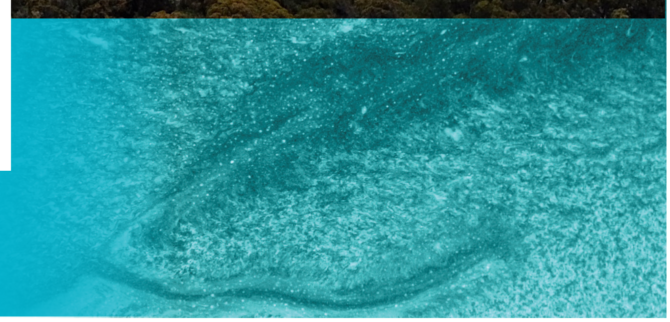
GOVERNMENT OF WESTERN AUSTRALIA

Department of **Water and Environmental Regulation**

Department of **Primary Industries and Regional Development**

REGIONAL ESTUARIES INITIATIVE

Estuary Condition Report: Wilson Inlet 2016/17



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Disclaimer

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Cover photograph: Wilson Inlet: Aerial view of the western end of the Inlet with Prawn Rock Channel in the bottom, left of image. (Source: Photo by Ash Ramsay, 3 February 2017)

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1. Summary

Wilson Inlet is a healthy and productive estuary. Nutrients entering the Inlet from the agricultural and urban catchments and reduced winter flows due to climate change remain the highest risks to the condition of Wilson Inlet.

The estuary is seasonally-closed due to the sand bar at the ocean entrance. In most years, for more than 60 years, the bar has been artificially opened towards the end of winter. In 2017, the bar naturally closed on 23 February and was opened on 24 August. Good rainfall during the current year resulted in high flows and a good opening. Reduced winter flows due to the changing climate will, however, change the frequency and duration of bar openings.

The condition of the estuary, in terms of water quality indicators, shows distinct differences depending on whether the bar was open or closed. During the bar-closed period, the water was brackish (~27 ppt), well-mixed from the surface to the bottom with low concentrations of nutrients, chlorophyll and phytoplankton. In contrast, during the bar-open period, salinities ranged from fresh to marine and nutrient and chlorophyll concentrations were higher due to the nutrient-rich inflows from catchment rivers. When open the Inlet became intermittently stratified due to the marine water intrusion forming a layer below the brackish estuary water. When stratified, nutrients were released from sediments due to low oxygen (hypoxic) conditions in the bottom layer. Additional freshwater flows brought about by an intense rainfall event in September 2017 reduced salinity to a low of 20 ppt.

Overall phytoplankton densities were low. However, three periods of higher phytoplankton densities were observed; two of them during the bar-open period in spring 2016 and 2017 and one in autumn 2017. There were no reported fish kills or harmful algal bloom events during this period.

The dominant phytoplankton group throughout the year was diatoms and with dinoflagellates being the second most abundant. In general, diatoms are indicative of good water quality, compared with dinoflagellate or cyanobacteria dominated systems. The dominant species observed during the peak phytoplankton density periods were *Chaetoceros spp*. (Diatom), *Cyclotella* spp. (Diatom), and *Prorocentrum minimum* (Dinophyta).

A few instances of potentially harmful dinoflagellate species (e.g. *Dinophysis acuminata*) were detected at all four phytoplankton monitoring sites. The guideline value for *D. acuminata* was met or exceeded on six occasions, mostly in spring 2016. Note that the guidelines used (WASQAP, 2016) are not specific to wild-caught shellfish; they are explicit management triggers for commercial shellfish farm operations only.

The estuary is resilient to nutrient inputs for several reasons – the sediments have good phosphorus-binding capacity, the abundant seagrass (*Ruppia)* absorbs nutrients, and strong prevailing winds regularly break down stratification.

From previous studies, it is known that *Ruppia* plays an important role in absorbing nutrients from the water. An intensive field study on the seagrass distribution in Wilson Inlet was undertaken in the 2017–18 summer and these results will be published in the 2018 Annual Condition Report. Previous mapping of seagrass presence and density in 2007 and 2008 are presented in this report for reference.

The water quality of Wilson Inlet is strongly influenced by the seasonal riverine input and the bar status. Management efforts to maintain or improve the health of Wilson Inlet must continue to address the delivery of nutrients from catchment land uses and to understand the impact of bar openings, in the context of both current and future climate scenarios.

The water quality indicators monitored fortnightly, as described in this report, and the seagrass monitoring, constitute only part of the estuary ecosystem. Other ecosystem elements such as invertebrates, fish diversity and abundance and bird diversity and abundance are also important elements, but are not part of the Regional Estuaries Initiative (REI) monitoring program.

In the current monitoring period, additional *in situ* loggers and drifters to measure currents have been deployed in Wilson Inlet over the summer months. These data, combined with the routine monitoring program, are being used to develop an estuary circulation model. Concurrently, a catchment model is also in development.

The monitoring program and modelling efforts provide foundational knowledge to support the development of a Water Quality Improvement Plan, which will support improved catchment management and be a key output of REI. Monitoring and modelling will also provide the information necessary to support a review of the Bar Opening Protocol (2009).

Regular monitoring and reporting of the condition of Wilson Inlet will continue for the duration of REI with information presented on the REI website (rei.dwer.wa.gov.au/wilson-inlet/).

2. Introduction

The Regional Estuaries Initiative (REI) started a comprehensive water quality monitoring program in the Wilson Inlet and its catchment in October 2016.

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

Long-term continuous monitoring is essential to assess the effectiveness of management actions and the impact of both natural variability and anthropogenic changes, such as climate change and significant land-use changes.

The current monitoring program builds on previous monitoring efforts in Wilson Inlet. The results of extensive monitoring from 1994 to 2006 have been reported in community reports. Less frequent monitoring occurred between 2006 and 2016.

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 Wilson Inlet for the period 1 October 2016 to 30 September 2017.

It is one of a series of reports, covering all REI estuaries (Peel-Harvey Estuary, Leschenault Estuary, Vasse-Wonnerup Estuary, Hardy Inlet, Wilson Inlet and Oyster Harbour) (Figure 1). It is anticipated that condition reports for all estuaries will be produced annually during the REI program.

The current reporting period is for data from October 2016 to September 2017, because REI sampling commenced in October 2016. The reporting period of subsequent annual condition reports may be adjusted to coordinate effectively with the catchment reporting program and other REI communication products such as community presentations.

Results from the catchment monitoring program will be reported later in 2018 for the 2017 calendar year. The catchment reports will provide information on the flows and delivery of nutrients to the estuary from the broader catchment.

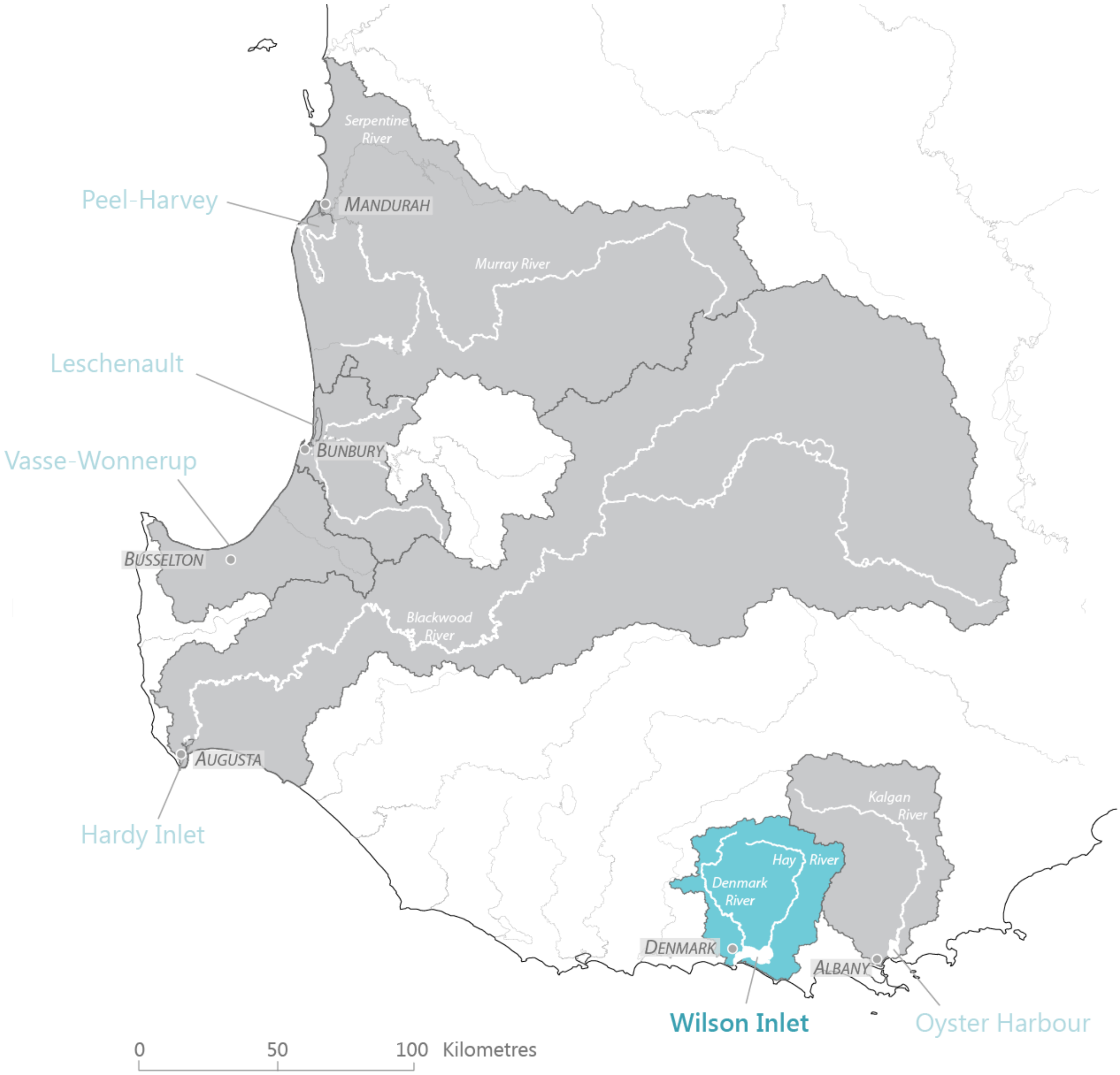

Figure 1 *Wilson Inlet catchment and catchment boundaries of the other Regional Estuaries Initiative estuaries*

Wilson Inlet is known for its natural beauty, diverse birdlife and opportunities for recreational activities, such as fishing and boating.

Wilson Inlet is a broad, shallow and flat-bottomed waterbody that is 14 km long with a maximum width of 4 km. The total area is 48 km^2 and the average depth is two metres.

It is a seasonally-closed estuary adjacent to the town of Denmark on Western Australia's South Coast. The sandbar, which closes naturally in summer, is artificially opened in winter to reduce flooding of low lying land surrounding the inlet. The inlet has been opened every year since 1958 except in three years – 2007, 2010 and 2014. These non-openings were due to reduced rainfall and low inflow volumes.

The Wilson Inlet catchment is approximately 2300 km^2, of which 47 per cent is cleared of native vegetation to support livestock grazing, cereal cropping, plantations, horticulture and residential land-use.

As a consequence of land-use change in combination with climate change, eutrophication caused by nutrient enrichment is one of the main concerns for Wilson Inlet.

Previous reports have indicated that Wilson Inlet can be considered as moderately healthy (Department of Water 2010 - Wilson Inlet Report to the Community No. 10). However, it has been shown that hypoxic conditions during persistent stratification can lead to the release of phosphorus and nitrogen from sediments, which can fuel algal growth.

In the 1970s, a large increase in seagrass (*Ruppia megacarpa*) biomass was observed in Wilson Inlet and concern was expressed by the community about changes of estuary function and effect on fisheries in combination with the increased occurrence of nuisance wracks on beaches. Since that time *Ruppia* abundance has decreased and has been relatively stable for the last 20 years. *R. megacarpa* is now the dominant species in Wilson Inlet and is an important part of the ecosystem. It provides habitat for fish, recycles and incorporates nutrients, which would otherwise be available for macroalgae and phytoplankton (Department of Environment 2003 - Wilson Inlet Report to the Community No. 7). The key parts of the ecosystem that absorb nutrients from the water column are the sediment and *Ruppia*. Settling of organic matter transports nutrients from the water column to the sediment and *Ruppia* uptakes nutrients directly from the water column as well as from the sediment through their roots.

The goal of REI with respect to Wilson Inlet is to support the improvement of water quality through reduction of nutrients and organic matter from the catchment, determine its health and assist in the revision of the sandbar opening protocol, informed by a hydrodynamic model. Specifically, REI will:

- Establish a routine monitoring program for the estuary and its catchment.
- Support the Wilson Inlet Catchment Committee in the joint delivery of on-ground action and long-term management strategies to care for Wilson Inlet.
- In partnership with the Department of Primary Industries and Regional Development, farmers, industry and local groups, reduce nutrient runoff from farms through effective fertiliser management while supporting farm productivity.
- Work with local groups to restore stream function, move stock away from waterways and improve water quality by implementing river action plans.
- Develop numerical modelling tools that integrate our conceptual understanding and enables evaluation of estuary management scenarios of the Wilson Inlet and its catchments. This will provide information to support a new sandbar opening protocol and improved catchment management.
- Develop a Water Quality Improvement Plan.

3. Measuring estuary condition

Estuary condition is typically measured by a suite of biochemical and physical indicators.

In the South West of Western Australia the major threat to water quality of estuaries is 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 (an absence or deficiency of oxygen). Both of these effects can contribute to fish deaths and can even result in an ecosystem shift from a healthy macrophyte/seagrass dominated system to a less desirable phytoplankton dominated system (Figure 2).

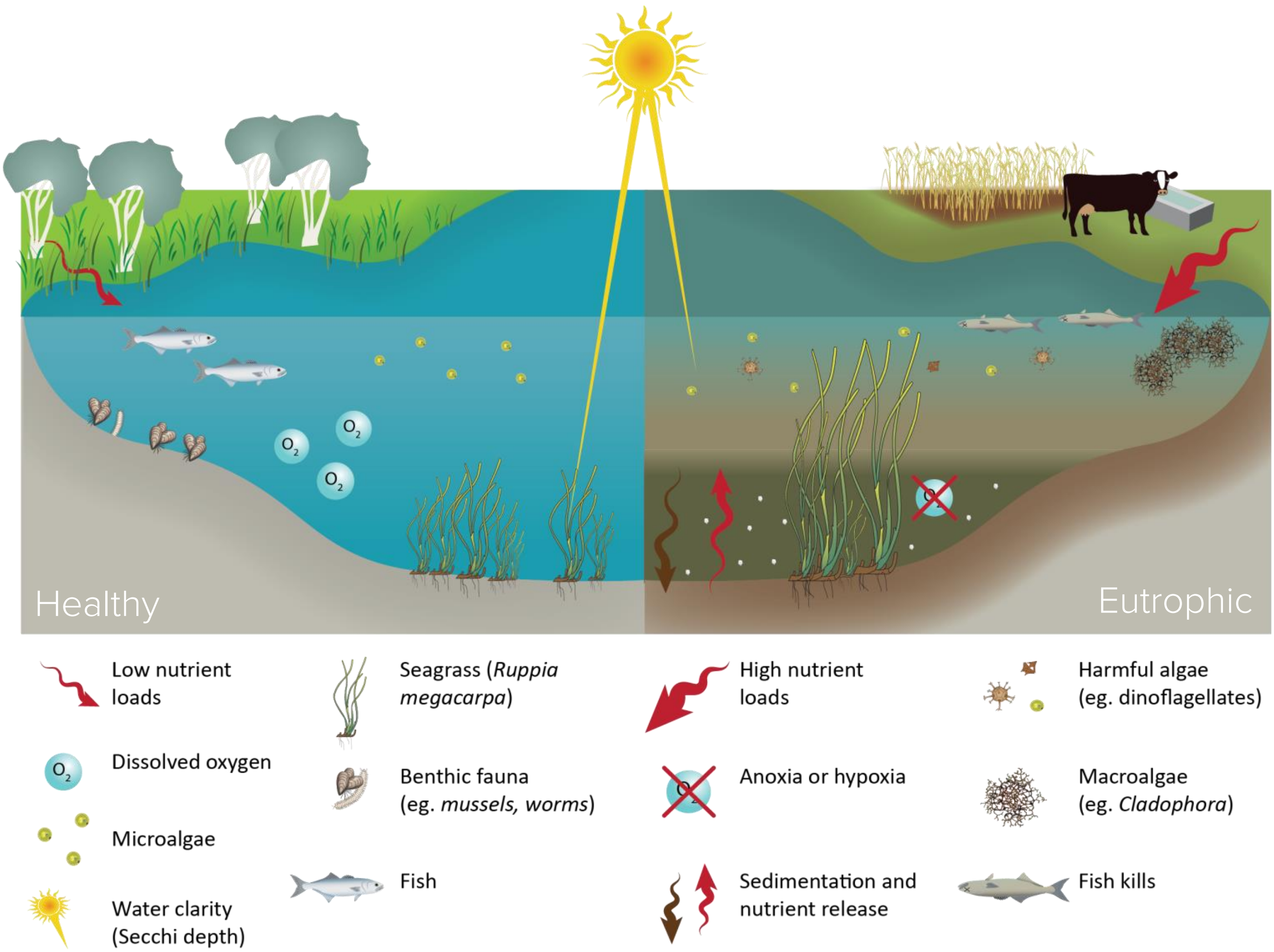

Figure 2 Conditions in a healthy and unhealthy estuary

Our goal 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 Regional Estuaries Initiative 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
- light penetration measured as Secchi depth
- nitrogen and phosphorus as both total concentrations and their bioavailable components
- chlorophyll *a*
- phytoplankton cell densities and their taxonomic group and species name.

The mean has been calculated for the surface water samples and bottom water samples at each site as a yearly average and as an average for the bar-open and bar-closed period. Means are also compared with the ANZECC guideline values (ANZECC & ARMCANZ 2000).

The ANZECC water quality guidelines are derived from biological and ecological effects data and through the use of reference data. If data exceed the guideline values then it is considered a trigger for further investigations or management actions, both of which are underway in Wilson Inlet. We have used the guideline default values as reference points to compare data between periods of different hydrological conditions, i.e. bar-open, bar-closed periods and between different zones within the estuary, i.e. surface and bottom water samples. For each analyte the data are plotted against the default guideline value for comparison and not as a pass or fail test. For a more detailed description of the use of ANZECC guideline values, see Appendix A.

4. The monitoring program

A suite of physical, chemical and biological variables (Table 1) were measured fortnightly at seven sites (Figure 3).

Profiles of the physical and chemical variables [i.e. temperature, dissolved oxygen, salinity and the scale of acidity (pH)] were taken at 0.5 m intervals throughout the water column and, in addition, 0.2 m above the sediment and below the water surface (Figure 4) with a probe.

Water samples were collected at 0.5 m below the surface, representing the surface layer and at 0.5 m above the sediment, representing the bottom layer, and analysed by an analytical laboratory for nutrient concentrations [total nitrogen (TN), nitrate and nitrite (total oxidised nitrogen; NO_x), ammonium (NH_3/NH_4), total phosphorus (TP), filterable reactive phosphorus (FRP)].

Surface samples were also analysed for chlorophyll concentrations.

A list of all variables, the analytical method and limits of reporting are presented in Appendix A.

Phytoplankton species were identified, cell densities determined and chlorophyll was quantified from integrated samples (surface to 0.5 m above the sediment) at four sites, i.e. WI–6, WI–7, WI–12, and WI–30.

Table 1 *Wilson Inlet 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/NH_4, TP, FRP	
		metres	metres	metres	km	Vertical profile	Surface	Int	Int	Surfa ce	Bottom
WI–6	6031350	535190	6127545	4.4	6.0	f	f	f	f	f	f
WI–7	6031351	533855	6129777	2.3	7.0	f	f	f	f	f	f
WI–9	6031352	537589	6127243	3.9	9.2	f	f			f	f
WI–12	6031346	540589	6127047	3.6	12.2	f	f	f	f	f	f
WI–14	6031347	542539	6126547	2.3	13.3	f	f			f	f
WI–30	6031349	530979	6126234	3.3	2.4	f	f	f	f	f	f
WI–35	6031353	536349	6128176	4.3	7.5	f	f			f	f

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

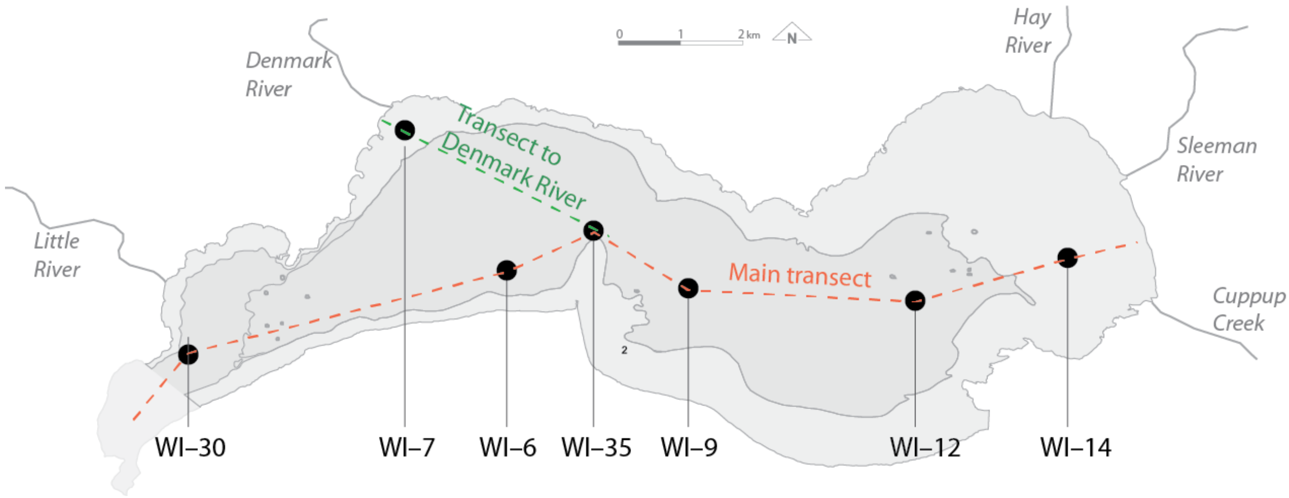

Figure 3 *Wilson Inlet site map with sampling locations. The transects (dashed lines) relate to the physical profiles shown in Section 8 and in Appendix B. The dark grey area is >3 metres deep.*

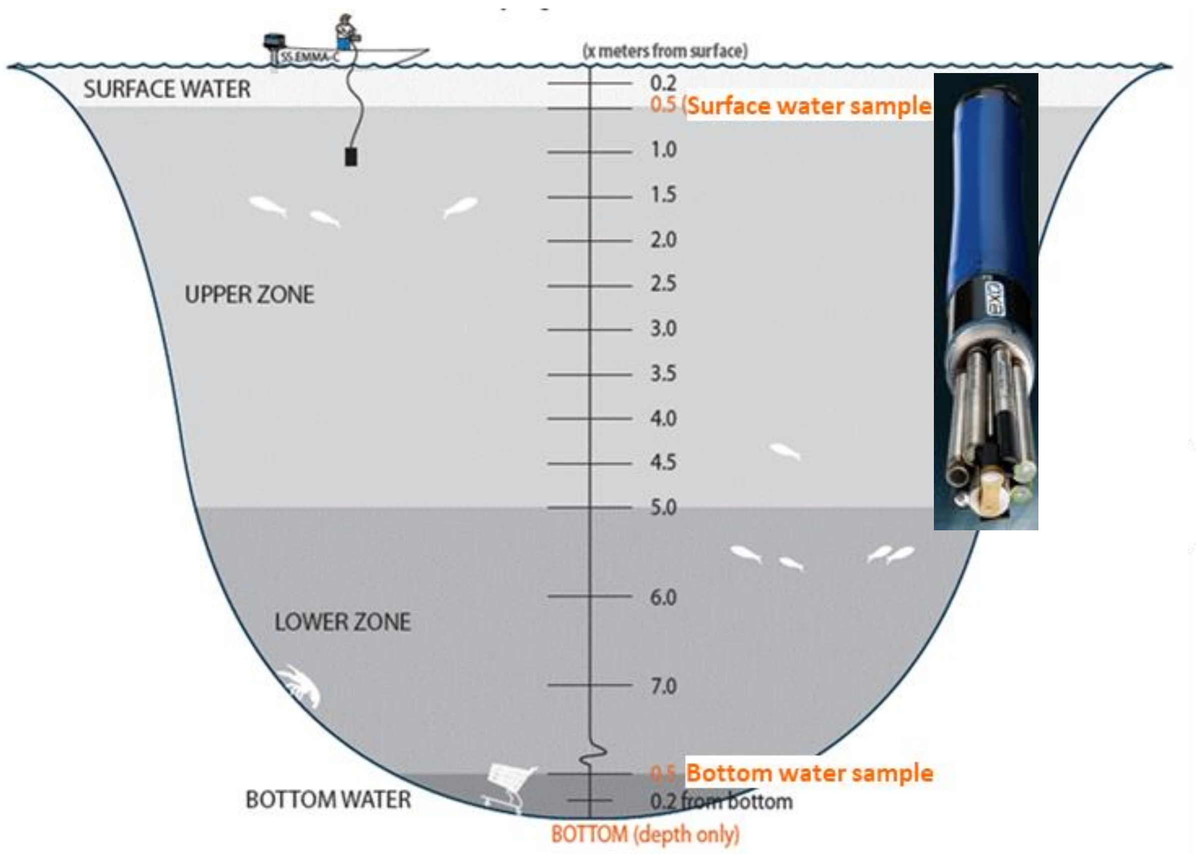

Figure 4 *Profiling and water sampling in Wilson Inlet. The insert shows the EXO2 used for physical-chemical profiles.*

5. Rainfall

Over the reporting period, 966 millimetres of rain was recorded at Denmark's weather station (Department of Primary Industries and Regional Development station ASWWSTNDM001), which is similar to the 10-year average of 976 millimetres.

Most rain fell during late winter and spring, with two intense rainfall events in August and late September 2017 (Figure 5).

The resulting discharge volumes from the catchment into the estuary will be discussed in the Wilson Catchment Report to be published in 2018.

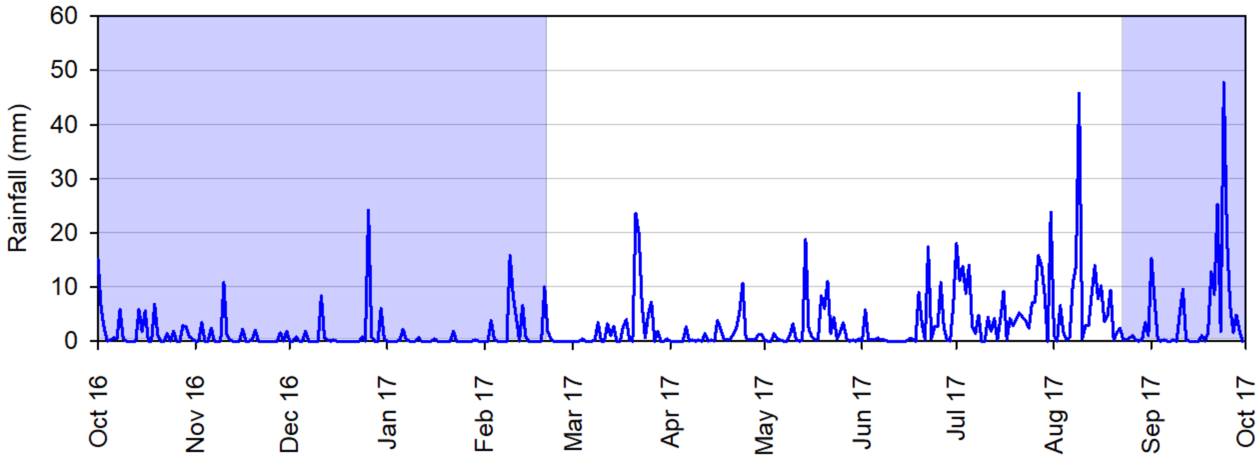

Figure 5 *Daily rainfall (in millimetres) in Denmark (Station ASWWSTNDM001). The shaded area represents the time period when the sandbar was open.*

6. Bar dynamics

At the start of the monitoring period the bar was open, having been opened on 18 July 2016 at an estuary water level of 1.2 m.

In 2017, the bar closed on 23 February. The deposition of sand at the entrance from wave energy naturally closes the estuary over the summer months.

In the 2016–17 summer, the bar was open for 220 days – longer than the average 177 days (average from 1958–2016).

In 2017, the bar was opened at 12:30 pm on Thursday, 24 August 2017 at an estuary water level of 1.27 metres Australian Height Datum (AHD) by dredging a channel to the ocean 100 metres from the western cliffs reference point. This was the highest bar opening since records began in 1958.

Approximately 27 GL of water (around 14 per cent of the estuary volume) was discharged to the ocean in the first 24 hours post-opening.

Water flow rate was recorded at 210 m^3s^{-1} on the day after the opening (25 August 2017) at 2 pm.

The high water level and strong flow effectively scoured the bar to a width of approximately 150 m.

The estuary water level, the opening, the impact on the bar and ocean discharge was captured with a drone by the Department of Water and Environmental Regulation (https://rei.dwer.wa.gov.au/estuary/wilson-inlet/estuary/the-bar).

7. Salinity, temperature, dissolved oxygen, pH and water clarity

Salinity and temperature measurements provide the physical data from which the water circulation (hydrodynamics) in Wilson Inlet can be inferred. The data also support the development and validation of numerical estuarine response models currently under development. Dissolved oxygen concentrations measure the capacity of the water to support aquatic animals and indirectly can serve as an indicator of the potential for nitrogen and phosphate release from sediments.

The strong temporal patterns of the physical and chemical variables seen during the reporting period are aligned with the bar-open and bar-closed periods.

Similar ranges in salinities, dissolved oxygen concentrations and water clarity (measured as Secchi depths) have previously been reported (Department of Water 2007 - Wilson Inlet Report to the Community No. 9; Twomey and Thompson 2001; Water and Rivers Commission 2002 - Wilson Inlet Report to the Community No. 5).

Salinity showed a strong temporal pattern (Figure 6). During the bar-open period, bottom salinity is higher than surface salinity at most sites, indicating stratified conditions (see also Surfer plots in Appendix B).

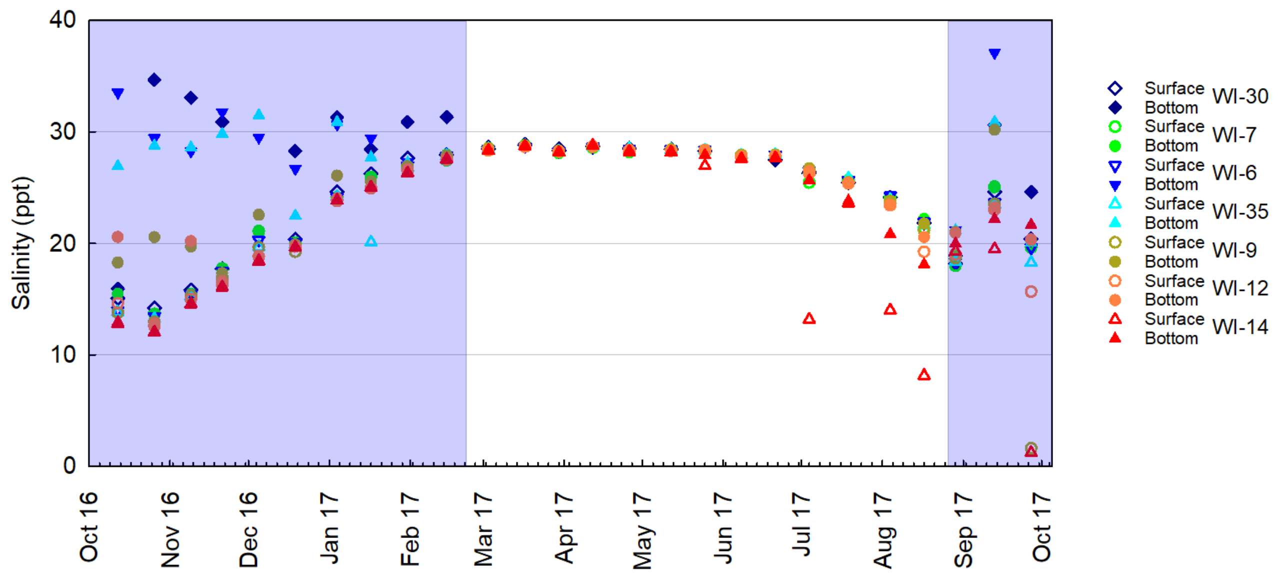

Figure 6 *Salinity (ppt) in Wilson Inlet over time. The shaded area represents the time period when the sandbar was open.*

The stratification is most pronounced in the west basin sites (closest to the ocean opening) and is created by the denser, more saline marine water intruding along the bottom beneath the brackish estuary water.

Site WI–7 is largely influenced by the Denmark River and is shallower (2.3 m) and therefore not directly impacted by the marine intrusion, as is site WI–14, the site furthest away from the ocean entrance.

The low salinities measured at the surface at site WI–14 from July 2017 onwards, indicate the freshwater inflow from the rivers during rainfall events, which expresses itself as a shallow freshwater lens on top of the more brackish water column.

Mean salinity in Wilson Inlet was brackish to saline, between 17 and 29 ppt (Figure 7) (seawater is 35 ppt).

For most sites, mean salinity was higher during the bar-closed period due to decreased flow from the rivers and increased evaporation. During this period, mean salinity of surface and bottom water was similar, indicating a well-mixed system.

The slightly lower mean salinity in the surface water at WI–14 during the bar-closed period was due to the input of freshwater from the Hay River, Sleeman River and the Cuppup Creek in August 2017, just before the bar was opened.

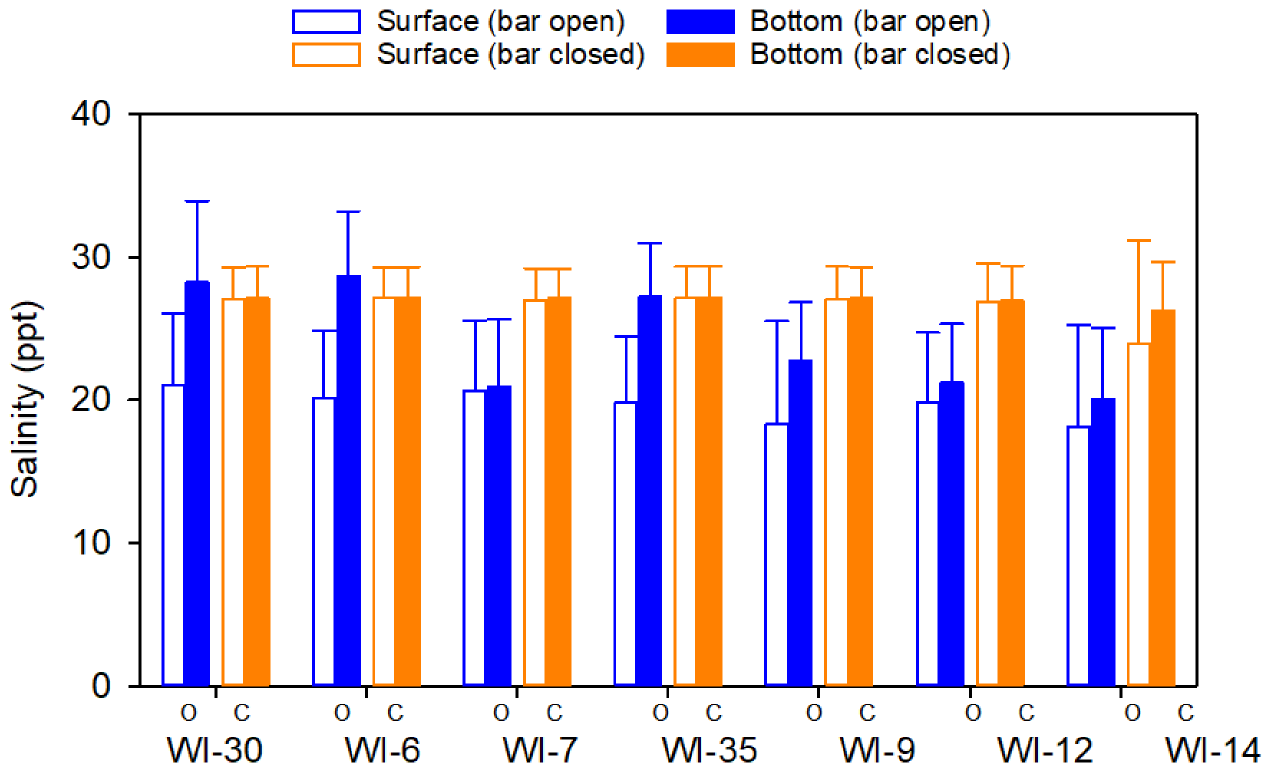

Figure 7 *Site mean and standard deviation of salinity (ppt) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period; o labels bar-open period, c labels bar-closed period*

Similar to salinity, dissolved oxygen (DO) concentration in the water column showed a strong pattern aligned with the bar-open and bar-closed periods (Figure 8).

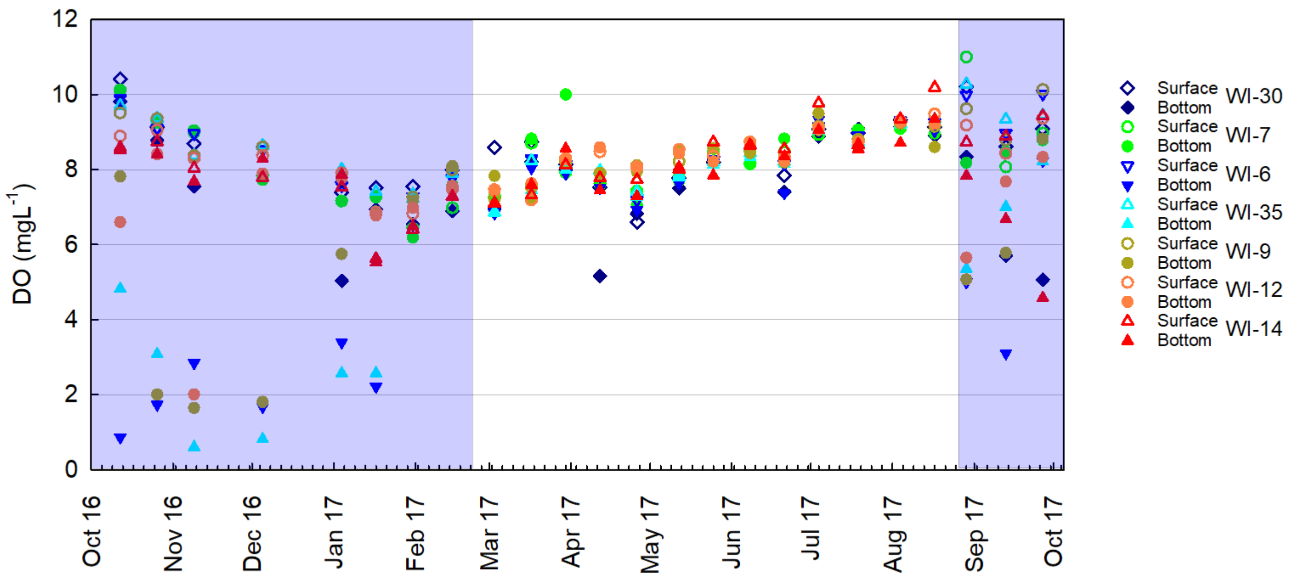

Figure 8 *Dissolved oxygen (mgL^{-1}) in Wilson Inlet over time. The shaded area represents the time period when the sandbar was open.*

During the bar-open period, DO concentrations were lower at the bottom than at the surface, while concentrations were similar in the two layers during the bar-closed period indicative of a well-mixed water column.

During the bar-open period, DO concentrations in the bottom waters were between 0.6 and 4 mgL^{-1} at some sites. Such hypoxic conditions are a consequence of salinity stratification and organic matter decomposition.

Dissolved oxygen concentrations below 4.8 mgL^{-1} are stressful to fish. Anoxia (absence of oxygen) also enables release of sediment-bound nutrients (Department of Water 2010 - Wilson Inlet Report to the Community No. 10).

Mean DO concentrations in surface and bottom waters were in the range 4.0 to 8.8 mgL^{-1} throughout the monitoring period (Figure 9).

The lower mean DO concentrations in the bottom water compared to surface water during the bar-open period, were more prominent at sites closer to the ocean.

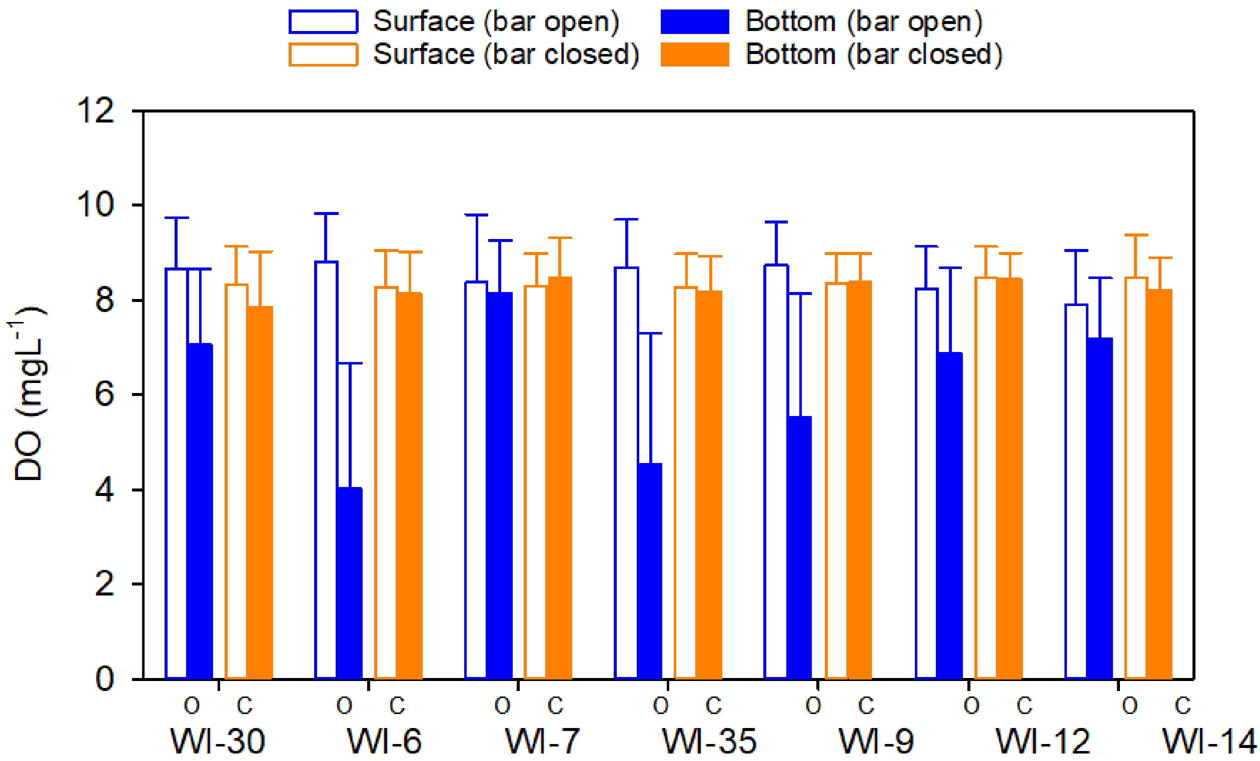

Figure 9 *Site mean and standard deviation of dissolved oxygen (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period; o labels bar-open period, c labels bar-closed period*

Temperatures followed a consistent seasonal pattern with summer and autumn highs of 20 to 25°C and winter lows of 10 to 15°C (Figure 10).

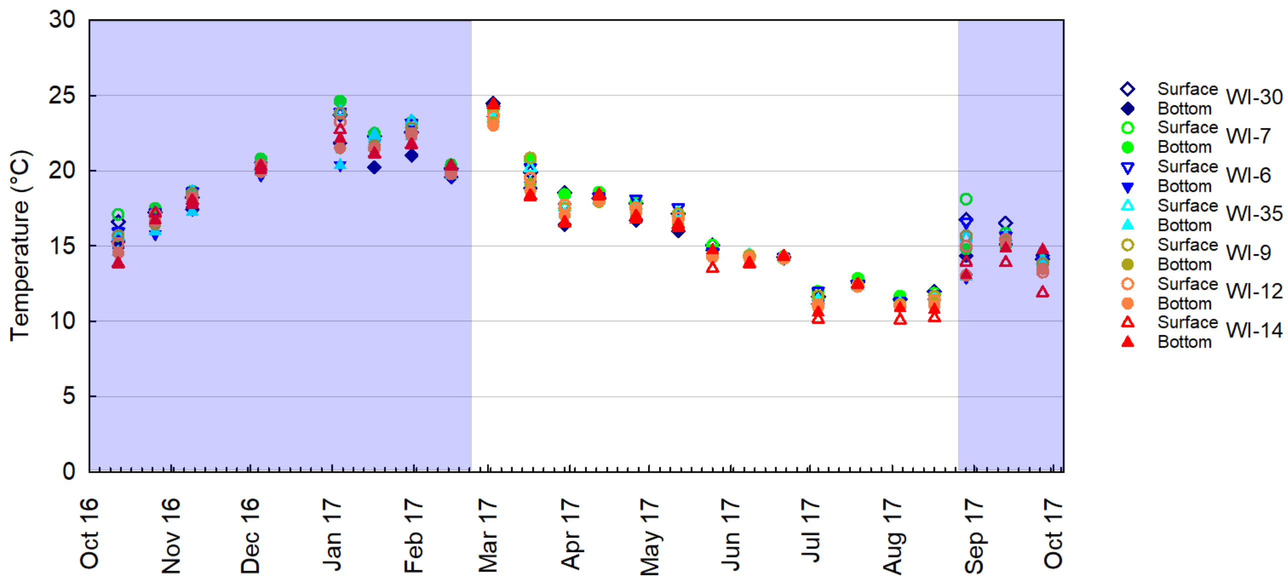

Figure 10 *Temperature (°C) in Wilson Inlet over time. The shaded area represents the time period when the sandbar was open.*

Mean temperature in both surface and bottom waters were between 15 and 19°C (Figure 11). Mean temperature was higher during the bar-open period in summer than during the bar-closed period in winter.

Mean temperature was slightly lower at the bottom compared to the surface layer during the bar-open period due to the cooler ocean water intrusion into the estuary.

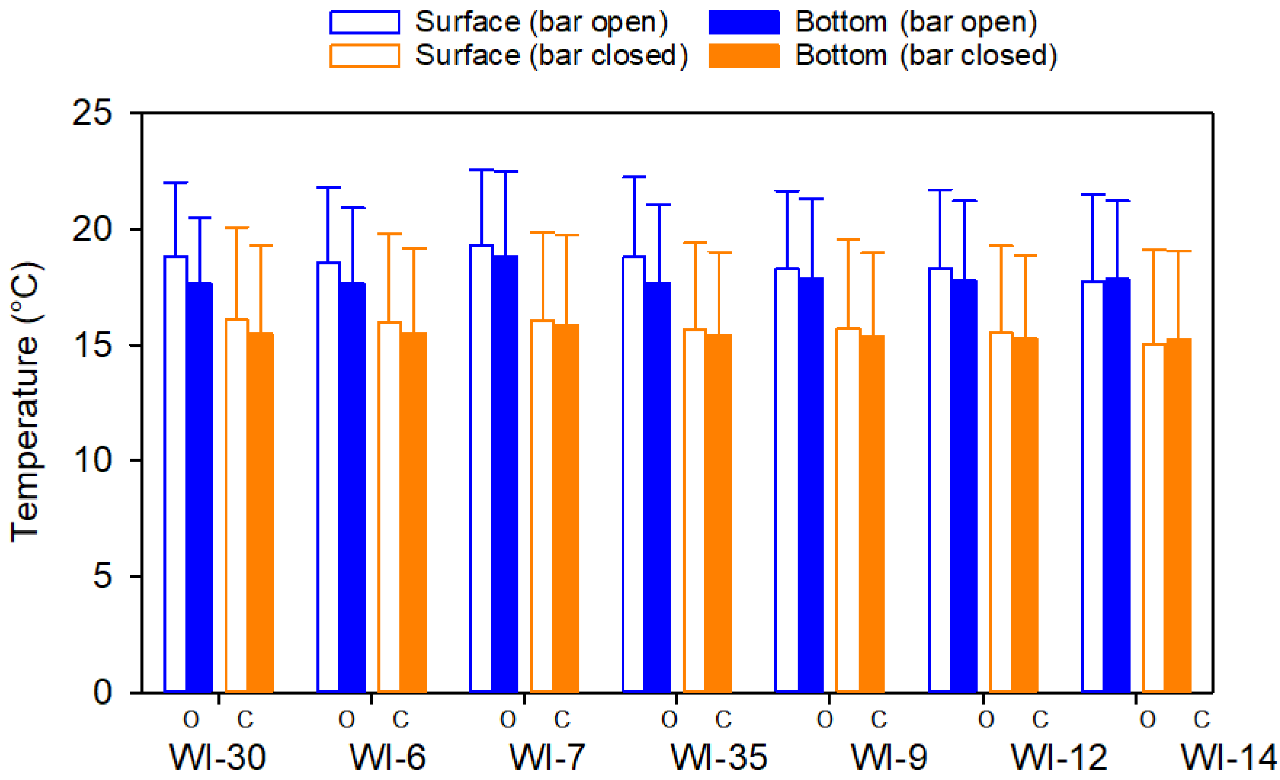

Figure 11 *Site mean and standard deviation of temperature (°C) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period; o labels bar-open period, c labels bar-closed period*

The seasonal pattern for pH is complex and is influenced by input from the catchment and by biological and chemical processes in the water column and at the sediment-water interface. During summer and autumn, pH is between 7.5 and 8 at all sites (Figure 12).

The higher pH in November at some surface sites could have been influenced by high photosynthesis rates as chlorophyll *a* values were highest on that day (15 to 27 microgram chlorophyll a per litre).

During photosynthesis, carbon dioxide (CO_2) is removed from the water column, which increases the pH.

The lower pH after the onset of rain in winter 2017 was likely influenced by the inflow of river water, which has a lower pH compared to the estuary.

During this time, the pH was below the lower ANZECC limit for south west estuaries of 7.5 (ANZECC & ARMCANZ 2000).

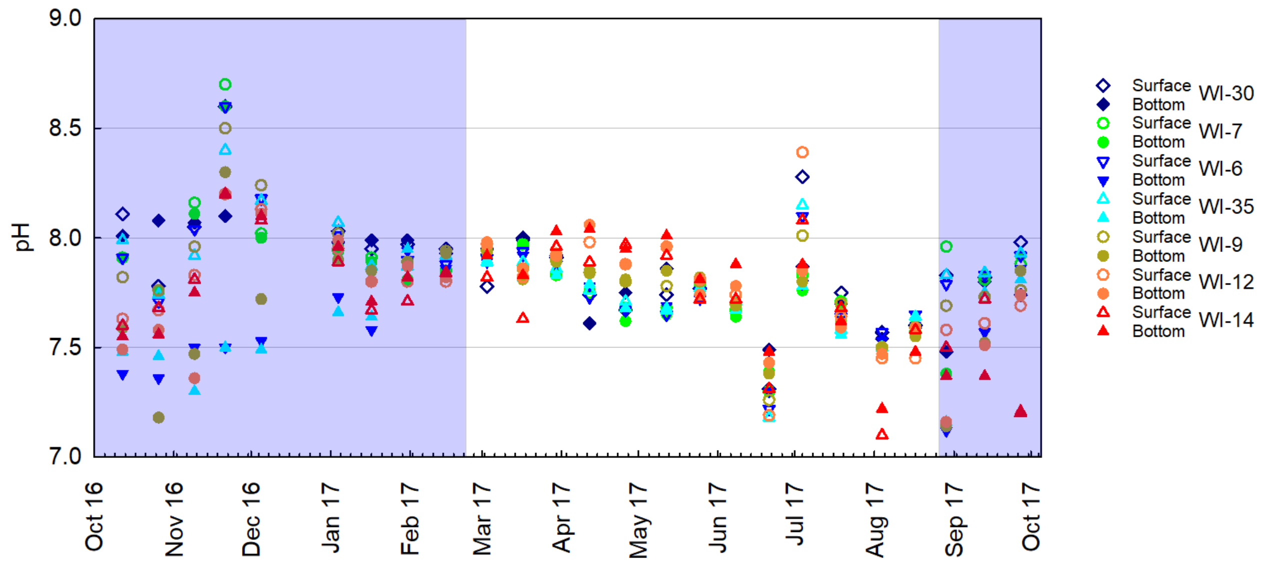

Figure 12 *pH in Wilson Inlet over time. The shaded area represents the time period when the sandbar was open.*

Mean pH values ranged from 7.6 to 8.0, all within the ANZECC limits for south west estuaries, 7.5 to 8.5 (Figure 13) (ANZECC & ARMCANZ 2000).

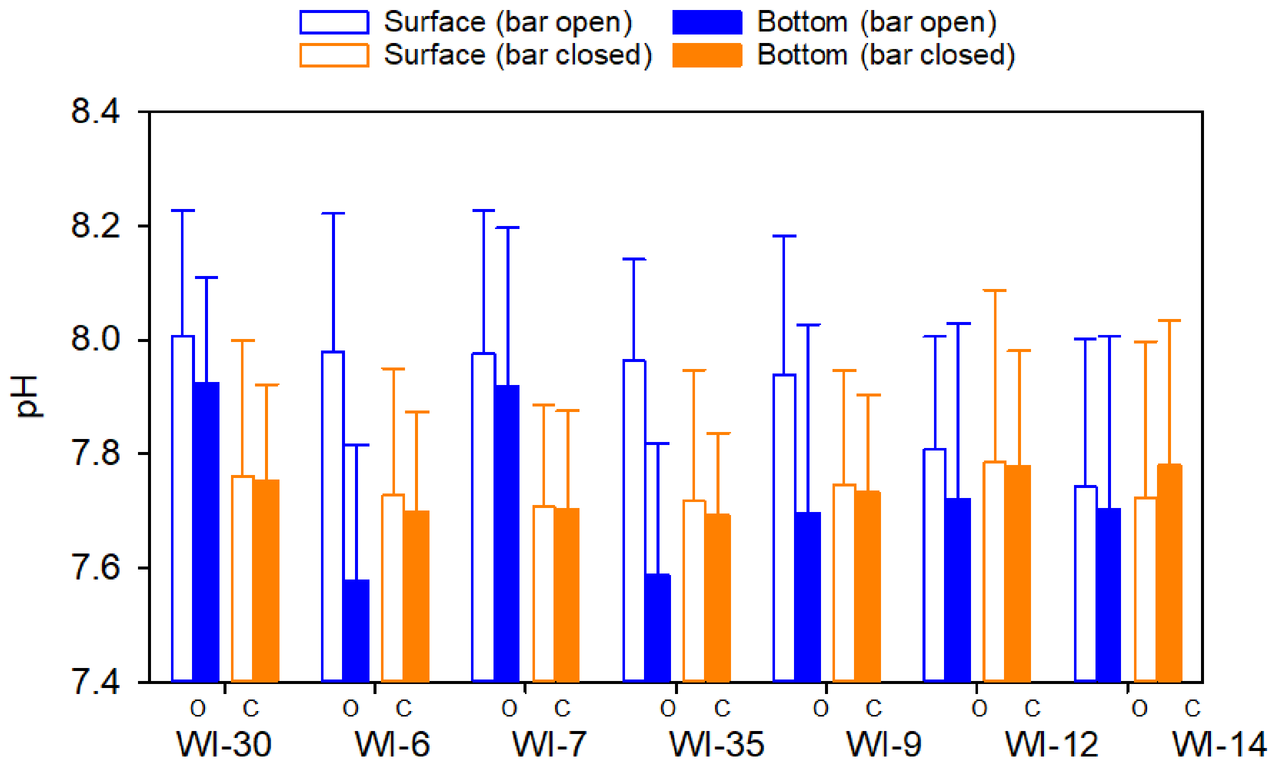

Figure 13 *Site mean and standard deviation of pH in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period; o labels bar-open period, c labels bar-closed period*

During the bar-open period, pH means were lower in the bottom than in the surface water, which might be caused by the release of CO_2 during bacterial decomposition in the hypoxic bottom water. This was most prominent at the deeper sites (WI–6, WI–35 and WI–9), the sites with the most persistent salinity stratification during the bar-open period in 2016 (see Surfer plots in Appendix B).

Secchi depths, which are a measurement of water clarity, were shallower during the bar-open period (*Figure 14*).

This lower water clarity during the bar-open period is likely due to catchment inputs and higher chlorophyll *a* values (see *Figure 30*).

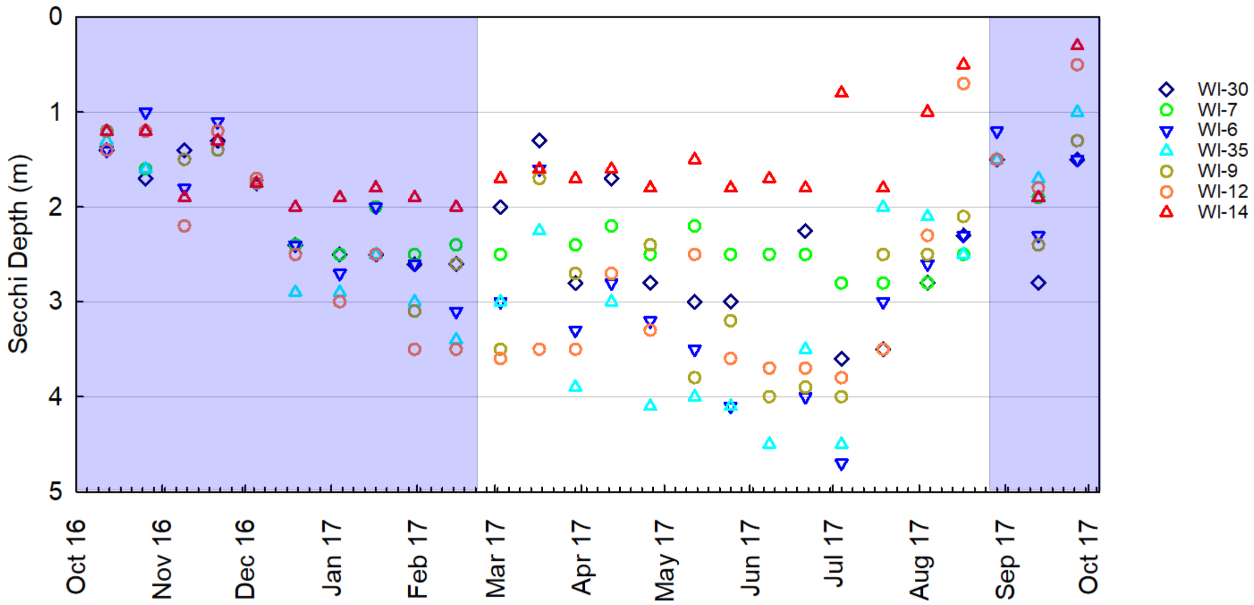

Figure 14 *Secchi depth (metres) in Wilson Inlet over time. The shaded area represents the time period when the sandbar was open.*

At most sites, mean Secchi depths were deeper during the bar-closed period (Figure 15).

During this period, Secchi depths were close to the mean bottom depth at each site, especially at the shallower sites WI–14, WI–7, WI–30. Such conditions, which indicate that light can penetrate deep into the water column, are beneficial for benthic phytoplankton and seagrass growth.

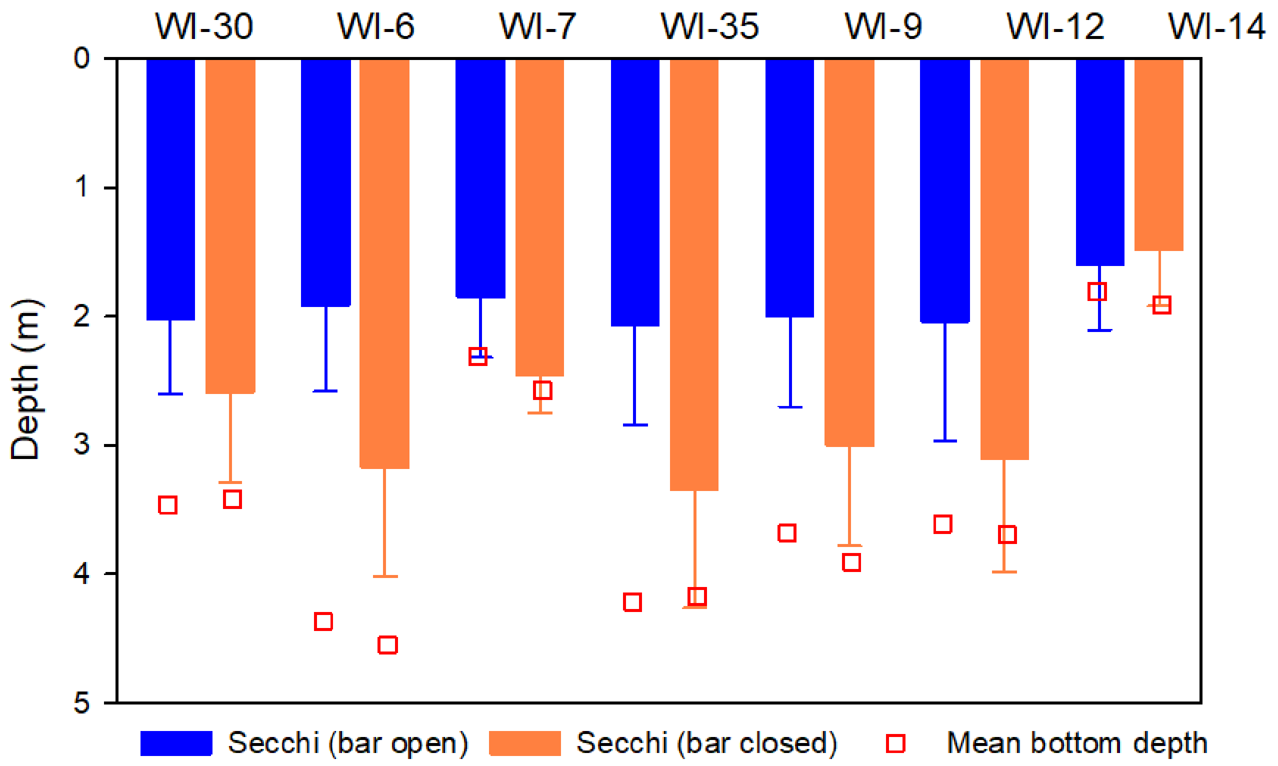

Figure 15 *Site mean and standard deviation of Secchi depths and mean bottom depths at each site during the bar-open (blue) and bar-closed (orange) period*

8. Salinity, dissolved oxygen and temperature profiles

The physical contour plots show the salinity, dissolved oxygen and temperature conditions as a vertical slice through the estuary along two transects (Figure 3).

At each site, the variables are measured at about 0.5 m intervals vertically down through the water (dots on the contour plots). Contours are determined by interpolating between data points using *SURFER®$_{v13}$* (Golden Software, LLC), therefore lines on the plots join points of equal concentration/magnitude. All contour plots of salinity, dissolved oxygen and temperature are presented in Appendix B.

In October 2016, at the start of the monitoring period, the Inlet was stratified with a denser, saline bottom layer close to marine salinity. By November, peak stratification was observed with an approximate 1.5 m deep saline bottom layer under the two to three metre brackish layer of around 18 ppt (Figure 16).

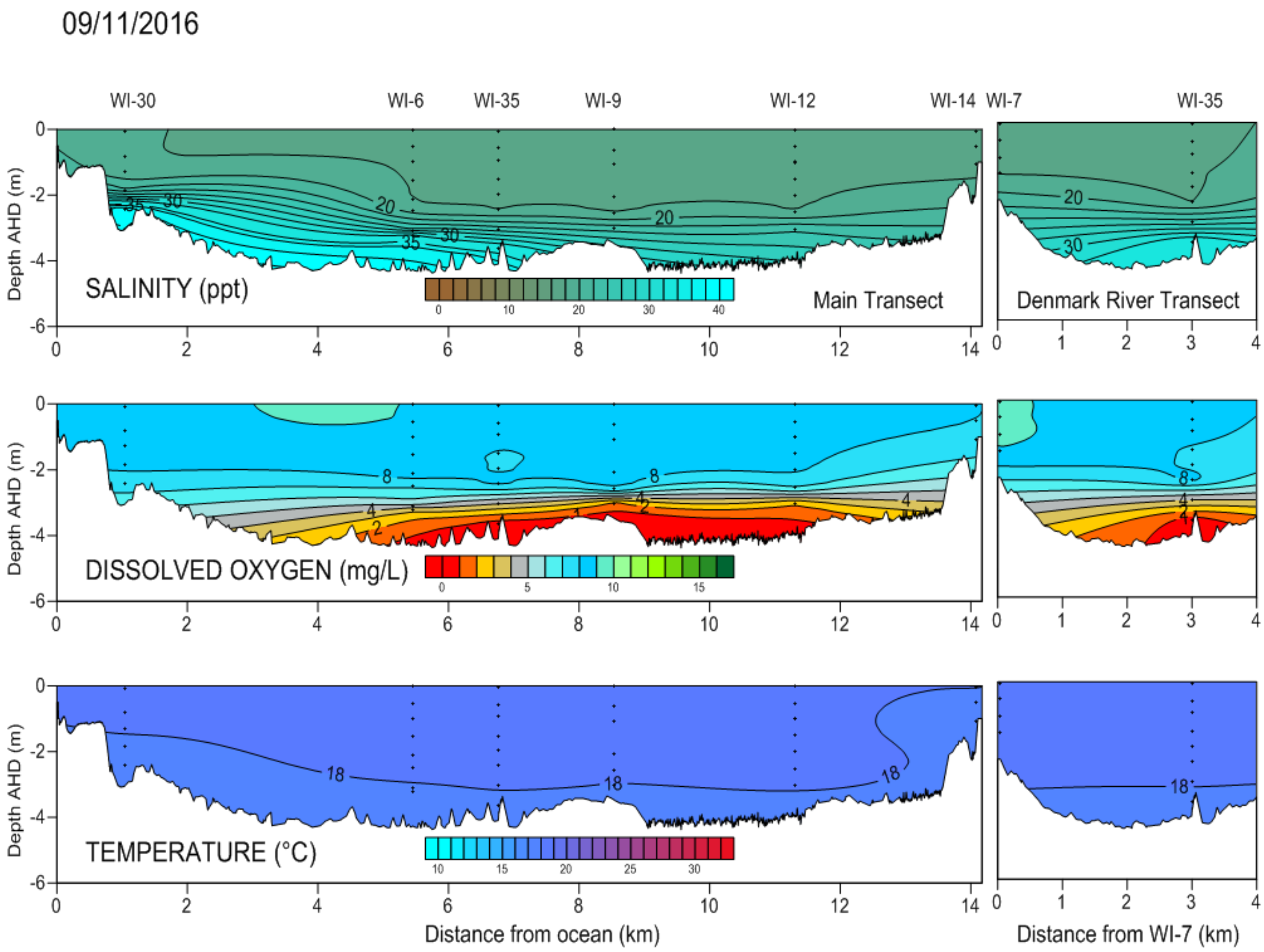

Figure 16 *Salinity (ppt), dissolved oxygen (mgL^{-1}) and temperature (°C) profiles for Wilson Inlet on 9/11/2017, representing stratified conditions*

Dissolved oxygen concentrations in the bottom layer were anoxic or hypoxic in all sites of depth greater than three metres, due to the strong stratification and rapid breakdown of organic matter, which consumes oxygen (Figure 16).

Oxygen concentrations below 4.8 mgL^{-1} are stressful to fish and below 2 mgL^{-1} can be lethal to fish and aquatic invertebrates. Low oxygen conditions in bottom waters also enables the release of sediment-bound nutrients (Department of Water 2010 - Wilson Inlet Report to the Community No. 10). This, in turn, can lead to excessive algal growth.

Over the summer, as the bar gradually closed there was less exchange with marine waters and the stratification weakened most likely due to wind mixing. By the time the bar closed, the water column was fully mixed and oxygenated (Figure 17).

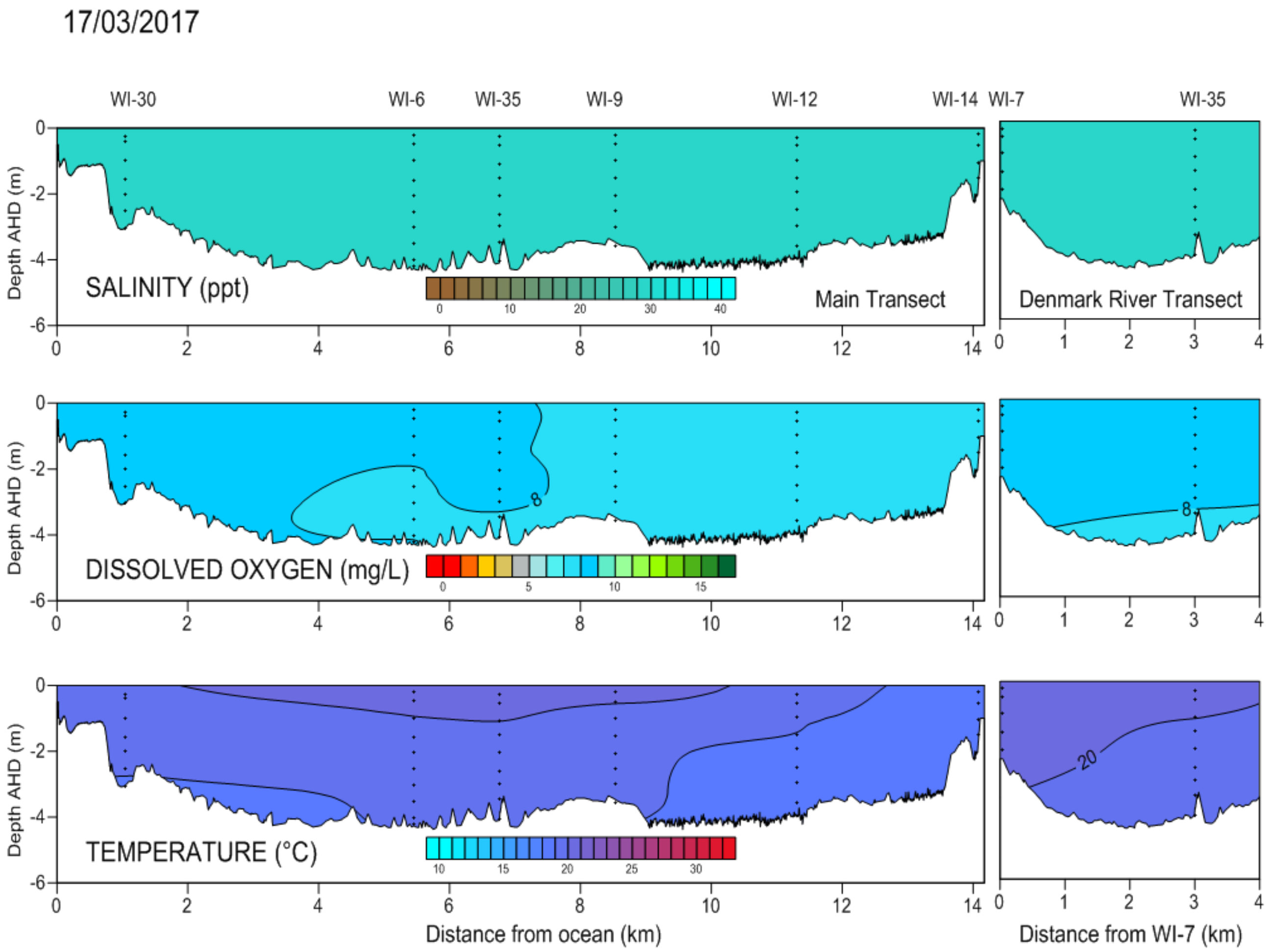

Figure 17 Salinity (ppt), dissolved oxygen (mgL^{-1}) and temperature (°C) profiles for Wilson Inlet on 17/3/2017, representing well-mixed conditions

The well-mixed condition persisted over approximately four months until the end of June. During this period, the bar was closed and wind was most likely providing sufficient energy to mix the waterbody.

When the waters are well-mixed, shown as uniform salinity, dissolved oxygen concentrations tend to be above 6 mgL^{-1}, provide healthy conditions for aquatic fauna.

In July and August the catchment inflows were observed as a low salinity surface layer at site WI–14 (see Appendix B).

Increased rainfall intensity in August raised the Inlet water level rapidly leading to the decision to open the bar, which took place on 24 August 2017.

Two weeks later (13 September 2017), the marine salinity bottom layer intrusion was observed in the estuary and site WI–6 became anoxic at the bottom.

By 27 September 2017 there was another strong catchment inflow event due to intense rainfall– 90 millimetres from 23 to 26 September 2017. The input of freshwater from the Cuppup Creek and the Hay River during this rainfall event can clearly be seen in the surface at sites WI–14 and WI–9, respectively (Figure 18). These inflows flushed the marine water back out of the Inlet. No anoxia was observed at this sampling event (Figure 18).

Interestingly, site WI–7, which is close to the mouth of the Denmark River, did not show this rainfall signal (Figure 18).

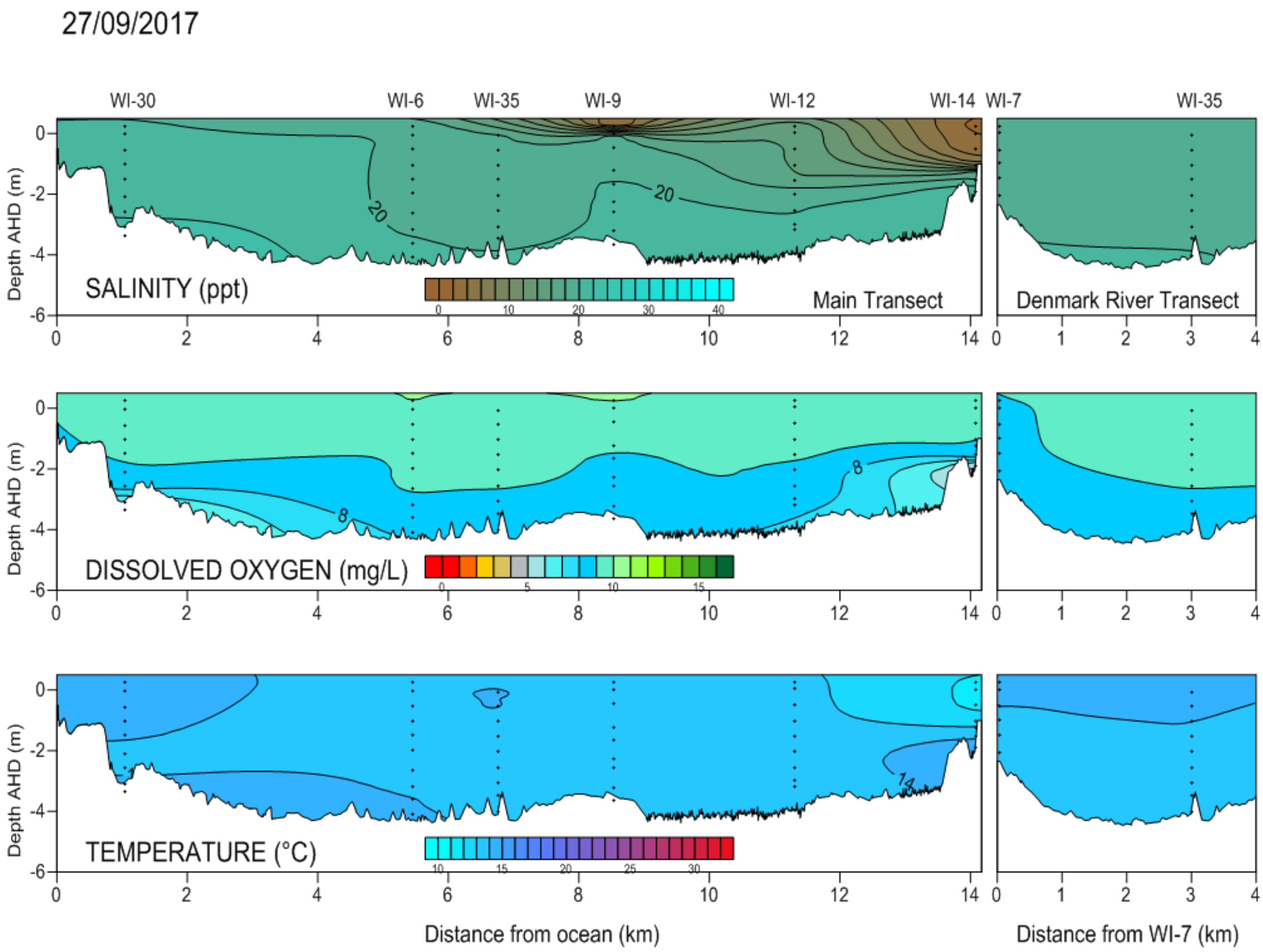

Figure 18 Salinity, dissolved oxygen and temperature profiles for Wilson Inlet on 27/09/2017

9. Nutrients and chlorophyll *a*

The enrichment of a waterbody with nutrients that can lead to a rapid increase of algal or plant biomass is known as eutrophication. Chlorophyll *a*, a plant pigment, is widely used as an indicator of algal activity. Monitoring of nutrients and chlorophyll tells us how the estuary responds to inputs from the catchment and to changes in the circulation and exchange dynamics, for example the difference between bar-open and bar-closed conditions.

For a full interpretation of the Wilson Inlet nutrient concentrations, this report should be read in conjunction with the Wilson Catchment Report to be published in 2018.

All nutrient concentrations were in the same range and show similar seasonal patterns to what has been reported for the periods of 2006–2013 (data available on the Water Information Reporting webpage: http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx) and 2002–2006 (Department of Water 2007 - Wilson Inlet Report to the Community No. 9).

Total nitrogen (TN) concentrations were highest during the bar-open period, from October to December 2016 and again from August 2017 (Figure 19). The increase in TN, mostly in the surface water starting in August 2017 before the bar was opened, points towards an increased input of nitrogen from the catchment in late winter.

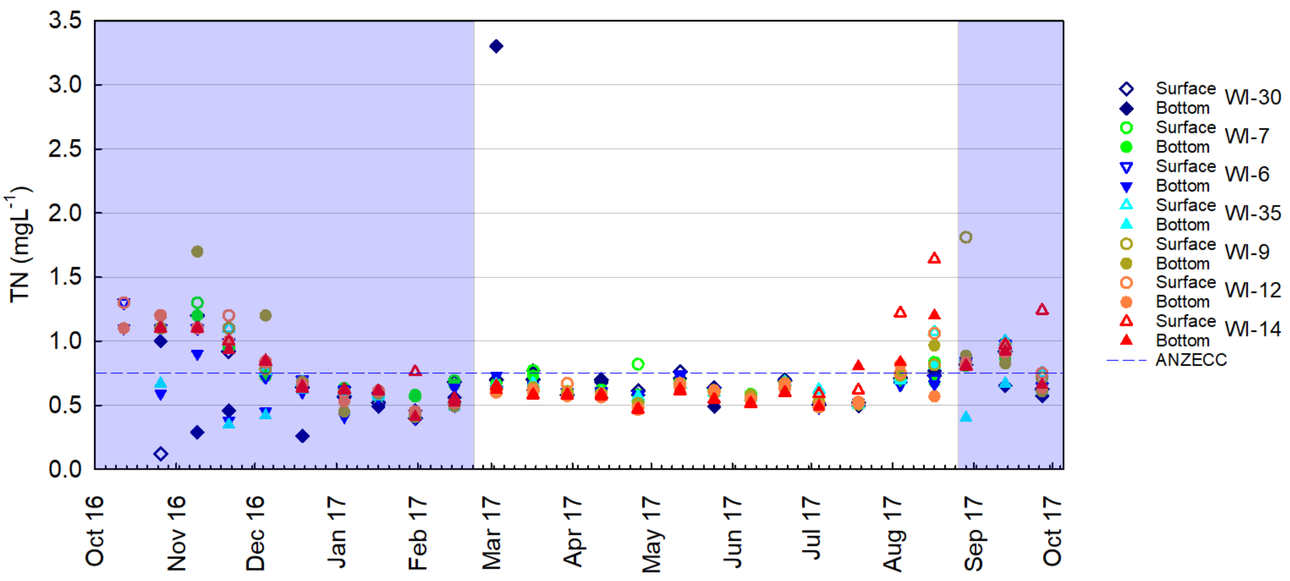

Figure 19 *Total nitrogen (TN) concentration (mgL^{-1}) in Wilson Inlet over time. The limit of reporting (LOR) is 0.025 mgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

The difference in TN concentrations between the two periods can also be seen in Figure 20.

Most mean values during the bar-open period were above the ANZECC guideline of 0.75 mgL^{-1} (ANZECC & ARMCANZ 2000), while all mean values were below this guideline value during the bar-closed period.

It should be noted that the sites in the eastern basin together with WI–7 recorded the highest TN concentrations pointing to riverine nitrogen input.

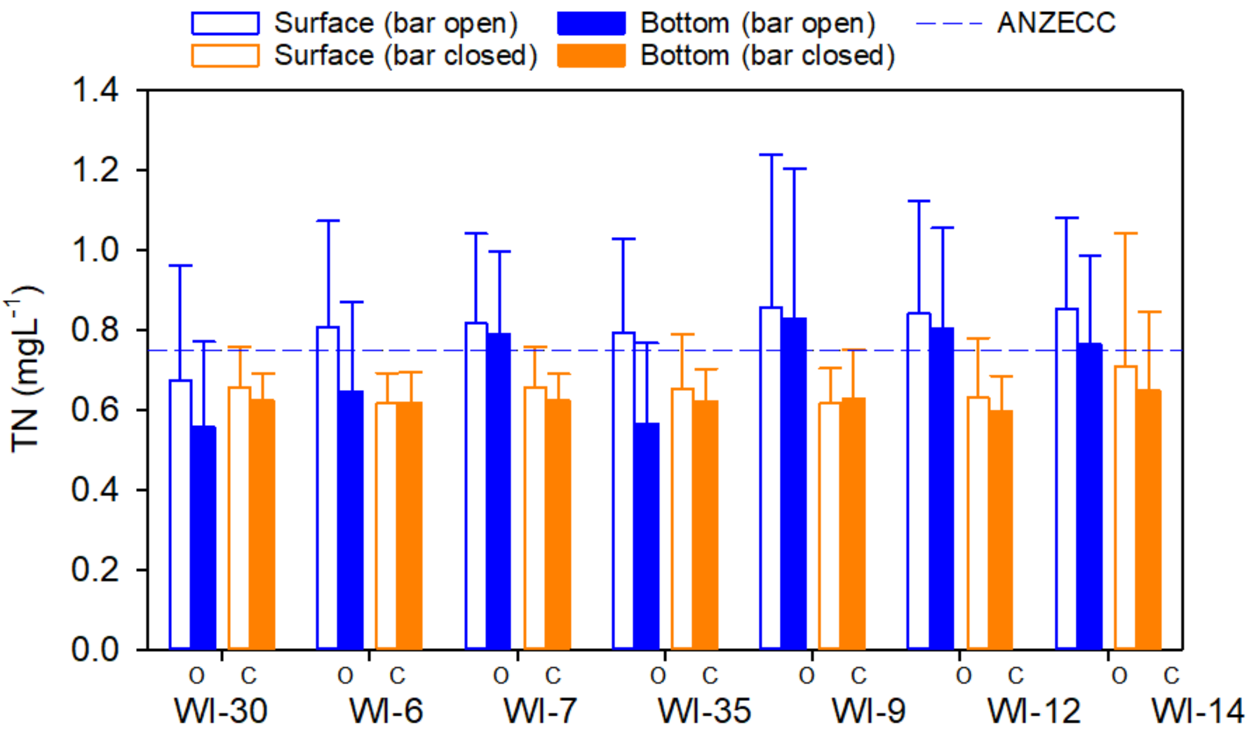

Figure 20 *Site mean and standard deviation of total nitrogen (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

Nitrate concentrations were well above the ANZECC guideline of 0.045 mgL^{-1}(ANZECC & ARMCANZ 2000) in spring (Figure 21). These higher concentrations in October and November 2016 are likely the result of input from the catchment during times of high discharge.

The nitrate inputs during spring, together with the ammonium inputs (Figure 23), are likely to fuel the spring algal growth (see chlorophyll in Figure 29). Nitrate concentrations rapidly decreased in summer to well below the ANZECC guideline and remained below it during the bar-closed period.

Concentrations started to increase slightly again in late August, when flow from the catchment started to increase, but not to the level of 2016.

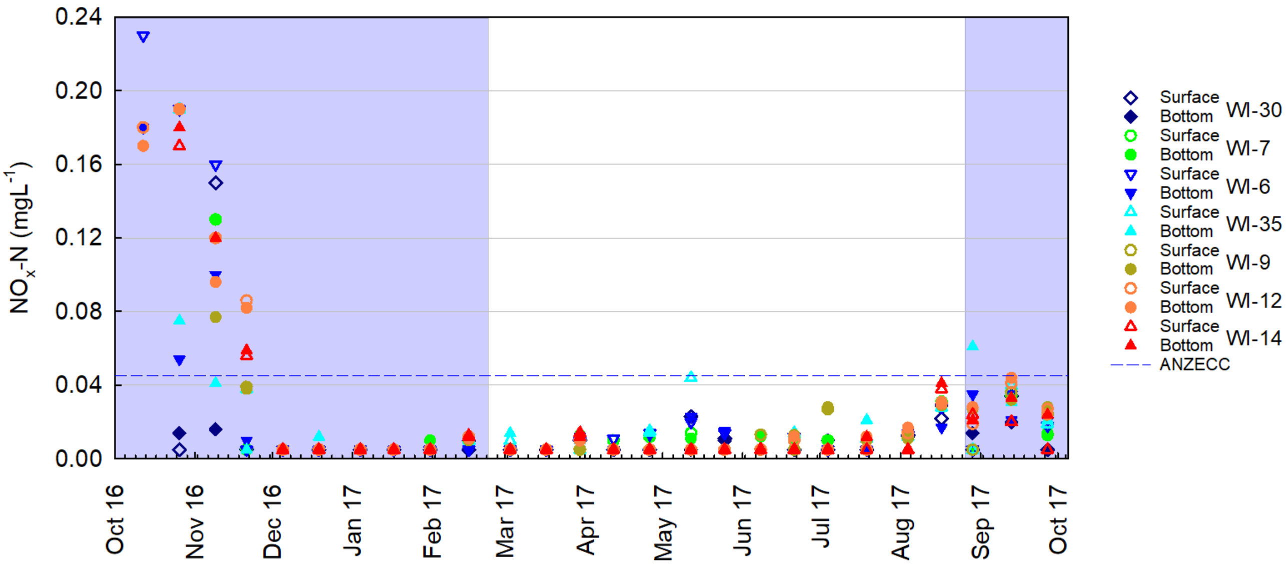

Figure 21 *Nitrate as NO_x-nitrogen concentration (mgL^{-1}) in Wilson Inlet over time. NO_x is the sum of nitrate and nitrite. The limit of reporting (LOR) is 0.01 mgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

Looking at the mean values for nitrate (as NO_x) concentrations, these were well below the ANZECC guideline of 0.045 mgL^{-1}(ANZECC & ARMCANZ 2000) during the bar-closed period (Figure 22).

Although most mean values during the bar-open period were below the ANZECC guideline of 0.045 mgL^{-1}, the large standard deviations indicate that concentrations were highly variable during the bar-open period.

During the bar-closed period, mean nitrate concentrations were low and similar for all sites with the small standard deviations indicating low variability over the year.

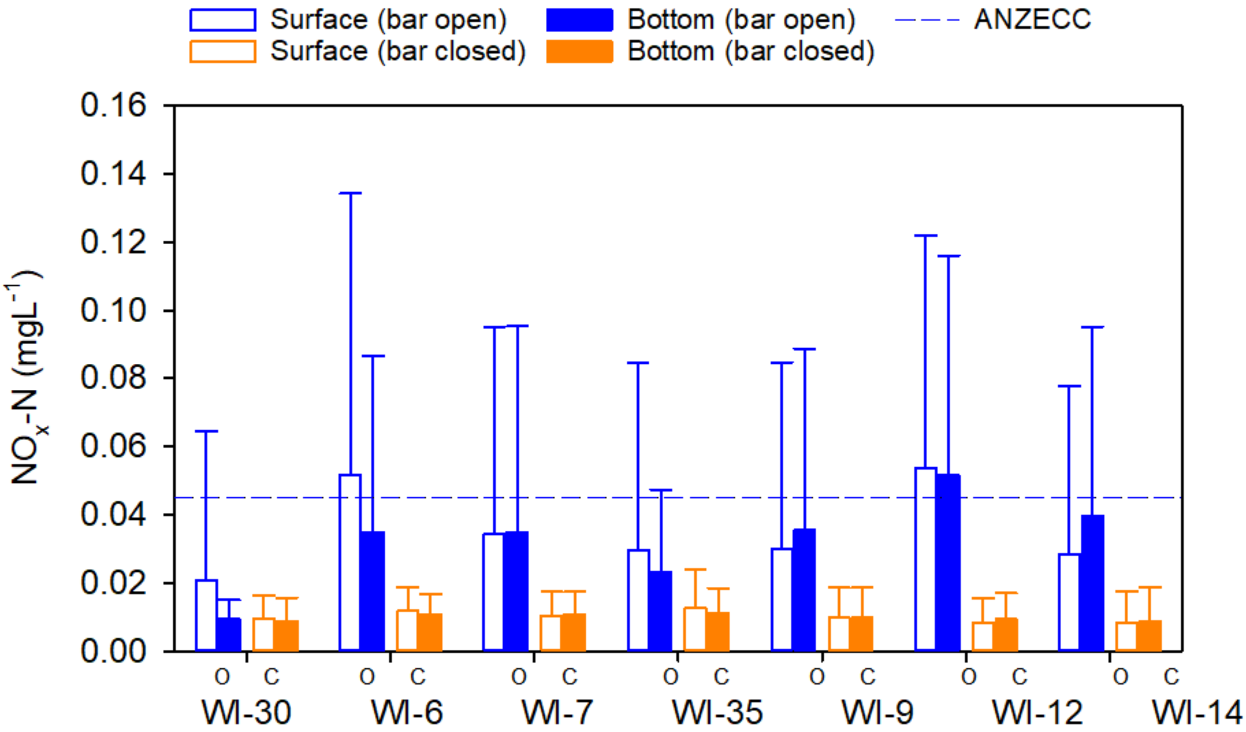

Figure 22 *Site mean and standard deviation of nitrite + nitrate nitrogen (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

Ammonium concentrations were well above the ANZECC guideline of 0.04 mgL^{-1} (ANZECC & ARMCANZ 2000), predominantly in the bottom samples in spring 2016, in May 2017 and in August–September 2017 (Figure 23). Values were slightly above the guideline in July 2017.

The elevated concentrations during the bar-open periods were associated with stratified conditions and low oxygen bottom waters, which suggests the source is from the sediments.

Previous Wilson Inlet community reports have identified that dissolved oxygen concentration <4 mgL^{-1} increases the nutrient release from the sediment (Department of Water 2010 - Wilson Inlet Report to the Community No. 10; Water and Rivers Commission 2002 - Wilson Inlet Report to the Community No. 5). In May 2017, the estuary was unstratified and well-oxygenated and therefore the source of the ammonium may have been from localised inputs.

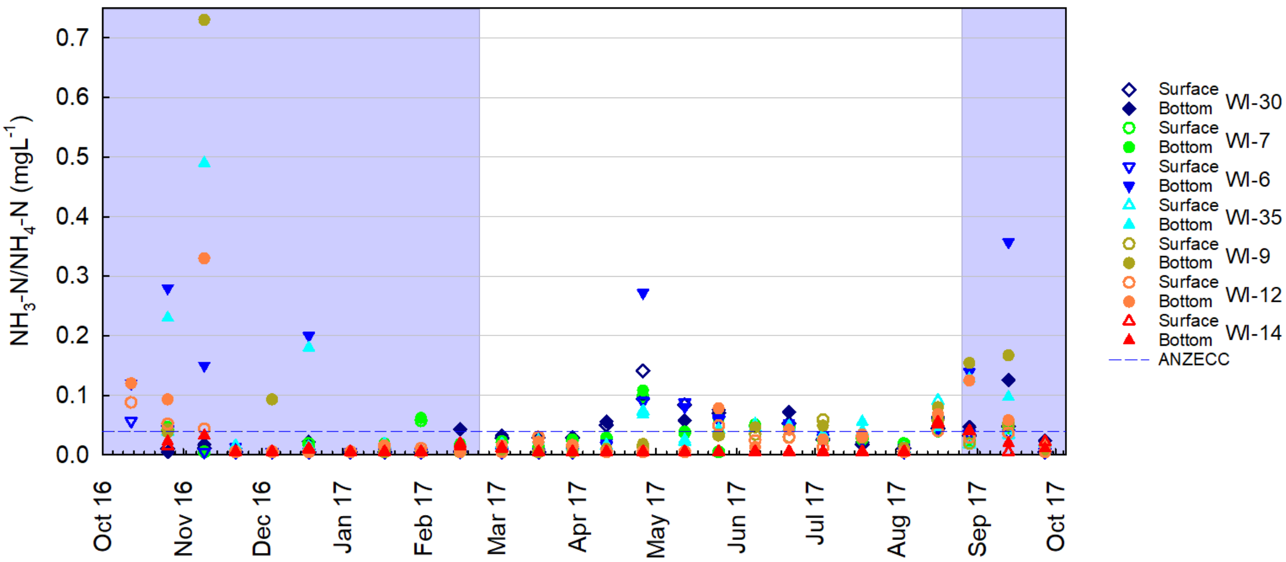

Figure 23 *Ammonium as NH_3/NH_4-nitrogen concentration (mgL^{-1}) in Wilson Inlet over time. The limit of reporting (LOR) is 0.01 mgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

Mean ammonium concentrations were well above the ANZECC guideline of 0.04 mgL^{-1} (ANZECC & ARMCANZ 2000), predominantly in the bottom water during the bar-open period (Figure 24).

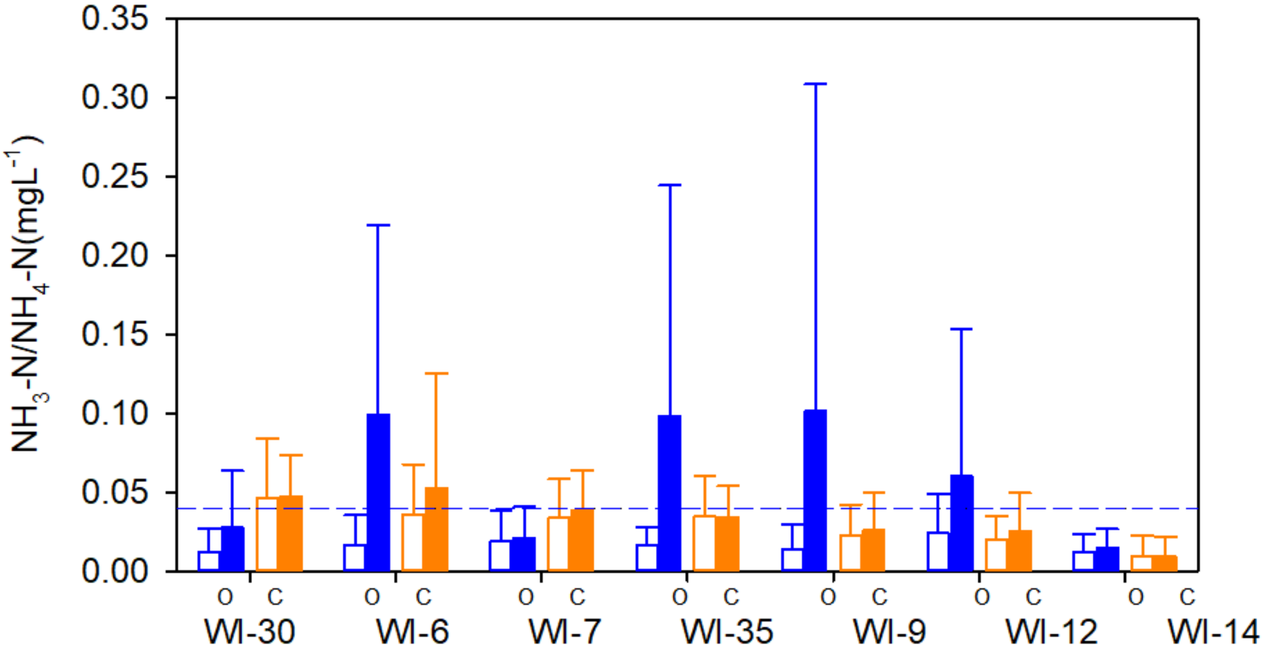

Figure 24 *Site mean and standard deviation of ammonium (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

The higher mean values during the bar-open period at the sites where hypoxic conditions were prevalent (WI–6, WI–35 and WI–9) (Figure 9) is an indication that ammonium is sediment derived.

At the sites closer to the bar, mean ammonium concentrations were around the ANZECC guideline value, while WI–14, the site furthest away from the bar, showed the lowest mean value which was well below the guideline value.

Total Phosphorus (TP) concentrations were mostly slightly above (December 2016) or below the ANZECC guideline of 0.03 mgL^{-1} (ANZECC & ARMCANZ 2000) (Figure 25).

Values were lowest from May through to July throughout the estuary. The higher concentrations in November and December 2016 were partly due to filterable reactive phosphorus (FRP) release from the sediment (Figure 27), while the higher concentrations in the August 2017 surface samples were most likely due to catchment input.

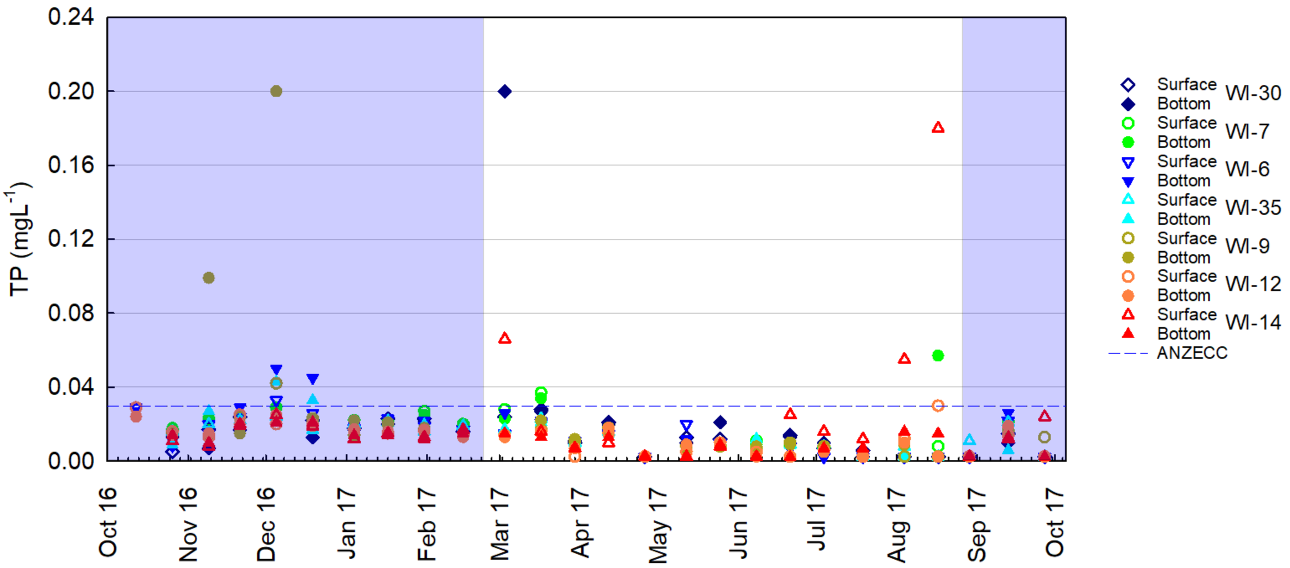

Figure 25 *Total phosphorus (TP) concentration (mgL^{-1}) in Wilson Inlet over time. The limit of reporting (LOR) is 0.005 mgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

Mean TP concentrations were mostly below the ANZECC guideline of 0.03 mgL^{-1} (ANZECC & ARMCANZ 2000) (Figure 26).

At most sites, concentrations were slightly higher during the bar-open period, which was partially due to the release of phosphate (FRP) from hypoxic sediments (Figure 28).

The high standard deviations at WI–30, WI–9 and WI–14 are due to one-off outliers (Figure *25*).

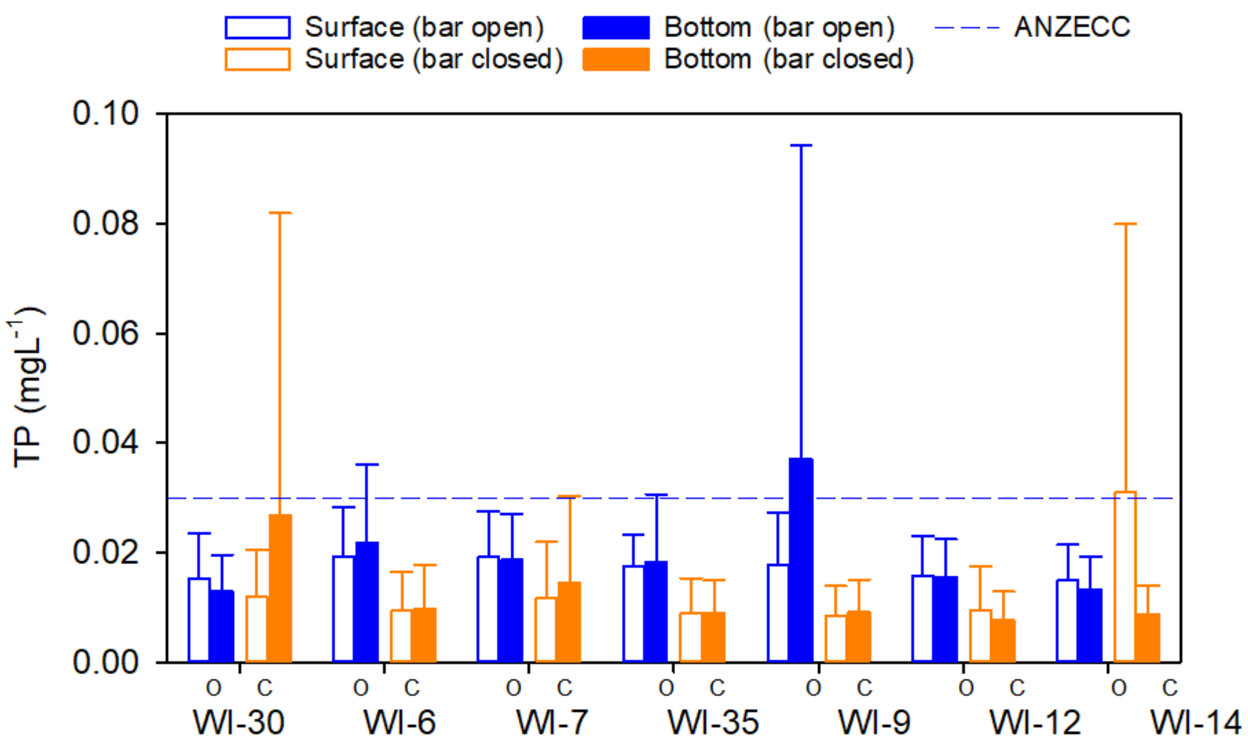

Figure 26 *Site mean and standard deviation of total phosphorus (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

FRP concentrations were above the ANZECC guideline of 0.005 mgL^{-1} (ANZECC & ARMCANZ 2000) in November to December 2016 in bottom samples due to FRP release from the sediment under anoxic conditions and after August 2017 in surface samples due to catchment inputs (Figure 27).

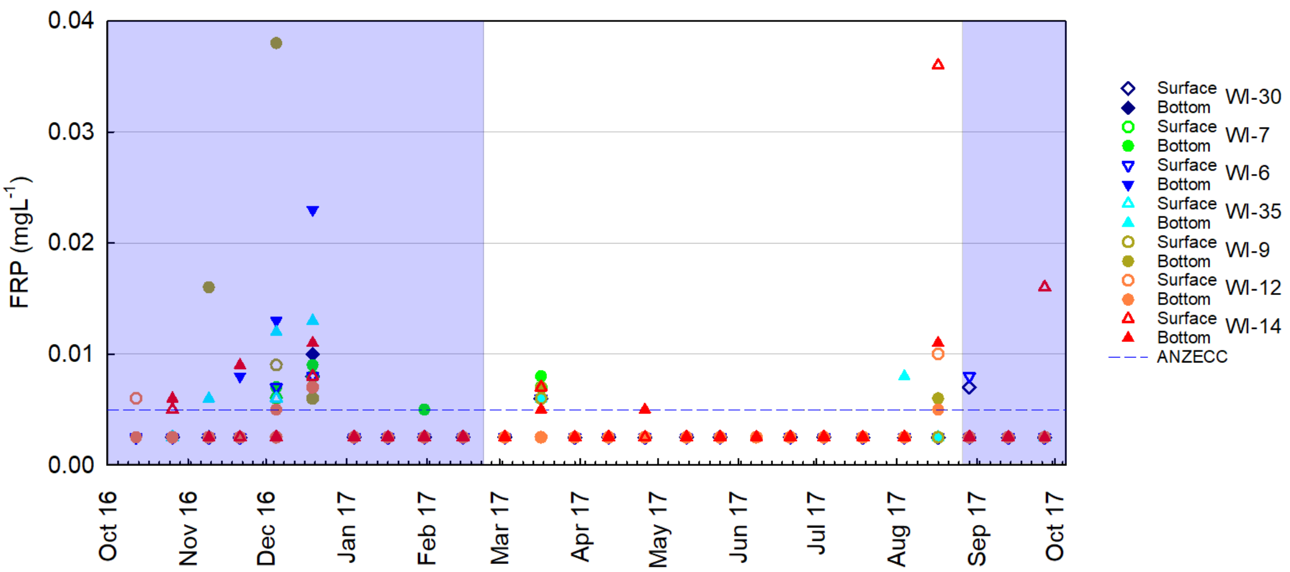

Figure 27 *Filterable Reactive Phosphorus (FRP) (mgL^{-1}) in Wilson Inlet over time. The limit of reporting (LOR) is 0.005 mgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

There were slightly increased FRP concentrations mid-March, potentially due to point source inputs or resuspension during a high wind event on 13 March (average wind speed of 19.8 km/h).

During other times FRP concentrations were below the reporting limit of 0.005 mgL^{-1}.

Mean FRP concentrations were mostly below the ANZECC guideline of 0.005 mgL^{-1} (ANZECC & ARMCANZ 2000), with the exception of the bottom water mean concentrations at WI–6 and WI–9 where FRP was released under hypoxic conditions during the bar-open period (Figure 28).

The high mean concentration at WI–14 during the bar-closed period indicate the source of FRP was most likely from the catchment.

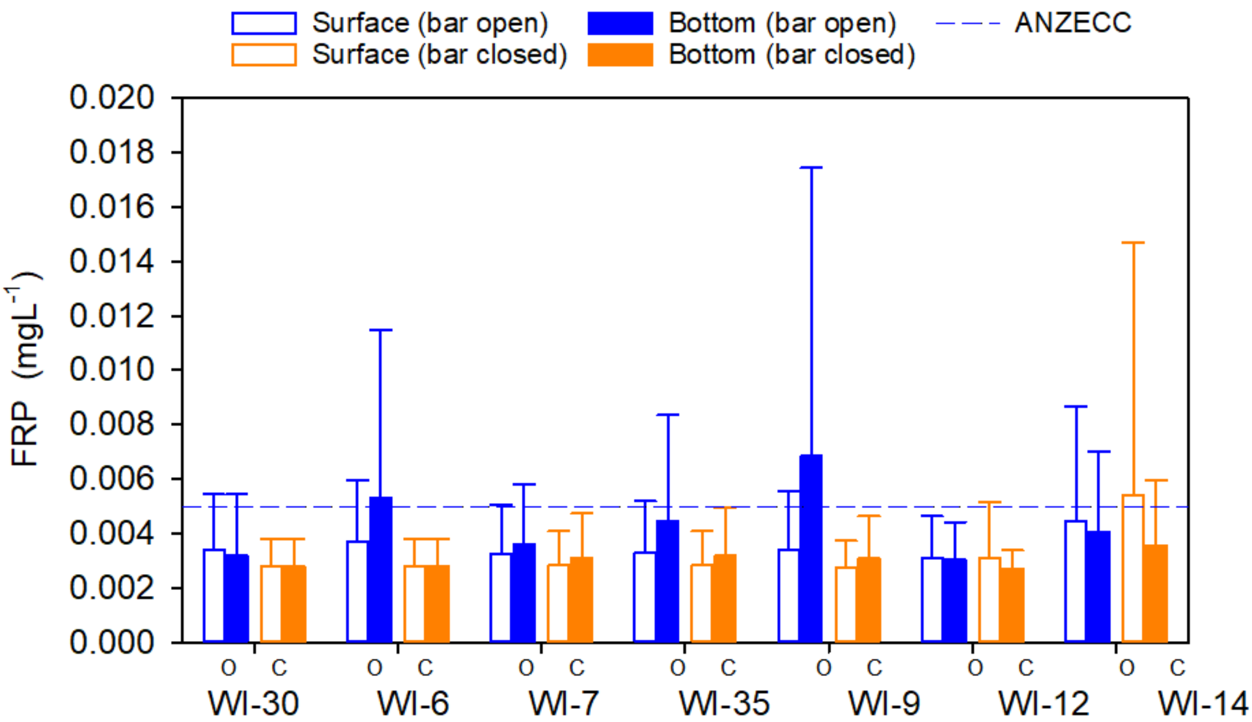

Figure 28 *Site mean and standard deviation of filterable reactive phosphate (mgL^{-1}) in surface (white bars) and bottom (coloured bars) waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

Chlorophyll *a* is an indicator of phytoplankton activity in the water; routine samples only quantify chlorophyll *a* in the surface layer although algae can be found throughout the depth.

Peak chlorophyll *a* concentrations occurred in spring 2016 and late winter 2017 during the bar-open period and were well above the ANZECC guideline value of 3 µg^{-1} (ANZECC & ARMCANZ 2000) (Figure 29).

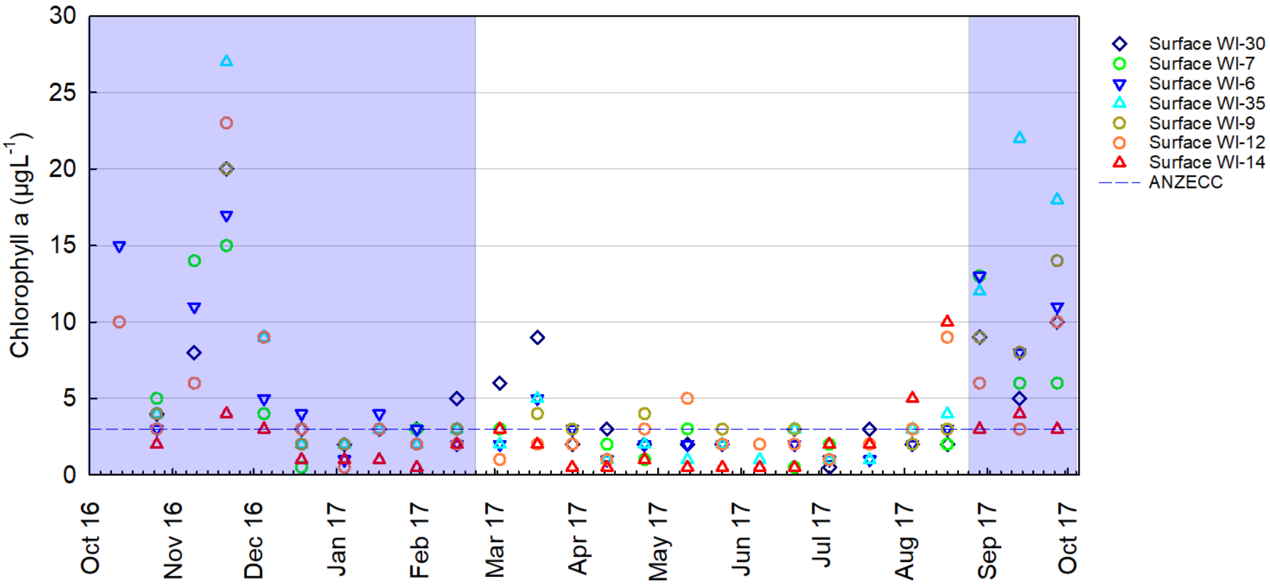

Figure 29 *Chlorophyll a (µg/L) in Wilson Inlet over time. The limit of reporting (LOR) is 1 µgL^{-1}, values below the LOR are displayed as 0.5 × LOR. The shaded area represents the time period when the sandbar was open.*

This seasonal pattern and the chlorophyll *a* concentrations are comparable with an earlier study in 1997–1999 by Twomey and Thompson (2001).

Chlorophyll *a* concentrations were also elevated in late summer at site WI–30, closest to the ocean opening. During summer, nutrient inputs from point sources close to the entrance or bar may have contributed to algal growth.

Mean chlorophyll concentrations were well above the ANZECC guideline of 3 µgL^{-1} (ANZECC & ARMCANZ 2000) during the bar-open period, while they were at or below the guideline value during the bar-closed period (Figure 30).

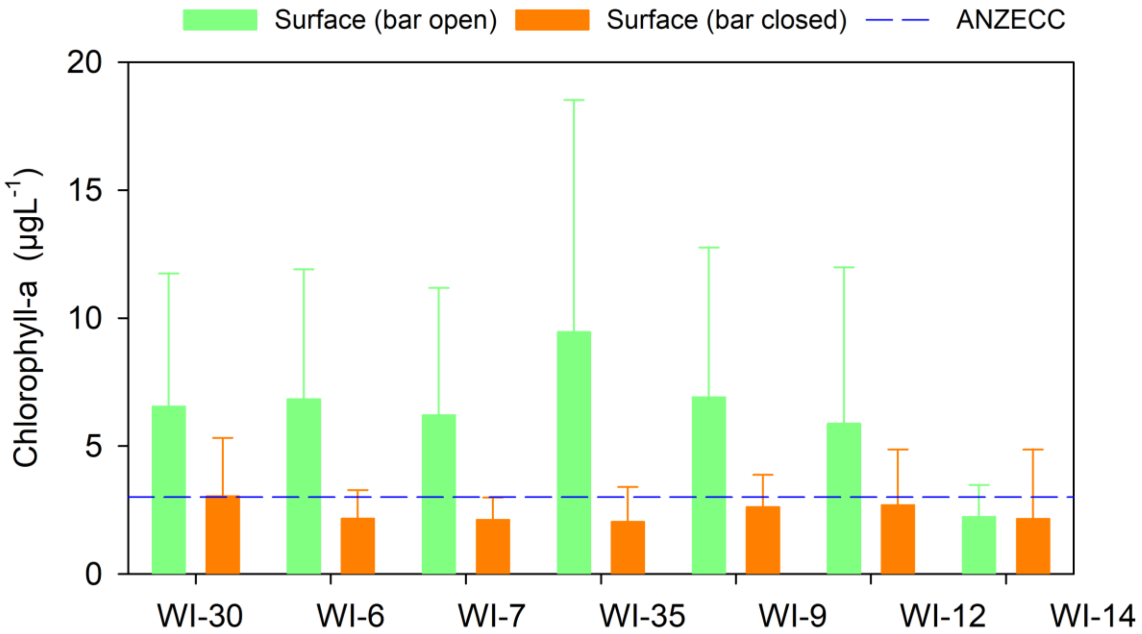

Figure 30 *Site mean and standard deviation of chlorophyll-a (µgL^{-1}) in surface waters during the bar-open (blue) and bar-closed (orange) period. O label bar-open period, C labels bar-closed period*

10. Phytoplankton

Fortnightly phytoplankton samples were analysed taxonomically and cell densities counted at four sites in Wilson Inlet. The densities (cells per ml) of the main phytoplankton groups are shown in Figure 31.

The main groups were diatoms and dinoflagellates throughout the year at all sites.

Cryptophytes and chlorophytes, which had both been found at high densities for some periods in previous years (Department of Water 2007 - Wilson Inlet Report to the Community No. 9) were less prominent. Comparing the four sites, WI–7, the site closest to the Denmark River, had the lowest densities and showed a slightly different pattern with peak densities in August 2017 (Figure 31).

At WI–12, WI–6 and WI–30, the highest cell densities were found in spring (December 2016 and September 2017), when ammonium and filterable reactive phosphorus (FRP) concentrations were high. These represent typical diatom spring blooms that have been reported previously (Pearce et al. 2000) (Department of Water 2007 - Wilson Inlet Report to the Community No. 9).

There was a second spike in cell densities in autumn (March 2017) after the bar closed when ammonium and FRP concentrations were increased. This was most prominent at sites WI–6 and WI–30. Such a density spike in the beginning of autumn has been noted in an earlier study (2003) (Department of Water 2007 - Wilson Inlet Report to the Community No. 9), but is not a regularly occurring event. Densities were generally low in winter.

The dominant species were the same that have previously been reported as being dominant (Department of Water 2007 - Wilson Inlet Report to the Community No. 9).

While the two diatom species *Chaetoceros tenuissimus* and *Cyclotella* spp, were responsible for the density spikes in November and December 2016 at sites WI–12, WI–30 and WI–6, the dinoflagellate *Prorocentrum minimum* was the dominant species at WI–7 during this time.

The density spikes during March–April 2017 were dominated by *Cyclotella* spp at all sites.

In September 2017, the phytoplankton community at WI–12 was dominated by *Cyclotella* spp. again, while *Chaetoceros* spp. and *Chaetoceros throndsenii* were dominant at sites WI–30, WI–6 and WI–7.

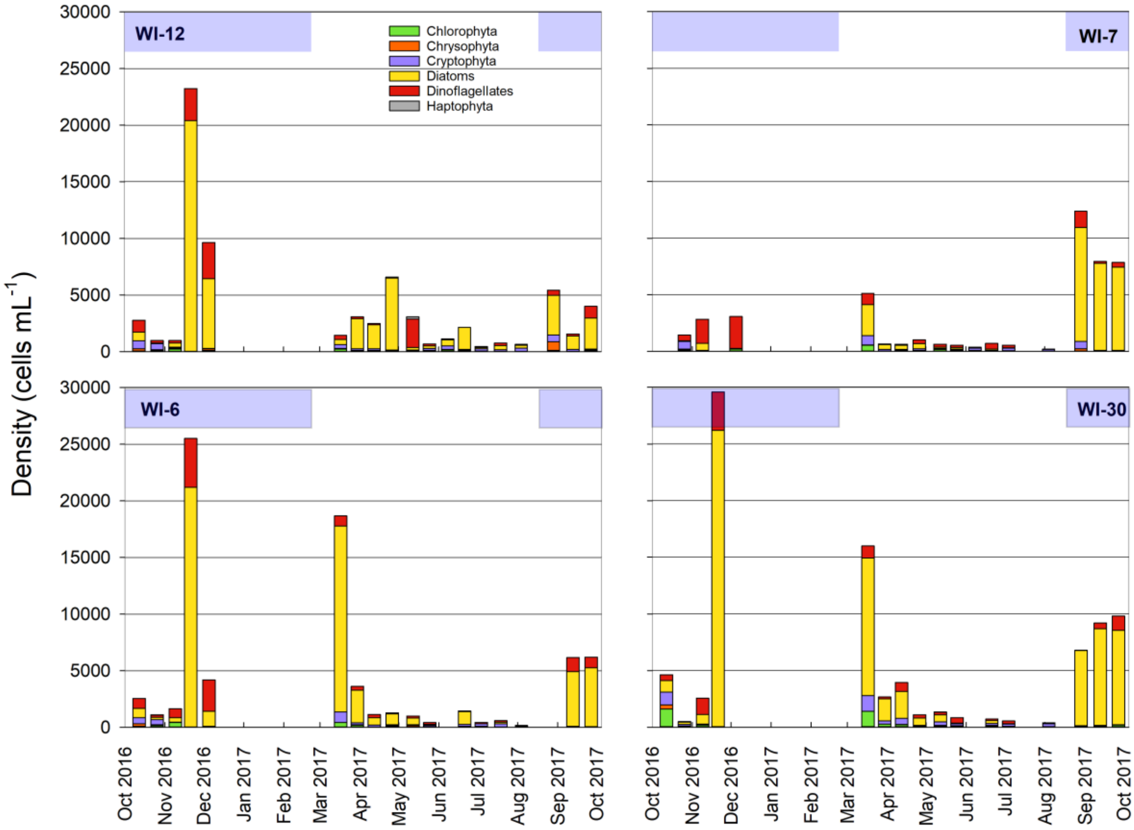

Figure 31 Density of the main algae groups as cells mL^{-1} at four sites in Wilson Inlet over time

10.1 Algal blooms and fish kill events

No algal blooms or fish kills have been reported to the Department of Water and Environmental Regulation during the reporting period.

10.2 Potentially harmful algae species

The potentially diarrhoeic shellfish poisoning (DSP) producing dinoflagellate *Dinophysis acuminata* was recorded on 6 of the 26 sampling events (Figure 32). *D. acuminata* had previously been reported in Wilson Inlet (Department of Water 2007 - Wilson Inlet Report to the Community No. 9).

On two occasions (26 October 2016 and 12 May 2017), haptophytes which are potentially toxic to fish (ichthyotoxic), were recorded at concentrations between 6 and 185 cells per millilitre (mL^{-1}).

Karlodinium spp. and members of the *Gymnodinium karenia* complex, all potential Neurologic Shellfish Poisoning (NSP) producing organisms, were observed. However, they were at densities below the Western Australia Shellfish Quality Assurance Program (WASQAP) trigger (Department of Health 2016).

On 12 May 2017, *Karenia* spp. (potentially NSP producing) was detected at 33 cells mL^{-1}, which is above the WASQAP trigger (Department of Health 2016).

Organisms of the dinoflagellate group of *Karenia* / *Karlodinium* / *Gymnodinium* have also been previously recorded in Wilson Inlet (Department of Water 2007 - Wilson Inlet Report to the Community No. 9).

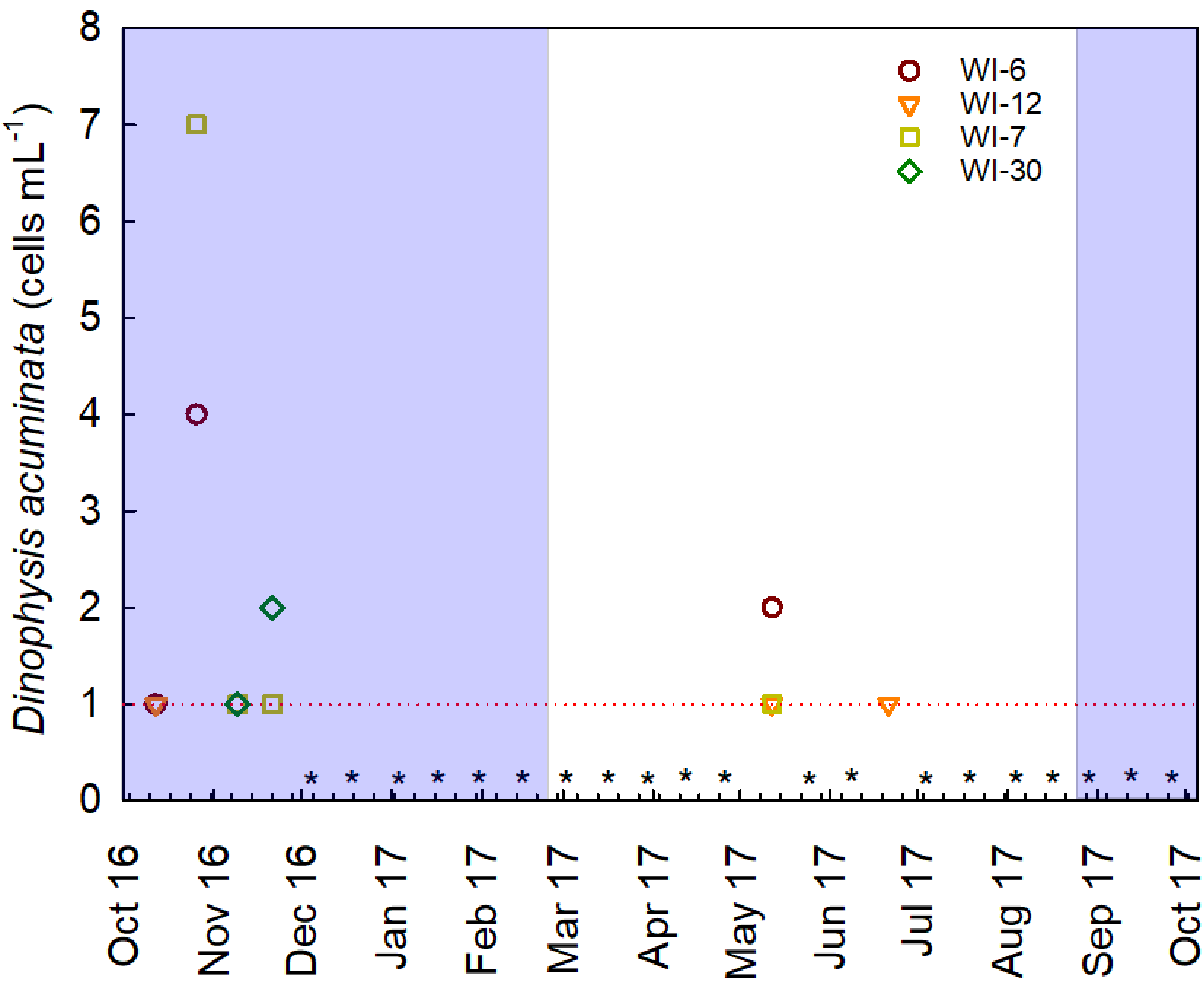

Figure 32 *Concentration of Dinophysis acuminata (cells/mL) over time*

The red line indicates the WASQAP trigger (Department of Health 2016). Asterisks indicate that samples were taken but no *D. acuminata* was found.

11. Seagrass

The colonising seagrass species *Ruppia megacarpa* is the dominant seagrass within the Wilson Inlet. *Ruppia* is a flowering marine plant and requires good water quality in terms of water clarity to receive sufficient light to grow (Carruthers et al. 1999).

A number of studies from the 1990s to late 2000s have investigated the ecological roles of *Ruppia* in the estuary, as well as its abundance and distribution.

Although seagrass has not been directly monitored in the current monitoring period, the most recent seagrass distributions are presented here as the seagrass is an important part of the ecosystem.

Seagrass distribution surveys in Wilson Inlet were conducted in 1994 (Bastyan et al. 1995), 1996 (Department of Environment 2003 - Wilson Inlet Report to the Community No. 7), 2007 and 2008.

Ruppia plays an important part in maintaining the health of the Wilson Inlet by:

- providing a framework for macro- and microalgal epiphytes, which underpin the food web by supporting invertebrates (fish food)
- providing shelter for juvenile fish; by helping to prevent water quality issues by adsorbing and buffering nutrients
- actively transporting oxygen derived from photosynthesis into the sediment
- stabilising the sediment preventing resuspension of mud and silt
- providing a food source for swans and other water fowl

The *Ruppia* in Wilson Inlet has also been identified as playing a major role in the uptake of nutrients from the water column (Carruthers et al. 2007; Dudley et al. 2001) and thus likely reducing the occurrence of algal blooms.

Similar seagrass spatial cover was observed in 2007 (Figure 33) and 2008 (Figure 34) to the survey in 1996 (Department of Environment 2003 - Wilson Inlet Report to the Community No. 7). The density of cover was higher in February 2008 compared to November/December 2007 (Figure 35, Figure 34). The difference in density is likely due to natural variability caused by grazing pressure and natural growth patterns, which depend on water level, water clarity and temperature.

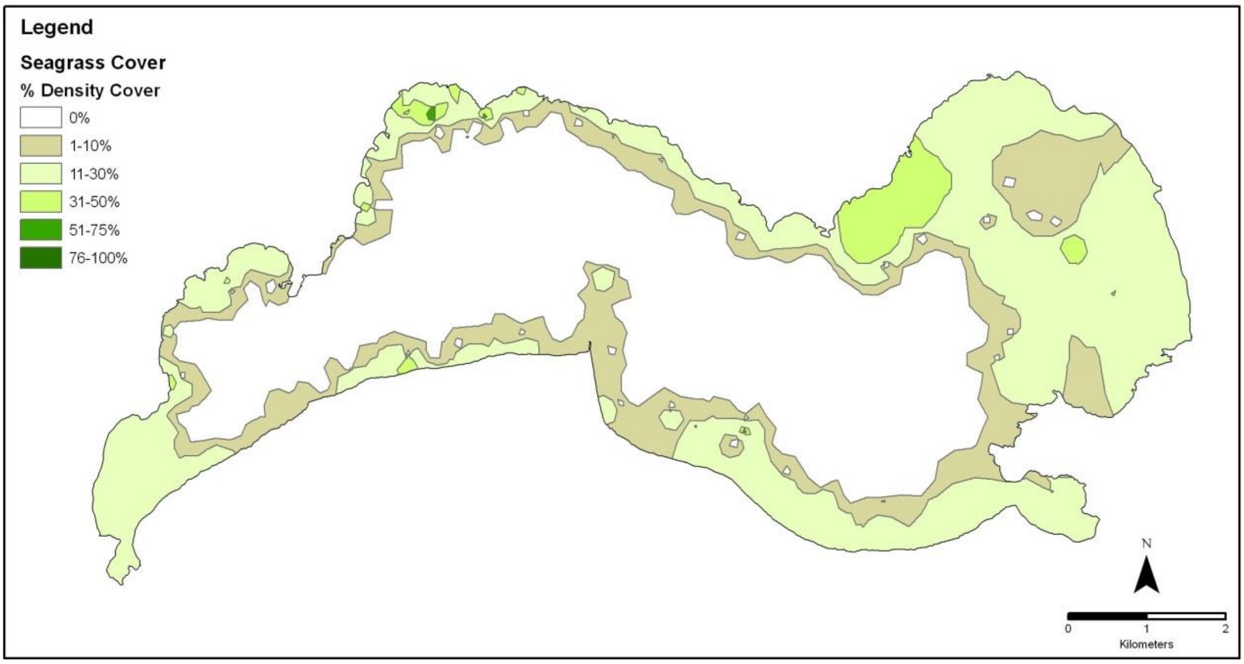

Figure 33 *Seagrass distribution in Wilson Inlet (2007)*

The distribution was mainly around the perimeter of the estuary and *R. megacarpa* was still the main species. The slight increase in seagrass habitat between 2007 and 2008 may be real or as a result of using the maximum depth at which seagrass was recorded in the 2008 survey (three metres) rather than the *assumed* reported depth limit of two metres used in 2007.

The Regional Estuaries Initiative is funding an update of the seagrass distribution in Wilson Inlet. The data has been collected over the 2017–2018 summer and will be presented in the 2018 Annual Condition Report.

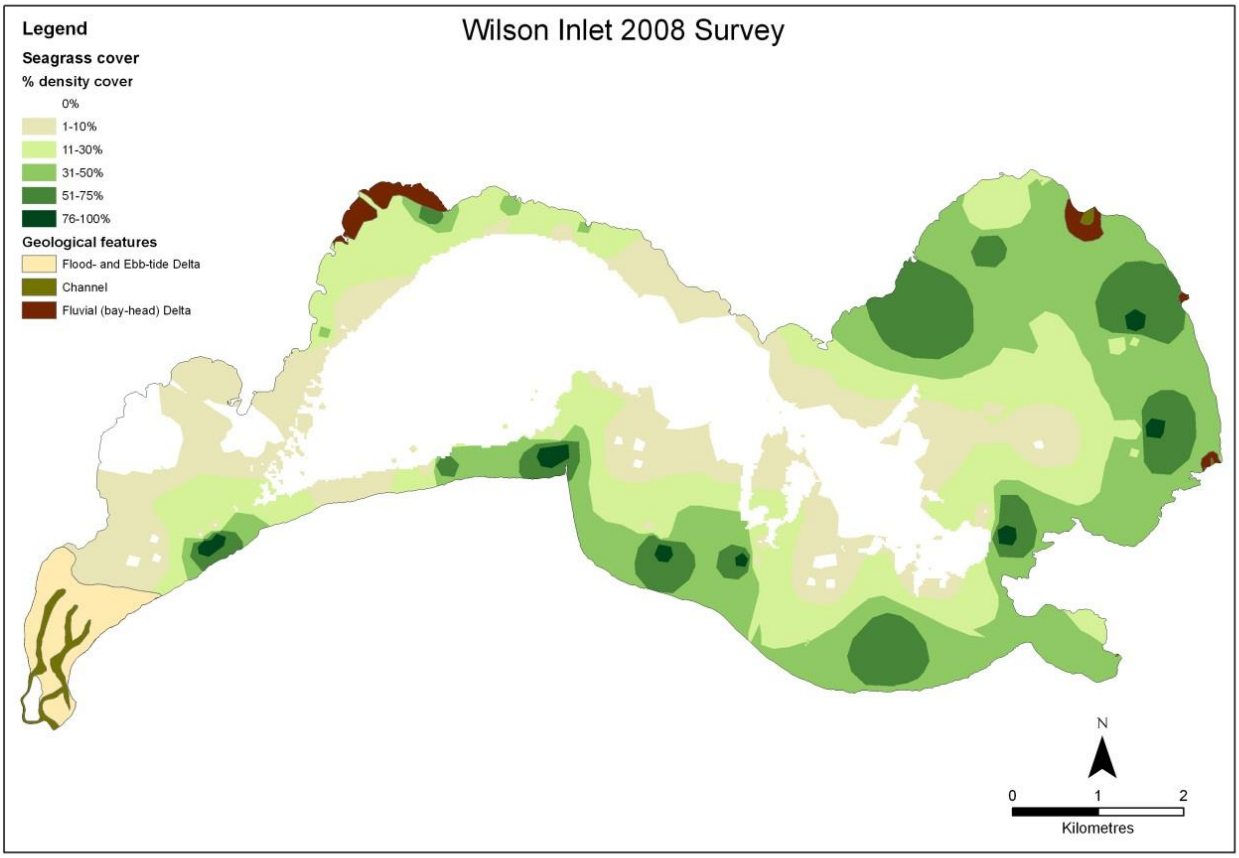

Figure 34 *Seagrass distribution in Wilson Inlet (2008)*

12. Conclusions and recommendations

From July 2016 the bar was open for approximately 7 months (the average is 6 months) and closed naturally on 23 February, 2017. The 2017 year had an average rainfall of 966 mm, with most of the rain brought in late winter and early spring. This resulted in a relatively late bar opening on August 24 and at a record high water level.

During the bar-closed period the water of the Inlet was brackish, well-mixed, well-oxygenated, low in nutrients and phytoplankton activity. Conditions varied considerably following the bar opening. Initially the surface layer was fresh and relatively high in nutrients and marine waters intruded as a bottom layer creating strong stratification followed by hypoxia. Stratified conditions did not persist, most likely due to the mixing by strong prevailing winds.

In spring, following the freshwater inflows, combined with warmer temperature peak phytoplankton activity was observed, mostly diatom blooms.

There were no harmful algal blooms or fish kill events during the monitoring period. Four potentially harmful species were recorded, all at low cell densities. The density of *Dinophysis acuminata* exceeded the guideline for safe seafood consumption for farmed shellfish on 4 occasions.

Recommendations

- Two additional monitoring sites be added to the program; one mid-way between WI-30 and WI-6 during the sand-bar open period to provide more information on the saline intrusion, hypoxia and potential nutrient release; and the second between sites WI-12 and WI-14 towards the Hay River mouth during the sand-bar closed period to monitor inputs from the Hay River.

Shortened forms

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment Conservation Council
CO_2	Carbon dioxide
DO	Dissolved oxygen
DSP	Diarrhoeic shellfish poisoning
DWER	Department of Water and Environmental Regulation
FRP	Filterable reactive phosphorus
kL	Kilolitres
km^2	Square kilometres
m^3/s	Cubic metres per second
mgL^{-1}	Milligrams per litre
mL^{-1}	Cell per millilitre
NH_3/NH_4	Ammonia/ammonium
NO_x	Nitrate + nitrite
NSP	Neurologic shellfish poisoning
NTU	Nephelometric turbidity units
pH	Measure of acidity or alkalinity in water and sediments
ppt	Parts per thousand
REI	Regional Estuaries Initiative
Secchi	Secchi depth
TN	Total nitrogen
TP	Total phosphorus
μgL^{-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 2 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'.
Ecological integrity	A measure of the "health" or "condition" of an ecosystem. The ability of the aquatic ecosystem to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation as comparable as possible to that of natural habitats within a region (Schofield and Davies 1996).
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
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
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.
Phosphate	
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

Nitrogen and phosphorous 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 soluble phosphate are also measured. Dissolved nutrients are readily bioavailable to plants and phytoplankton for growth.

Table 2 summarises the suite of nutrient analytes programmed for Wilson Inlet.

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.

- 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. The objective of the ANZECC guidelines with respect to the protection of aquatic ecosystems is: *to maintain and enhance the ‘ecological integrity’ of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes*.

  In addition to biological indicators, chemical and physical water quality indicators are widely used for assessing and/or protecting ecosystem integrity.

  The ANZECC water quality guidelines are derived from biological and ecological effects data and through the use of reference data. In the case of non-toxic direct effect stressors (e.g., nutrients) the guideline trigger values are derived from reference data. If data exceed the guideline value then it is inferred that a ‘potential’ risk exists. The guideline emphasises that the trigger values are not standards and that they are designed to be used in conjunction with professional judgement, to provide an initial assessment of the state of a water body with respect to maintaining the environmental values of a water body.

  The intention regarding the use of the guidelines is to invoke two responses. One, is to continue monitoring, if the monitoring site value is below the trigger value, showing that there is a ‘low risk’ that a problem exists. The alternative response, management/remedial action or further site-specific investigations, occurs if the trigger value is exceeded — i.e. a ‘potential risk’ exists.

The guideline also recommend that the default trigger values be used only in the absence of the site-specific reference values. As we develop a database of monitoring data these reference values may change to be site-specific to the Regional Estuaries Initiative (REI) estuaries. In the interim, we have used the guideline default values as a reference point to compare data between estuary zones and also to compare REI estuaries regionally. The data may be summarised within a zone as annual or seasonal means or medians, or depending on hydrological conditions such as bar-open or bar-closed scenarios. In each case the data are plotted against the default guideline value for comparison and not as a pass or fail test.

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 2 *Nutrient suite and sampling rationale*

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 mg/L **LOR** 0.025 mg/L
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/fertilizer inputs from the catchment, often closely related to flow volume.	**ANZECC guideline** 0.045 mg/L **LOR** 0.01 mg/L
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. Bottom water ammonium can be an indicator of sediment source.	**ANZECC guideline** 0.04 mg/L **LOR** 0.01 mg/L
Total Phosphorous (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 mg/L **LOR** 0.005 mg/L

Parameter	Description and sampling rationale	Limit of reporting (LOR) and ANZECC guideline
Filtered Reactive Phosphorus (FRP)	Filtered Reactive Phosphorus (FRP) describes the dissolved phosphates. This is a dissolved form of phosphorus, readily available to phytoplankton and higher plants for growth. Bottom water FRP can be an indicator of sediment source.	**ANZECC guideline** 0.005 mg/L **LOR** 0.005 mg/L

Table 3 summarises the analysis methods for nutrients and biological parameters measured.

Table 3 *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 4 summarises the biological measures of water quality for Wilson Inlet.

Phytoplankton are a natural component of the estuaries 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 activity.

Table 4 *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 mg/L
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 activity. Phaeophytin is a common chlorophyll degradation product.	**ANZECC guideline** 3 µg/L (Chl *a*) **LOR** 0.001 mg/L

Table 5 summarises the physicochemical data collected from water column profiling in Wilson Inlet.

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

Table 5 *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. 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	Measured in the field using a calibrated EXO2 sonde **Units**: ppt and mS/cm
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 freshwaters 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

The measurements described in Table 6 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 6 *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

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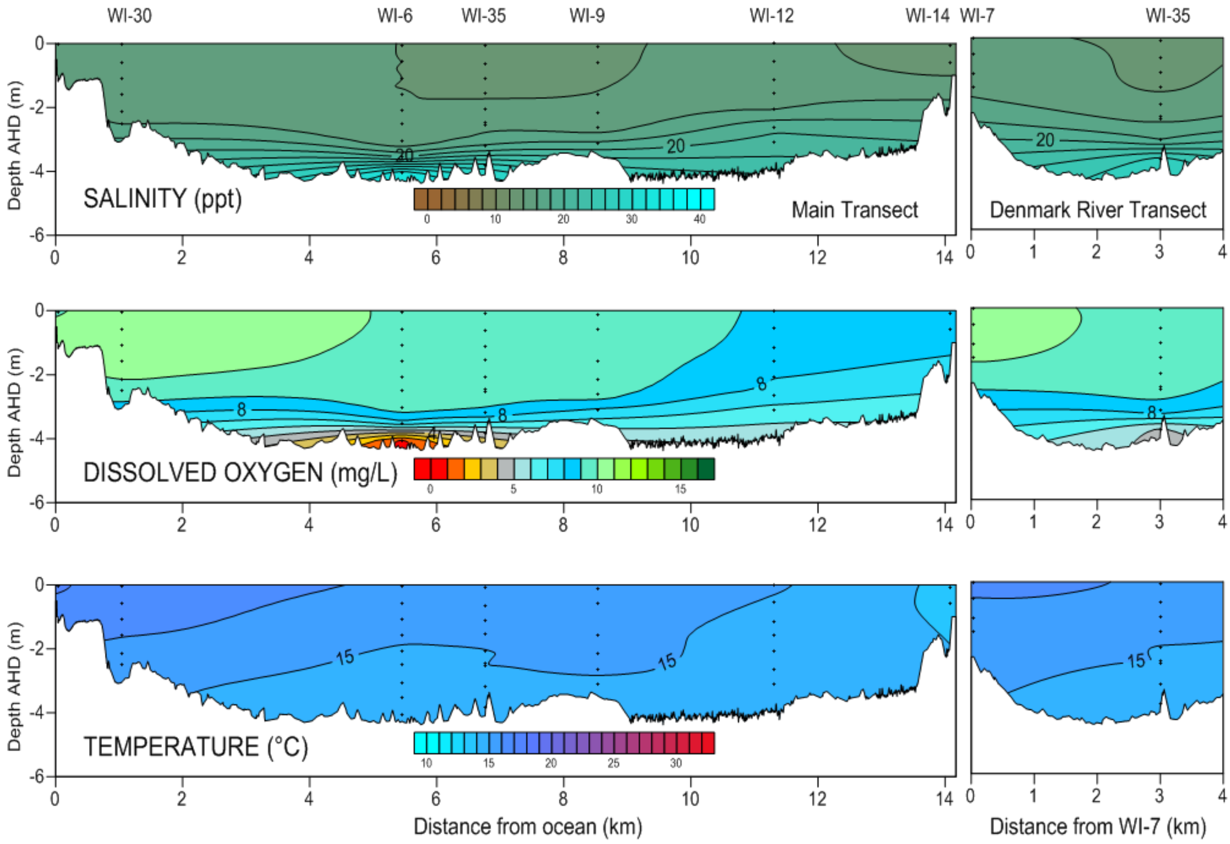

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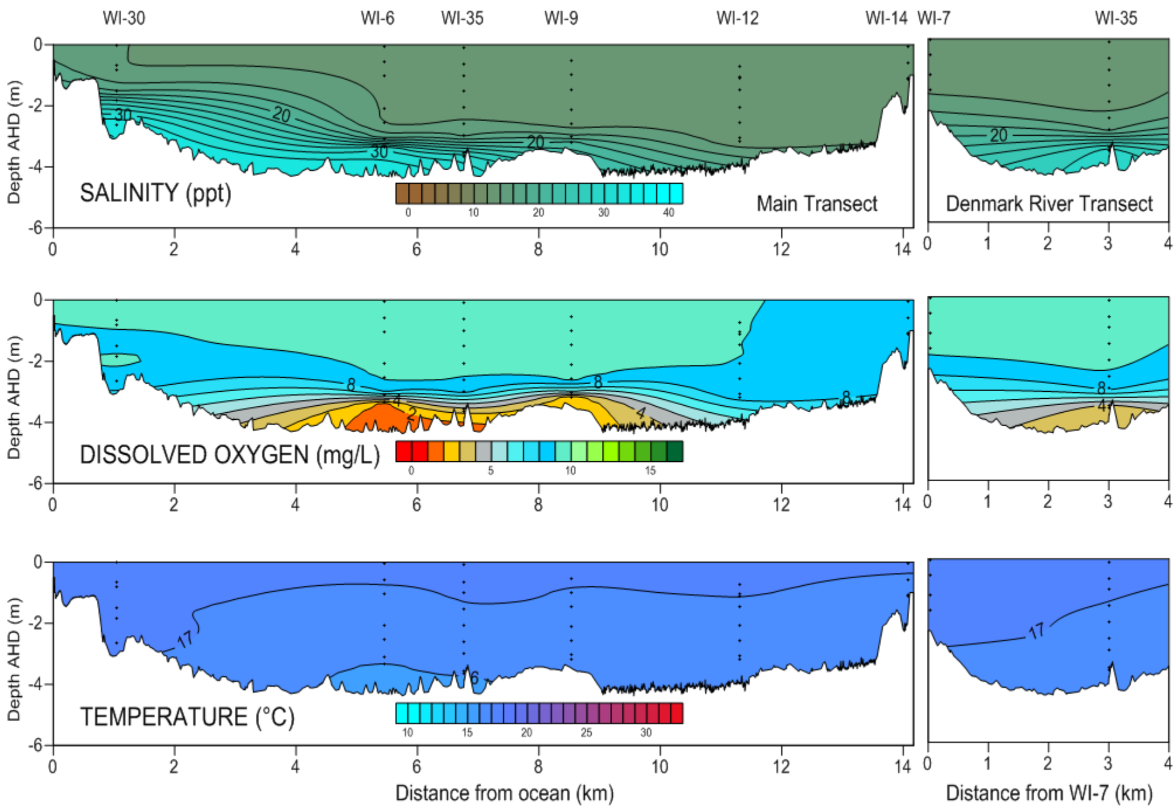

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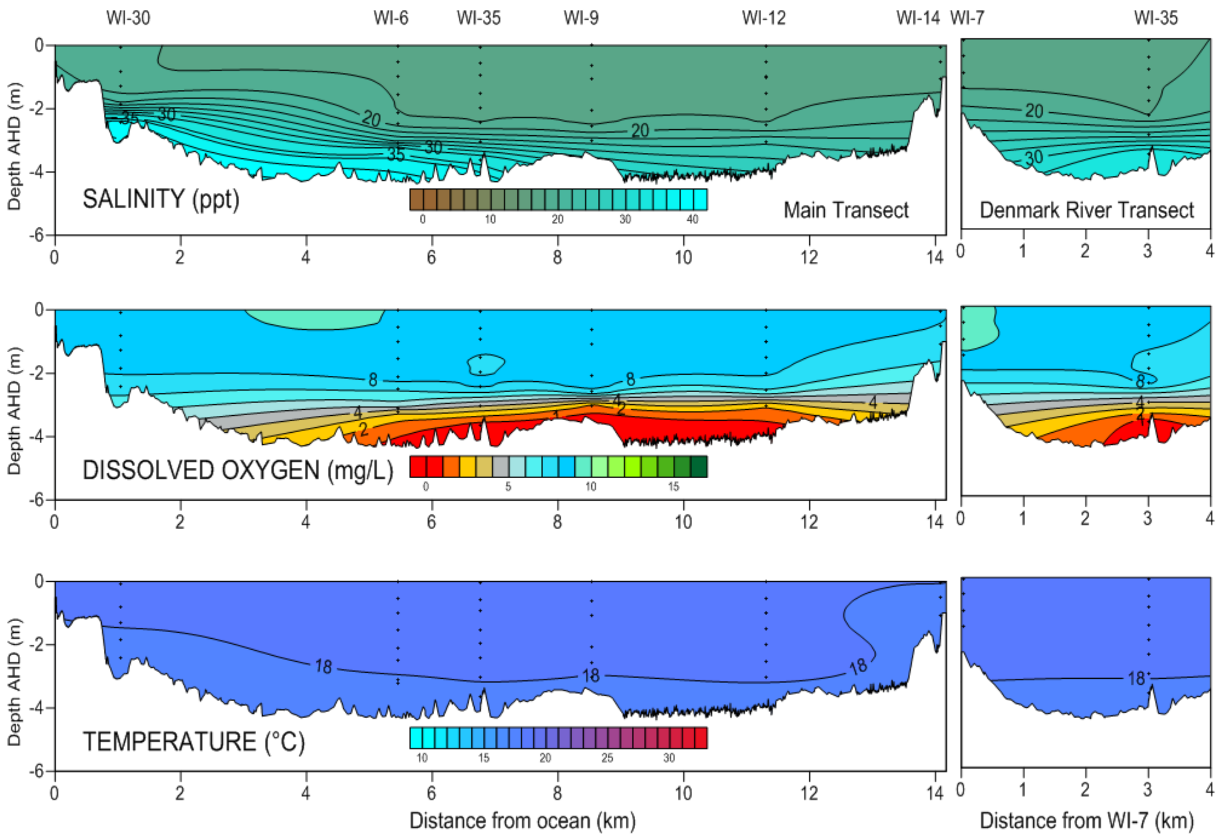

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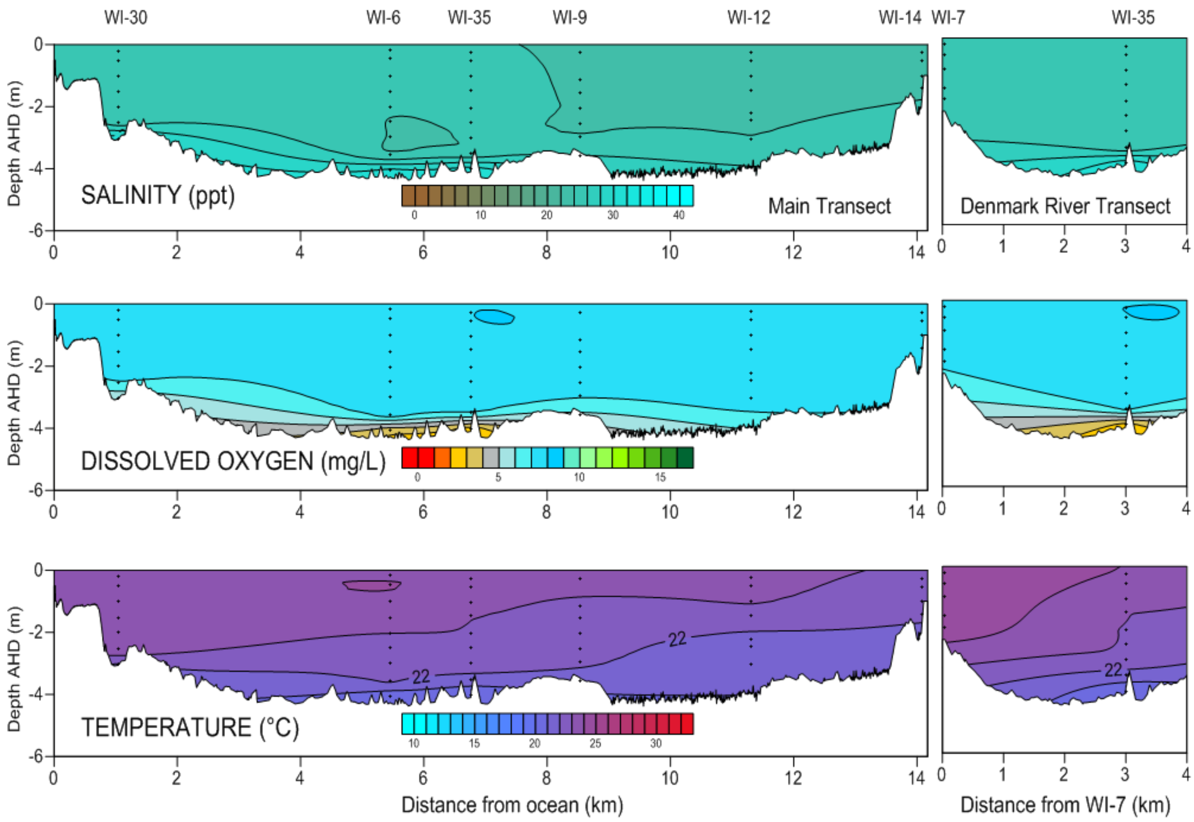

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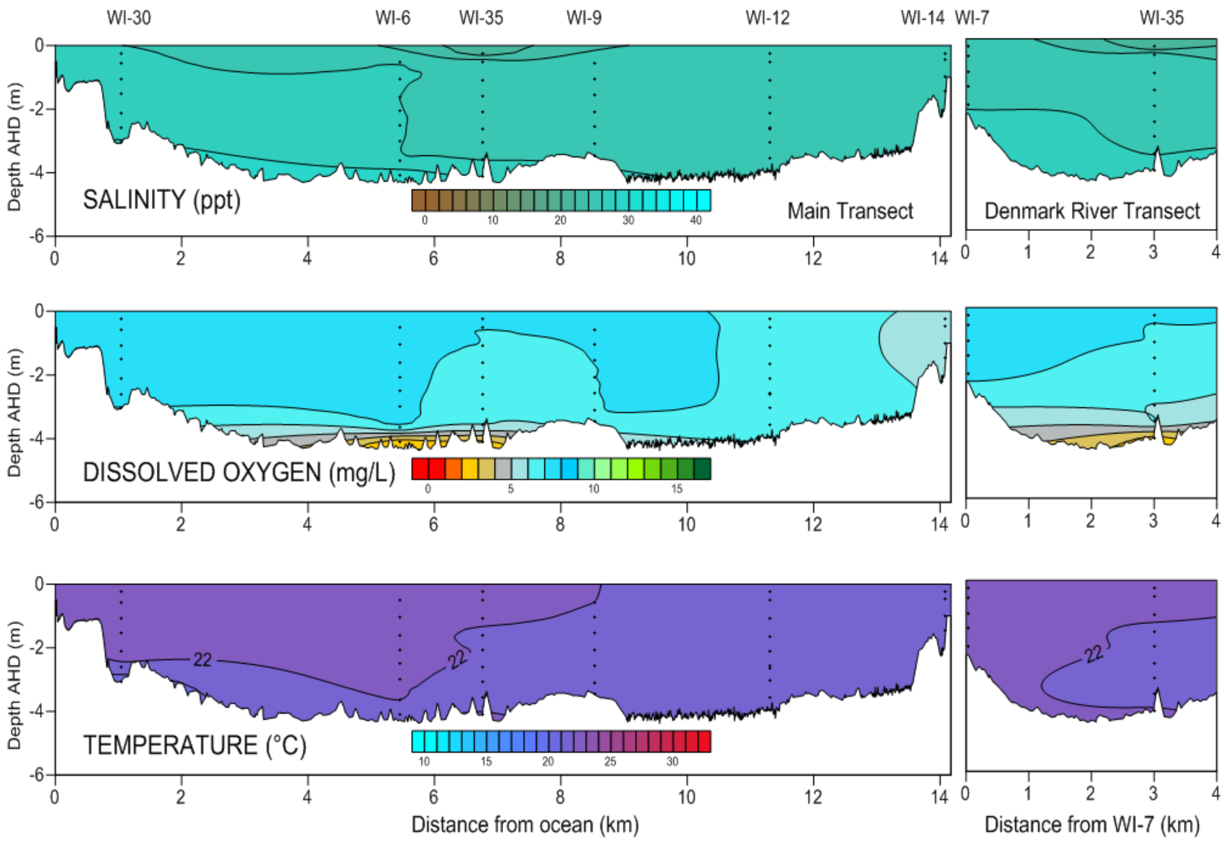

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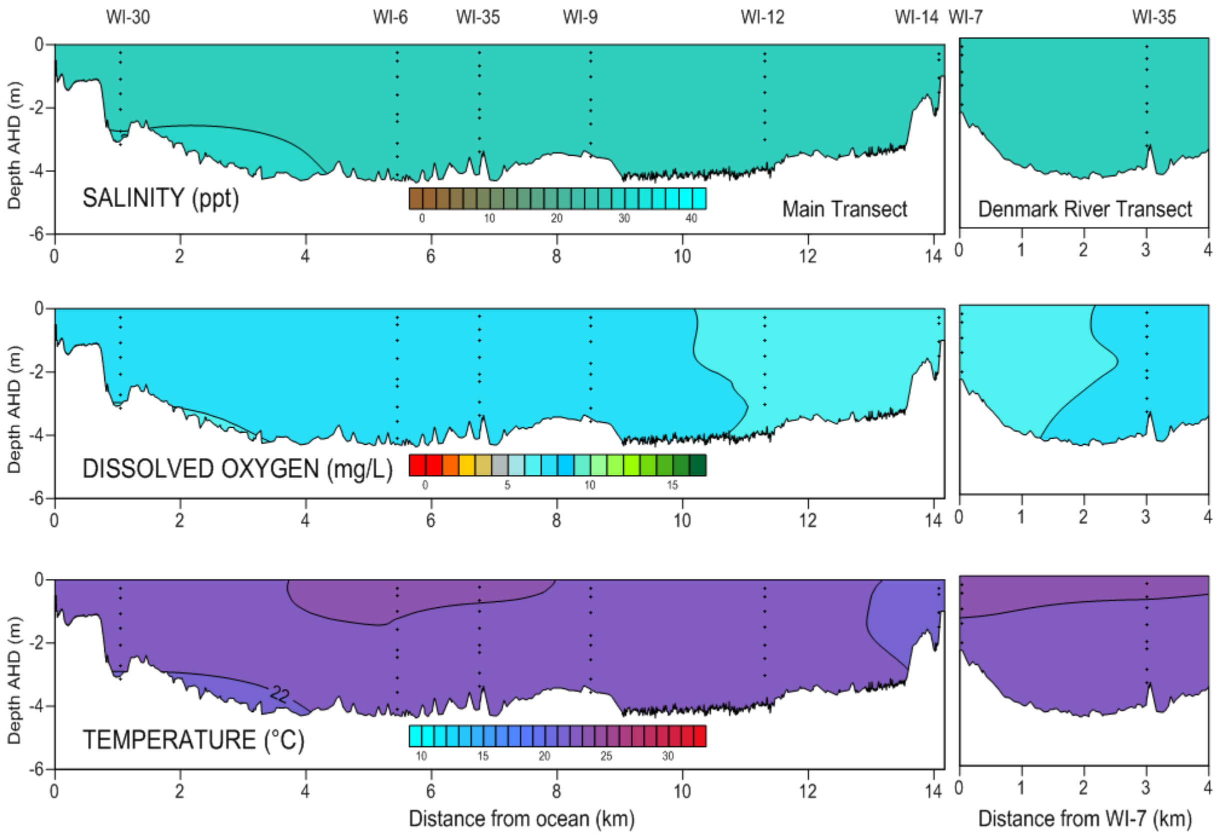

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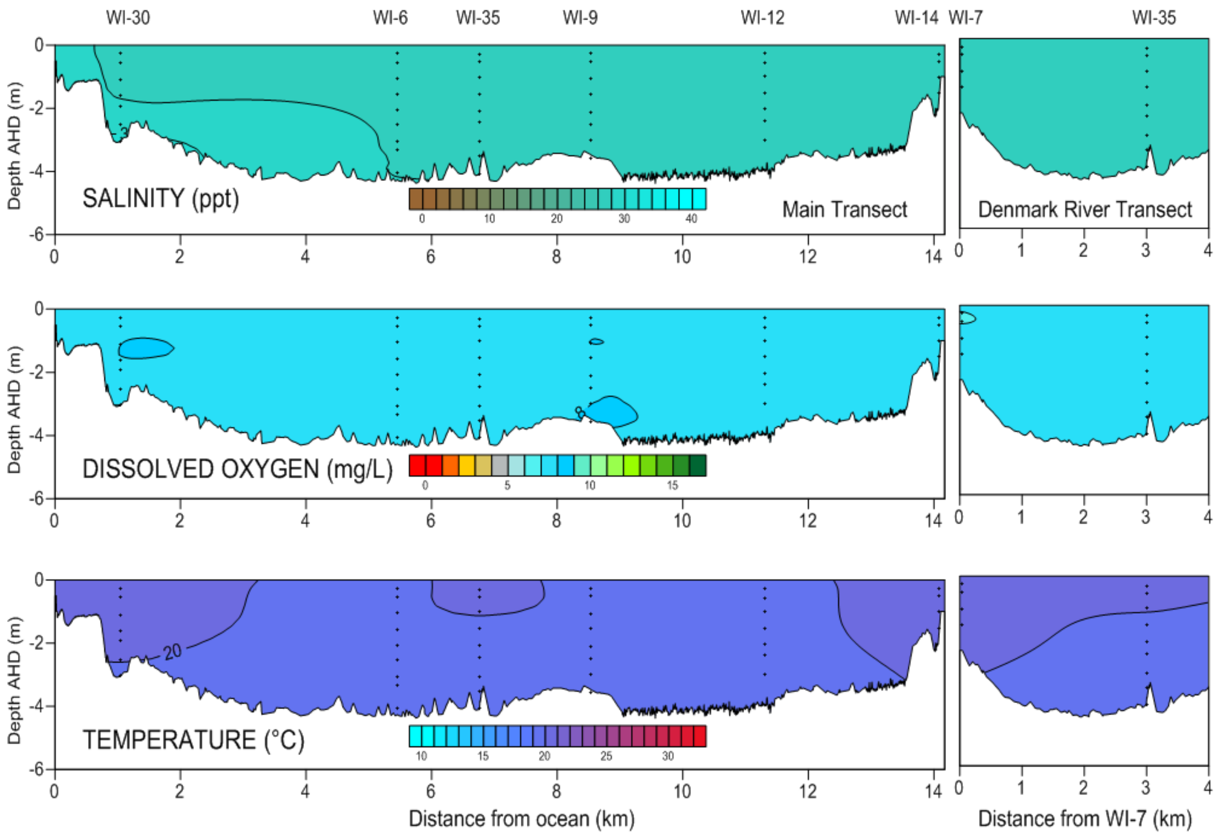

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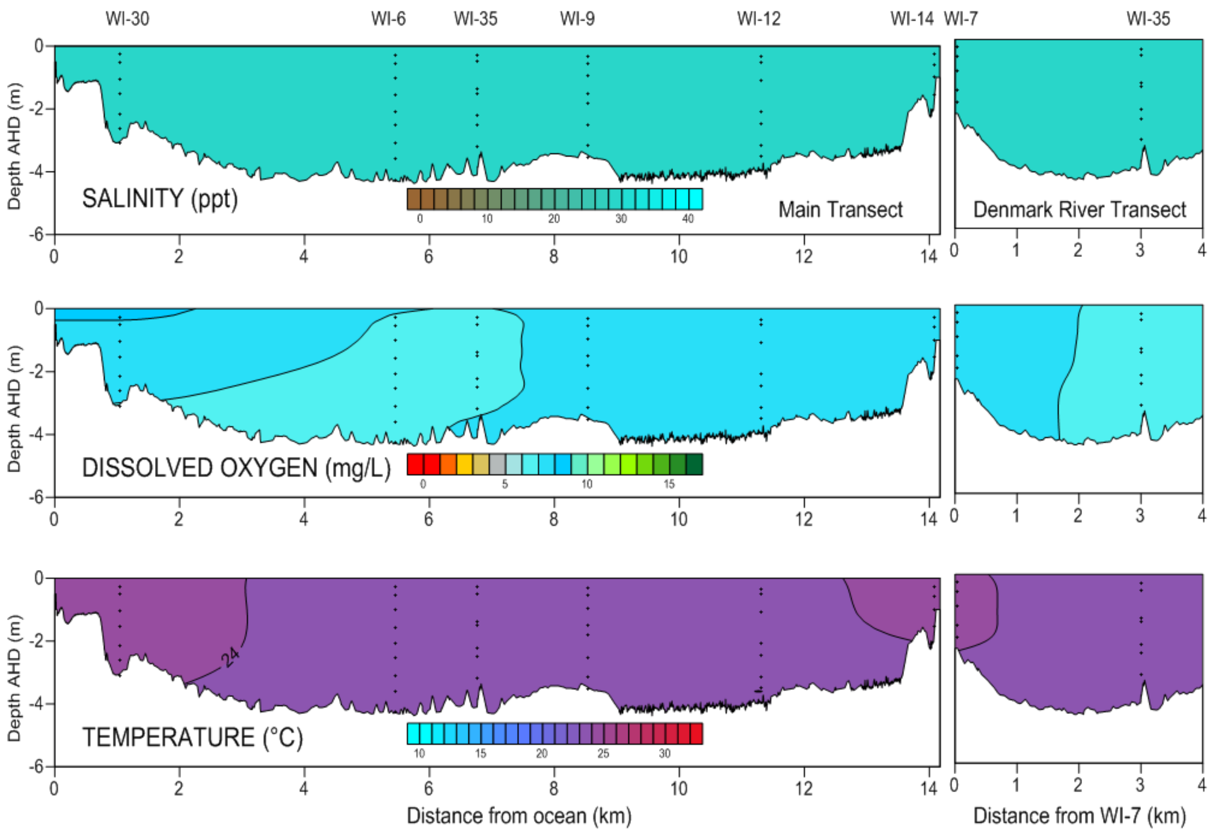

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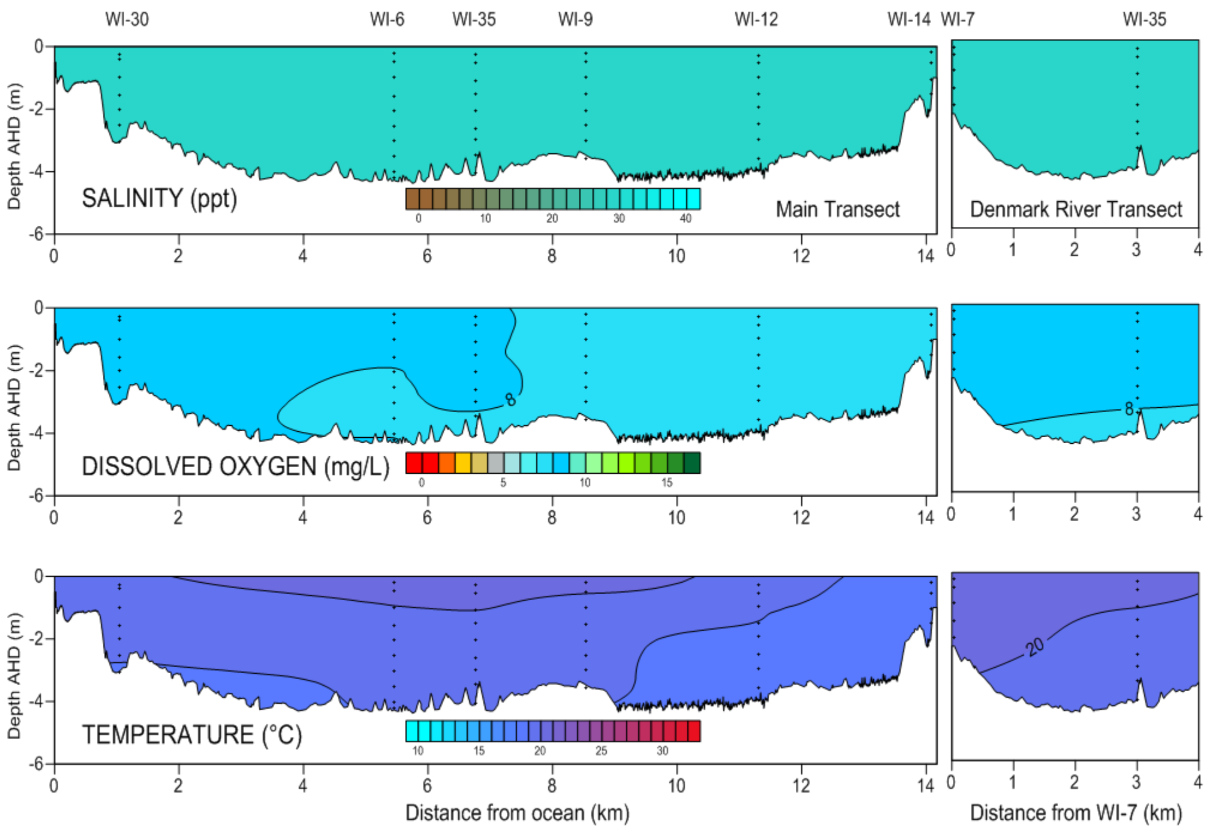

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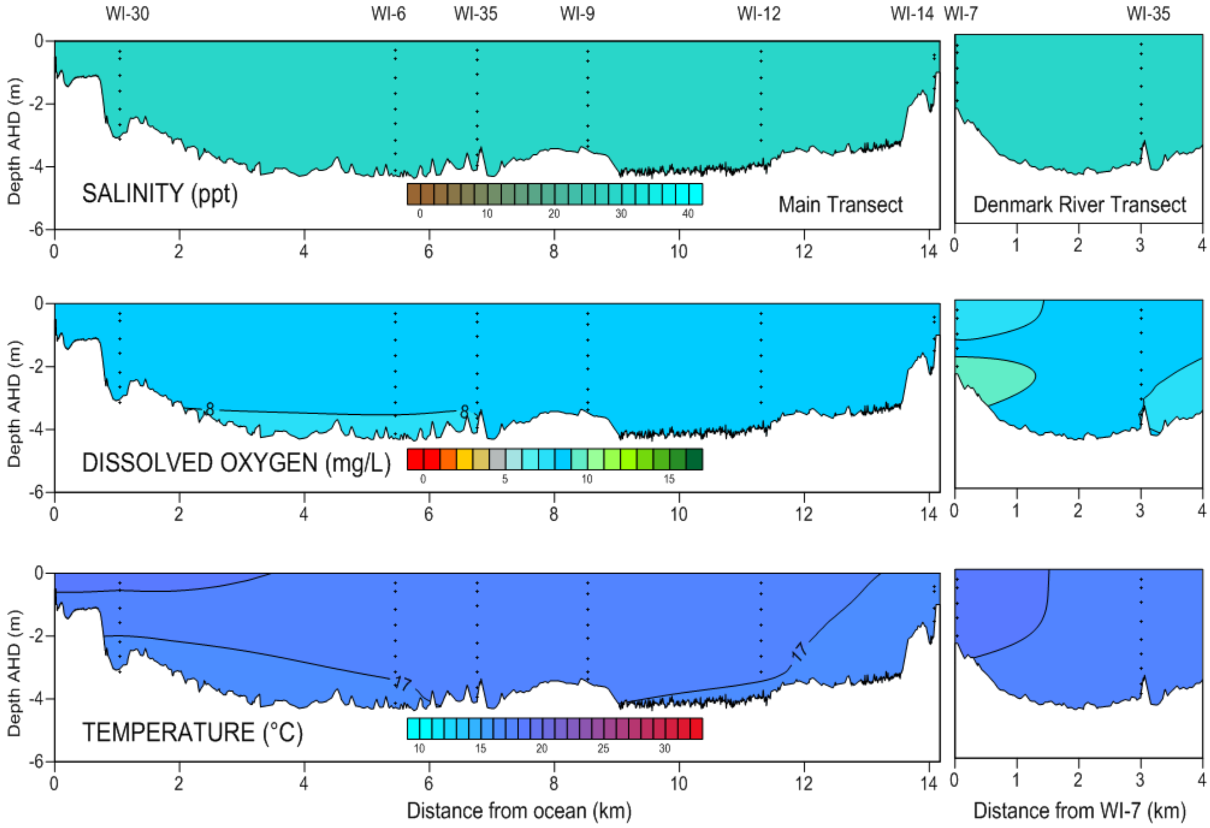

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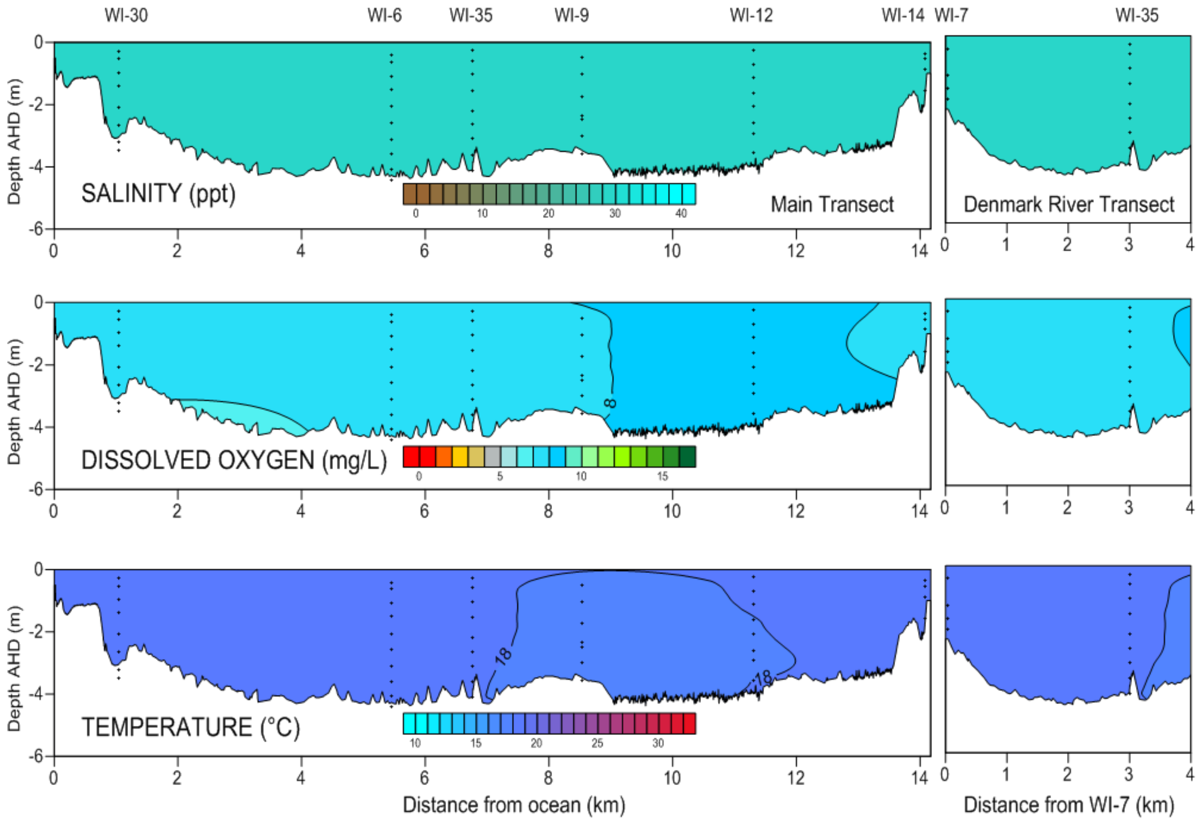

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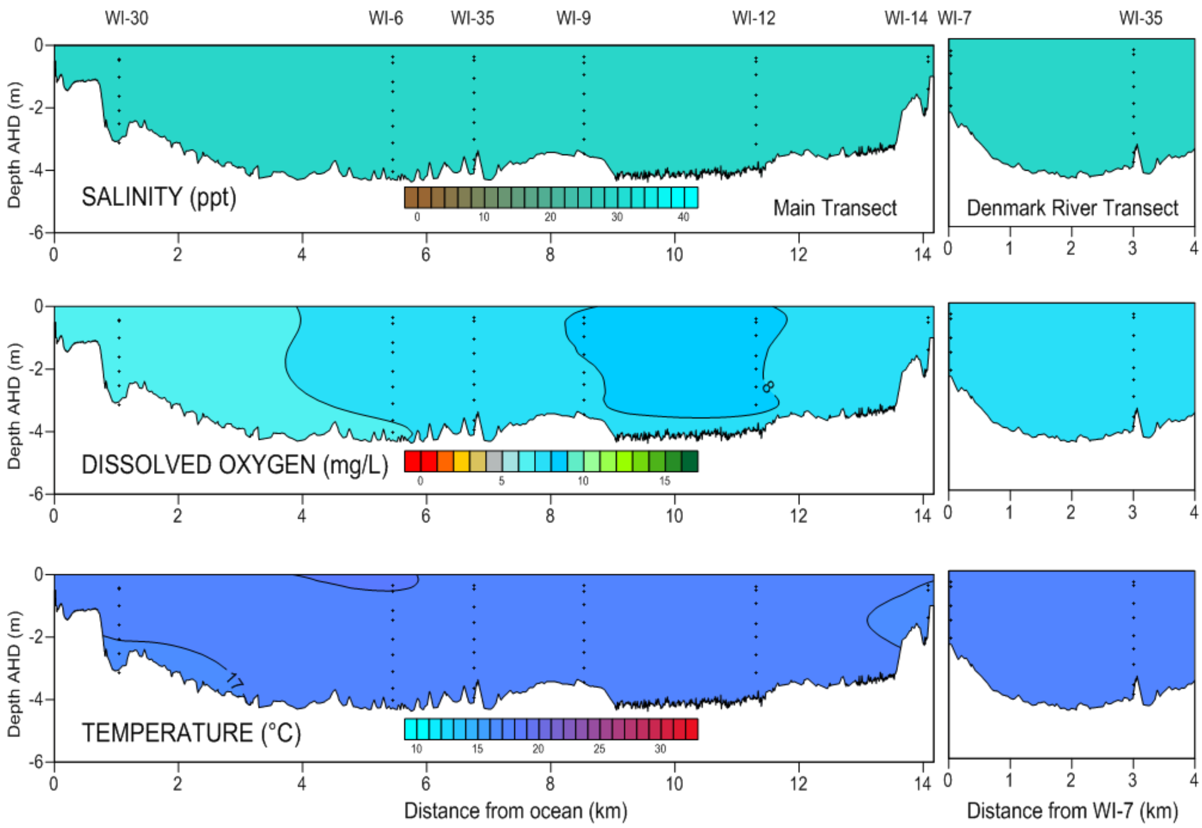

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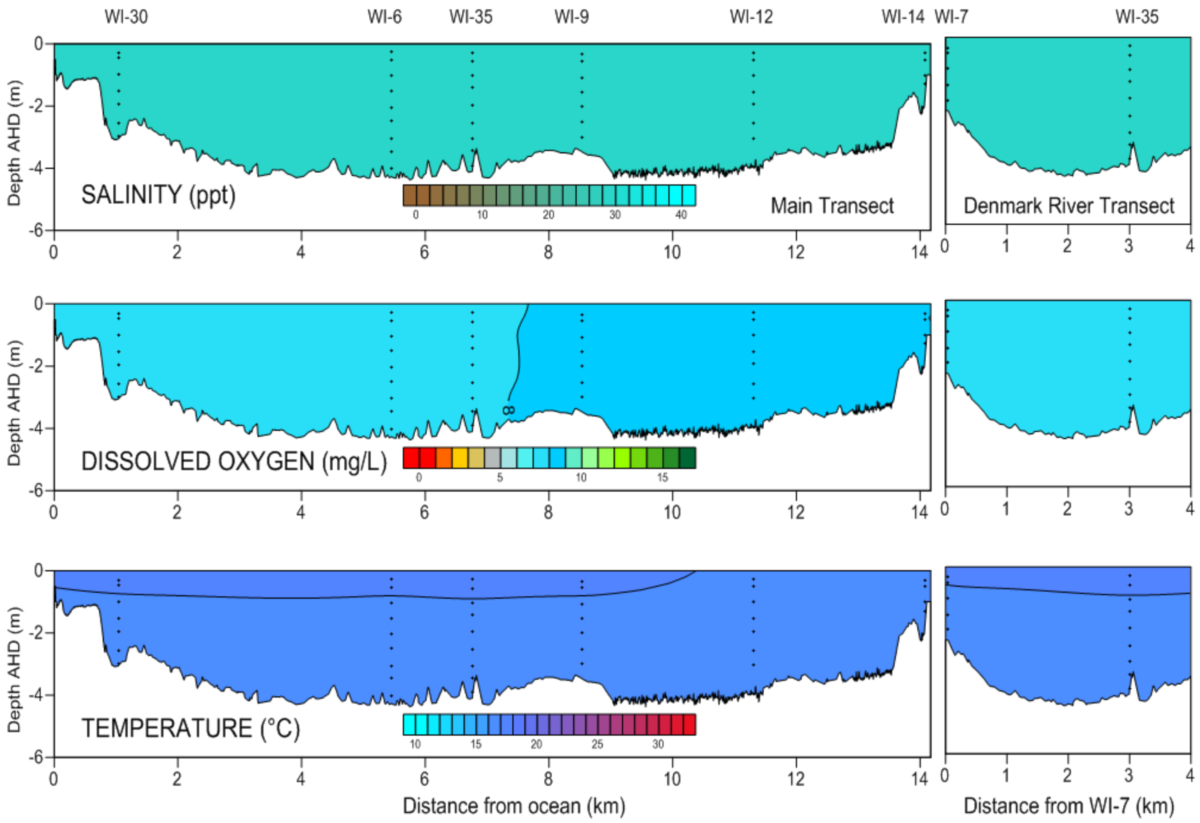

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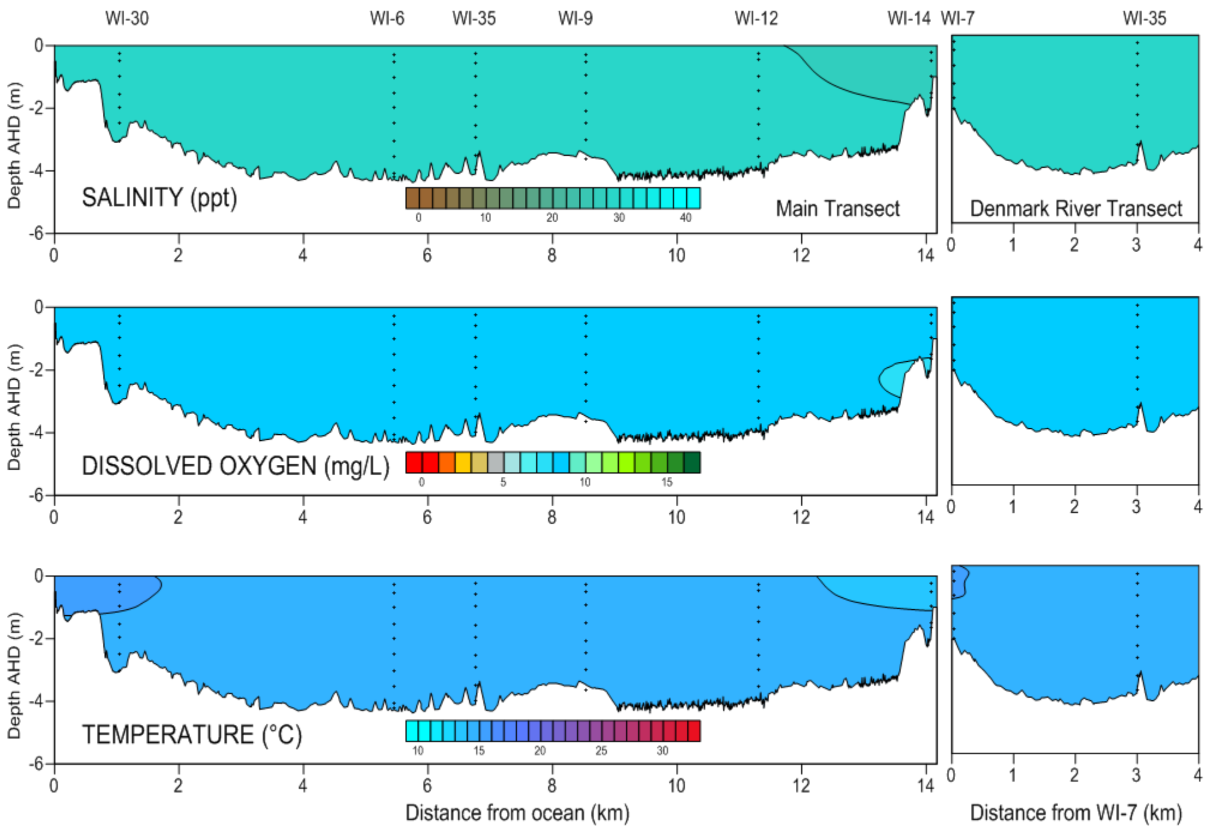

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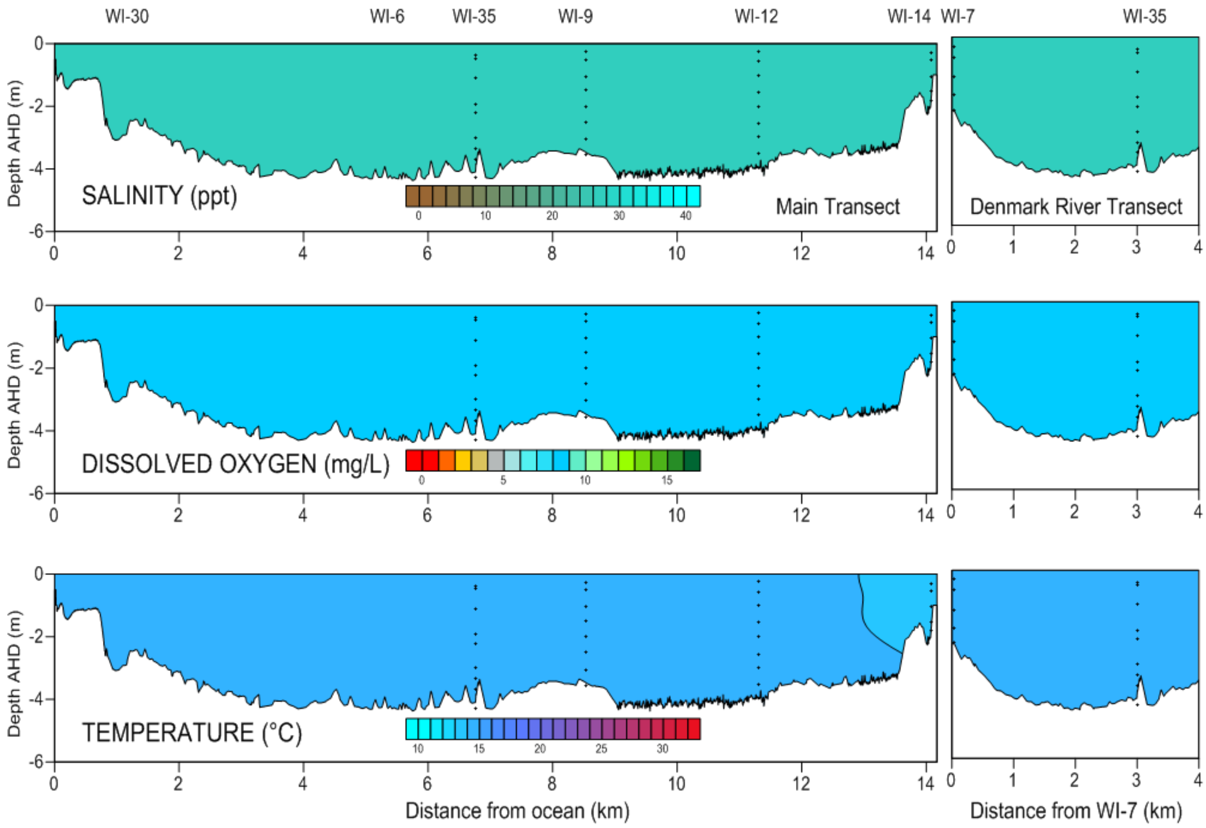

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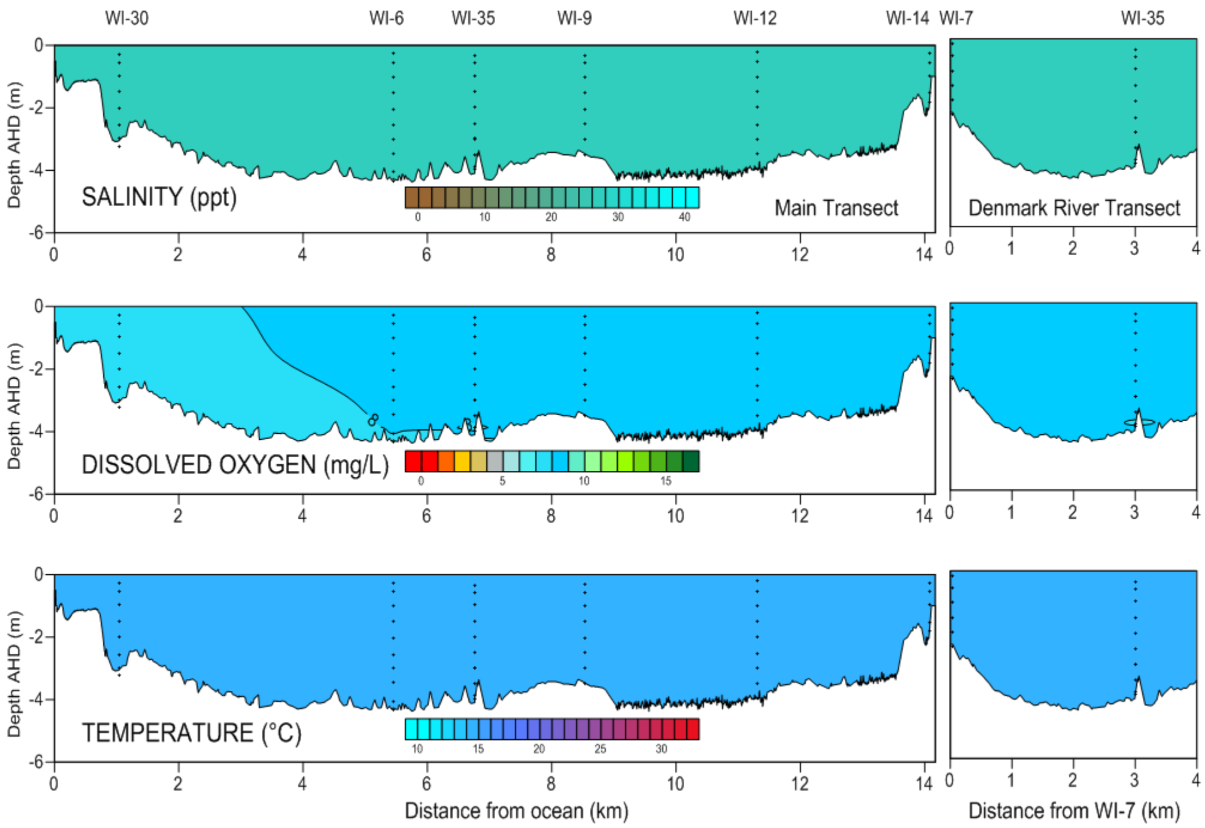

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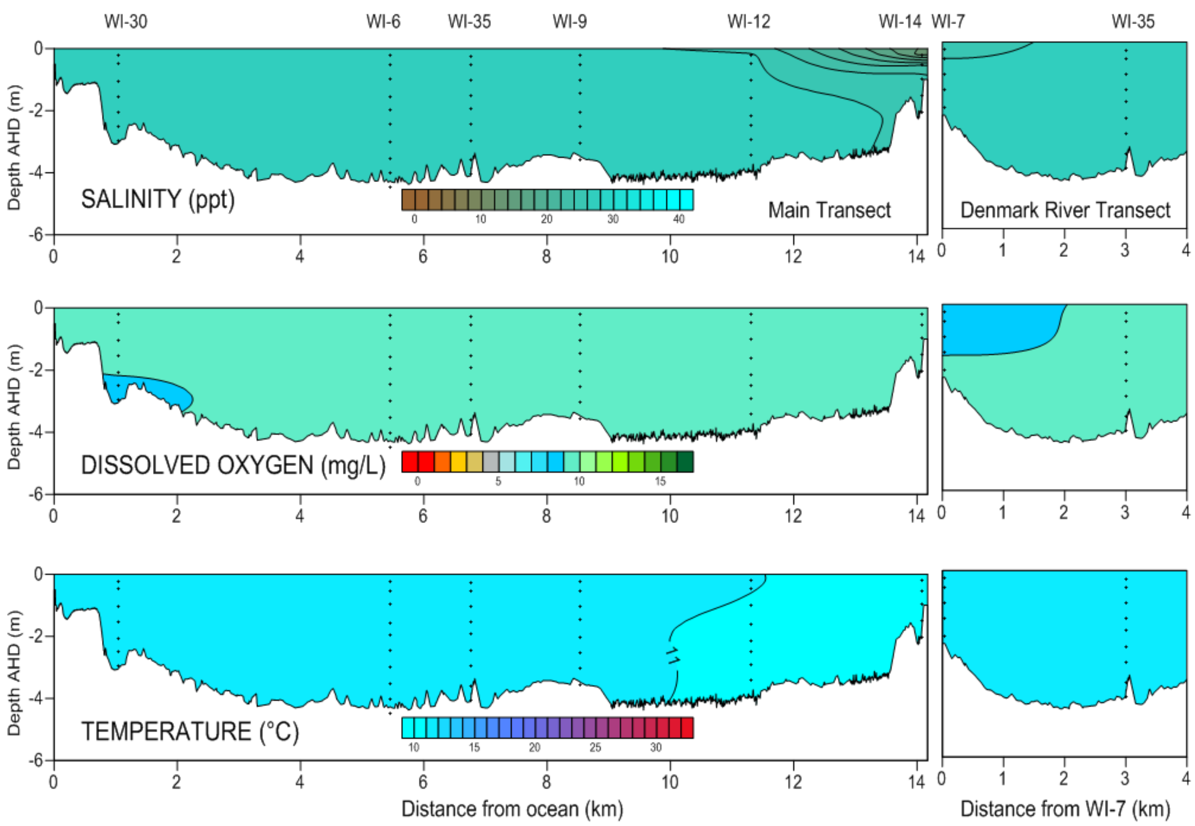

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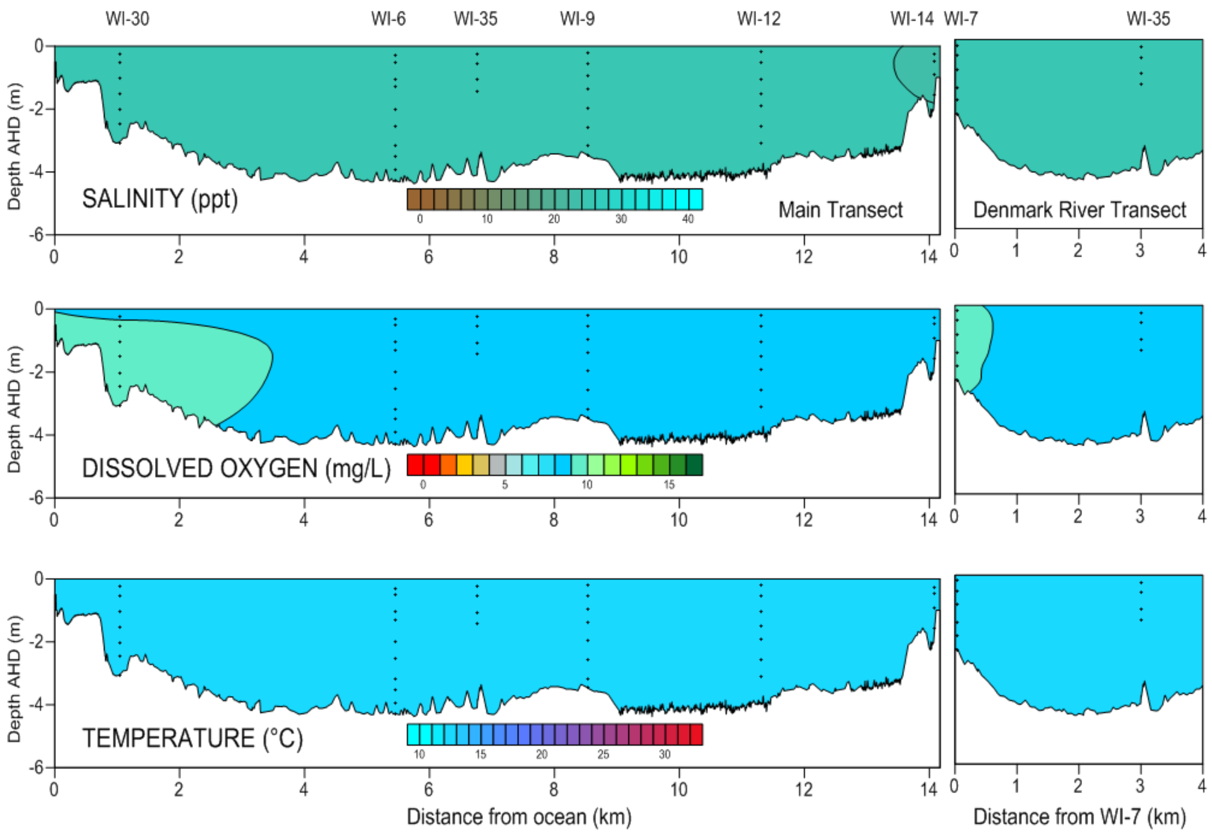

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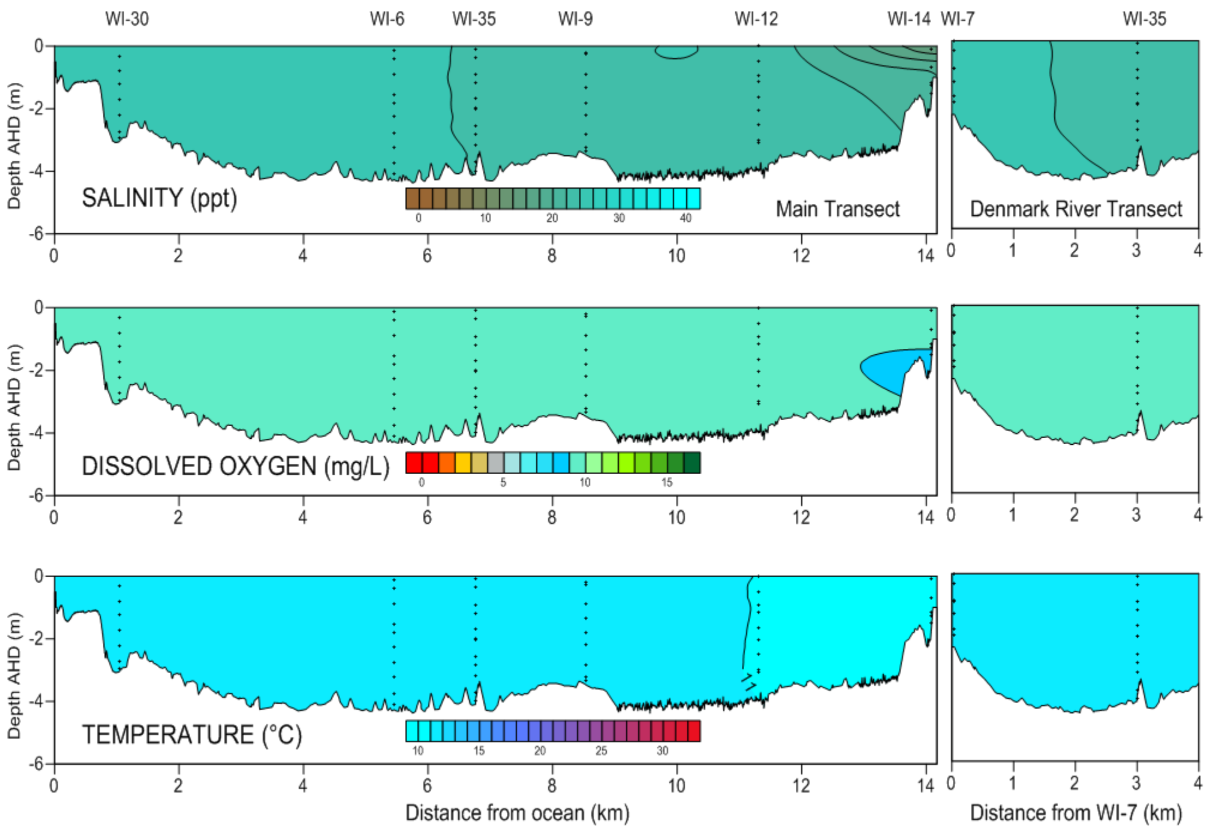

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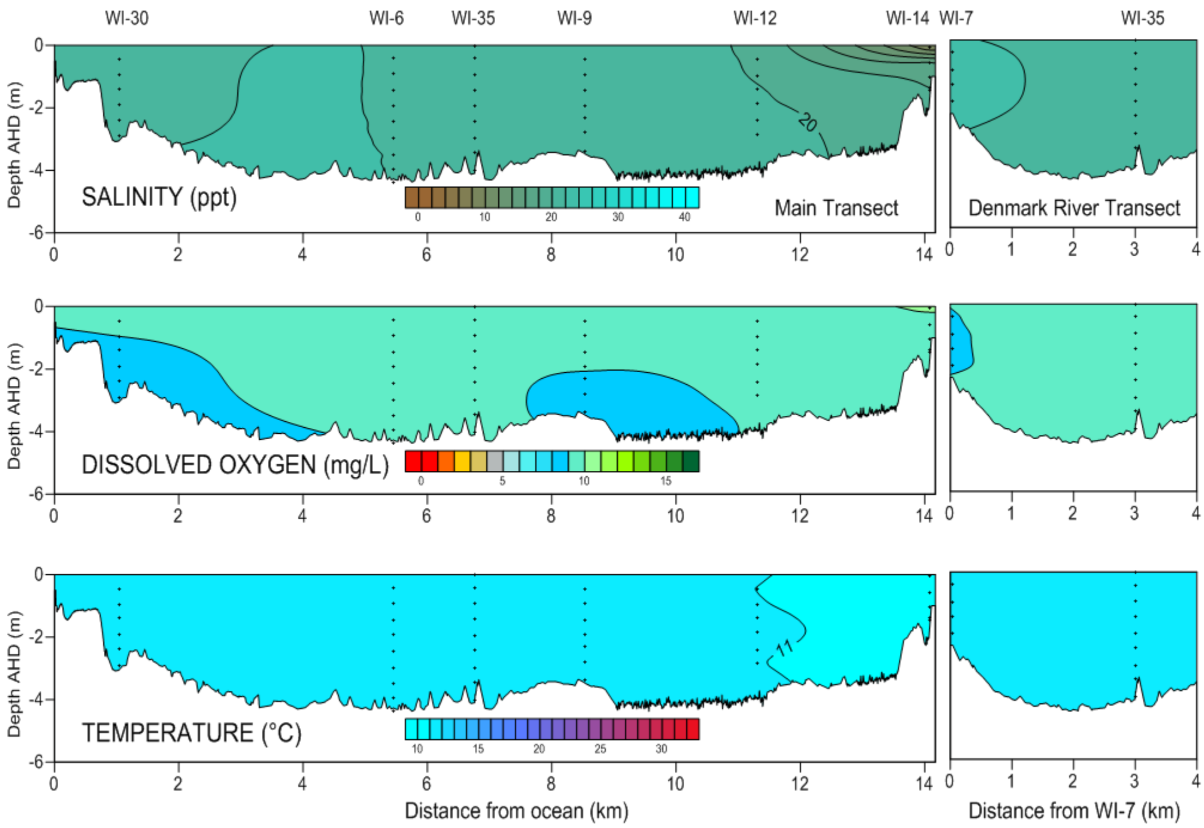

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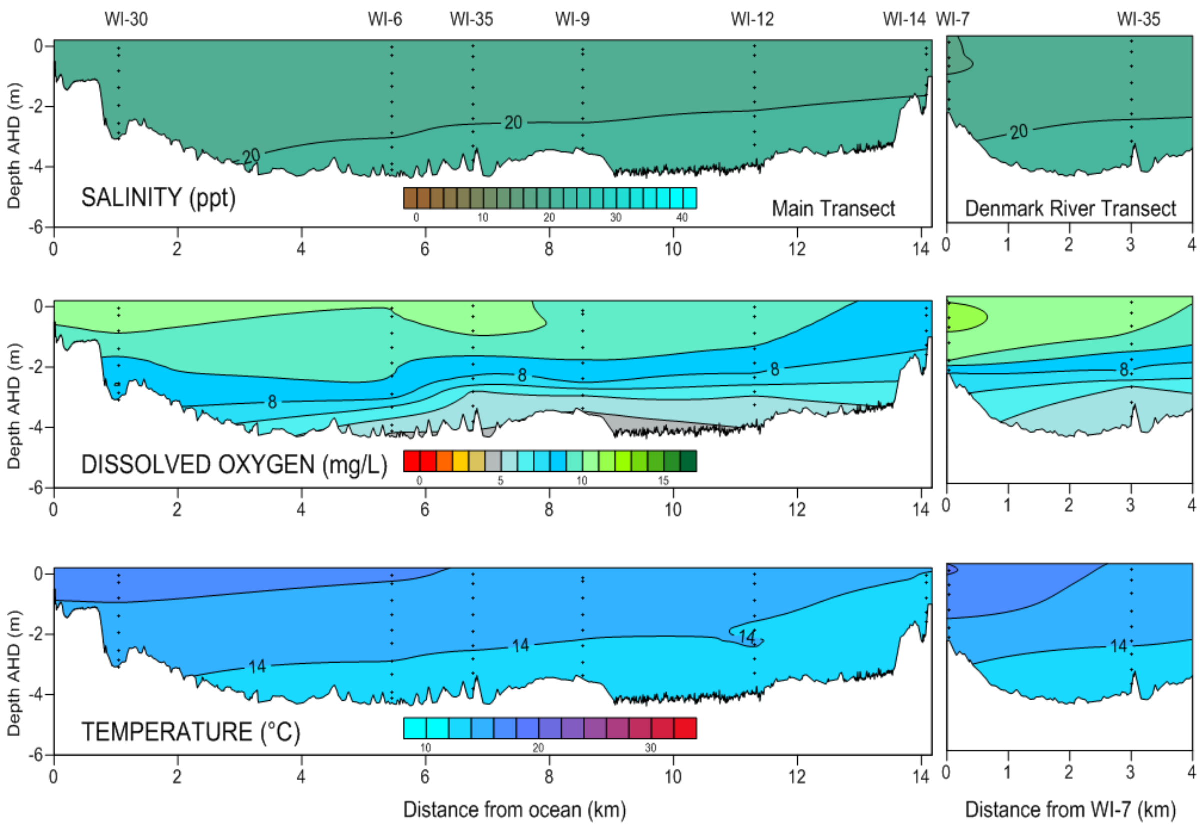

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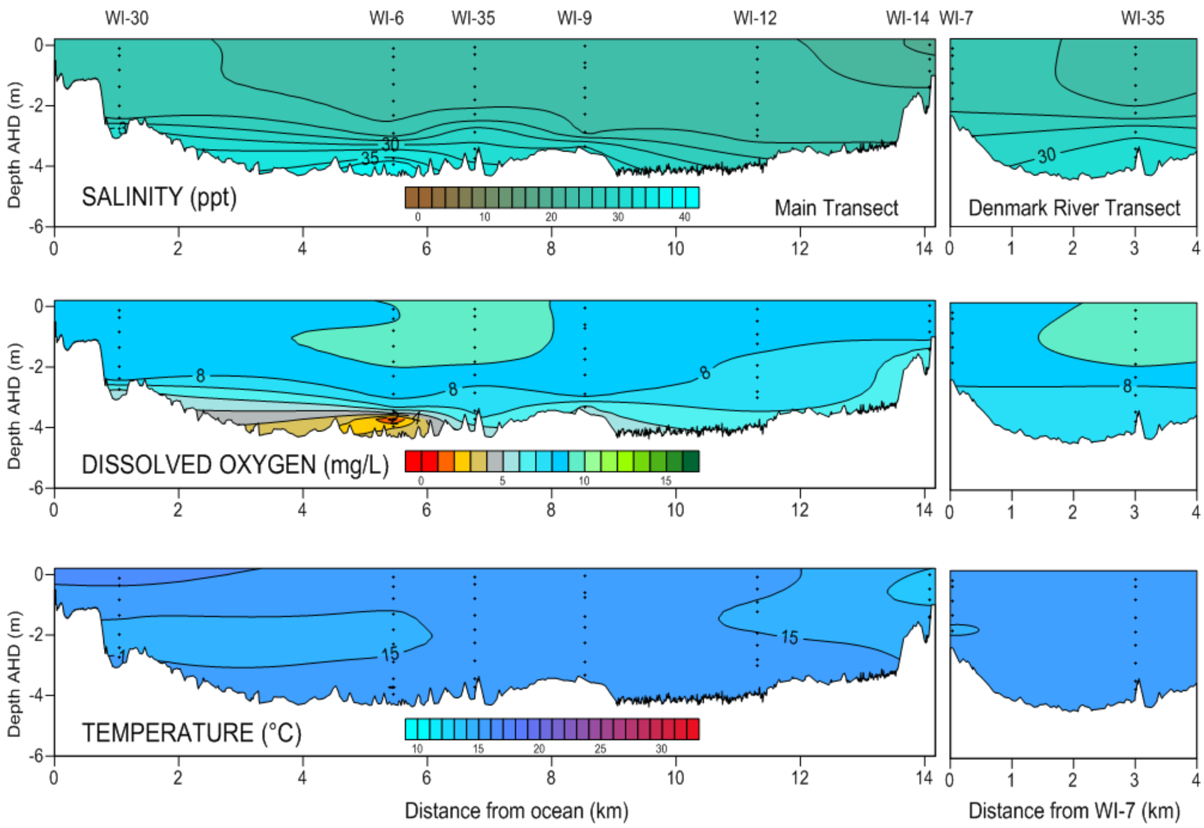

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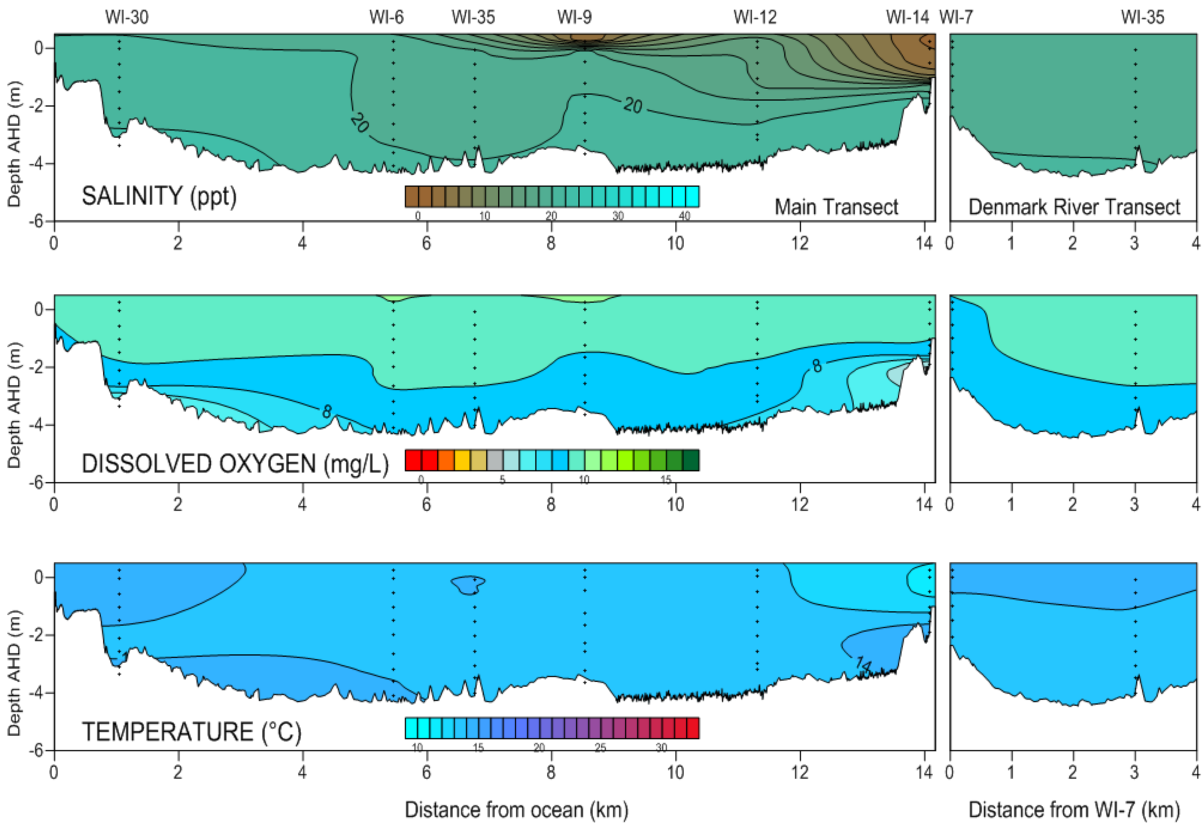
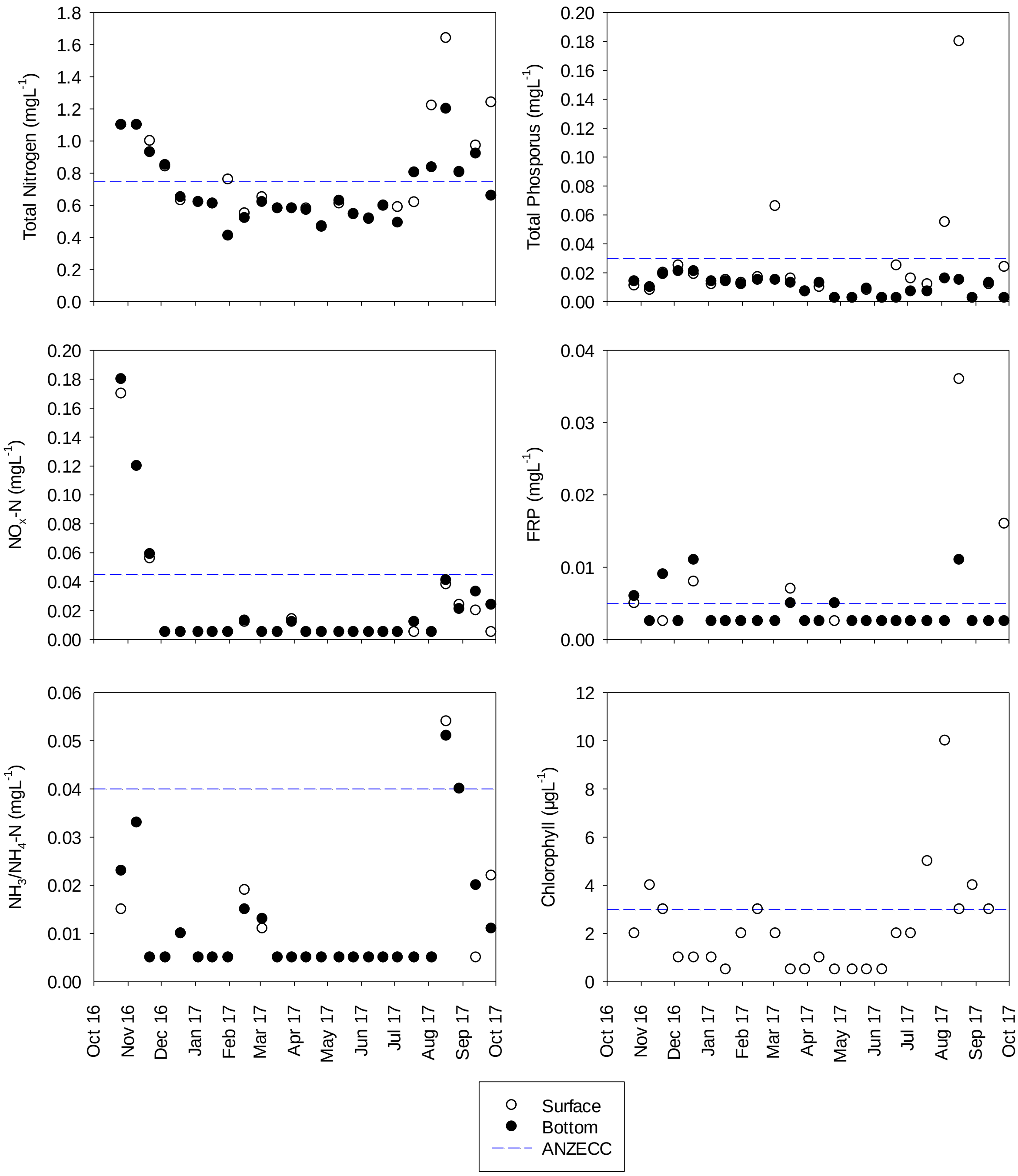


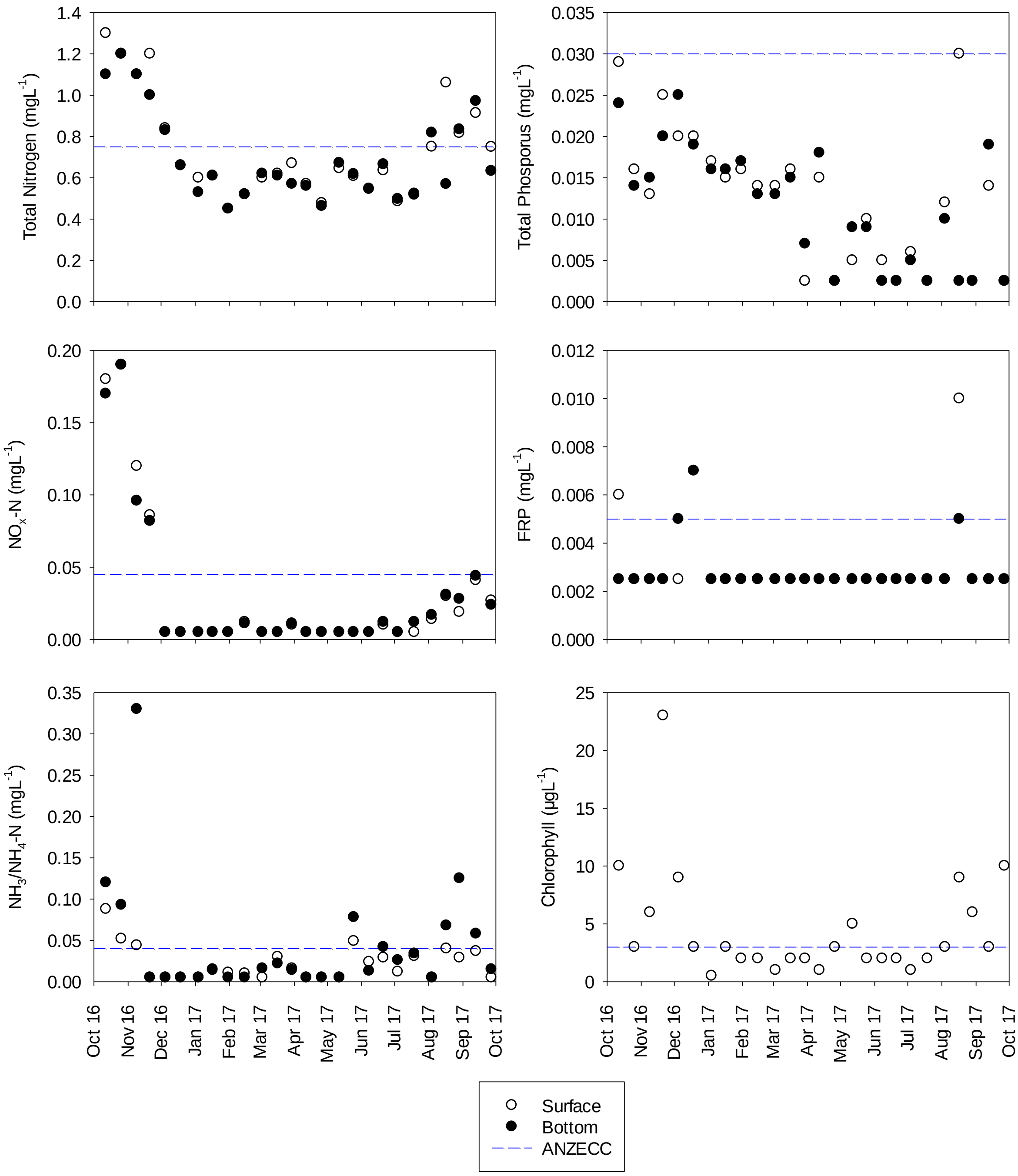
Appendix C: Water quality indicators time series

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

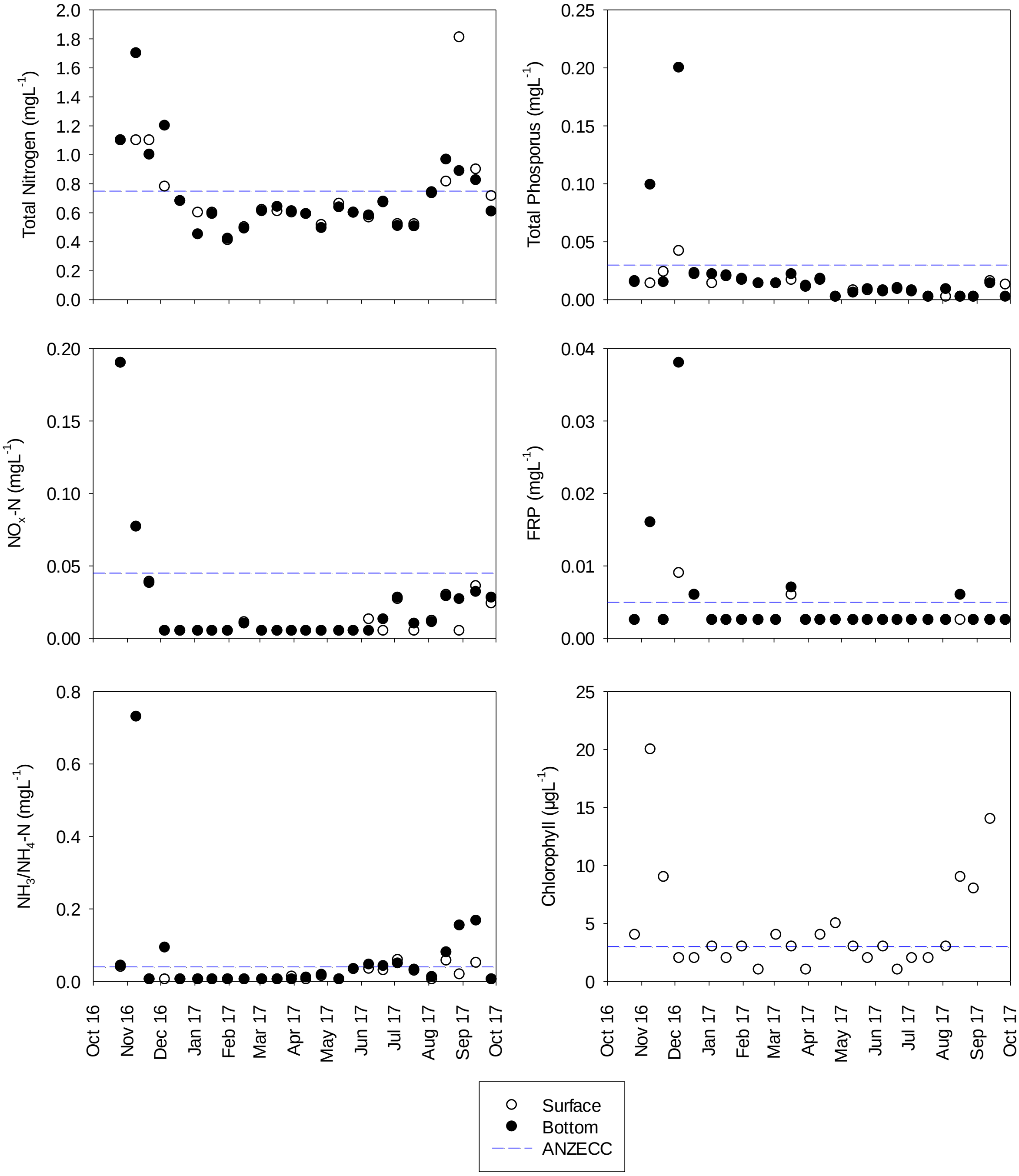
Monitoring site WI–14



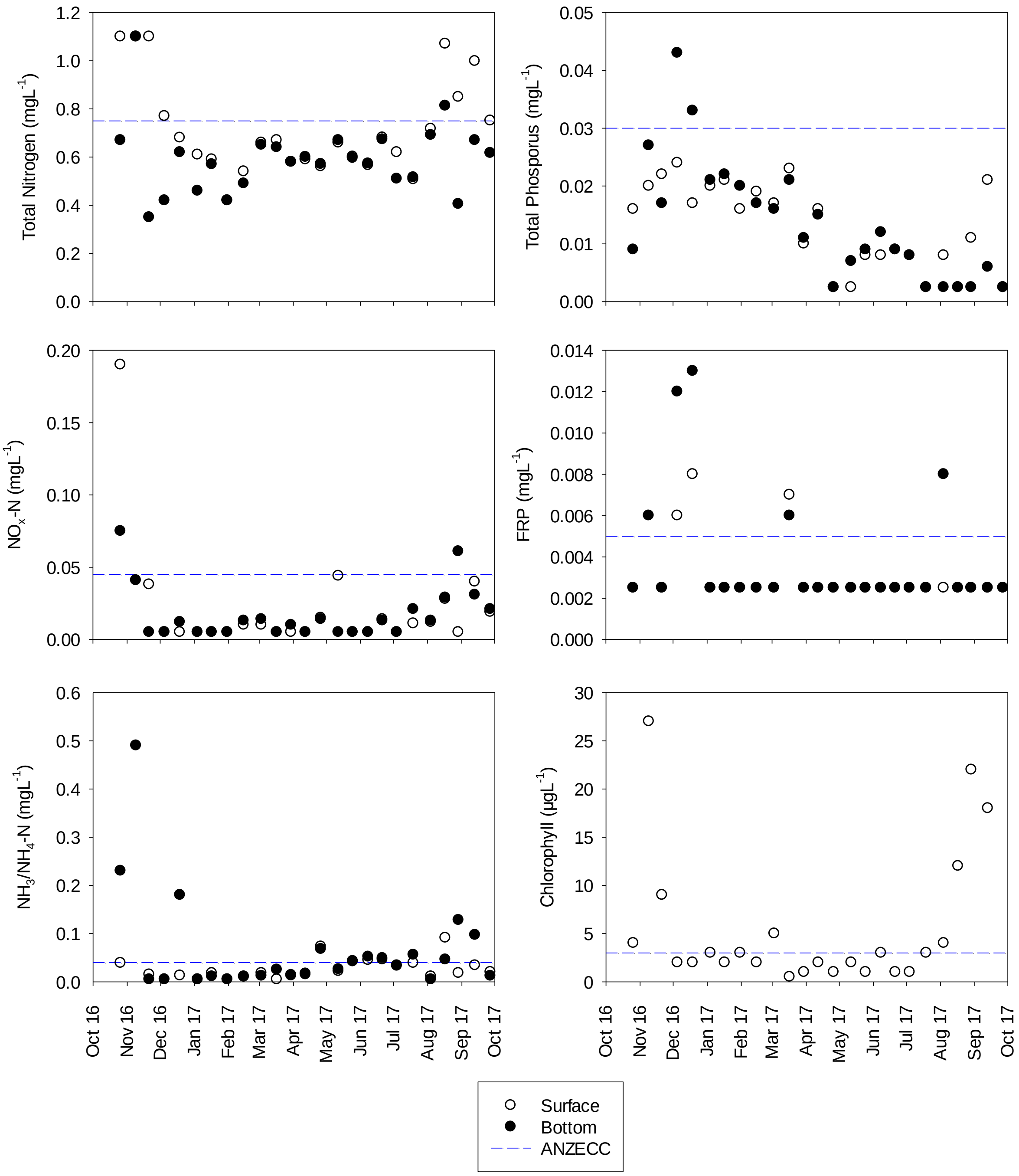
Monitoring site WI–12



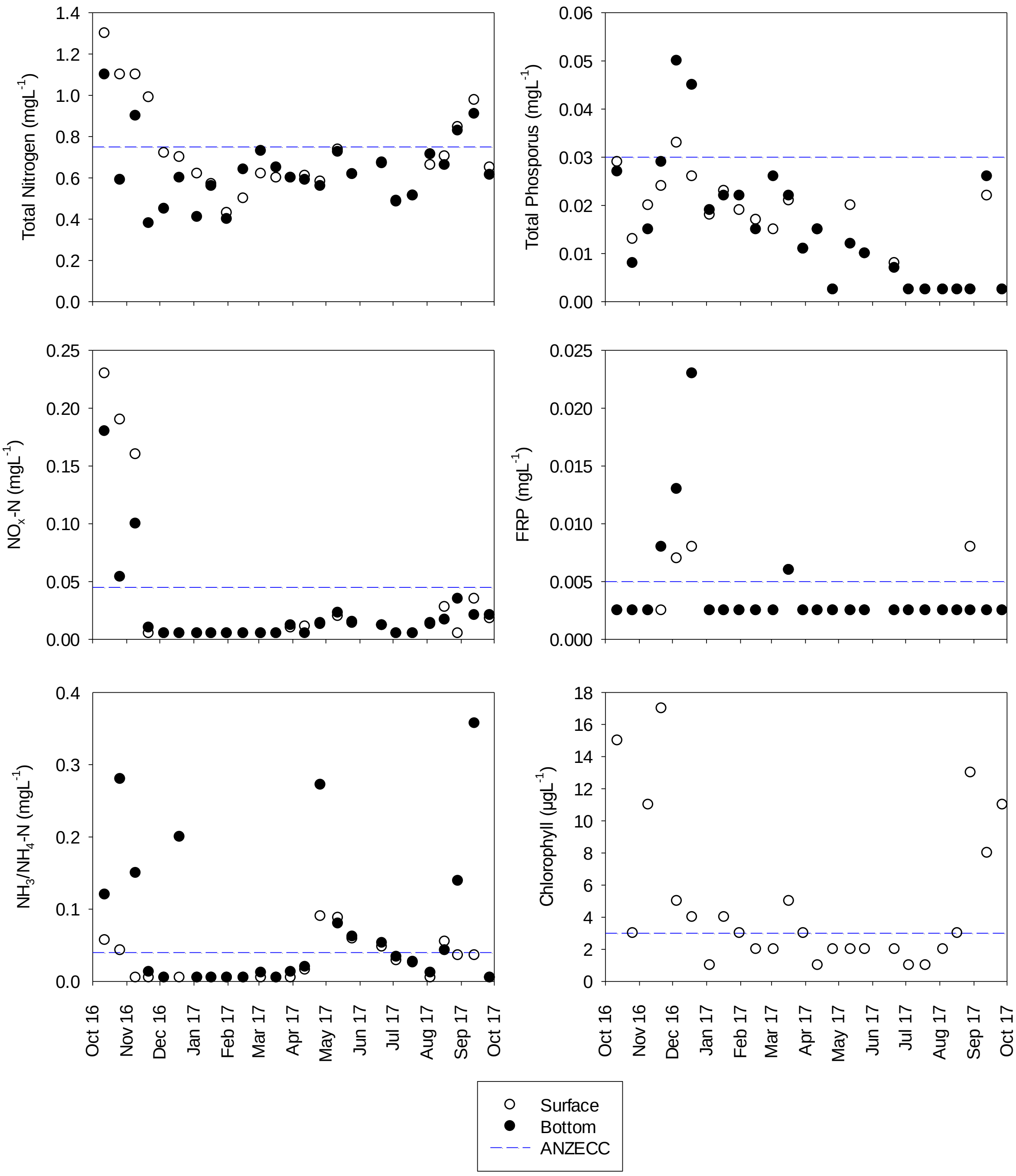
Monitoring site WI–9



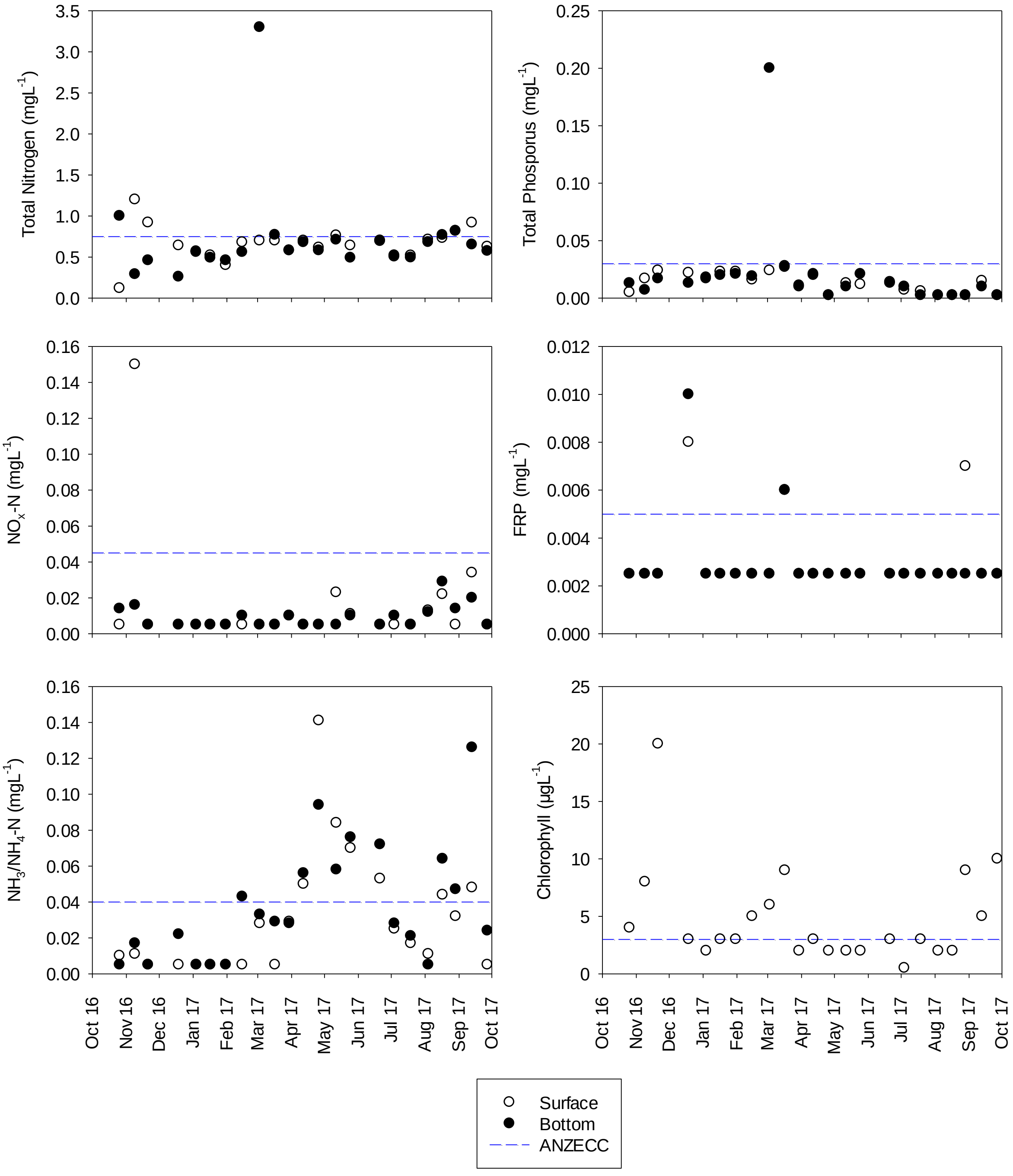
Monitoring site WI–35



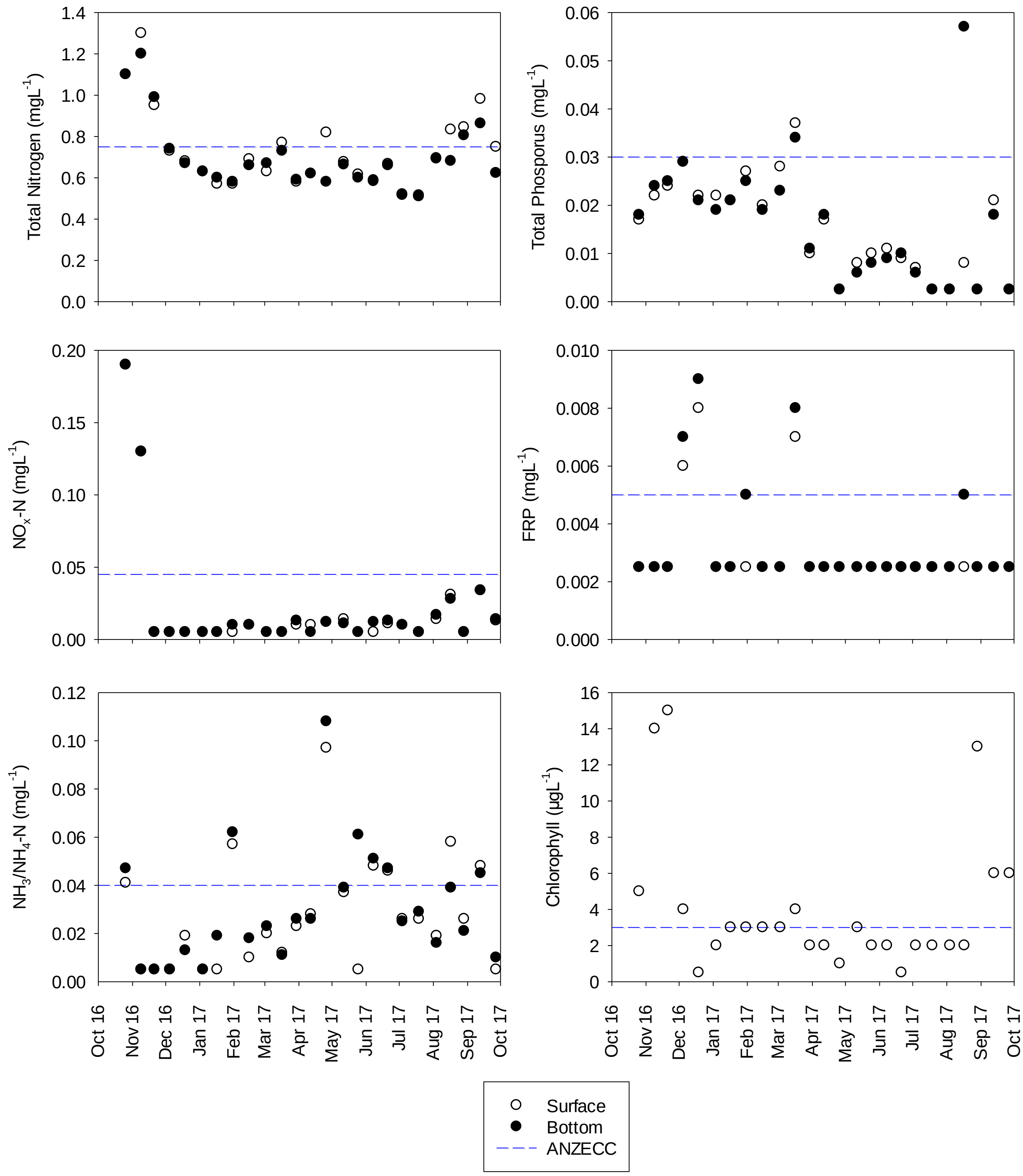
Monitoring site WI–6



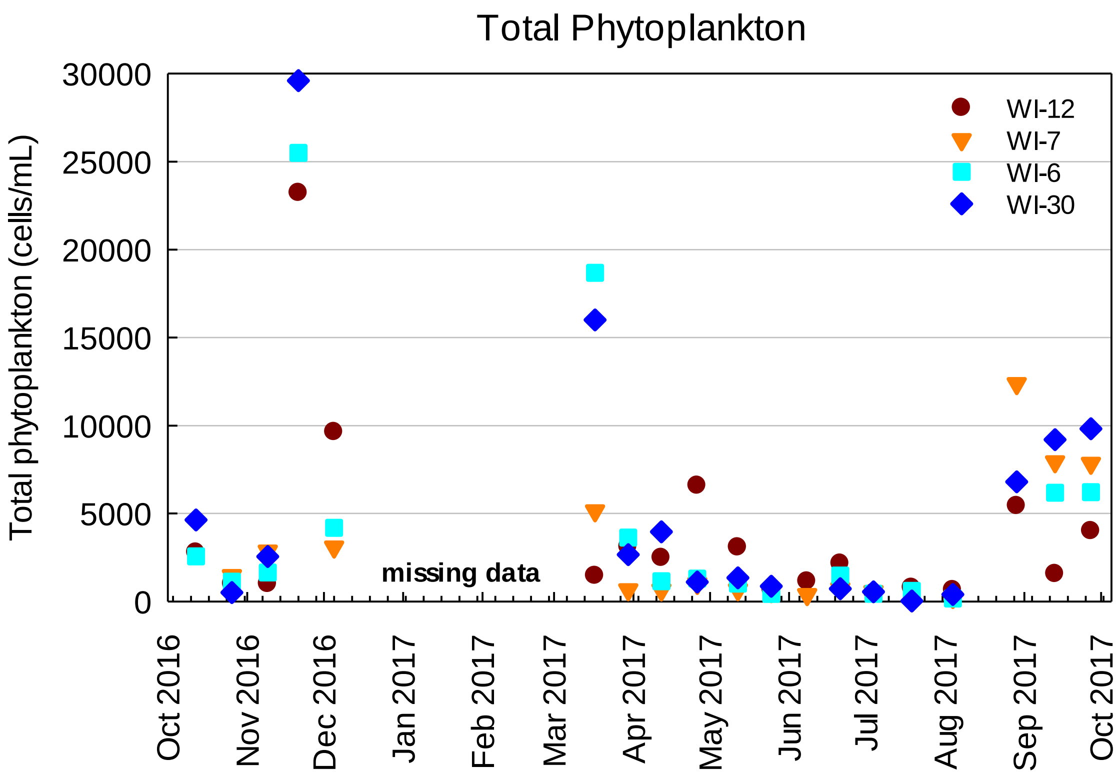
Monitoring site WI–30

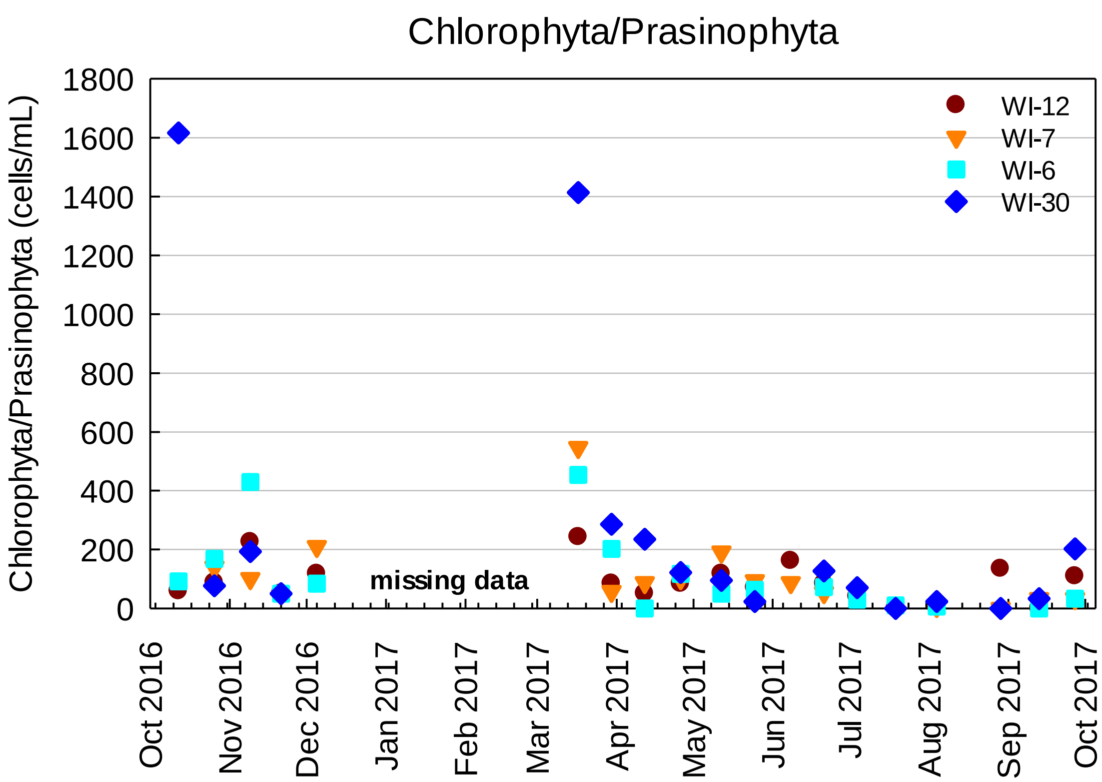


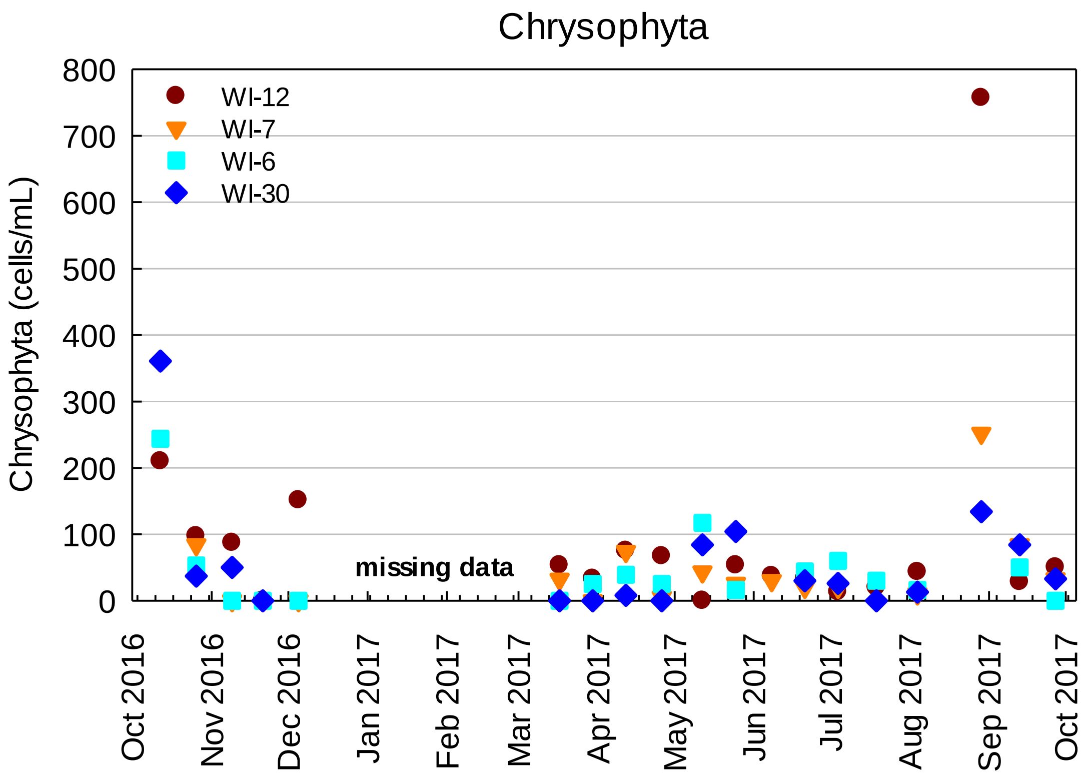
Monitoring site WI–7



Appendix D: Phytoplankton groups time series







Chrysophyta
Chrysophyta (cells/mL)
800
700
600
500
400
300
200
100
0
WI-12
WI-7
WI-6
WI-30
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Nov 2016
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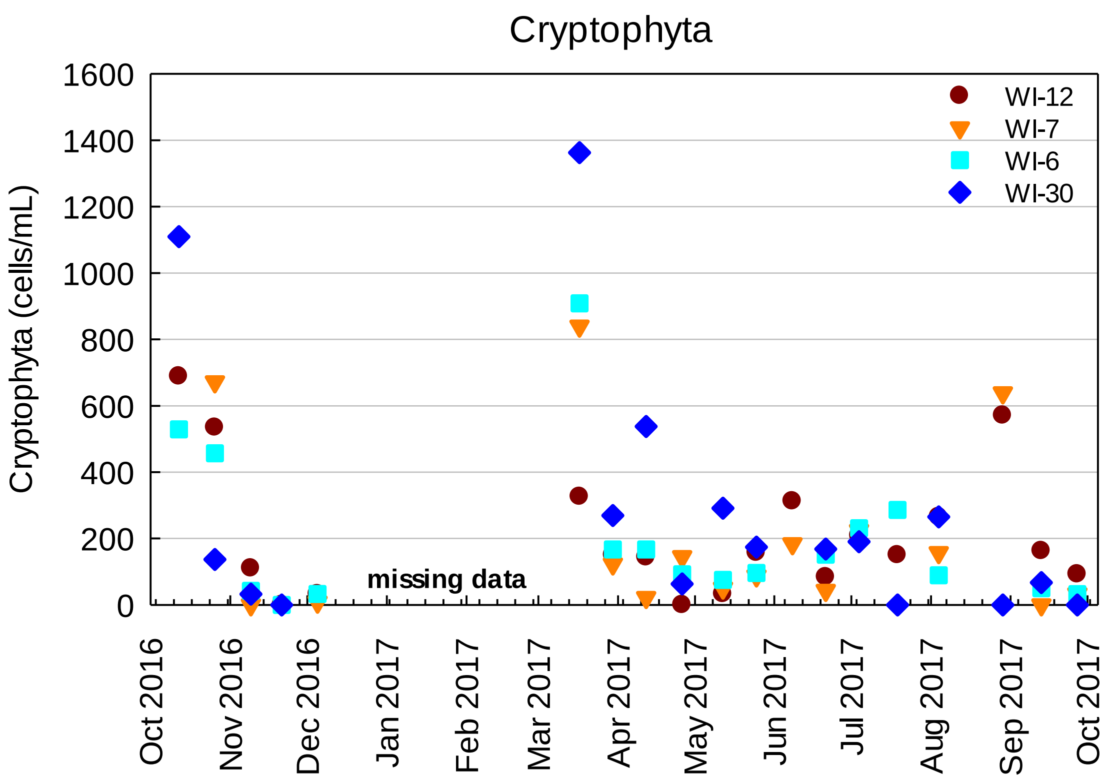
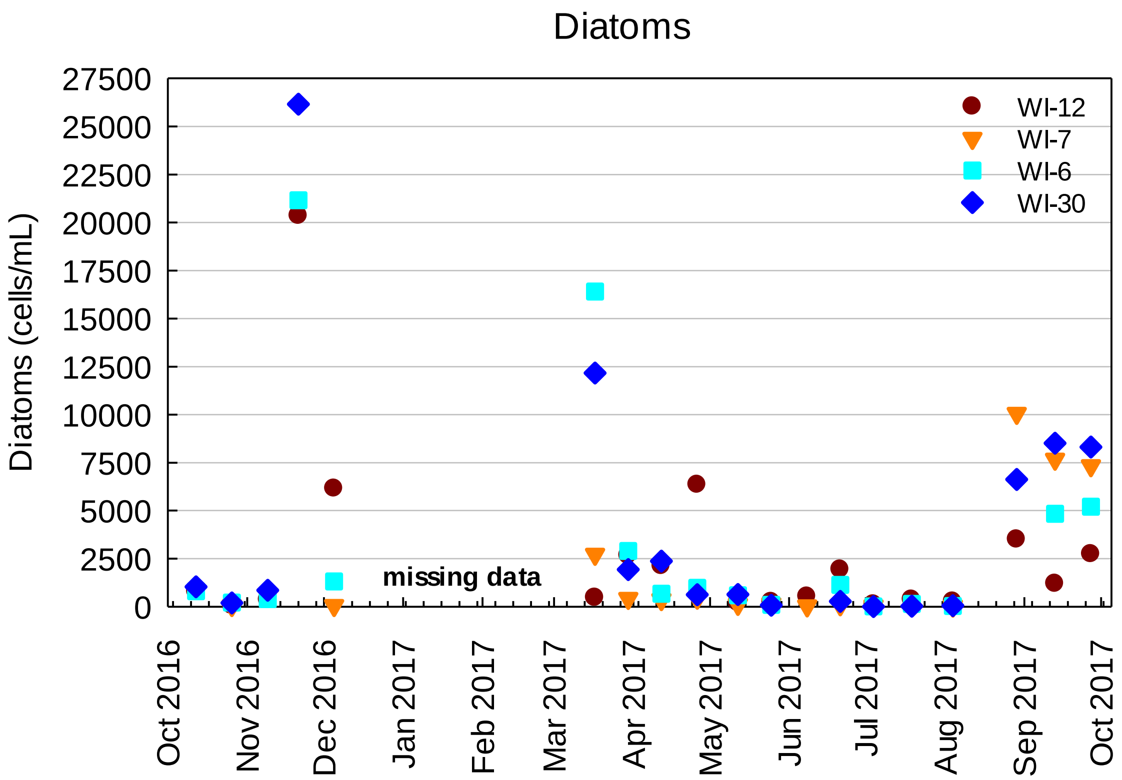
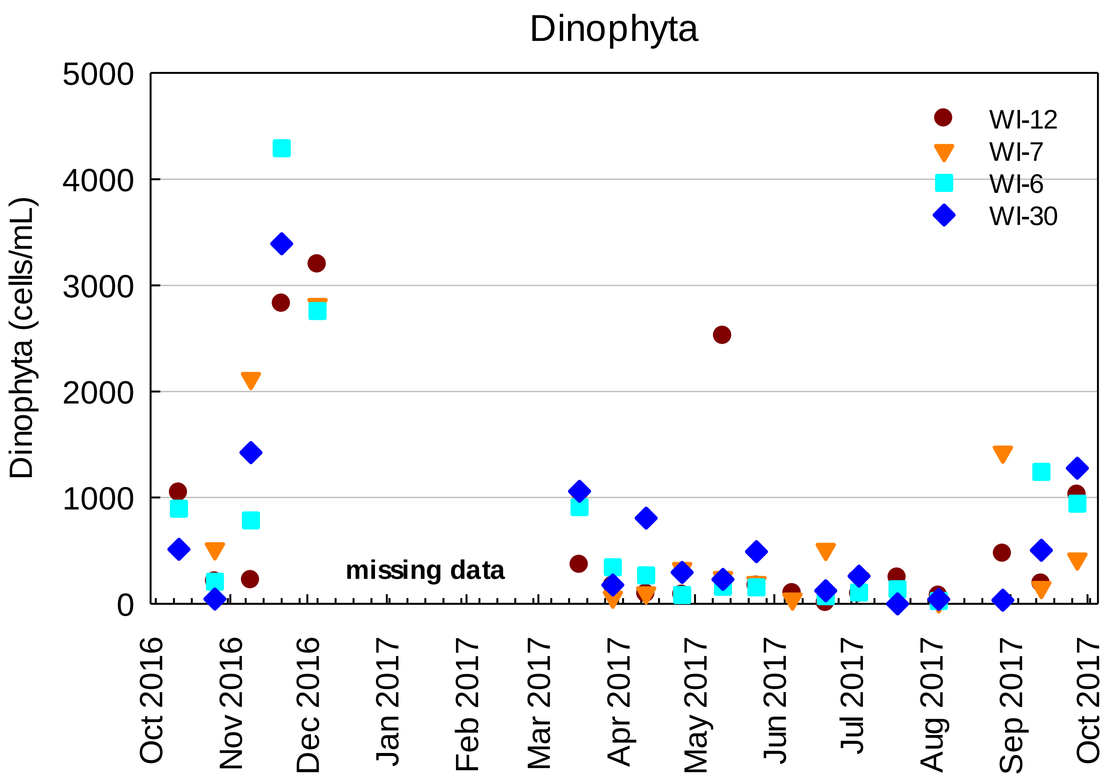
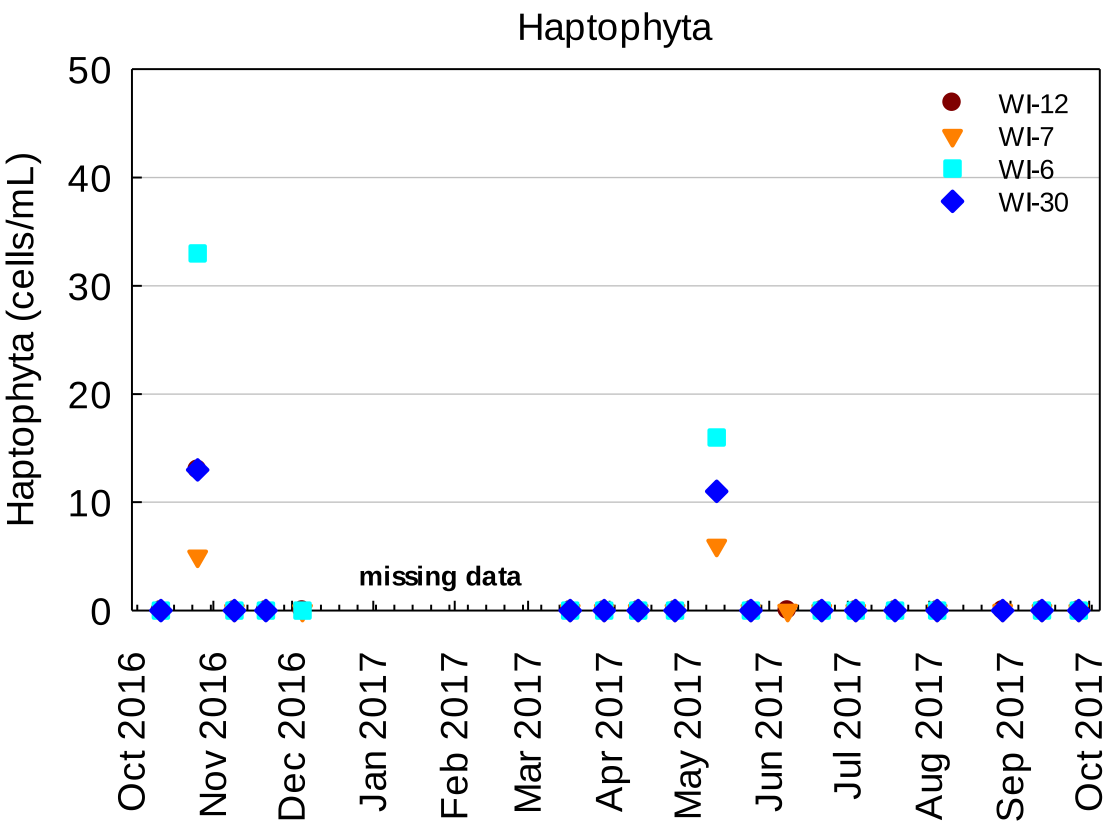
Jul 2017
Aug 2017
Sep 2017
Oct 2017

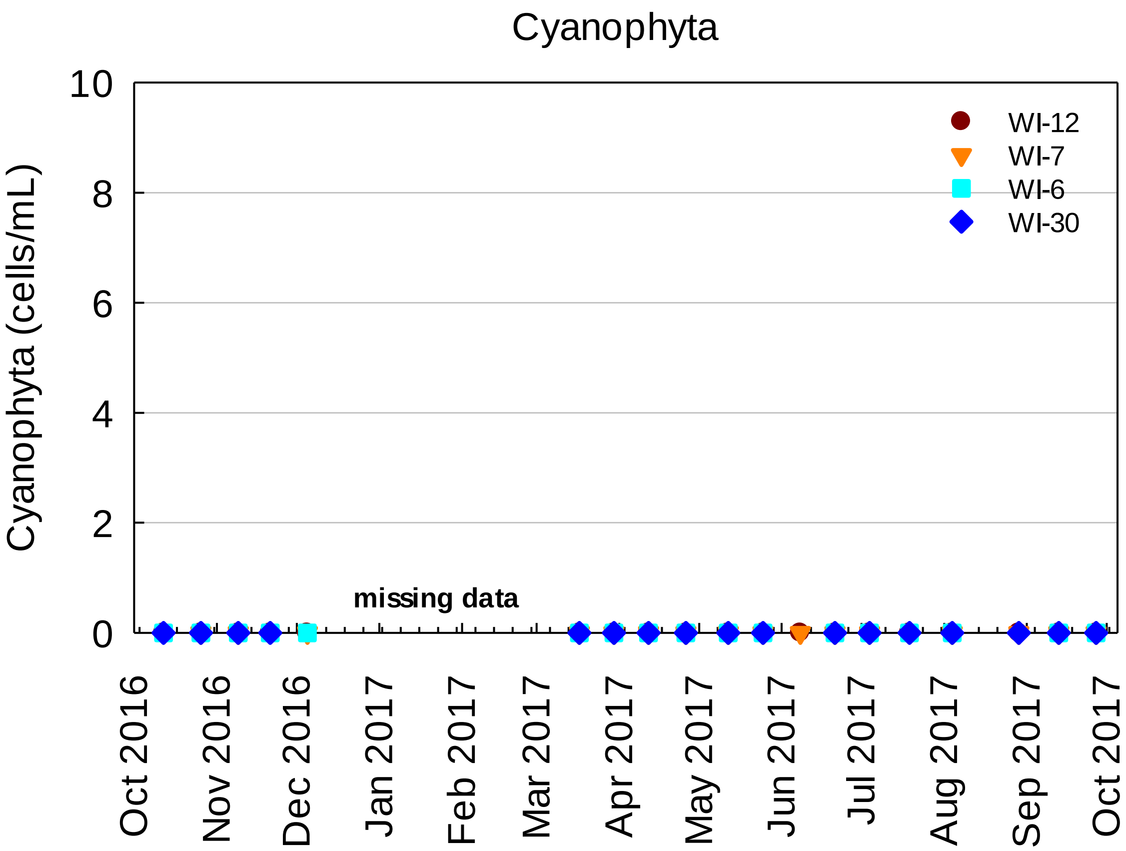


Cryptophyta
Cryptophyta (cells/mL)
1600
1400
1200
1000
800
600
400
200
0
WI-12
WI-7
WI-6
WI-30
missing data
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
Sep 2017
Oct 2017


Diatoms
Diatoms (cells/mL)
27500
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
WI-12
WI-7
WI-6
WI-30
missing data
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
Sep 2017
Oct 2017


Dinophyta
Dinophyta (cells/mL)
5000
4000
3000
2000
1000
0
WI-12
WI-7
WI-6
WI-30
missing data
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
Sep 2017
Oct 2017


Haptophyta
Haptophyta (cells/mL)
50
40
30
20
10
0
WI-12
WI-7
WI-6
WI-30
missing data
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
Sep 2017
Oct 2017


Cyanophyta
Cyanophyta (cells/mL)
10
8
6
4
2
0
WI-12
WI-7
WI-6
WI-30
missing data
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
Jul 2017
Aug 2017
Sep 2017
Oct 2017

References

ANZECC & ARMCANZ, 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC & ARMCANZ, 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition edn. American Public Health Association, Water Environment Federation, American Water Works Association, Washington, USA.

APHA, 2017. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Water Environment Federation, American Waterworks Association, Washington, USA.

Bastyan, G., L. Latchford & E. I. Paling, 1995. Macrophyte distribution and sediment chemistry in Wilson Inlet Report 95/8, Marine and Freshwater Research Laboratory.

Carruthers, T. J. B., W. C. Dennison, G. A. Kendrick, M. Waycott, D. I. Walker & M. L. Cambridge, 2007. Seagrasses of south–west Australia: A conceptual synthesis of the world's most diverse and extensive seagrass meadows. Journal of Experimental Marine Biology and Ecology 350:21-45.

Carruthers, T. J. B., D. I. Walker & G. A. Kendrick, 1999. Abundance of *Ruppia megacarpa* Mason in a seasonally variable estuary. Estuarine, Coastal and Shelf Science 48:497-509.

Department of Environment, 2003. *Ruppia* in Wilson Inlet. Wilson Inlet Report to the Community No 7.

Department of Health, 2016. Marine Biotoxin Monitoring and Management Plan 2016 - Western Australia Shellfish Quality Assurance Program. In: Health, D. o. (ed). Perth, Western Australia.

Department of Water, 2007. Water Quality in Wilson Inlet from 2002 to 2006. Wilson Inlet Report to the Community No 9.

Department of Water, 2010. Role of Sediments in Nutrient Cycling. Wilson Inlet Report to the Community No 10.

Dudley, B. J., A. M. E. Gahnström & D. I. Walker, 2001. The role of benthic vegetation as a sink for elevated inputs of ammonium and nitrate in a mesotrophic estuary. Marine Ecology Progress Series 219:99-107.

Pearce, A., S. Helleren & M. Marinelli, 2000. Review of productivity levels of Western Australian coastal and estuarine waters for mariculture planning purposes Fisheries Research Report No 123. Fisheries Western Australia, Perth, Western Australia.

Schofield, N. J. & P. E. Davies, 1996. Measuring the health of our rivers. Water May/June:39-43.

Twomey, L. & P. Thompson, 2001. Nutrient limitation of phytoplankton in a seasonally open bar-built estuary: Wilson Inlet, Western Australia. Journal of Phycology 37:16-29.

Water and Rivers Commission, 2002. Water quality in Wilson Inlet 1995 to 2002. Wilson Inlet Report to the Community No 5.

Bastyan, G., L. Latchford & E. I. Paling, 1995. Macrophyte distribution and sediment chemistry in Wilson Inlet Report 95/8, Marine and Freshwater Research Laboratory.

Carruthers, T. J. B., W. C. Dennison, G. A. Kendrick, M. Waycott, D. I. Walker & M. L. Cambridge, 2007. Seagrasses of south–west Australia: A conceptual synthesis of the world's most diverse and extensive seagrass meadows. Journal of Experimental Marine Biology and Ecology 350:21-45.

Carruthers, T. J. B., D. I. Walker & G. A. Kendrick, 1999. Abundance of *Ruppia megacarpa* Mason in a seasonally variable estuary. Estuarine, Coastal and Shelf Science 48:497-509.

Department of Environment, 2003. *Ruppia* in Wilson Inlet. Wilson Inlet Report to the Community No 7.

Department of Health, 2016. Marine Biotoxin Monitoring and Management Plan 2016 - Western Australia Shellfish Quality Assurance Program. In: Health, D. o. (ed). Perth, Western Australia.

Department of Water, 2007. Water Quality in Wilson Inlet from 2002 to 2006. Wilson Inlet Report to the Community No 9.

Department of Water, 2010. Role of Sediments in Nutrient Cycling. Wilson Inlet Report to the Community No 10.

Dudley, B. J., A. M. E. Gahnström & D. I. Walker, 2001. The role of benthic vegetation as a sink for elevated inputs of ammonium and nitrate in a mesotrophic estuary. Marine Ecology Progress Series 219:99-107.

Pearce, A., S. Helleren & M. Marinelli, 2000. Review of productivity levels of Western Australian coastal and estuarine waters for mariculture planning purposes Fisheries Research Report No 123. Fisheries Western Australia, Perth, Western Australia.

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Twomey, L. & P. Thompson, 2001. Nutrient limitation of phytoplankton in a seasonally open bar-built estuary: Wilson Inlet, Western Australia. Journal of Phycology 37:16-29.

Water and Rivers Commission, 2002. Water quality in Wilson Inlet 1995 to 2002. Wilson Inlet Report to the Community No 5.

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