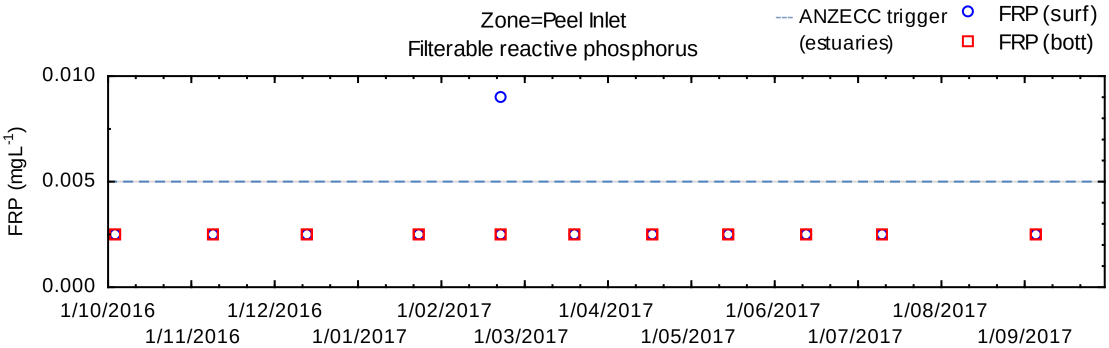

Zone=Peel Inlet
Total phosphorus
--- ANZECC trigger (estuaries)
TP (surf)
TP (bott)
TP (mgL-1)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017


Zone=Murray River
Total phosphorus
--- ANZECC trigger (lowland rivers)
TP (surf)
TP (bott)
TP (mgL-1)
0.10
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

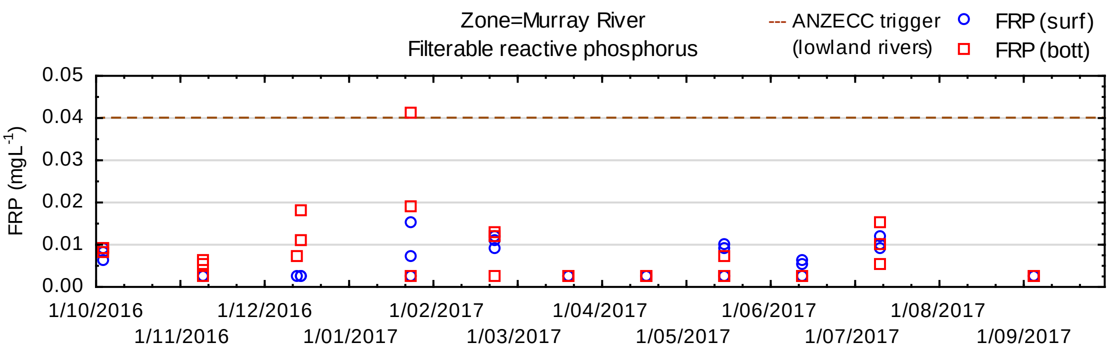

Zone=Serpentine River
Total phosphorus
--- ANZECC trigger (lowland rivers)
TP (surf)
TP (bott)
TP (mgL-1)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



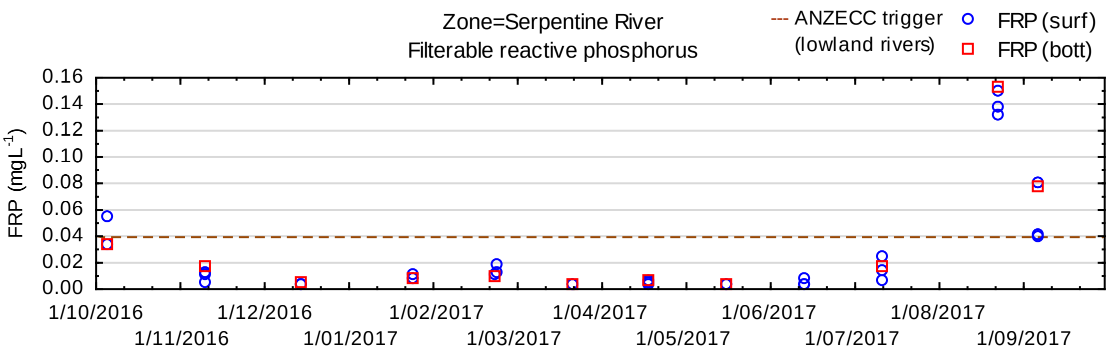
Zone=Harvey Estuary
Filterable reactive phosphorus
ANZECC trigger (estuaries)
FRP (surf)
FRP (bott)
FRP (mgL-1)
0.015
0.010
0.005
0.000
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



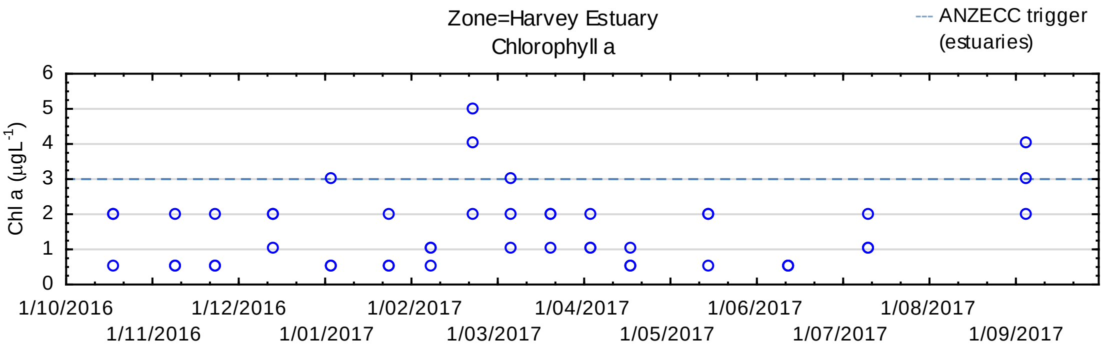
Zone=Peel Inlet
Filterable reactive phosphorus
ANZECC trigger (estuaries)
FRP (surf)
FRP (bott)
FRP (mgL-1)
0.010
0.005
0.000
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



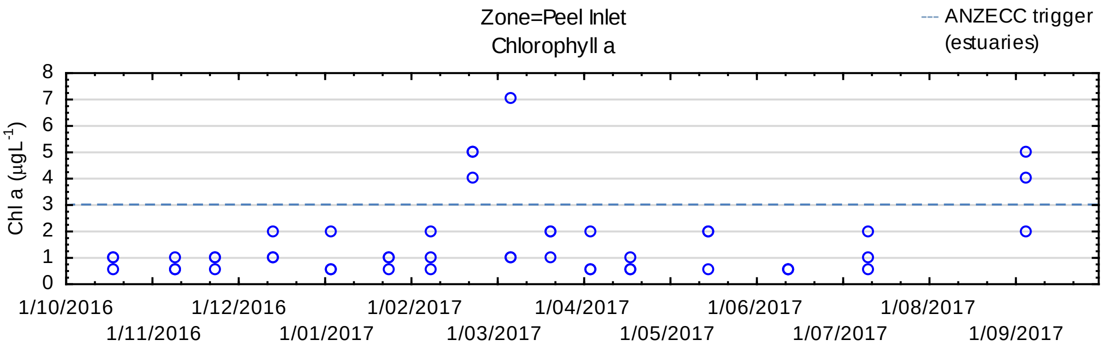
Zone=Murray River
Filterable reactive phosphorus
ANZECC trigger (lowland rivers)
FRP (surf)
FRP (bott)
FRP (mgL-1)
0.05
0.04
0.03
0.02
0.01
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



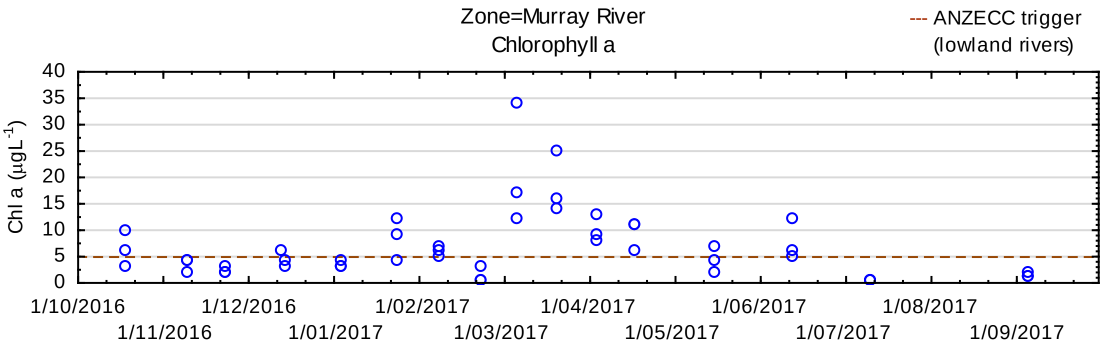
Zone=Serpentine River
Filterable reactive phosphorus
ANZECC trigger (lowland rivers)
FRP (surf)
FRP (bott)
FRP (mgL-1)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



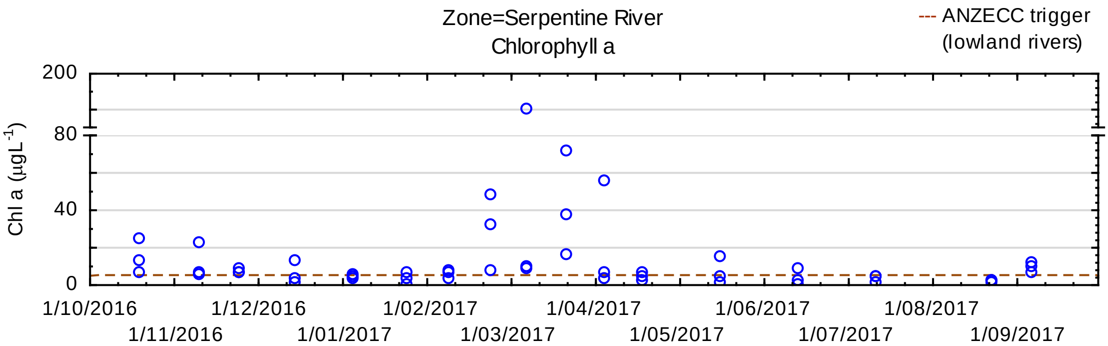
Zone=Harvey Estuary
Chlorophyll a
--- ANZECC trigger (estuaries)
Chl a ($\mu g L^{-1}$)
0
1
2
3
4
5
6
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017



Zone=Peel Inlet
Chlorophyll a
--- ANZECC trigger (estuaries)
Chl a ($\mu g L^{-1}$)
0
1
2
3
4
5
6
7
8
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

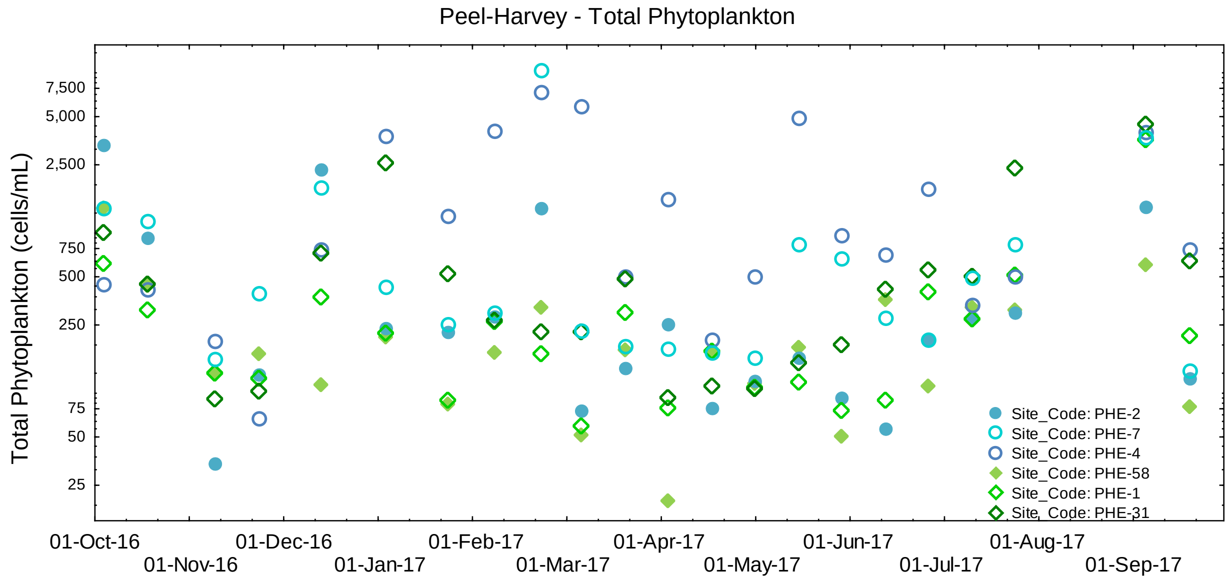


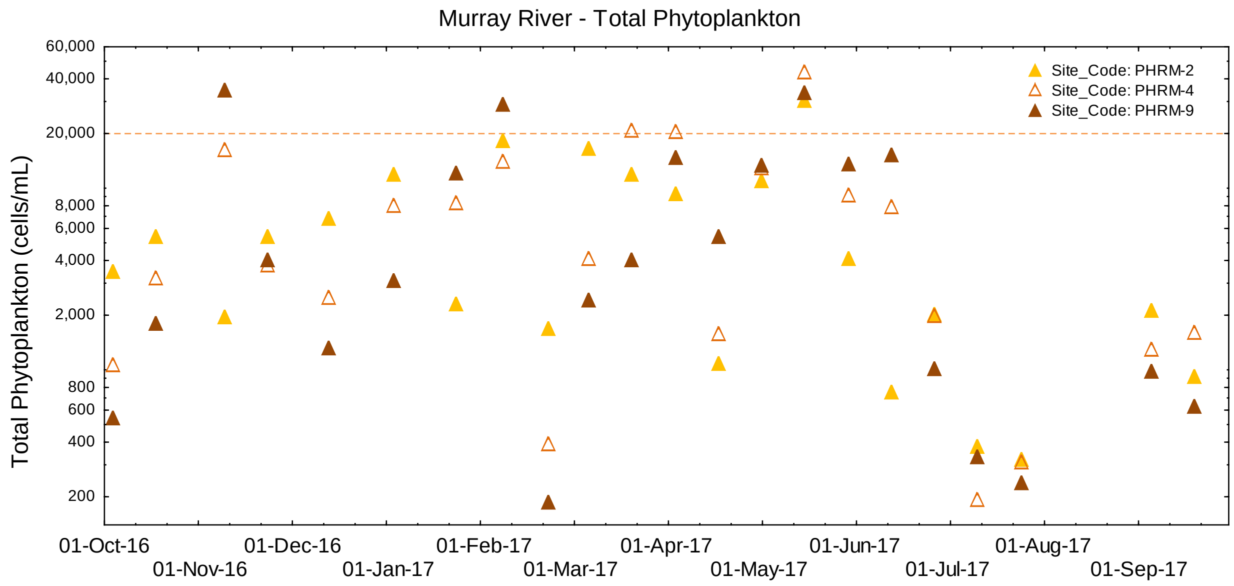
Zone=Murray River
Chlorophyll a
--- ANZECC trigger (lowland rivers)
Chl a ($\mu g L^{-1}$)
0
5
10
15
20
25
30
35
40
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

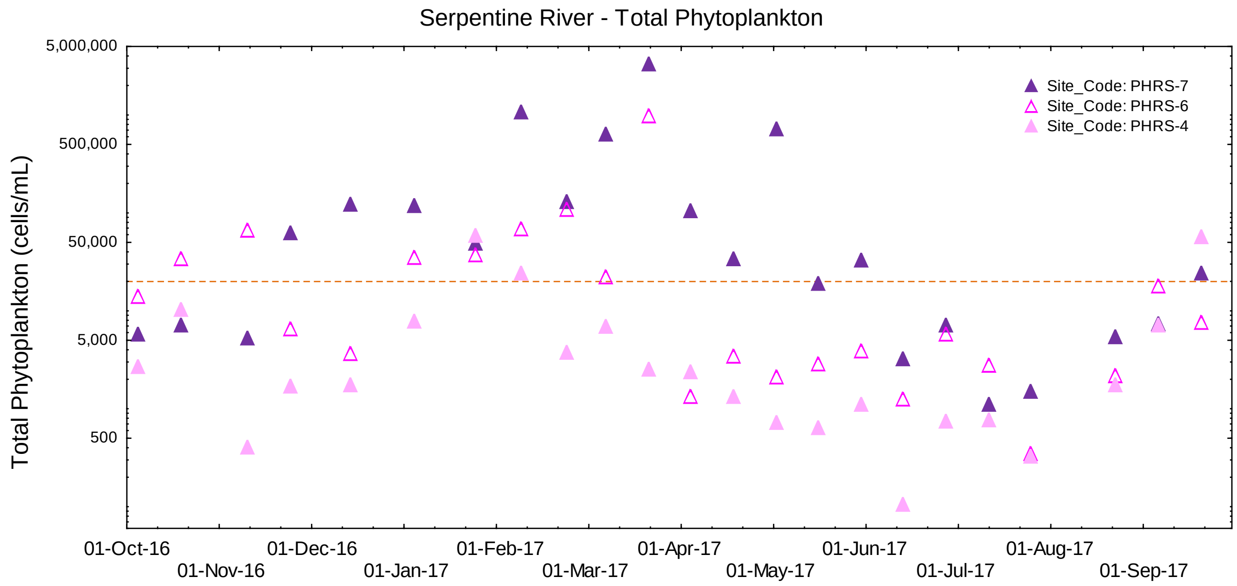


Zone=Serpentine River
Chlorophyll a
--- ANZECC trigger (lowland rivers)
Chl a ($\mu g L^{-1}$)
0
40
80
200
1/10/2016
1/11/2016
1/12/2016
1/01/2017
1/02/2017
1/03/2017
1/04/2017
1/05/2017
1/06/2017
1/07/2017
1/08/2017
1/09/2017

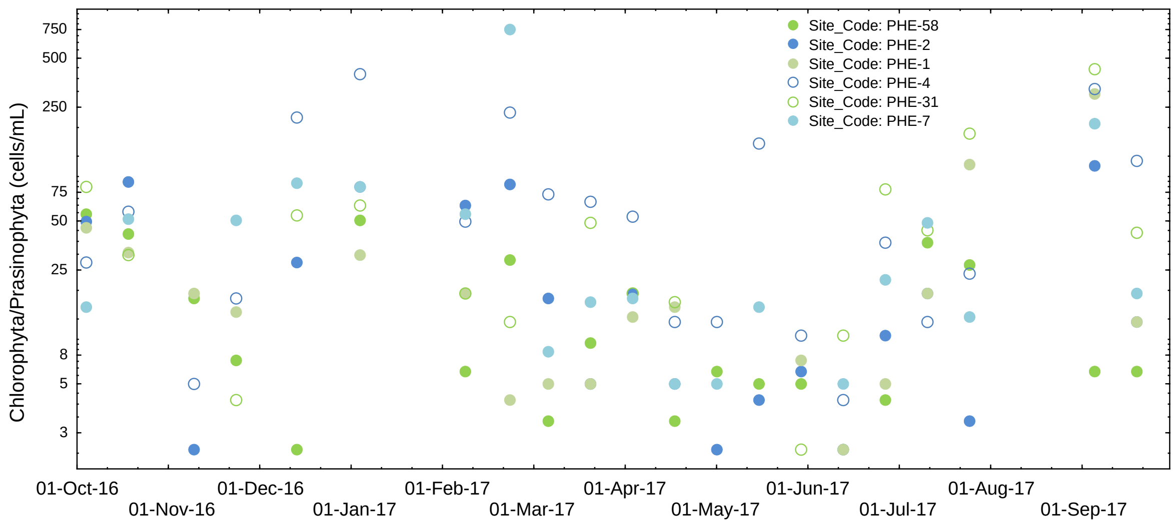
Appendix D: Phytoplankton groups time series


Peel-Harvey - Total Phytoplankton
Total Phytoplankton (cells/mL)
7,500
5,000
2,500
750
500
250
75
50
25
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHE-2
Site_Code: PHE-7
Site_Code: PHE-4
Site_Code: PHE-58
Site_Code: PHE-1
Site_Code: PHE-31

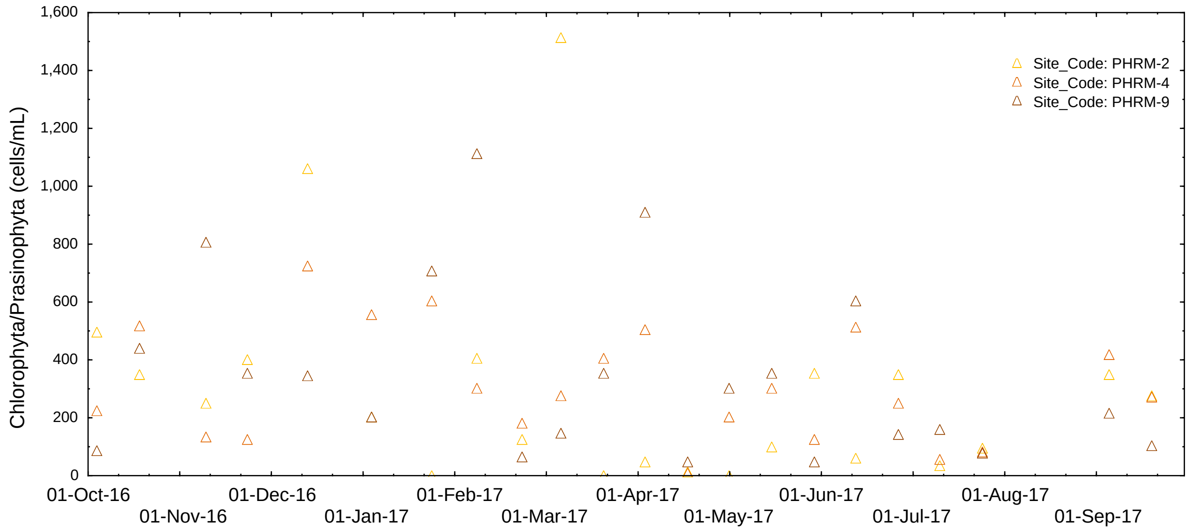

Murray River - Total Phytoplankton
Total Phytoplankton (cells/mL)
60,000
40,000
20,000
8,000
6,000
4,000
2,000
800
600
400
200
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9


Serpentine River - Total Phytoplankton
Total Phytoplankton (cells/mL)
5,000,000
500,000
50,000
5,000
500
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4

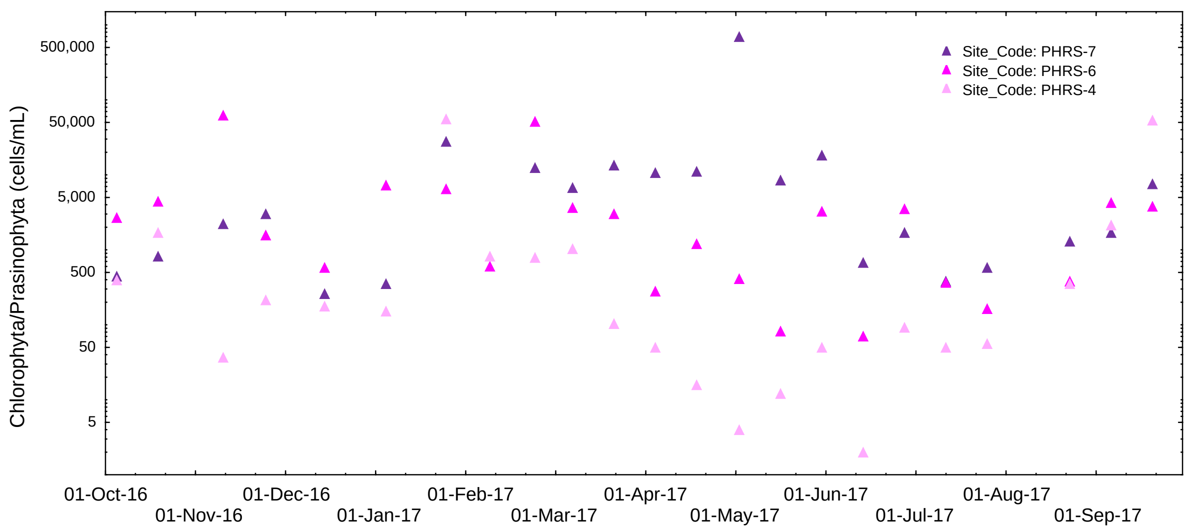
Peel-Harvey - Chlorophyta

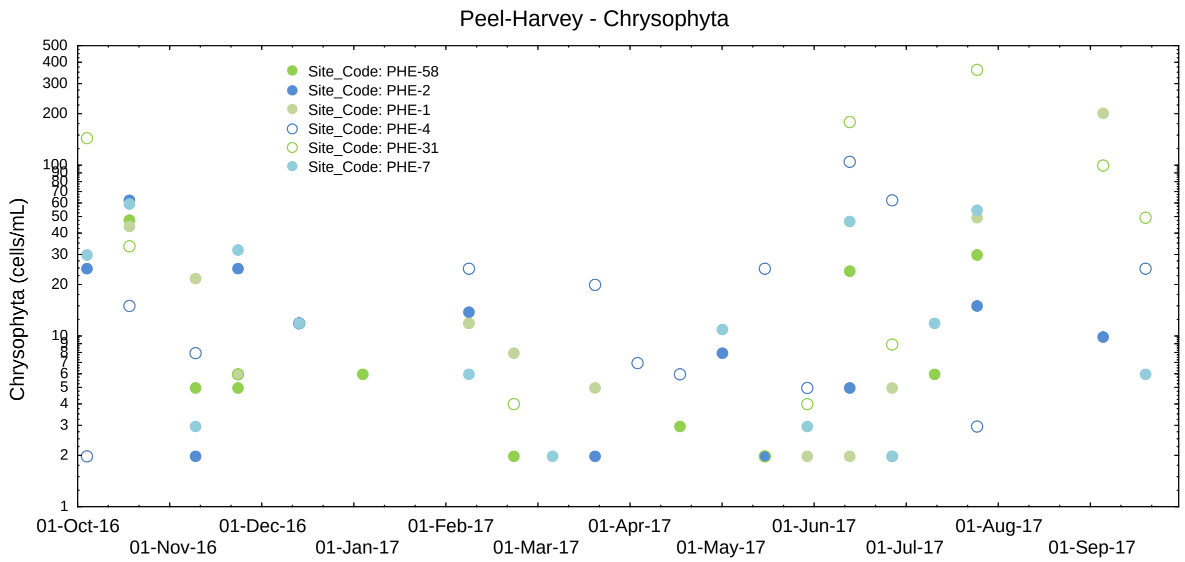


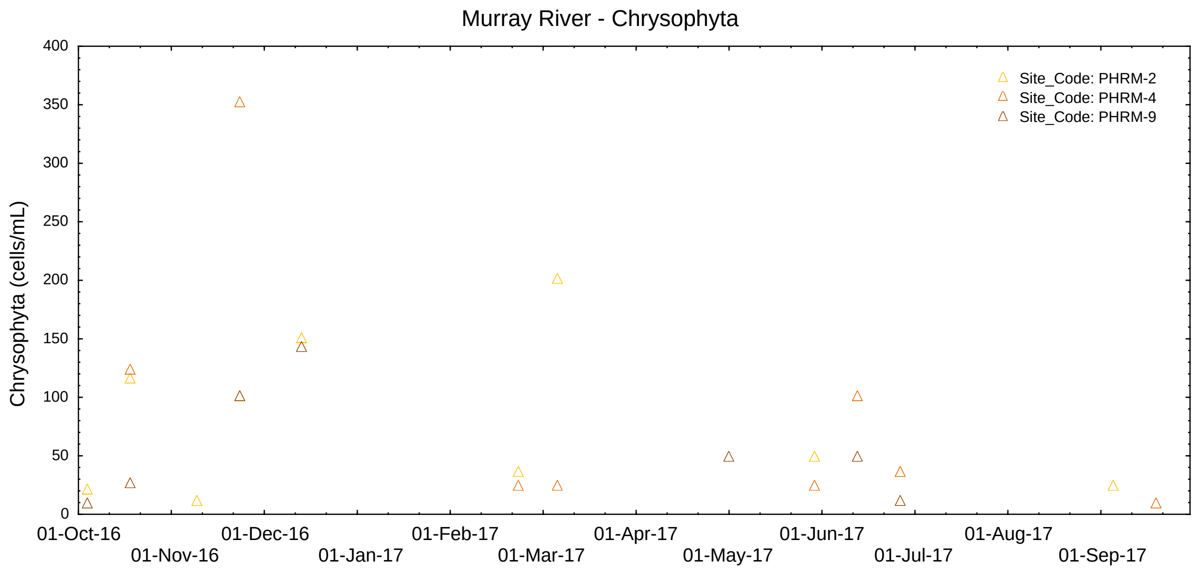
Murray River - Chlorophyta/Prasinophyta

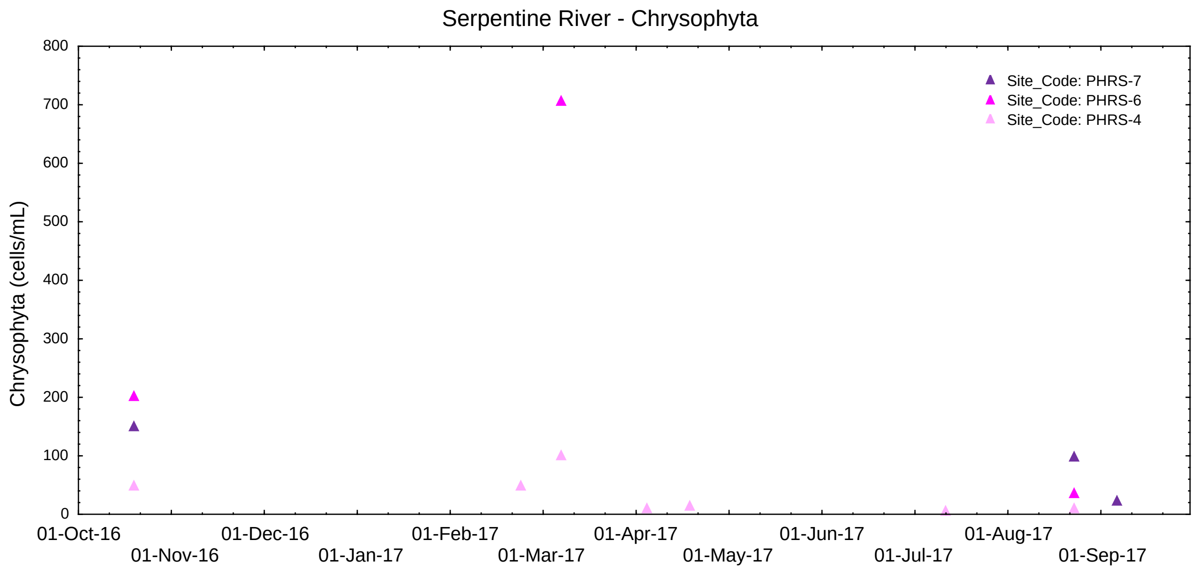


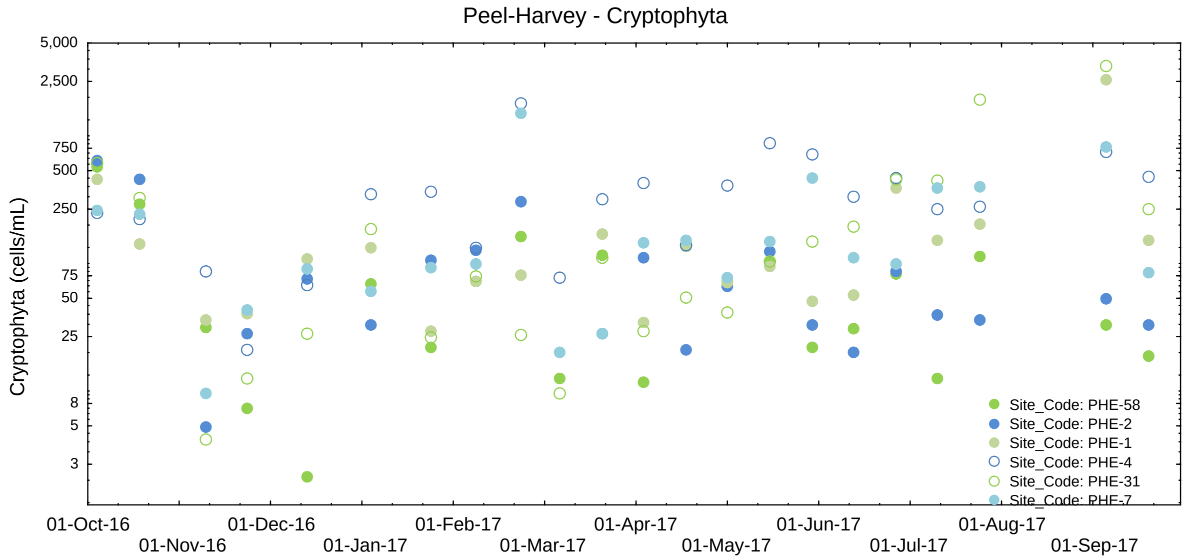
Serpentine River - Chlrophyta/Prasinophyta

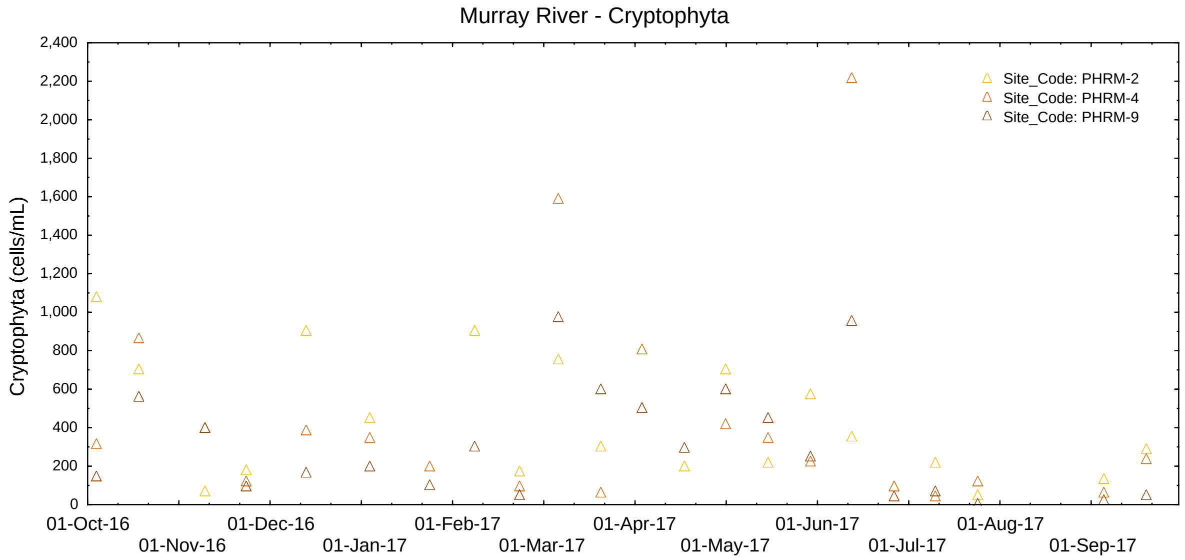


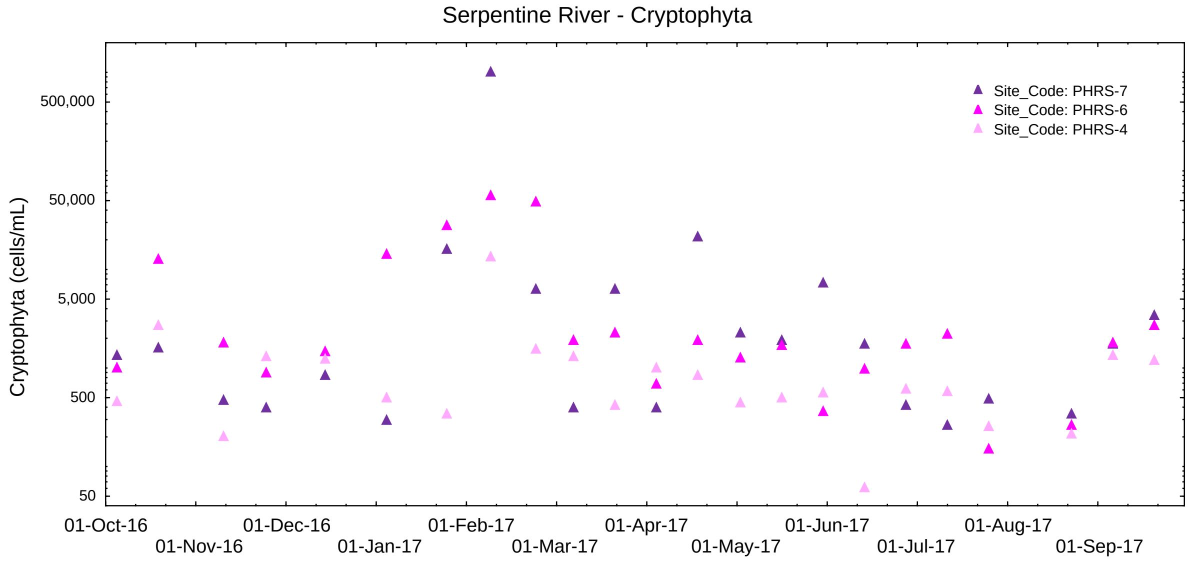

Peel-Harvey - Chrysophyta
Chrysophyta (cells/mL)
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

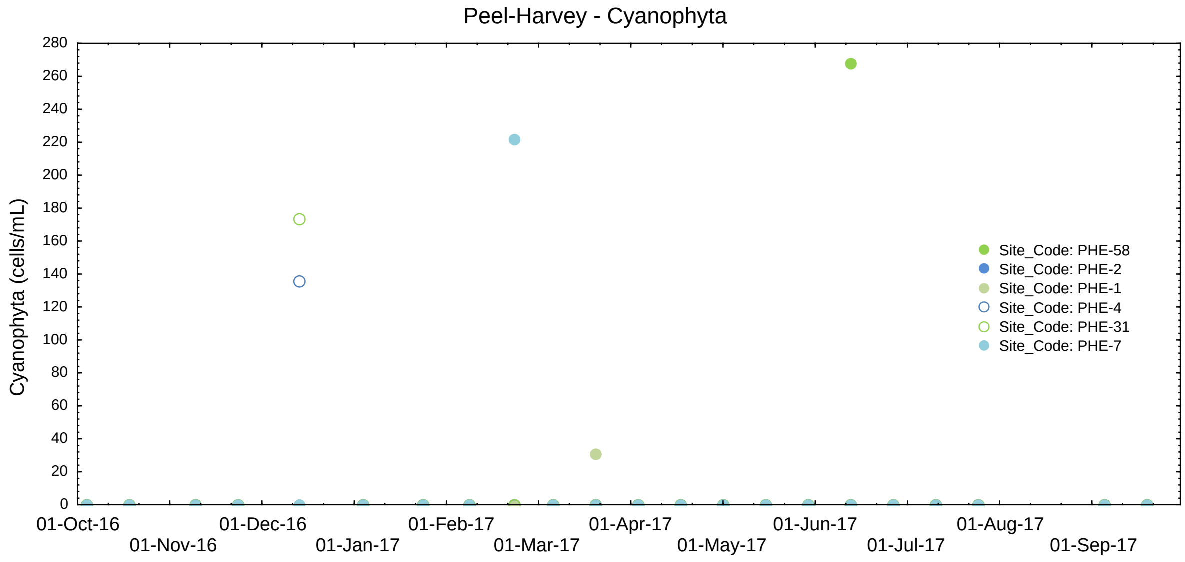

Murray River - Chrysophyta
Chrysophyta (cells/mL)
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

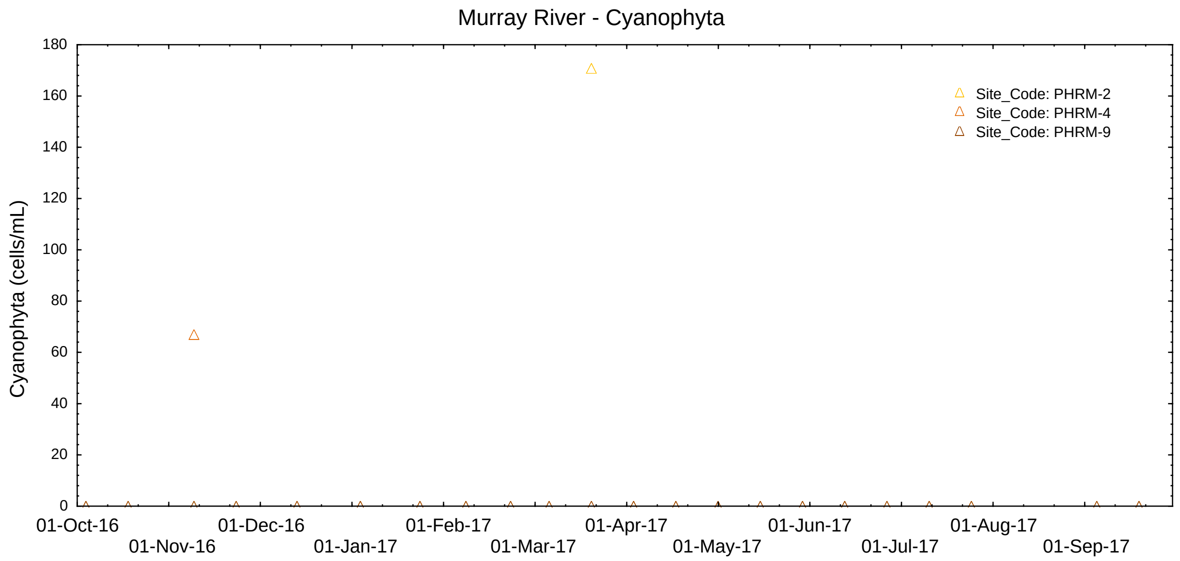

Serpentine River - Chrysophyta
Chrysophyta (cells/mL)
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

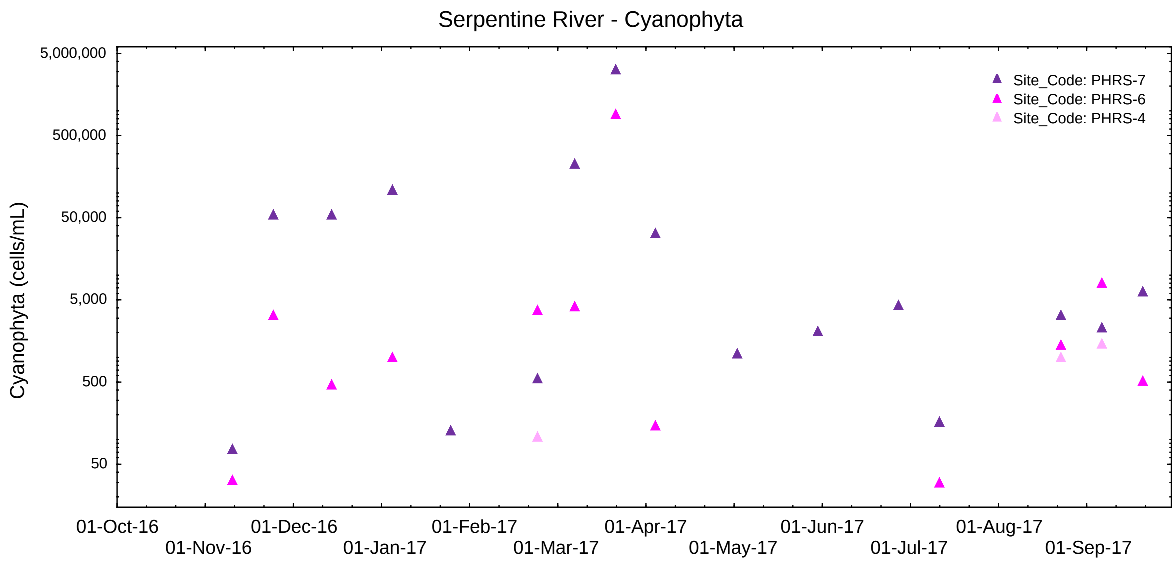

Peel-Harvey - Cryptophyta
Cryptophyta (cells/mL)
5,000
2,500
750
500
250
75
50
25
8
5
3
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7

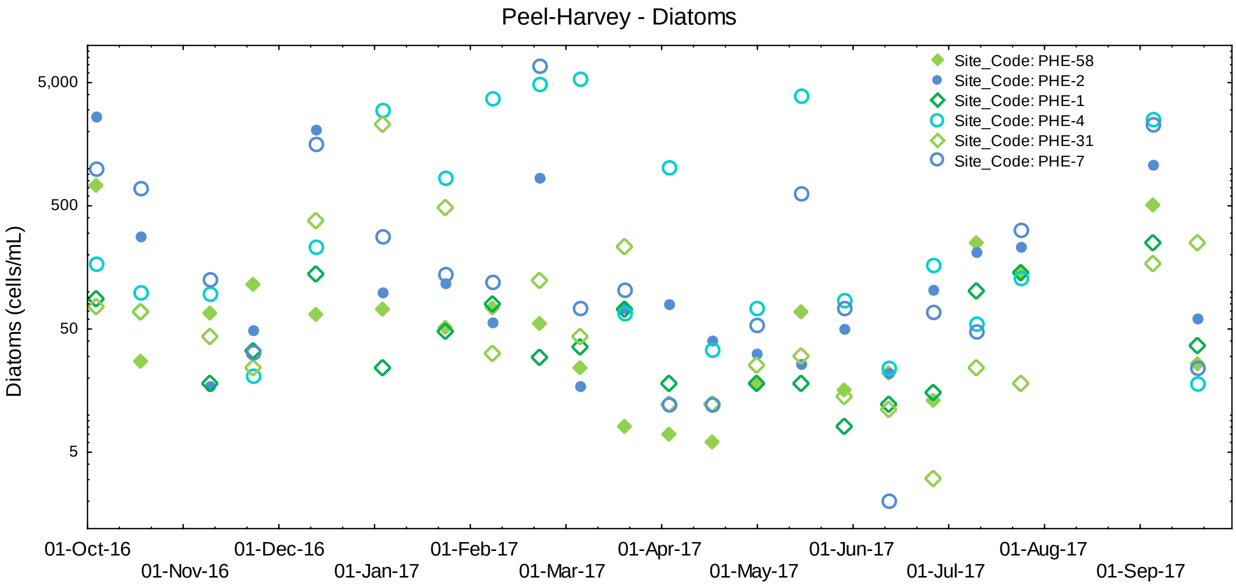

Murray River - Cryptophyta
Cryptophyta (cells/mL)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9

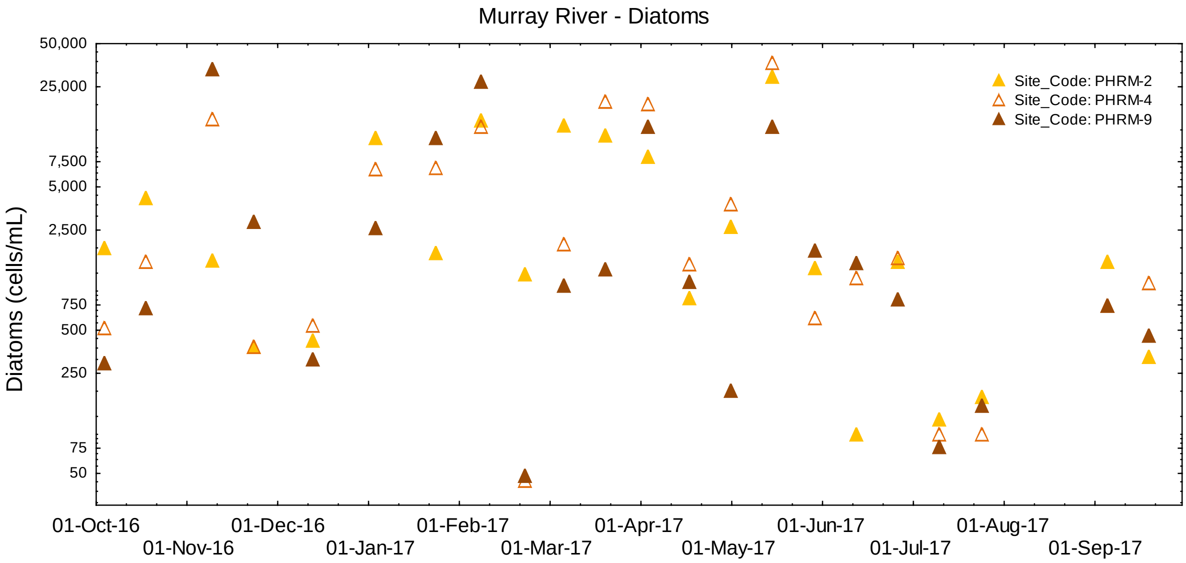

Serpentine River - Cryptophyta
Cryptophyta (cells/mL)
500,000
50,000
5,000
500
50
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4

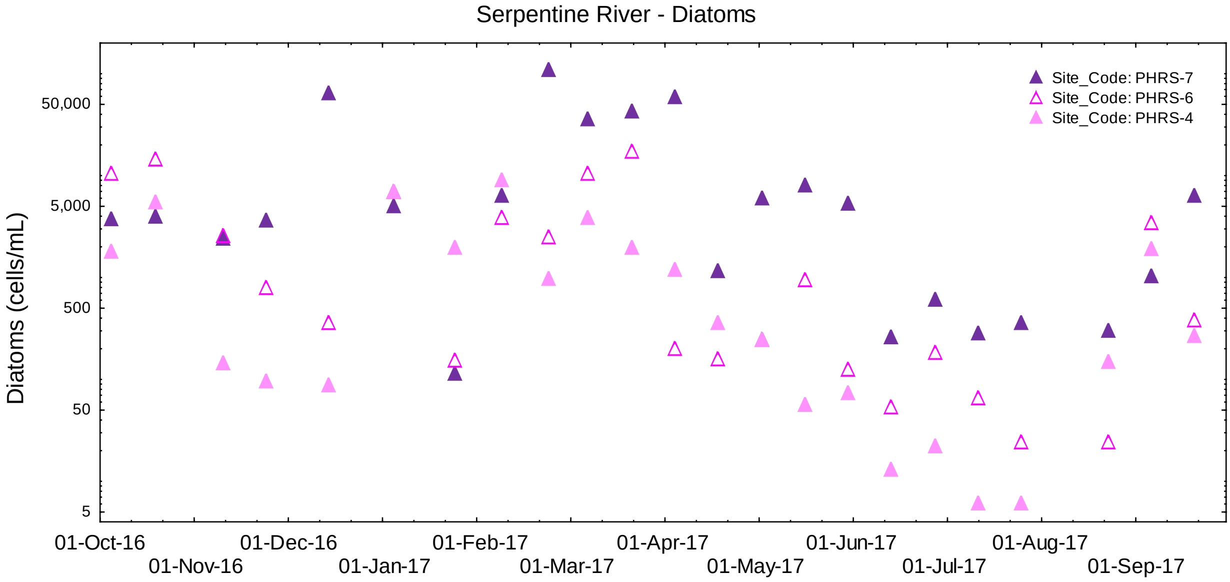

Peel-Harvey - Cyanophyta
Cyanophyta (cells/mL)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7


Murray River - Cyanophyta
Cyanophyta (cells/mL)
180
160
140
120
100
80
60
40
20
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9


Serpentine River - Cyanophyta
Cyanophyta (cells/mL)
5,000,000
500,000
50,000
5,000
500
50
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4


Peel-Harvey - Diatoms
Diatoms (cells/mL)
5,000
500
50
5
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17


Murray River - Diatoms
Diatoms (cells/mL)
50,000
25,000
7,500
5,000
2,500
750
500
250
75
50
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17


Serpentine River - Diatoms
Diatoms (cells/mL)
50,000
5,000
500
50
5
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
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01-May-17
01-Jun-17
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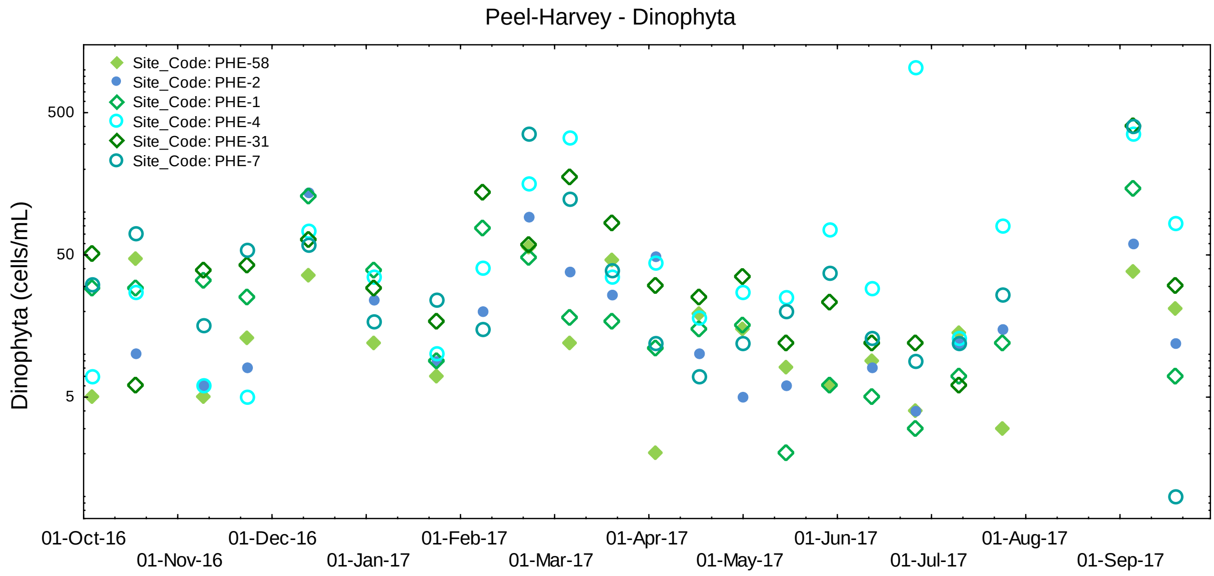
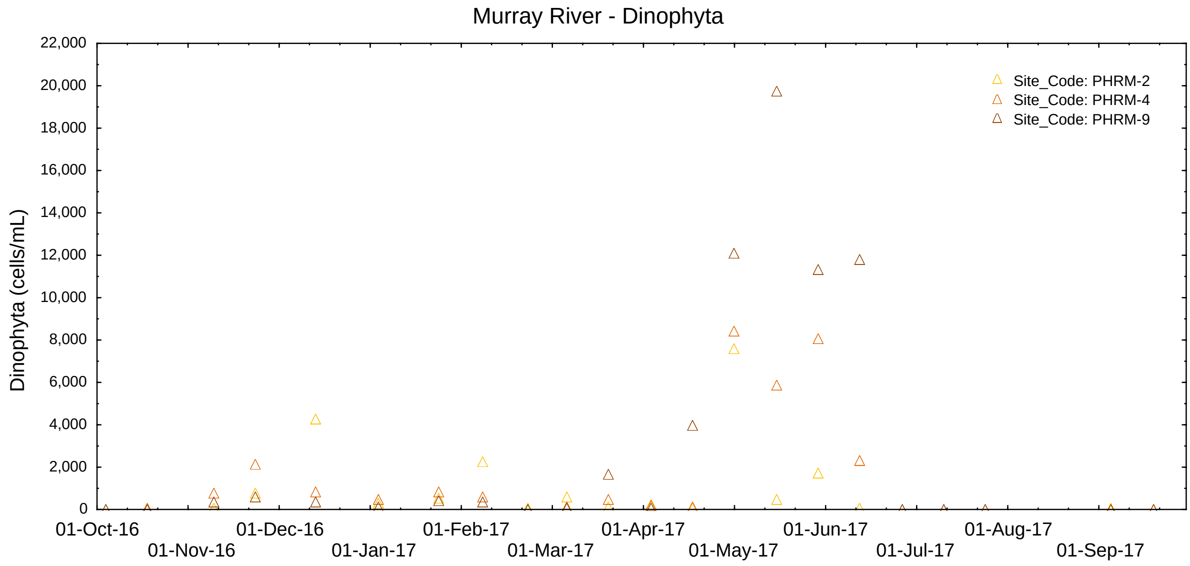
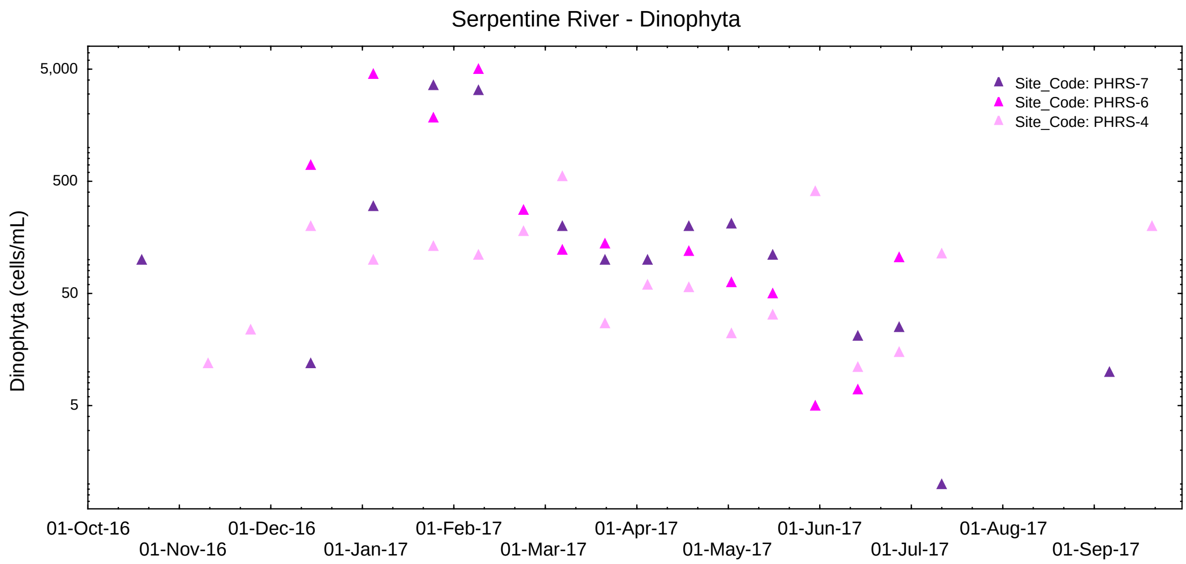
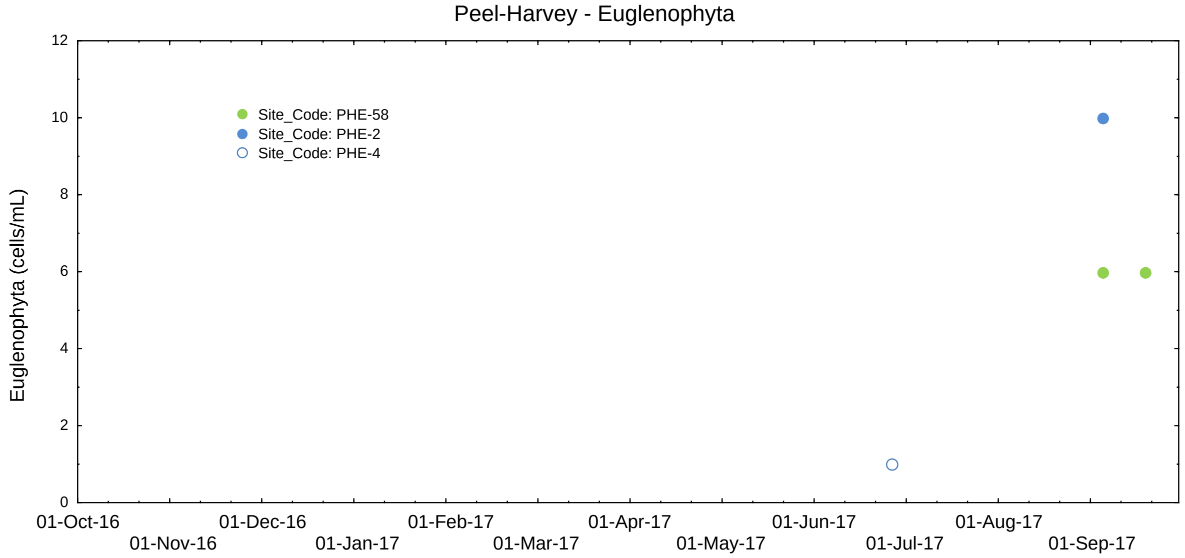
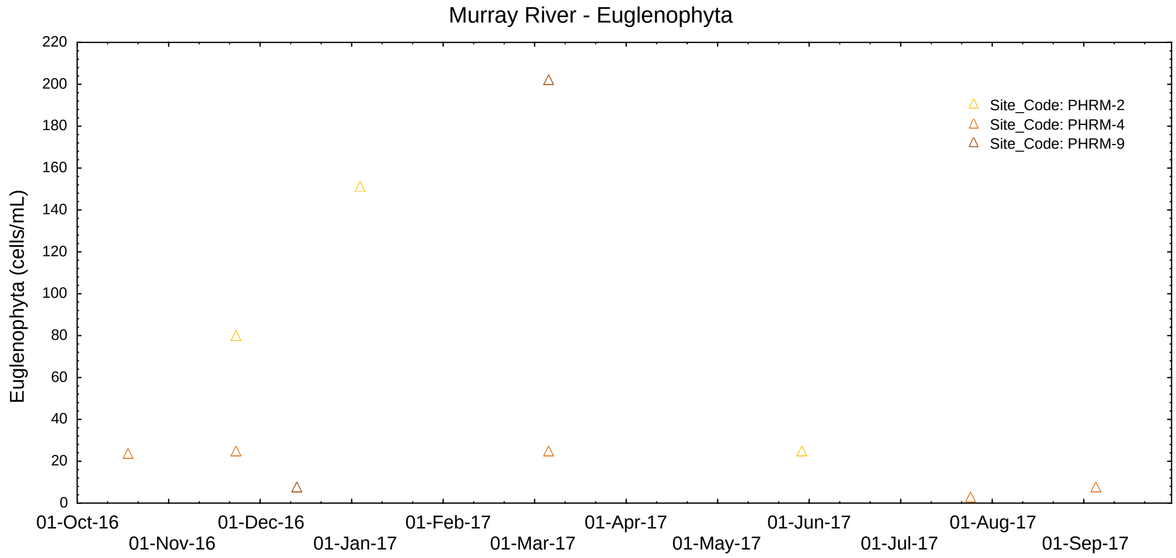
01-Aug-17
01-Sep-17

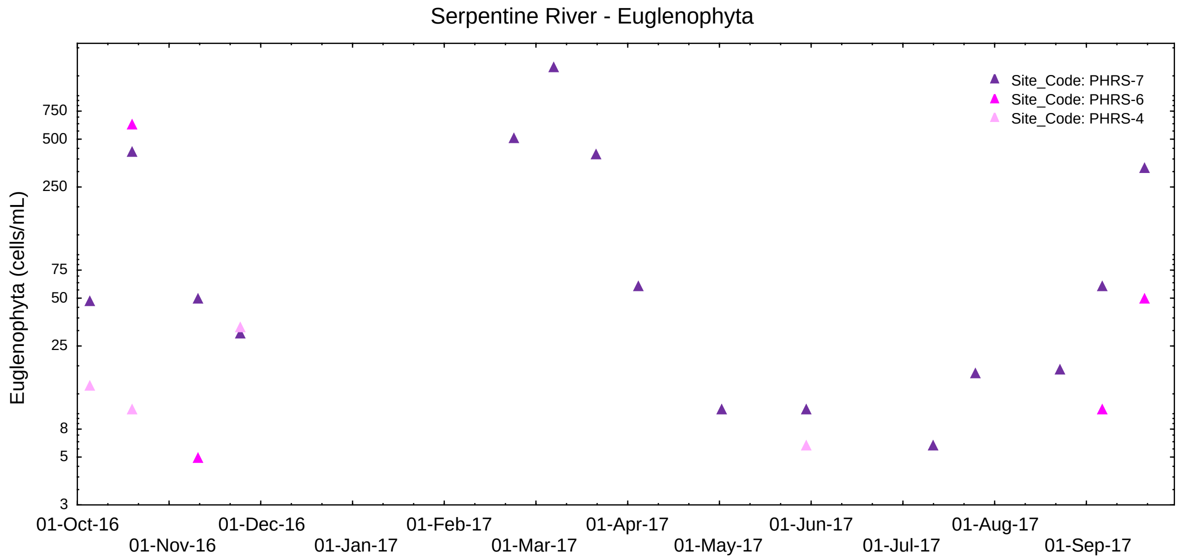

Peel-Harvey - Dinophyta
Dinophyta (cells/mL)
500
50
5
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

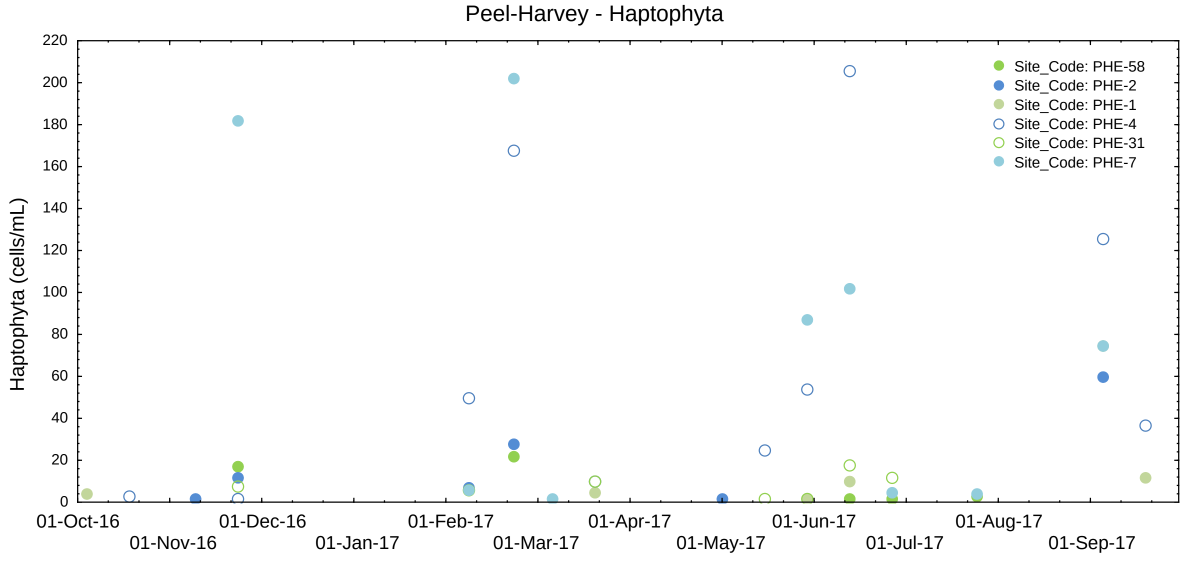

Murray River - Dinophyta
Dinophyta (cells/mL)
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

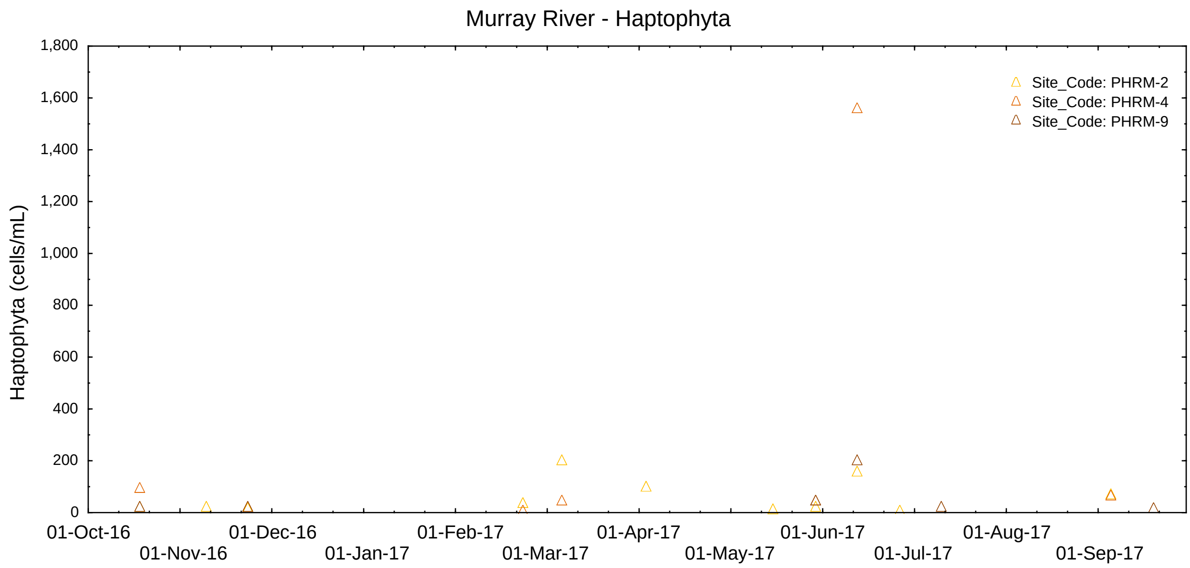

Serpentine River - Dinophyta
Dinophyta (cells/mL)
5,000
500
50
5
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

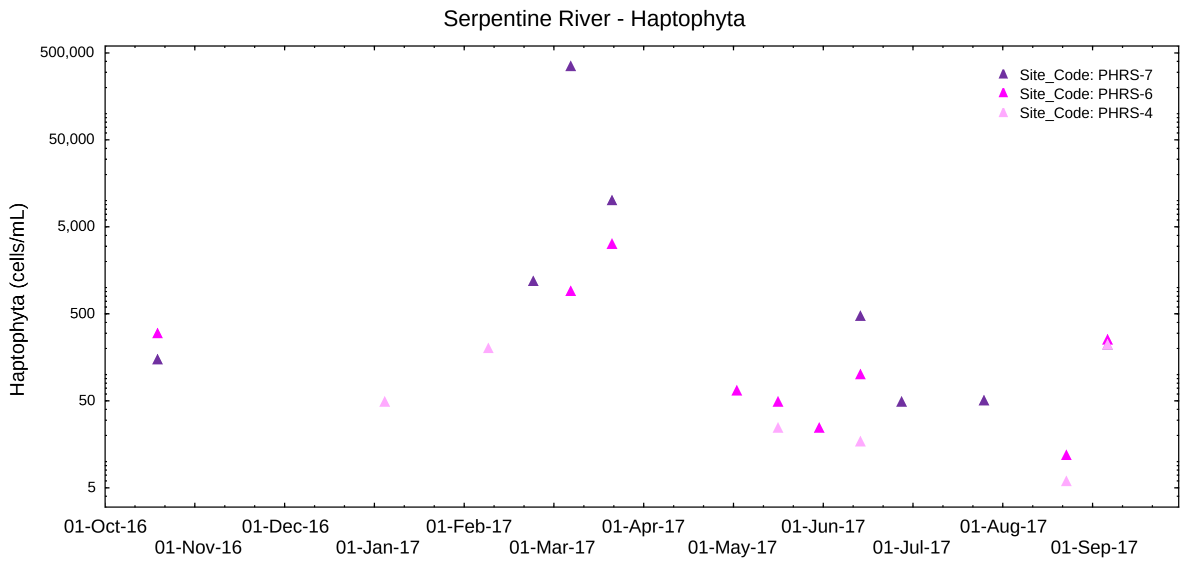

Peel-Harvey - Euglenophyta
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-4
Euglenophyta (cells/mL)
12
10
8
6
4
2
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

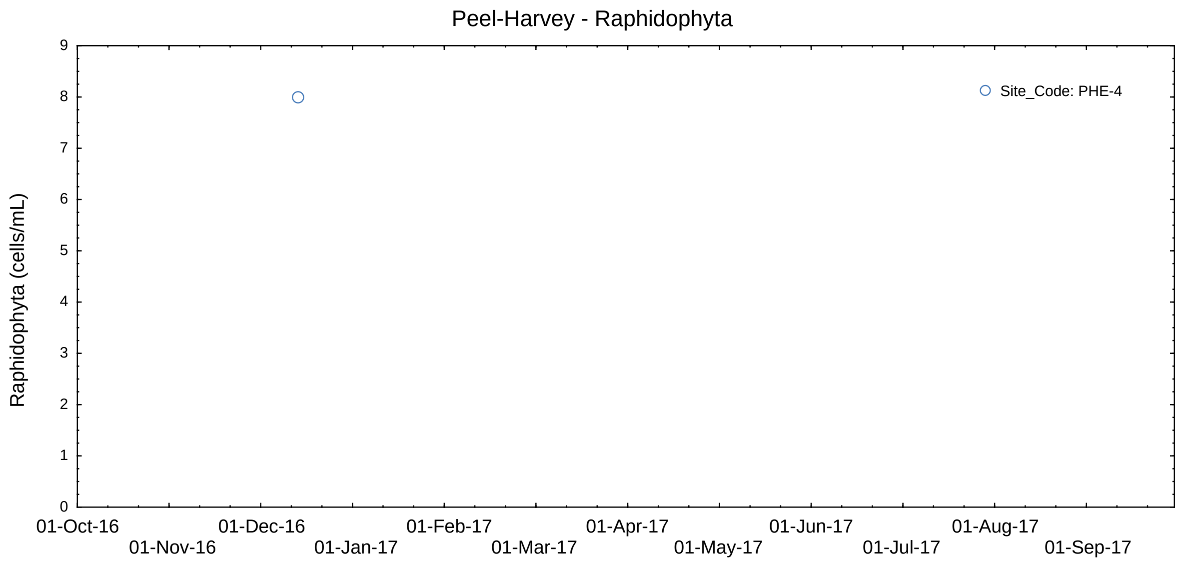

Murray River - Euglenophyta
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
Euglenophyta (cells/mL)
220
200
180
160
140
120
100
80
60
40
20
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

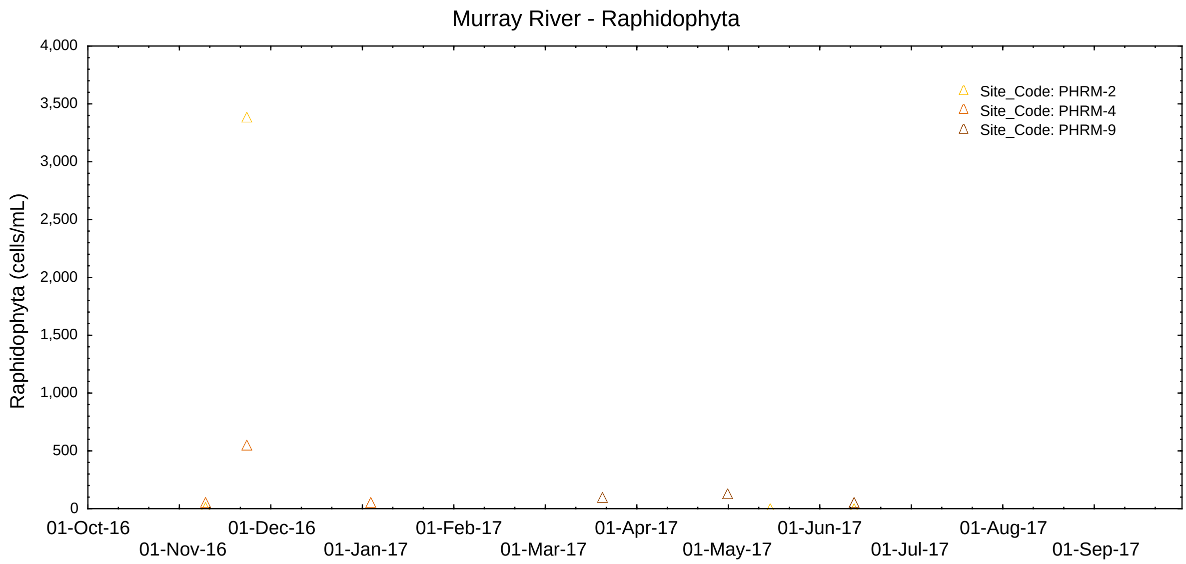

Serpentine River - Euglenophyta
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4
Euglenophyta (cells/mL)
750
500
250
75
50
25
8
5
3
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

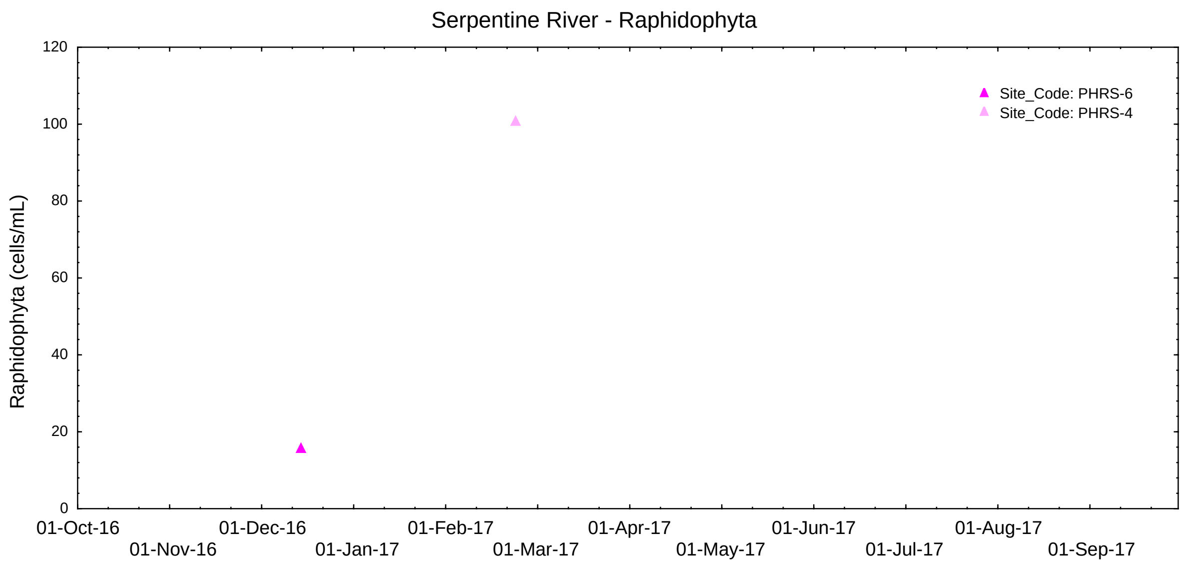

Peel-Harvey - Haptophyta
Haptophyta (cells/mL)
Site_Code: PHE-58
Site_Code: PHE-2
Site_Code: PHE-1
Site_Code: PHE-4
Site_Code: PHE-31
Site_Code: PHE-7
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

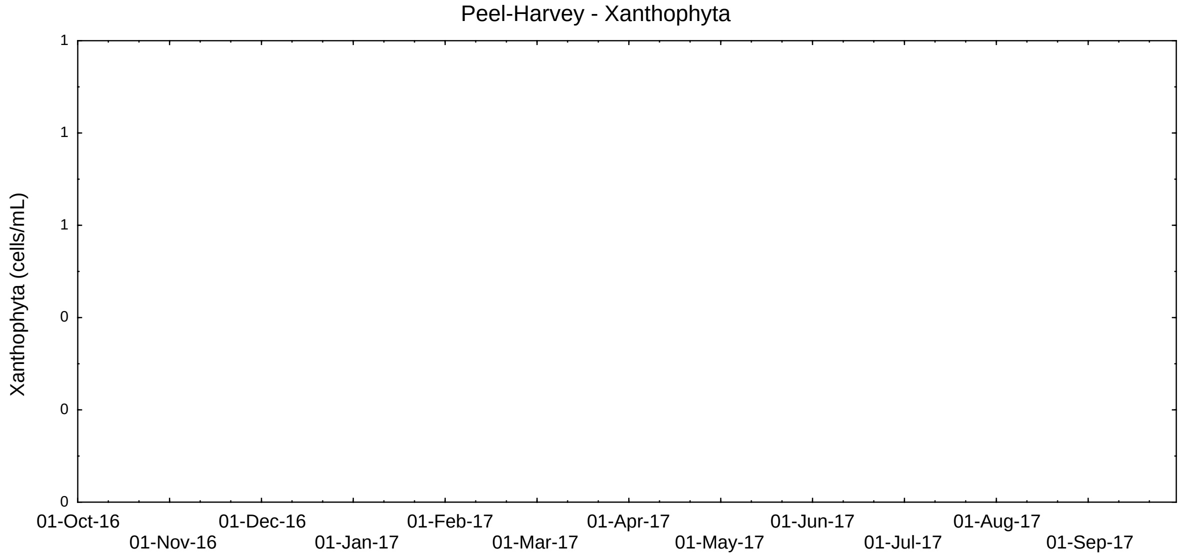

Murray River - Haptophyta
Haptophyta (cells/mL)
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17


Serpentine River - Haptophyta
Haptophyta (cells/mL)
Site_Code: PHRS-7
Site_Code: PHRS-6
Site_Code: PHRS-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

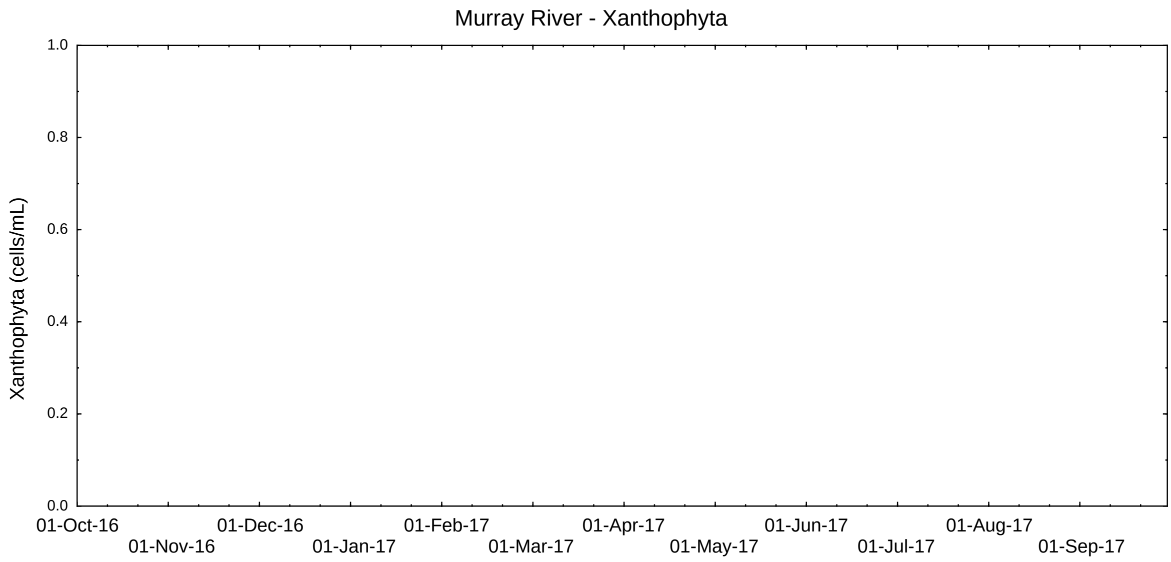

Peel-Harvey - Raphidophyta
Raphidophyta (cells/mL)
Site_Code: PHE-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17


Murray River - Raphidophyta
Raphidophyta (cells/mL)
Site_Code: PHRM-2
Site_Code: PHRM-4
Site_Code: PHRM-9
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

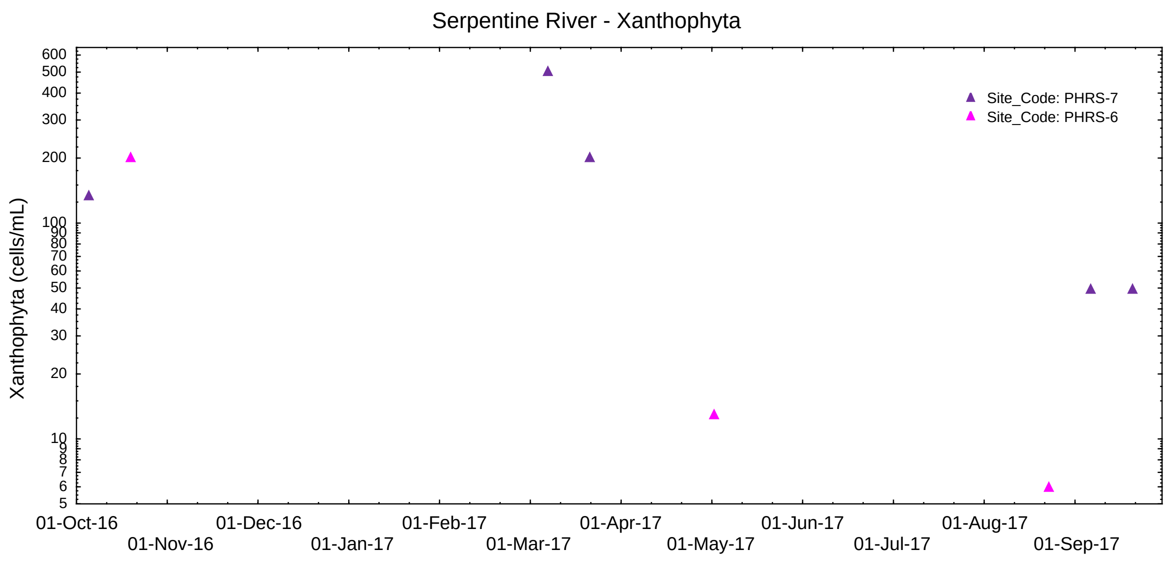

Serpentine River - Raphidophyta
Raphidophyta (cells/mL)
Site_Code: PHRS-6
Site_Code: PHRS-4
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17



Peel-Harvey - Xanthophyta
Xanthophyta (cells/mL)
1
1
1
0
0
0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17



Murray River - Xanthophyta
Xanthophyta (cells/mL)
1.0
0.8
0.6
0.4
0.2
0.0
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17



Serpentine River - Xanthophyta
Xanthophyta (cells/mL)
Site_Code: PHRS-7
Site_Code: PHRS-6
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
01-Oct-16
01-Nov-16
01-Dec-16
01-Jan-17
01-Feb-17
01-Mar-17
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17

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