GOVERNMENT OF WESTERN AUSTRALIA
Department of **Water and Environmental Regulation**
Department of **Primary Industries and Regional Development**

Wilson Inlet

Nullaki

HEALTHY ESTUARIES WA

Condition of the estuary 2016–19

#WAestuaries

Acknowledgements

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Photos on page 4 (Red-necked Avocet) and page 13 (Curlew Sandpiper) by Anthony Peterson. Photo on page 26 (Black-winged Stilts) by Brad Kneebone. All other photos by Ash Ramsay, Department of Water and Environmental Regulation.

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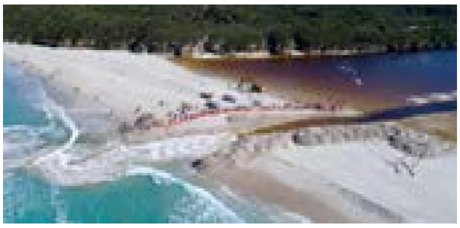
About estuaries



Estuaries are dynamic environments where freshwater and seawater meet. They provide safe harbours and places of beauty for recreation and quiet reflection. They connect people to the natural environment, act as nurseries for recreational and commercial fisheries, provide sanctuaries for birds and are highly productive and biodiverse ecosystems.

Estuaries face numerous pressures, primarily from excessive nutrient inputs from catchment land uses, and climate-related changes (such as reduced river inflows, increased temperatures, ocean acidification and rising sea levels). These pressures can diminish estuary health and consequently the social, economic and environmental values they hold.

Our vision of healthy estuaries requires collaboration with landowners, farmers, non-profit catchment and conservation groups, government agencies and local communities. The Healthy Estuaries WA program (2020–24) aims to build on the collaborative model we started through the Regional Estuaries Initiative (2016–20).

The Regional Estuaries Initiative extended scientific monitoring programs in six estuaries in the South West to provide foundational knowledge of the current ecosystem health, seasonal variation in water quality, and key drivers of estuary dynamics (for example, river flow, catchment nutrient inputs and marine exchange). This information helps us assess whether estuarine health is changing over time.

Insight into the condition of our estuaries enables more effective management. It allows, for example, for the development of targeted fertiliser practices; pinpointing of high-priority stream restoration sites; identification of public health risks and notification of the public if needed; and an understanding of where more research is needed.

Report at a glance

This report summarises three years of the Regional Estuaries Initiative Wilson Inlet water quality monitoring program (2016–19) and compares these recent results with historical data. We report on the main drivers of estuary health (rainfall, river flow, catchment condition, sandbar dynamics) and on the estuary's response (water quality, seagrass condition).

Nutrient input from the catchment remains high, but Wilson Inlet is currently a resilient estuary. Nutrient concentrations in the inlet have remained similar since monitoring started in the 1990s, with water quality being good most of the year. Higher levels of nutrients and microalgal activity occur when rivers start to flow and the inlet is open to the ocean.

Wilson Inlet had healthy oxygen levels for most of the monitoring period. Some periods of oxygen depletion in the deeper parts of the inlet occurred when the sandbar was open. Periods of low oxygen were particularly pronounced during the two long openings in 2016 and 2017, as opposed to the short opening in 2018.

Although water quality is currently good, climate change together with the continuing supply of nutrients from the catchment are ongoing threats to the health of the inlet.

The declining rainfall in the catchment will result in less water being discharged into the inlet and consequently a lower winter water level than in the past. If the water level remains below the threshold water level identified in the *Wilson Inlet sandbar opening protocol*[1] (currently under review), the inlet will not be opened. The drying climate might therefore lead to an increase in the number of years the inlet will remain closed, potentially changing Wilson Inlet as an ecosystem.

Key points:

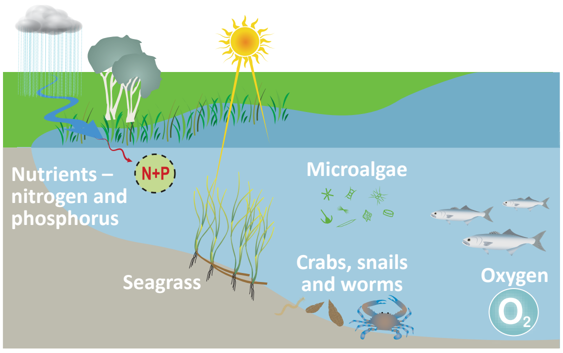
- Wilson Inlet shows resilience to the continuing input of nutrients from the catchment
- the Sleeman River and Cuppup Creek in the east are the major contributors of phosphorus to the inlet
- nutrient levels in Wilson Inlet are low to moderate with higher levels and increased microalgae activity when the rivers start to flow in winter and the sandbar is open
- nutrient levels have remained similar in the inlet over the last 20 years
- when the sandbar is closed, the inlet is well mixed with good oxygen levels; when the inlet is open to the ocean, parts of it are stratified with lower oxygen levels
- seagrass grows in extended meadows in water depths up to two metres; some decline in its extent has been seen in the last 10 years
- rising sea levels and reduced river flow caused by climate change are altering sandbar dynamics; we're adapting sandbar management to achieve the best sandbar openings in the face of a changing climate.

[1] Shire of Denmark 2009, *Wilson Inlet sandbar opening protocol,* available denmark.wa.gov.au

Estuary health refers to the ecological integrity of an estuary. Many things can compromise the ecology of an estuary: overfishing, contamination from industrial waste or the invasion of foreign species. However, for estuaries in the South West of Western Australia, eutrophication is the main threat.

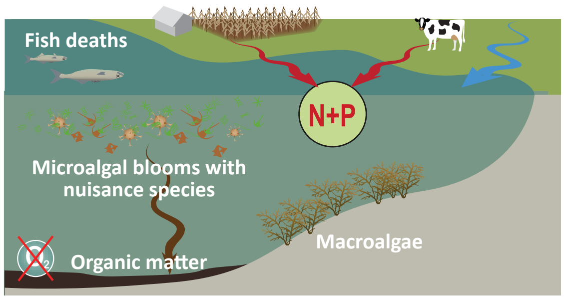
Eutrophication is the overgrowth of aquatic plants (usually micro- or macroalgae) caused by excessive nutrients: nitrogen and phosphorus. High algal growth (or algal blooms) leads to high organic matter decomposition rates, which deplete oxygen in the water. Eutrophication can also cause fish and other fauna to die, and even lead to an ecosystem shift from a healthy seagrass-dominated system to a less desirable microalgae-dominated one.

What is estuary health?



Healthy estuaries

Estuary waters are clear and free from algal blooms, litter and high turbidity. Fish are diverse and abundant. Estuary and river foreshores have healthy native trees and sedges. Small amounts of nutrients are naturally transported to the estuary by rivers and groundwater. Low concentrations of microalgae support the base of the food web. Bottom waters and sediments are well oxygenated. Seagrasses thrive in well-lit, low-nutrient waters. Seagrasses also stabilise sediments, shelter fish, provide food for birds such as swans, and oxygenate bottom waters.



Unhealthy estuaries

Catchments and foreshores are extensively cleared for agriculture, urban and/or industrial land uses, leading to excessive nutrient concentrations. High nutrients fuel algal growth reducing the light available to bottom-rooted seagrass which cannot thrive in low-light environments. Decomposing algae contribute to high levels of organic matter and oxygen consumption. Algal communities change from healthy species to less desirable and sometimes toxic species. Low oxygen and toxins from algae potentially lead to fish and fauna deaths.

What we measure

In the catchment

Flow: The volume of water per unit of time determined at hydrological gauging sites.

Temperature, dissolved oxygen, salinity, pH: Measured by an insitu probe, approximately mid-channel.

N+P

Nitrogen and phosphorus: Concentrations measured in rivers, and when multiplied by flow volume, provide and estimate of the load that enters the estuary.

In the estuary

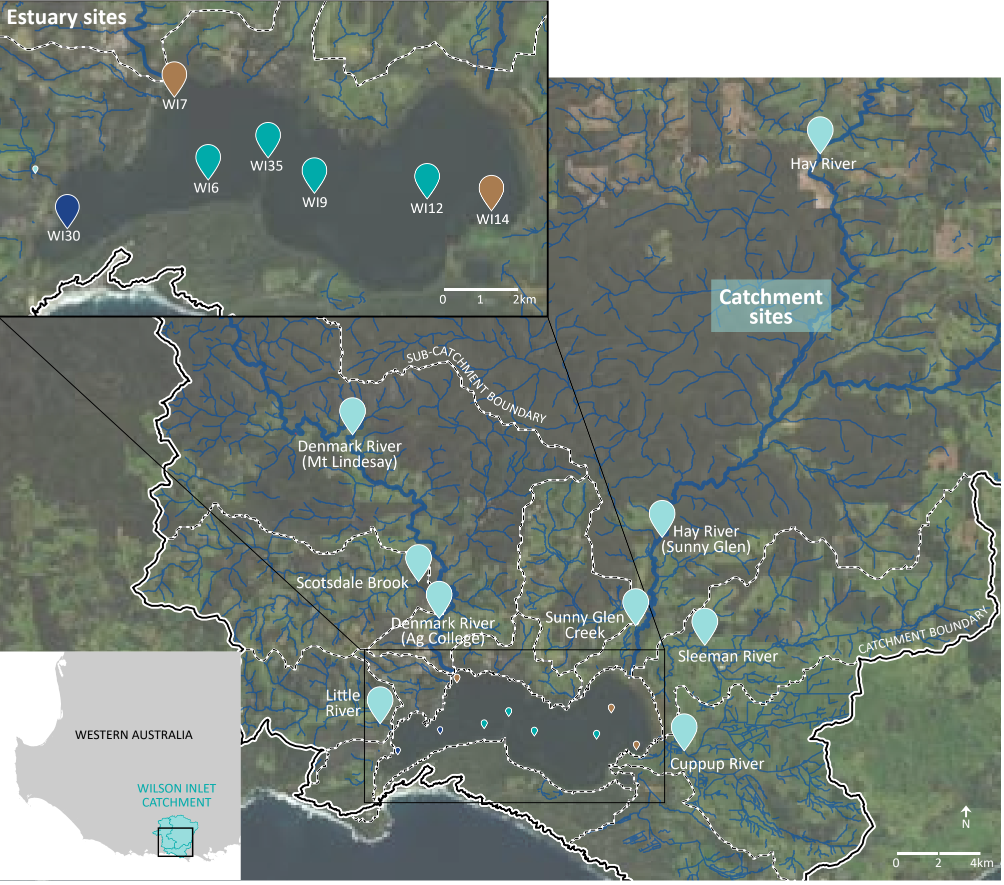
Temperature, dissolved oxygen, salinity, pH: Measured by an insitu probe at 0.5–1 metre depth intervals.

N+P

Nitrogen and phosphorus: Concentrations measured in surface and bottom water samples. Analyses include totals and dissolved nutrients (nitrate, ammonium and phosphate).

Microalgae: Chlorophyll *a* concentration in surface samples, and species identification and cell density in depth-integrated samples.

Seagrass: Mapping of extent and health status.



About Wilson Inlet and its catchment

Wilson Inlet is located on the south coast of Western Australia near the town of Denmark. Natural changes in the estuary occur annually and seasonally, affecting water quality and how people use the estuary.

Wilson Inlet is a broad, shallow and flat-bottomed waterbody that is 14 km long with a maximum width of 4 km and an average depth of 2 m. It is a seasonally closed estuary. The sandbar is artificially opened in winter to reduce flooding of low-lying land surrounding the inlet. The sandbar closes naturally, usually in summer, due to waves transporting sand into the channel (a process called siltation). The sandbar has been manually opened since the beginning of the 19th century, but reliable records only start in 1958. Since then, the sandbar has been opened every year except 2007, 2010, 2014 and 2019, when rainfall and therefore river inflow volumes were too low.

Five rivers enter Wilson Inlet: the Hay River, Sleeman River and Cuppup Creek on the eastern side, and the Denmark and Little rivers on the western side. The two largest rivers, the Hay River and Denmark, drain 88 per cent of the catchment and deliver on average 70 per cent of the total water flowing into Wilson Inlet. Scotsdale Brook and Sunny Glen Creek do not directly discharge into the inlet but join the Denmark and Hay rivers a few kilometres upstream.

Wilson Inlet catchment, which has an area of about 2,300 km^2, extends north to Muir Highway.

Water quality monitoring is undertaken fortnightly at seven sites in the estuary and nine in the catchment.

Opening the sandbar; circa 1933 (Photo courtesy of Denmark Historical Society)

Historical context

Pibbulman Wadandi and Menang people have lived around Nullaki, as Wilson Inlet is known to the traditional custodians, for thousands of years. The inlet was and is a place for rest, food and ceremony and remains a very important cultural Noongar gathering place today. The inlet and the surrounding area were and are known as 'places of plenty' and the large size of the fish traps suggest that the shores of the Inlet were an important place to camp and walk through. They remain so today. Sites of rock art, spear sharpening rocks and the burial site stand testimony to the continuous use of this area before Europeans arrived through to today.[2]

Since the colonisation of the area by European timber loggers, farmers and fishers in about 1895, the inlet has been one of the most productive estuarine fisheries on the south coast.

In the 1930s, the Elleker-Nornalup railway line was realigned close to the shores of Wilson Inlet to transport timber, people and goods along the south coast. To avoid flooding of the railway line during winter, the inlet was opened annually.

Public concerns about the health of Wilson Inlet started in the late 1970s when excessive growth of the seagrass *Ruppia megacarpa* was observed. The increased input of nutrients from the catchment, together with the high retention rate of these nutrients in the inlet, were quickly identified as one of the main triggers for the excessive growth of *Ruppia*.

Detailed monitoring and scientific studies began in the mid-1990s to address concerns that Wilson Inlet would soon become eutrophic. The findings of these studies led to coordinated efforts to decrease the amount of nutrients washed into the inlet from the catchment, such as streamline fencing and soil testing.

Today, Wilson Inlet is known for its natural beauty, diverse birdlife and opportunities for recreational activities such as fishing, boating, bird watching and hiking. Protecting cultural and heritage sites has been identified as an important community value for the inlet and its waterways. Wilson Inlet is still one of the most important fisheries in the South West of Western Australia, providing jobs and supporting the local economy.

Wilson Inlet fishtraps

[2] Information courtesy of cultural informants Ezzard Flowers, Lester Coyne, Lynette Knapp, Vernice Gillies, and Dr Wayne Wonitji Webb.

Climate change in the South West

Climate is a key driver of estuary health and it is changing

The South West of Western Australia has a Mediterranean climate: cold, wet winters and hot, dry summers.

Rainfall plays a key role in estuary dynamics as it determines freshwater inflows. The interplay between freshwater inflows and ocean water exchange affects the salinity, flushing rate and stratification patterns (see 'stratification' section) in estuaries. Temperature is also important, as it strongly influences biological growth rates.

Changes in the key climate drivers in the South West are already evident and predicted to continue. The region has become warmer and drier.

Since 2000, May to July rainfall in the South West has been about 28 per cent less than the long-term average.[3] There is strong evidence to suggest that rainfall in the region will decline further in future.[4 5] Not only has rainfall dramatically decreased in autumn and early winter, but there have also been large fluctuations in summer rainfall, which could lead to more frequent and intense storms.[3 4]

Freshwater flows have also decreased significantly by up to 70 per cent since the 1970s — a pattern which is expected to continue.[6]

Between 1910 and 2013, the average annual air temperature in the South West increased by 1.1 degrees Celsius (°C),[7] and is predicted to increase by a further 0.7°C by 2030 (relative to the 1961–90 baseline).[4]

How will estuaries be affected?

Reductions in freshwater flows will lead to increased average salinity in most estuaries. Some areas will be prone to hypersalinity, where a lack of freshwater inflows and summer evaporation mean that salt will concentrate in zones with restricted ocean exchange. Hypersalinity can already be seen in parts of the Peel-Harvey estuary and the Leschenault Estuary. Ecological consequences of hypersalinity are decreased phytoplankton diversity and restricted habitat for brackish and freshwater fish species.

Water quality may improve in some areas. For example, the zones closest to permanent openings with good connection to the marine environment will most likely increase in marine biodiversity and decrease in microalgal activity as they become less influenced by fresh, nutrient-rich catchment inflows. Conversely, intermittently closed estuaries (common on the south coast of Western Australia, including Wilson Inlet) are likely to have longer periods of sandbar closure. This change in environmental conditions may reduce biodiversity and increase the effects of nutrient-rich catchment inflows.

Stratification patterns will change as low flows cannot fully flush estuarine waters in winter in permanently open estuaries; rather, smaller freshwater flows sit as a layer above the saline bottom waters and may persist for longer periods of time. This can result in depleted oxygen (known as hypoxia) and the release of sediment-bound nutrients, which can fuel undesirable algal blooms (discussed in more detail later). Nutrients from catchment inflows could be retained in the estuary rather than being transported to sea. This can lead to adverse impacts such as increased algal activity and low light conditions for seagrasses. This is also true in seasonally closed estuaries, like Wilson Inlet, where the sandbar might not open in some years due to low flows. The estuarine river reaches of many South West estuaries already show patterns of extended periods of low oxygen levels due to high nutrient loads and persistent stratification.

Shallow estuaries will be particularly vulnerable to warming conditions. Higher temperatures favour algal growth and estuaries may have greater algal productivity as a result, which subsequently affects the entire food web. Extreme heat waves also have negative impacts on some fauna and flora, such as important seagrasses. Rising sea levels and more frequent summer storm events could increase the occurrence of coastal inundation events and unseasonal nutrient input.

The synergistic impact of these various stressors is difficult to predict, and recent studies show that these effects are happening at rates faster than those predicted by climate change models.[8]

3 Bureau of Meteorology 2020, *Australia's changing climate*, available from http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml.

4 Department of Water 2015, *Selection of future climate projections for Western Australia*, Water science technical series, report no. 72, Government of Western Australia, Perth.

5 Hope P et al. 2015, *Southern and south-western flatlands cluster report, Climate change in Australia projections for Australia's natural resource management regions*: cluster reports, ed Ekström M. et al., CSIRO and Bureau of Meteorology, Australia.

6 Petrone K et al. 2010, 'Streamflow decline in southwestern Australia, 1950–2008', Geophysical research letters, *Hydrology and land surface studies,* 37(11), available from: agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102.

7 Department of Primary Industries and Regional Development 2020, *Climate trends in Western Australia,* Government of Western Australia, Perth, available from: www.agric.wa.gov.au/climate-change/climate-trends-western-australia.

8 Scanes E, Scanes PR & Ross PM (2020), 'Climate change rapidly warms and acidifies Australian estuaries', *Nature Communications* 11(1803), available from https://www.nature.com/articles/s41467-020-15550-z.

Rainfall

In Denmark, the average annual rainfall from 2000–19 was 960 mm – a 20 per cent decline since the 1909–39 annual average of 1202 mm, and a seven per cent decline since the 1961–99 annual average of 1029 mm.

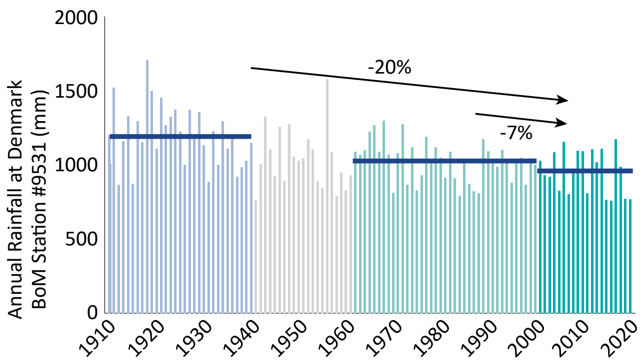
Six of the 10 driest years on record occurred after 2006; four of the driest five years have been in the past six years.

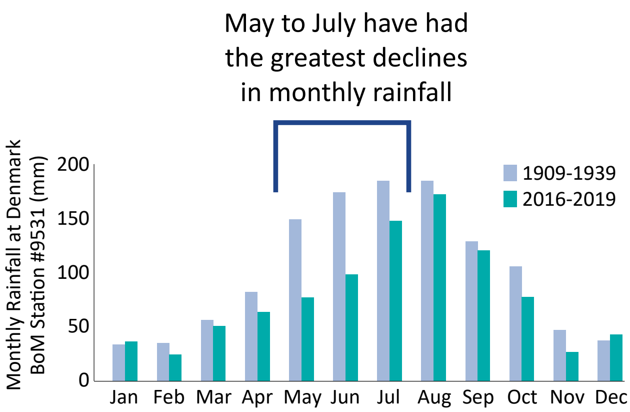
Annual rainfall in the reporting period varied considerably: 2016 was a relatively wet year (1176 mm), as was 2017 with 990 mm; 2018 and 2019 were dry with only 776 and 771 mm.

As highlighted by a regional climate report, the greatest decline has been in rainfall from late autumn to winter.[9] In Denmark, the May to July rainfall in 2016–19 was 36 per cent less than during the 1909–40 period. Additionally, peak rainfall has shifted from mid-winter to late winter.

Key points:

- rainfall in Denmark has declined by 20 per cent since 1940 and by seven per cent since 2000
- peak rainfall has shifted from mid-winter to late winter, with the greatest declines in May to July
- annual rainfall has been more variable recently, with some years being very wet while others are very dry, and rainfall in general is less predictable.





[9] Bureau of Meteorology 2020, *Australia's changing climate*, available from http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml.

River flow

Flow volumes of the rivers of the Wilson Inlet catchment vary greatly between years, due in part to varying rainfall. The amount of rainfall influences the volume of water discharged into the inlet.

Since 2000, the annual discharge of many rivers has decreased. In 2007, 2010, 2014 and 2019, for example, the rivers' low discharges resulted in the sandbar remaining closed.

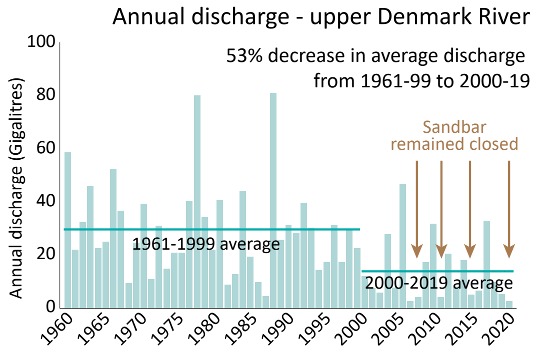
A good example of the decrease in streamflow in the catchment is the upper Denmark River, whose flow measurements have been steadily declining. The average flow volume from the river has dropped by 53 per cent from 30 GL per year before 1999 to 14 GL per year since 2000. However, the decline in rainfall across the same period was only seven per cent, which is disproportionate to the decrease in streamflow.

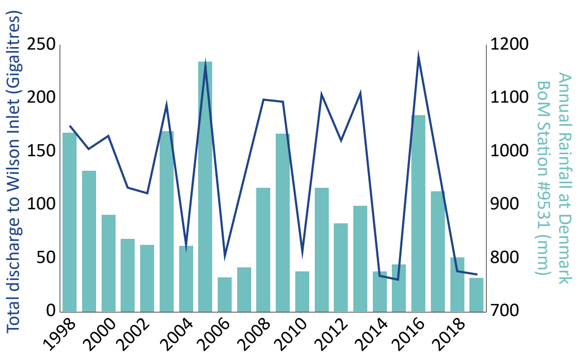
Key points:

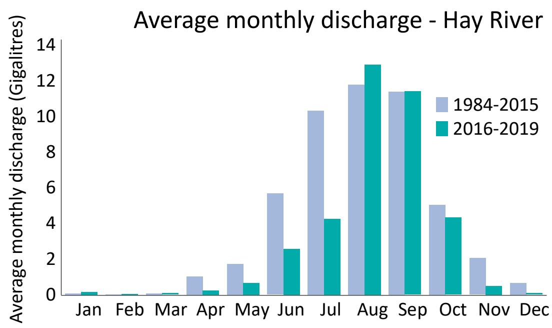
- ⇨ streamflow in the upper Denmark River has decreased by 53 per cent since 1961, a drop which is larger than the decline in rainfall
- ⇨ peak streamflow in the largest river, the Hay River, shifted from mid-winter to late winter, with the greatest declines in streamflow seen from April to July.

Similar patterns have been observed throughout the South West.[9a] This shows that the relationship between rainfall and river flow is complex, and that other factors come into play. Evaporation rates, for instance, also influence catchment runoff. A series of dry years reduces soil moisture and groundwater levels and results in a disproportionate decrease in runoff and river flow. This suggests a hydrological shift that will not be reversed without multiple years of high rainfall.

Similar to changing rainfall patterns, river flows into Wilson Inlet now start later in the year (August) and stop earlier (November) than previously, as can be seen in the Hay River.







[9a] Petrone K et al. 2010, 'Streamflow decline in southwestern Australia, 1950–2008', Geophysical research letters, Hydrology and land surface studies, 37(11), available from: agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102.

Sandbar dynamics

Key points:

- the sandbar remained open for about 200 days in 2016 and 2017, but only 98 days in 2018, which was the fourth shortest opening ever recorded
- the brief opening in 2018 was due to low river flow and a lack of rainfall after the sandbar opened.

Rainfall is the main factor which determines whether the Wilson Inlet sandbar is opened in a specific year or not. Plenty of winter rainfall increases the inlet's water level and inundates the adjacent land. This triggers the excavation of the sandbar and creation of a connecting channel between the inlet and the ocean.

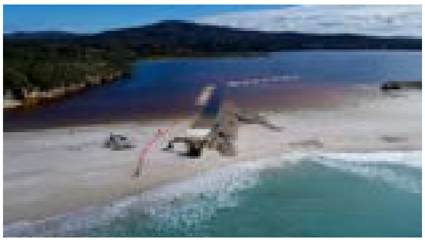
In 2016 and 2017, the water level of the inlet on the day of opening was high, so there was a big difference between the water levels of the inlet and the ocean. The water from the inlet consequently rushed into the ocean in the days following the sandbar's opening, in turn pushing a large amount of sand from the delta and the sandbar into the ocean and widening the channel to around 150 m.

Subsequent significant rainfall events in both years (August 2016 and September 2017) led to good river flows which re-scoured the bar. This allowed the channel to stay open for more than 200 days in both years before it eventually closed due to sand being deposited by ocean waves and storm activity.

In the drier year of 2018, the water level at the time of opening was lower than in previous years, leading to decreased scouring of the sandbar. In addition, the channel was excavated as a 'Y' shape, with two smaller, converging channels instead of one deeper channel. This meant there was less energy available to widen the main channel. There was also no large rainfall event during the period the sandbar was open, which allowed sand in the channel to build up by November and resulted in the fourth shortest opening since recording began in 1958.

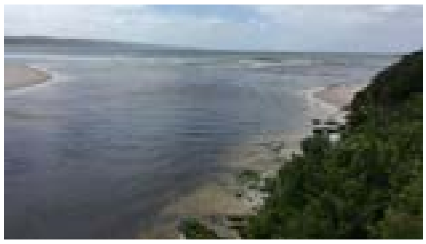
Day of opening | **20 hours later** | **2 months later**

2017



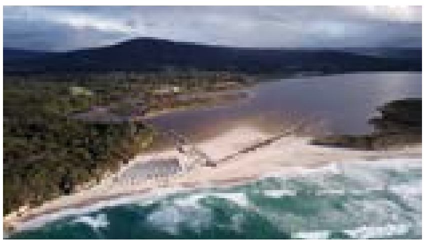
Inlet water level is higher

Wide channel, stronger flow



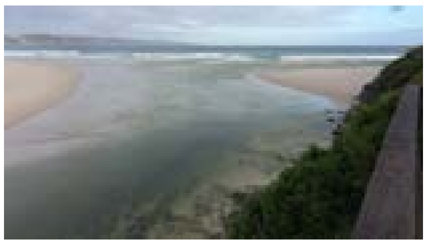
Wider and deeper channel

2018



Inlet water level is lower

Narrow Y-shaped channel, less flow



Narrower and shallower channel

Estuary water level

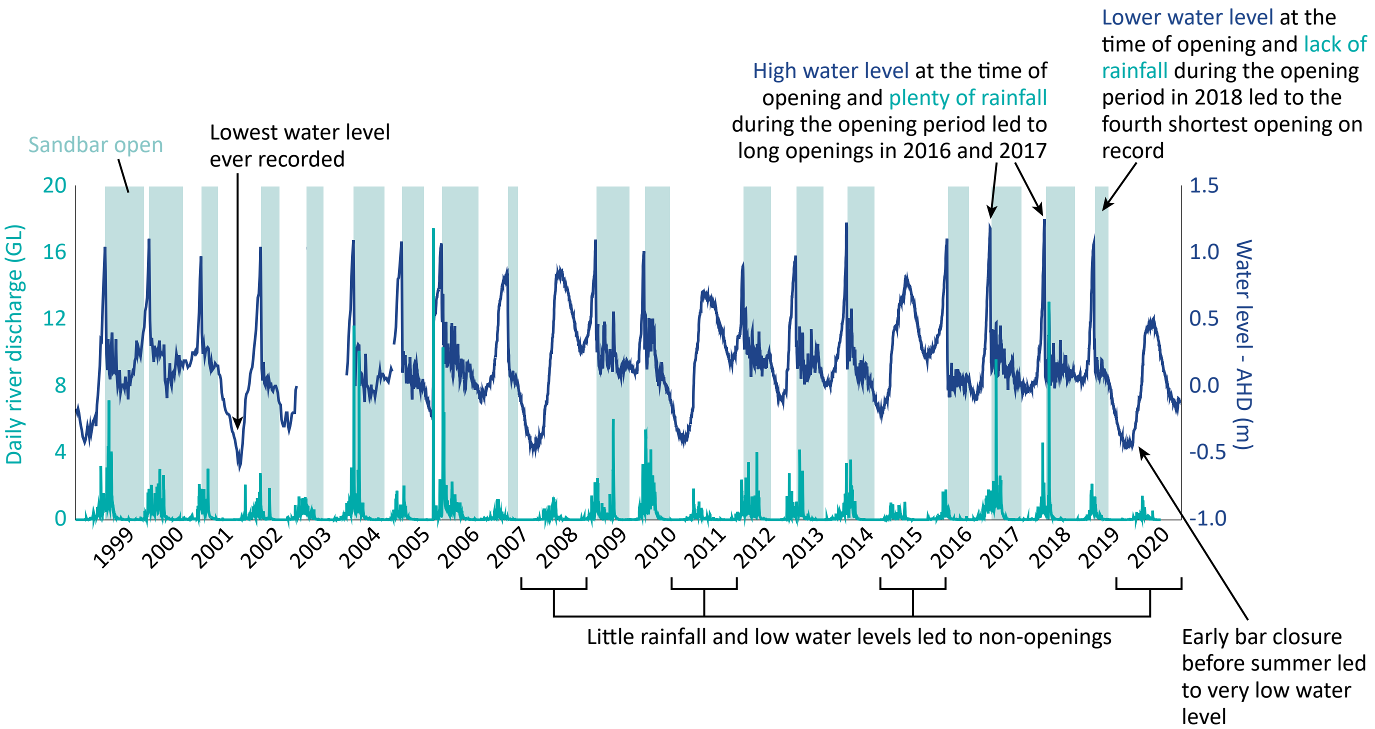
Key points:

- Wilson Inlet experienced the third lowest water level ever recorded on 16 April 2019
- this was due to the early closure of the sandbar, a lack of rain and high evaporation rates over summer and autumn.

In April 2019, Wilson Inlet recorded a very low water level, which was a result of the early closure of the sandbar in November 2018. Between November 2018 and April 2019, there was no water flowing in from either the rivers or the ocean and high summer evaporation rates decreased levels to -0.47 m Australian Height Datum (AHD), the third lowest level ever recorded.

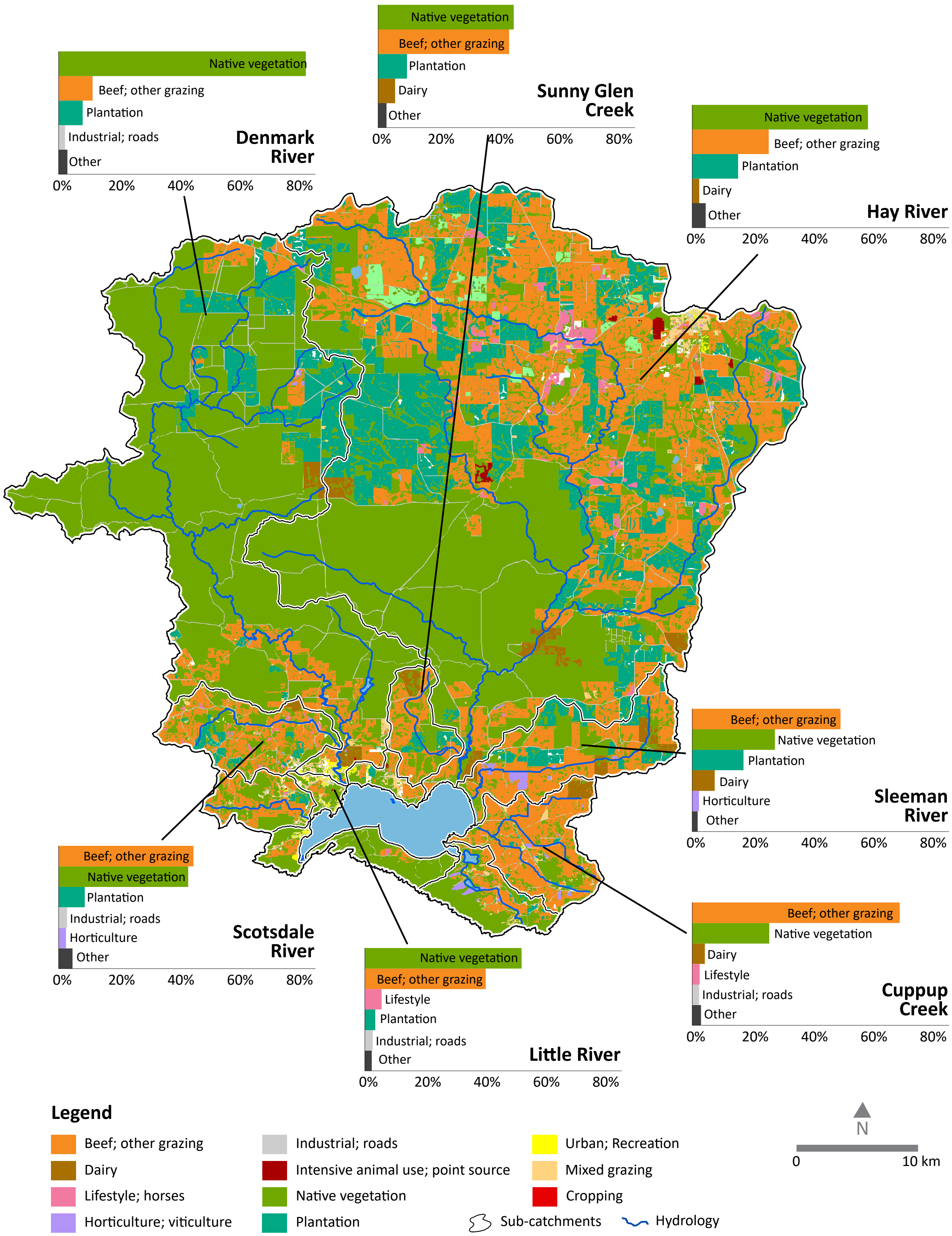
After April 2019, the very low rainfall in winter 2019 meant the water level of the inlet did not rise sufficiently to trigger an opening of the sandbar, and the channel remained closed. This was the fourth year without a sandbar opening since records began.

The processes driving the sandbar's dynamics have been described in detail in an earlier report.[10]



[10] Water and Rivers Commission 2002, *Managing the bar and the Inlet*, Wilson Inlet 6, report to the community, Government of Western Australia, Perth.

Catchment land use



Catchment nutrient sources

Wilson Inlet catchment is about 2,300 km^2, of which about 47 per cent is cleared and used for livestock grazing, plantations, horticulture and residential purposes. Such modifications change hydrological pathways (which determine how much and when water flows into Wilson Inlet), increase nutrient inputs and, together with climate change, put pressure on Wilson Inlet.

Different land use and soil types vary in the amount of nitrogen and phosphorus they export to receiving waters such as estuaries. Land covered by native vegetation exports the least. Pig, beef and dairy farms tend to export the highest amount of nutrients, and this reflects the amount of nutrients applied as well as the total area of the land use type. Urban garden fertiliser use, septic tanks and wastewater treatment plant discharges also impact eutrophication. Land use mapping and knowledge of the nutrient status of the major flows within the catchment help us to identify areas that currently have (or potentially may have) a negative impact on estuary health. This information is used to guide investment in mitigating land use impacts in large, diverse catchments.

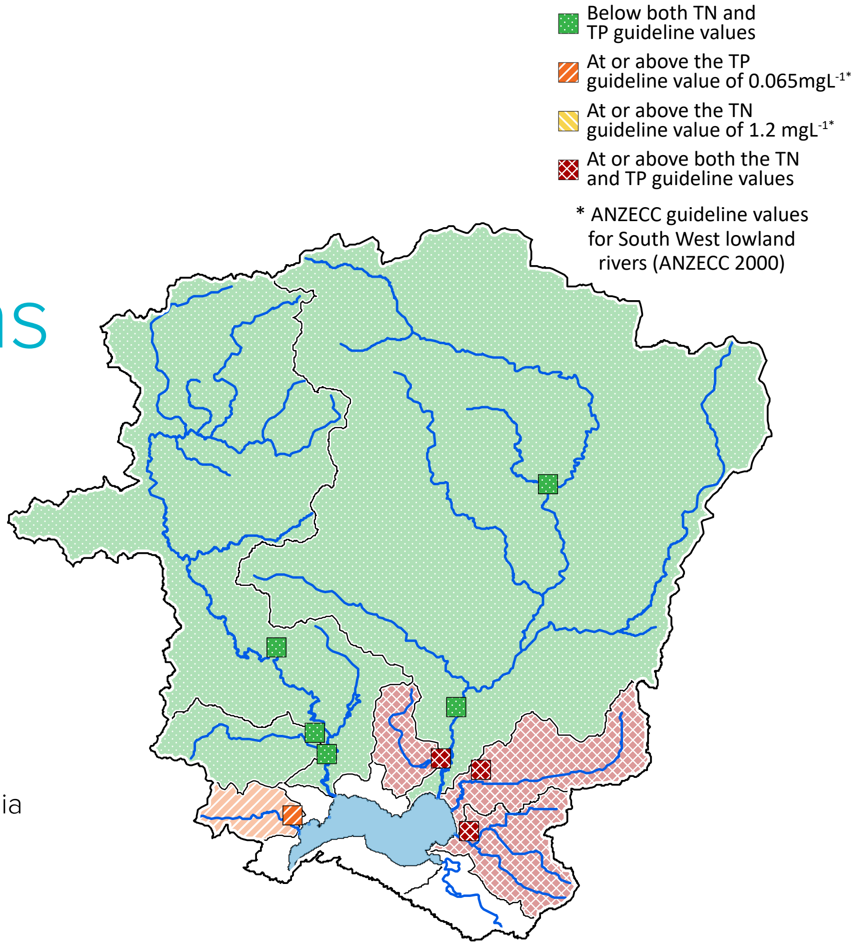
The two largest subcatchments are the Hay River, which drains about 54 per cent of the entire catchment, and the Denmark River, which drains about 26 per cent. These two subcatchments still have large areas of native vegetation – around 80 per cent for Denmark River subcatchment and 45 per cent for Hay River.

Facts and figures

Catchment area	2 241 km^2
Per cent cleared area (2018)	47%
Rivers flowing into Wilson Inlet	Denmark, Hay, Sleeman, Little rivers and Cuppup Creek
Average annual flow (2016–18)	114 GL
Main land use (2018)	Native vegetation, beef and sheep farming, plantations

Many of the other subcatchments have been cleared. The Cuppup Creek and Sleeman River catchments in particular contain very little native vegetation and both rivers have been partially modified to allow better drainage through the low-lying pastures which mainly support beef cattle grazing.

Catchment nutrient concentrations



During the 2016–19 monitoring period, nutrient concentrations were measured fortnightly in surface water samples from the main river or stream within the subcatchment. Winter median nutrient concentrations (May to October) were compared to the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) guideline values for lowland rivers in south-west Australia.[11] These guidelines provide a value above which there may be a risk of eutrophication. We used these winter medians because the effect of rivers on the estuary is highest during the wetter winter months.

The map shows where the total nitrogen and phosphorus winter median concentrations for 2016–19 were higher than the guideline values.

River nutrient concentrations reflect the subcatchment land use. Rivers discharging from cleared landscapes have historically had the highest nutrient loads[12] and they remain high. Winter median nitrogen and phosphorus concentrations in Cuppup Creek, Sunny Glen Creek and Sleeman River, for instance, were higher than the guideline values (nitrogen: 1.2 mgL^{-1}; phosphorus: 0.065 mgL^{-1}). By contrast, the three subcatchments with the highest proportion of native vegetation – Denmark River, Scotsdale Brook and Hay River – had winter median nutrient concentrations below the guideline values.

Key points:

- ⇨ Hay River, Denmark River and Scotsdale Brook had winter median nitrogen and phosphorus concentrations below the guideline values
- ⇨ Cuppup Creek, Sunny Glen Creek and Sleeman River had winter median nitrogen and phosphorus concentrations above the guideline values
- ⇨ Little River had winter median phosphorus concentrations above the guideline value.

Detailed catchment water quality monitoring results, including trends, are published online by the Department of Water and Environmental Regulation: https://estuaries.dwer.wa.gov.au/nutrient-reports/

[11] ANZECC & ARMCANZ 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, vol 1: the guidelines, available from https://www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-armcanz-2000.

[12] Department of Water 2008, *Wilson Inlet catchment water quality year to year*, Wilson Inlet 8, report to the community, Government of Western Australia, Perth.

Flows and nutrient loads to the estuary

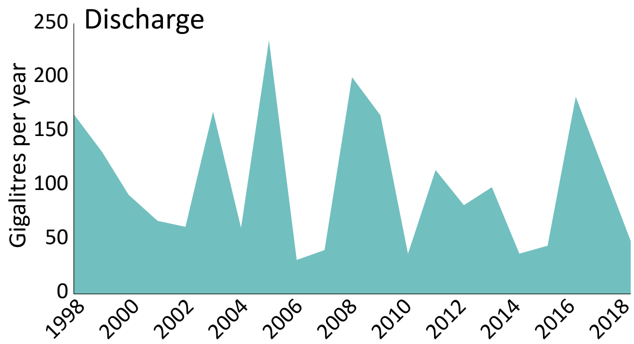
The total amount (or load) of nutrients entering the estuary is estimated by multiplying the nutrient concentration by the flow volume (discharge). The pattern of high interannual fluctuations in annual river flows is therefore reflected in the annual nutrient loads.

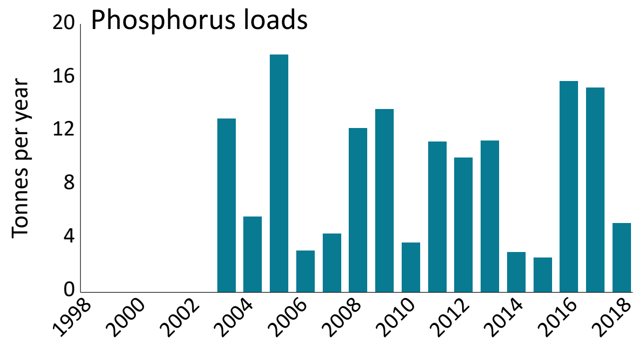
Three times as much nitrogen and phosphorus were discharged into the inlet in the wet year of 2016 compared with the dry year 2018.

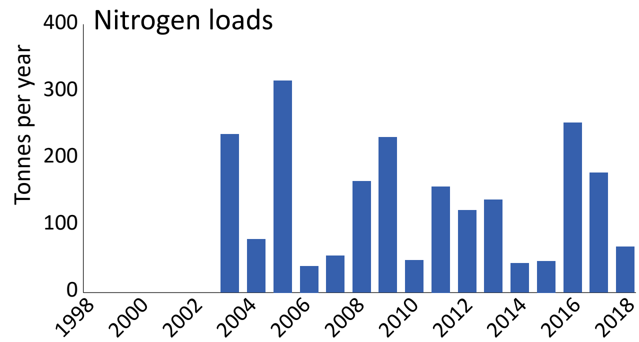
While low flows caused by a drying climate may seem potentially good for estuaries, as they mean low nutrient loads, the issue is more complex. The timing and distribution of flows and nutrients over the course of the year are important for how an estuary responds to nutrient inputs. For instance, unseasonal rainfall in summer could trigger a larger undesirable microalgal growth response than a winter rainfall event, even when the same amount of nutrients is discharged.

Low river flows can also result in other problems for the inlet, such as a low water levels and more years where the sandbar remains closed. In years when the bar does remain closed, the inlet's water level might then be high during the next year's peak migration season of migratory birds in February, reducing available habitat.

It is worth noting that a river's estimated load is based on data from one site within that river, situated upstream of the convergence of the river and the inlet. Any nutrients that enter the river downstream of that station, or any nutrients that enter the inlet through the groundwater (e.g. nutrients from septic tanks) are therefore not included in the load estimations. Nutrient inputs from unmonitored smaller subcatchments are also not included.



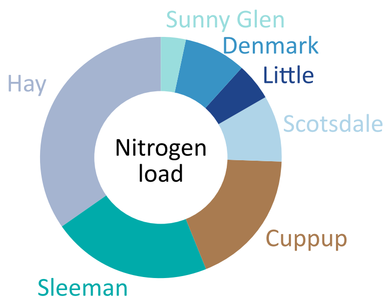


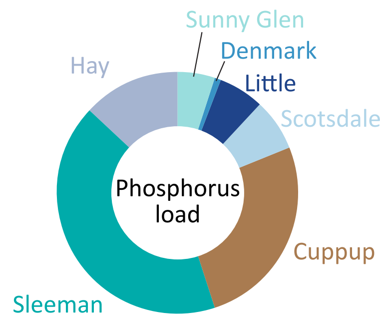


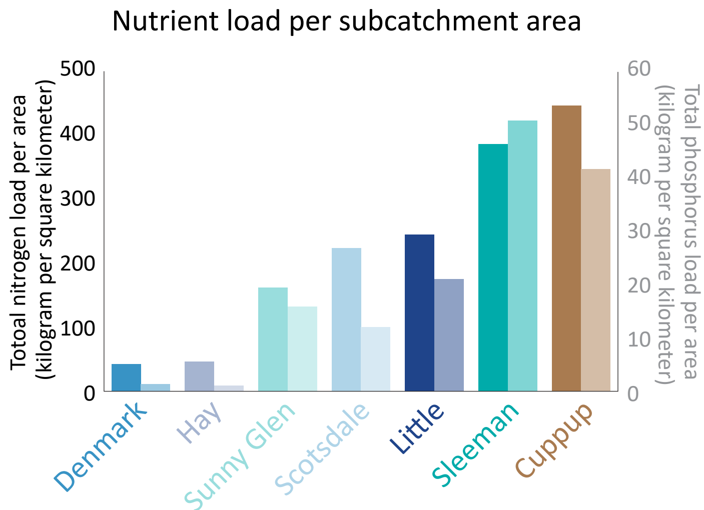
Subcatchment nutrient loads

Key points:

- 68 per cent of phosphorus was delivered to Wilson Inlet by Sleeman River and Cuppup Creek
- 75 per cent of nitrogen was delivered by Sleeman River, Hay River and Cuppup Creek
- it is important to continue reducing nutrient inputs into Wilson Inlet.







Each subcatchment contributes different amounts of nutrients to the estuary, depending on flow and nutrient concentrations.

The Sleeman River and Cuppup Creek contributed 68 per cent of the total phosphorus and 39 per cent of the total nitrogen loads to Wilson Inlet in 2016–18, but only drain 7 per cent of the Wilson Inlet catchment. These large contributions are because they drain mostly cleared, low-lying, flat, waterlogged agricultural land which has a high density of drainage channels. The Sleeman River subcatchment also has large areas of soil which doesn't retain much phosphorus, potentially contributing to high in-river nutrient concentrations.

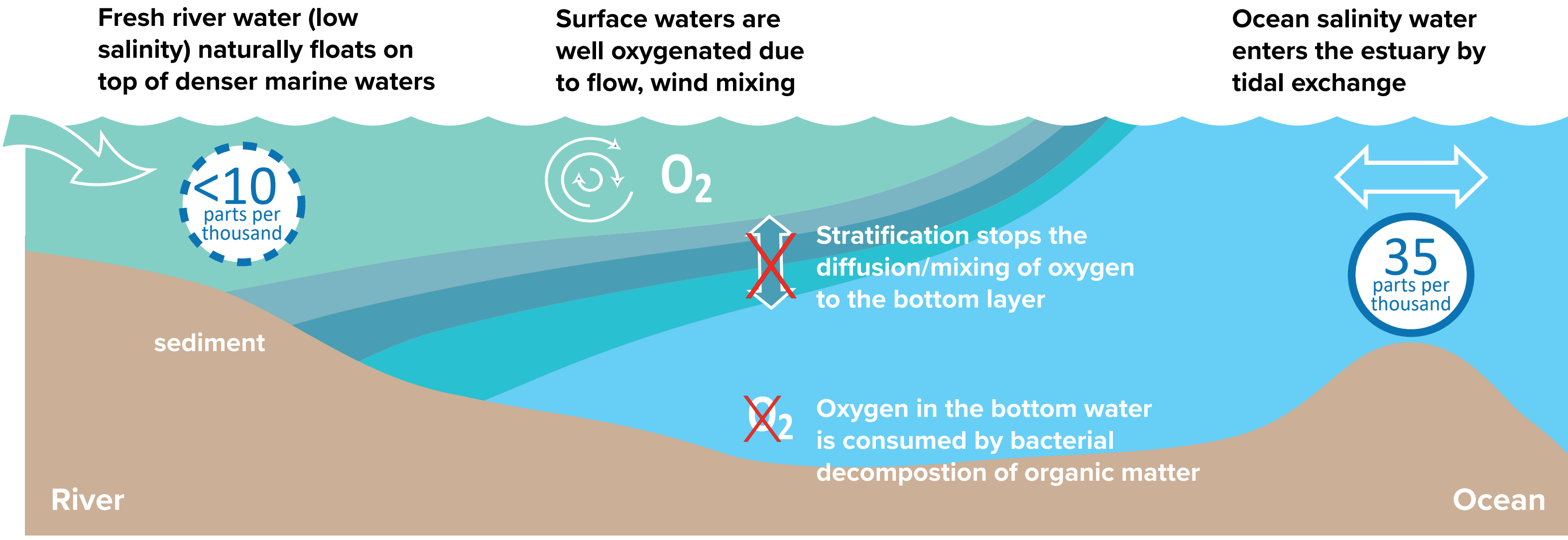
The Cuppup and Sunny Glen creeks had higher nutrient concentrations than the Sleeman River; however, they contributed less to Wilson Inlet's annual load because they only flow for part of the year.

The Hay River, which is the largest subcatchment, delivered 35 per cent of the nitrogen load to Wilson Inlet. This was mostly due to the vast catchment area and associated high flow volumes compared with the other subcatchments.

The significance of catchment size is revealed by dividing the nitrogen or phosphorus load exported by each subcatchment to the Wilson Inlet by the subcatchment's area. This is a way to express how degraded a catchment is and helps identify subcatchments where management actions might be most cost effective.

The Sleeman River and Cuppup Creek, the two subcatchments with the lowest percentage of native vegetation, have the highest load per km^2 for both nitrogen and phosphorus. Conversely, the Denmark and Hay rivers, whose catchments still retain vast areas of native vegetation, have low area-adjusted nutrient load contributions.

These results indicate that broadscale catchment actions to reduce nutrients to the inlet are important, as are targeted remediation activities in hotspots (for instance, areas that contain potato farms and dairy sheds). This is perhaps especially important in the Sleeman River and Cuppup Creek subcatchments, as they have the highest nutrient concentrations and the highest area-adjusted nutrient load contributions.



In the estuary:

the importance of stratification

Stratification in water is an important feature of most estuaries. It relates to vertical differences in salinity or temperature between water layers. These layers require energy to mix, either from wind, currents or the movement of the two layers.

In Wilson Inlet, stratification relates to salinity: freshwater from the rivers tends to sit at the surface because of its lower density, while the denser marine water entering from the ocean makes up the bottom layers. The strength and persistence of stratification in Wilson Inlet is strongly related to wind and to the volume of marine exchange. The latter depends on the channel shape (bathymetry) and on ocean and tidal conditions.[13]

Stratification influences estuarine chemistry and biology, and specifically, the oxygen level of bottom waters. Strong stratification causes a physical barrier to the diffusion of oxygen to the bottom waters.

In the estuary, fresher, tannin stained river water at the surface (left) overlies saltier marine water at the bottom (right)

In estuaries which have significant plant productivity (i.e. high macroalgae, seagrass or microalgae biomass), the bottom layer also has a large amount of organic matter which is decomposed by oxygen-consuming bacteria. Oxygen can be depleted rapidly and when stratification persists and low oxygen (hypoxic) or no oxygen (anoxic) conditions emerge. These conditions are inhospitable to bottom-dwelling animals, and no oxygen in the bottom waters gives rise to rotten-egg-smelling hydrogen sulfide gas, which is also toxic.

Anoxia also alters sediment chemistry, potentially resulting in the release of sediment-bound nutrients, which can add to eutrophication problems. In Wilson Inlet, this is especially true for nitrogen, while phosphorus is more likely to be retained in the sediment and is only released under prolonged periods of low oxygen (below 4 milligrams per litre).[14]

Anoxia further shuts down denitrification, where nitrogen is lost from the sediment directly to the atmosphere in the form of nitrogen gas. Denitrification has been identified as an important pathway of nitrogen loss from the inlet,[14] counteracting the accumulation of nitrogen in the sediment.

[13] Water and Rivers Commission 2002, *Managing the bar and the Inlet*, Wilson Inlet 6, report to the community. Government of Western Australia, Perth.

[14] Department of Water 2010, *Role of sediments in nutrient cycling*, Wilson Inlet 10, report to the community, Government of Western Australia, Perth.

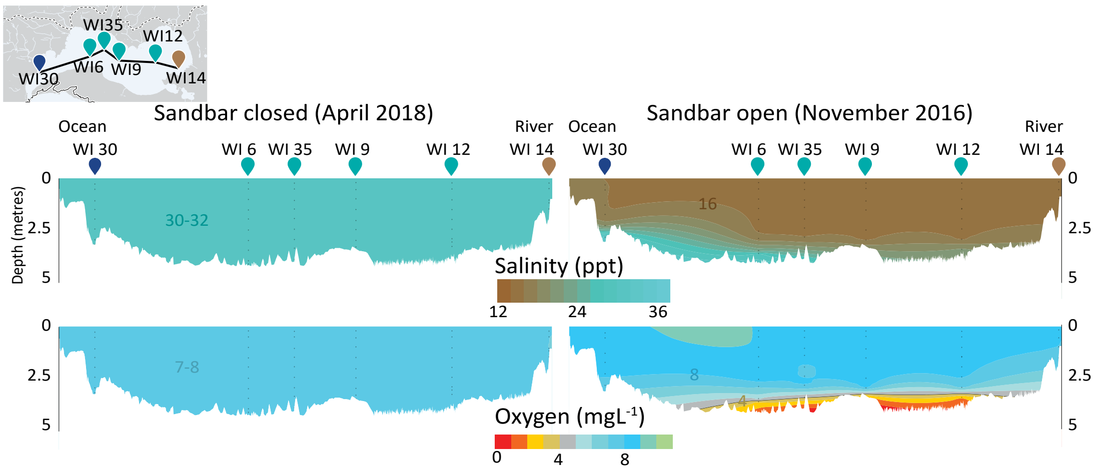
Bar status and inlet stratification

Key points:

- lower oxygen levels near the sediment occur periodically when the sandbar is open and stratified
- stratification and oxygen depletion were more pronounced during the two periods when the sandbar was open for longer in 2016 and 2017, compared with the short open period of 2018.

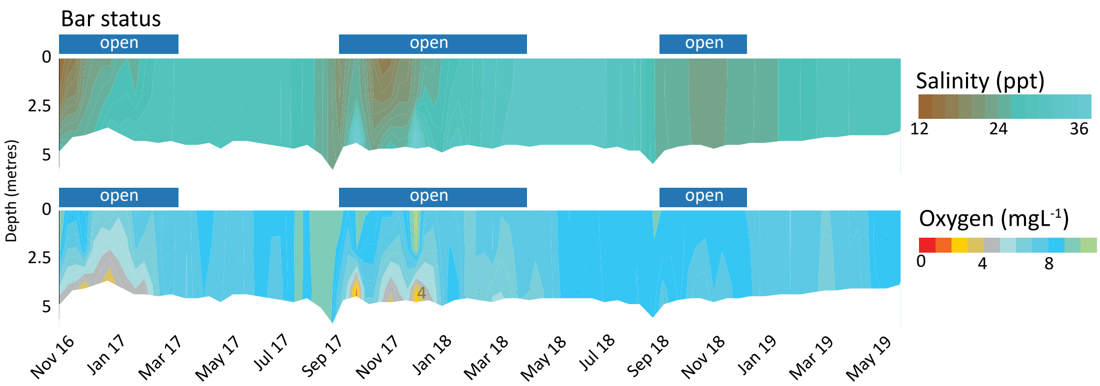
In April 2018, when the sandbar was closed, the inlet displayed the typical conditions associated with a closed sandbar: the discontinued river flow combined with wind mixing the water resulted in similar salinity levels and good oxygen levels throughout the inlet.

In comparison, two months after the opening of the sandbar in 2016, the saltwater that had entered the inlet intruded (in the form of a layer near the sediment) almost to the eastern end. This resulted in low oxygen levels (below four milligrams per litre) over large areas of the inlet, which allowed nutrients to be released from the sediment into the water.



Fortnightly monitoring helps us understand how salinity and oxygen change over time at each site. The effect of river flow and the status of the sandbar (open/closed) on salinity and oxygen can be seen most clearly at site WI6, the deepest site we regularly monitor.

During the longer sandbar openings in 2016 and 2017, this site was stratified for extended periods (represented by different colours over depth in the salinity plot) with low oxygen levels at the bottom developing regularly. During the shorter sandbar opening in 2018, there was no stratification and oxygen levels remained high.



Salinity and oxygen concentrations

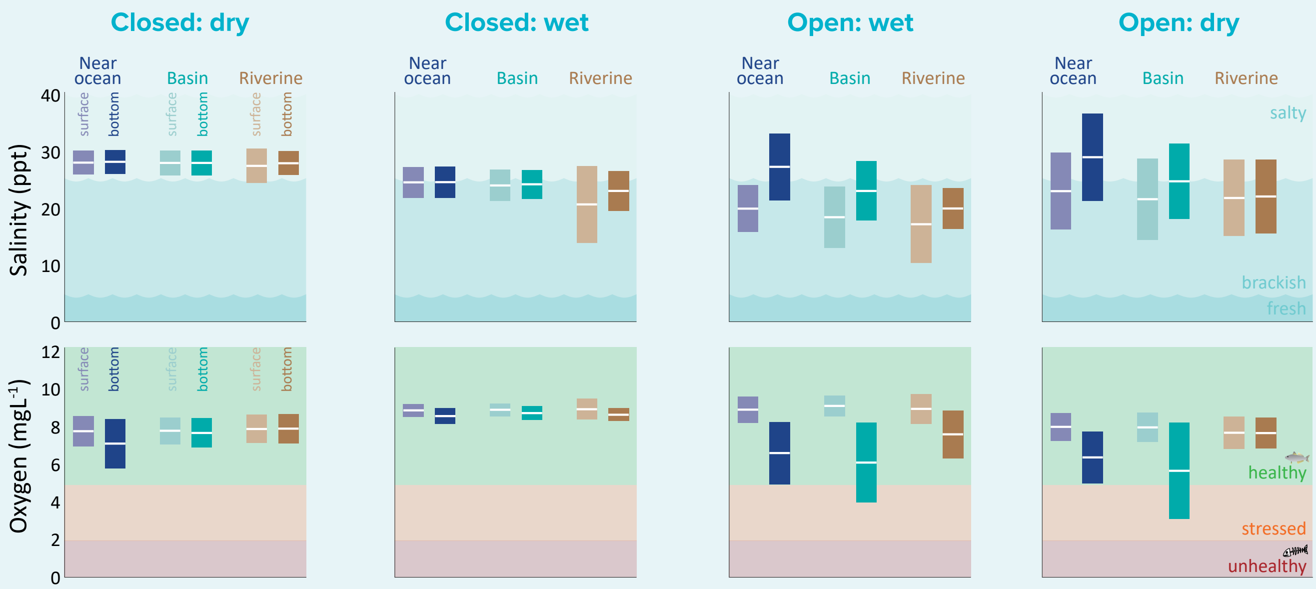
Key points:

- Wilson Inlet has four distinct states which are characterised by the status of the sandbar (open/closed) and by river flow (wet/dry)
- the inlet is well mixed and has healthy oxygen levels most of the time
- low oxygen levels only occur when the sandbar is open

Wilson Inlet is a saline to brackish estuary with slightly higher salinity in the bottom waters when the sandbar is open. Oxygen levels are typically healthy but are lower at the bottom when the sandbar is open, especially in the main basin.

Wilson Inlet has four distinct states, which are aligned with the annual cycle of hydrodynamic events and are determined by whether the sandbar is open or closed and how much water is flowing in the rivers (wet or dry). The timing and duration of each state has shifted considerably since they were first described in the 1990s: the period when the rivers flow (wet period) now starts later (in August as opposed to June/July) and is shorter (nine compared to 11 months).[16]

[16] Water and Rivers Commission 2002, *Managing the bar and the Inlet*, Wilson Inlet 6, report to the community. Government of Western Australia, Perth.



4–6 months in summer to autumn

The inlet is saline because evaporation rates are high, and the salinity is similar throughout the water column due to wind mixing.

Oxygen is at healthy levels, although slightly lower concentrations occur in the bottom water layer at the site closest to the ocean. Decaying aquatic plants, washed into the inlet while the sandbar was open, may contribute to lower oxygen concentration in the bottom waters.

~1 month in winter

The inlet becomes more brackish as rivers start to flow at the beginning of winter. At the sites close to where the rivers join the inlet, salinity at the surface is lower due to the fresher river water.

Oxygen levels are slightly higher than in the previous period, in part due to the higher solubility of oxygen at lower water temperatures in winter.

1–2 months in winter to spring

Now that the sandbar is open, seawater enters the inlet and sits below the brackish water (stratification). This is strongest near the sandbar (ocean site) and in the deeper central basin.

During persistent stratification, oxygen levels decrease at the bottom due to bacterial degradation of organic matter. They can reach levels which are low enough to stress fauna, like fish.

2–6 months in spring to autumn

When river flows start to slow in summer, the inlet becomes more saline due to the continuing ocean exchange. Because the sandbar is still open, weak stratification remains.

Oxygen levels remain lower at the bottom at most sites due to bacterial degradation of organic matter.

Estuary nutrient levels

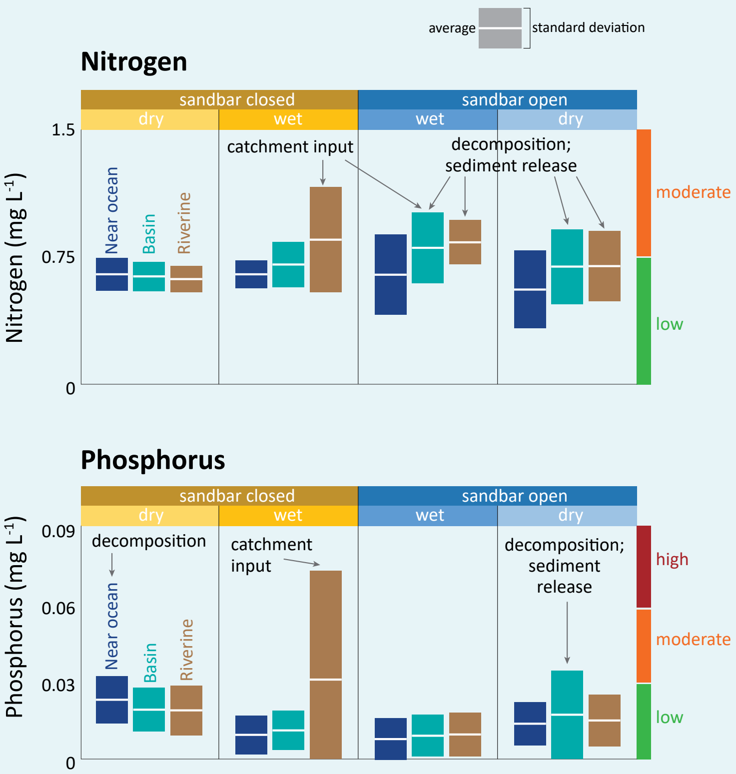
Key points:

- nutrient concentrations are low to moderate most of the time
- periods of moderate nitrogen and phosphorus concentrations occur during times of high river flow and stratification.

Nitrogen and phosphorus are the most important nutrients for plant growth. They exist in many forms. The dissolved inorganic nutrients – such as ammonium, nitrate and phosphate – are immediately available for plants and algae to use. Other nutrient forms (organic or particulate) are not immediately available and must be remineralised by bacteria first.

As discussed earlier, catchment inflows are a key source of nutrients to most estuaries. Sediments can also be a significant source of dissolved nutrients where there is persistent stratification and large amounts of organic matter. By measuring the seasonal pattern of nutrient concentrations in the surface and bottom water samples, we can determine whether these nutrients are coming from catchment inflows, sediments or both.

In Wilson Inlet, nutrient levels were low most of the time but varied over the course of a year. Higher concentrations were measured during periods of high river flow and when the system was stratified with low oxygen levels in the bottom waters.



Nitrogen levels increased when the rivers started to flow (wet period) while the sandbar was still closed especially at the sites close to the rivers (riverine). Higher nitrogen levels when the sandbar was open were due to nitrogen input from the catchment, ammonium release from the sediment and the release of nitrogen from decaying biological matter.

Phosphorus concentrations were low most of the time. Once the rivers started to flow in winter (sandbar closed/wet), elevated levels were measured at the sites closest to the rivers, indicating input from the catchment. Slightly higher levels were also observed in summer (dry period), when the sandbar was open. These can be attributed to phosphate being released through bacterial degradation of organic matter which accumulated on the bottom of the inlet, and/or phosphate being released from the sediment during extended periods of low oxygen.

Microalgal activity

The first response of an estuary to higher nutrient concentrations is usually increased microalgal activity. We monitor this by measuring the concentration of chlorophyll *a*, a plant pigment, in water.

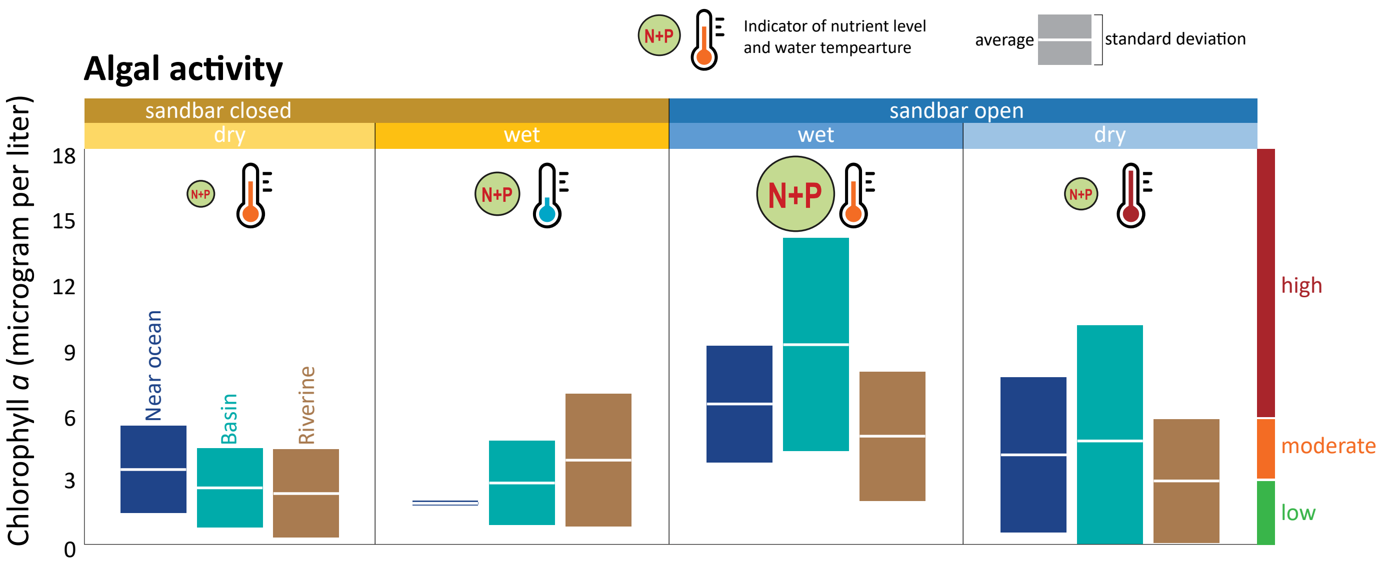
The presence of high levels of dissolved nutrients are most concerning when they coincide with warmer temperatures, because microalgae can grow quickly under these conditions. In Wilson Inlet, the concentration of dissolved nutrients, such as nitrate, ammonium and phosphate are usually low, but begin to increase in winter when the rivers start to flow (wet period). By spring, the temperature also increases. This combination triggers higher microalgal growth. Microalgal activity (measured as chlorophyll *a*) was highest in 2016–19 during the warmer, nutrient-rich sping periods when the sandbar was open, and the rivers were still flowing strongly.

Key point:

- microalgal activity is highest when dissolved nutrient levels are elevated and temperatures are warmer.

In summer and autumn when the sandbar was closed and rivers ceased to flow microalgal activity was highest near the ocean. At this site, dissolved nutrients released through bacterial decay of accumulated biological matter likely stimulated microalgal growth.

Algal activity



Water quality:

Comparison with historical data

Detecting water quality trends in estuaries is inherently difficult because these complex ecosystems have large interannual variability, and monitoring programs can change. One way to ensure that extreme years are not dominating the interpretation of trends is to combine data from several years and compare average concentrations across different periods.

Nitrogen and **phosphorus** levels have remained fairly consistent since 1997. Average nitrogen levels during the wet months have been slightly above the ANZECC guideline values for south-west Australian estuaries since 2002.[17]

Nitrate has remained consistent since 1997 with average concentrations below the guideline value during the dry periods, and above the guideline value during the wet periods. This highlights that nutrient loads primarily originate from catchment inflows.

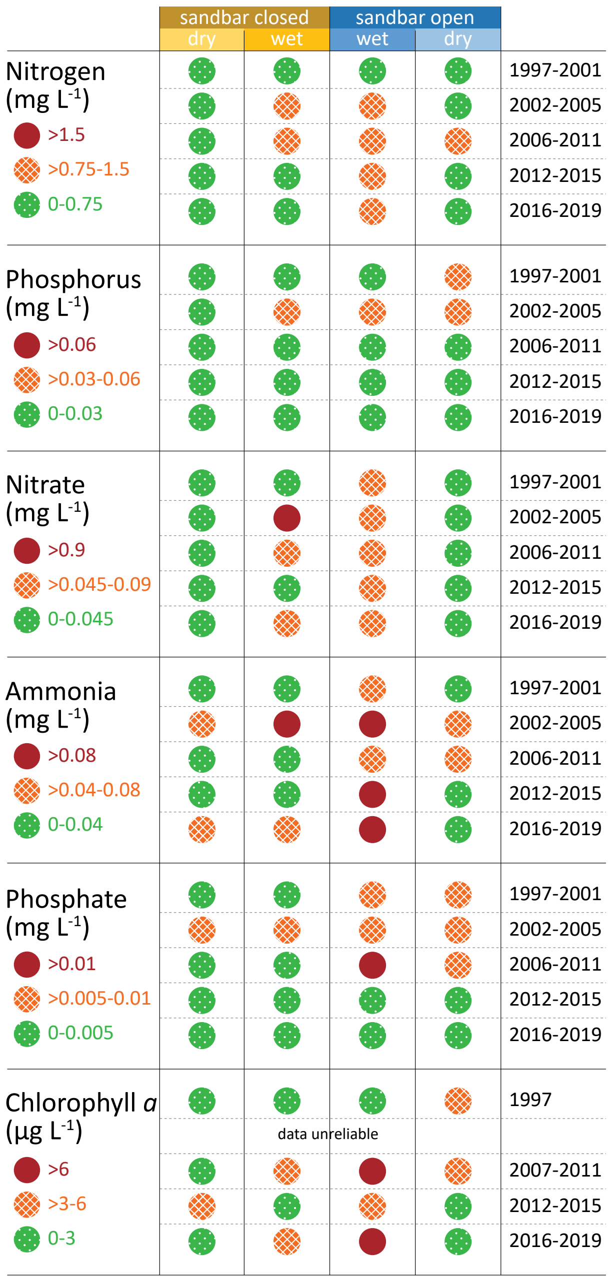
Average **ammonium** levels have always been (and remain) above the guideline value when the sandbar is open and rivers are flowing (wet period). In 2016–2019, ammonium was also higher when the sandbar was closed (wet and dry periods). Ongoing monitoring will identify if this trend continues.

Phosphate has been below the guideline value since 2012. As concentrations are low even when river flow is high, it is likely that this soluble form of phosphorus is quickly taken up by seagrass and algae in the inlet.

Microalgal activity, measured as **chlorophyll *a***, has remained fairly consistent since 2007. The greatest activity in 2016–19 was during the wet conditions when the sandbar was open, because dissolved nutrient levels were highest and water temperature was increasing. It is important to note that although average microalgal activity has been above the guideline values since 2007, this is because of short-lived periods of very high microalgal activity rather than sustained high levels. Microalgal activity is at healthy levels 65 per cent of the time.

Key points:

- nitrogen and phosphorus levels have been, and remain, below guideline values most of the time
- nitrate, ammonium and microalgal activity remain high during the sandbar open/wet period
- phosphate levels have been low since 2012.



[17] ANZECC & ARMCANZ 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, vol 1: the guidelines, available from https://www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-armcanz-2000.

[Chlorophytes] are a large and diverse group of green algae, with over 7,000 species. Like land plants, green algae contain chlorophylls *a* and *b*.

Cyanophytes, also known as cyanobacteria, are primitive, single-celled organisms, often blue-green in colour. Cyanobacteria in estuaries are indicative of poor water quality, when abundant.

Diatoms are single-celled or chain-forming algae and are generally indicative of healthy aquatic flora.

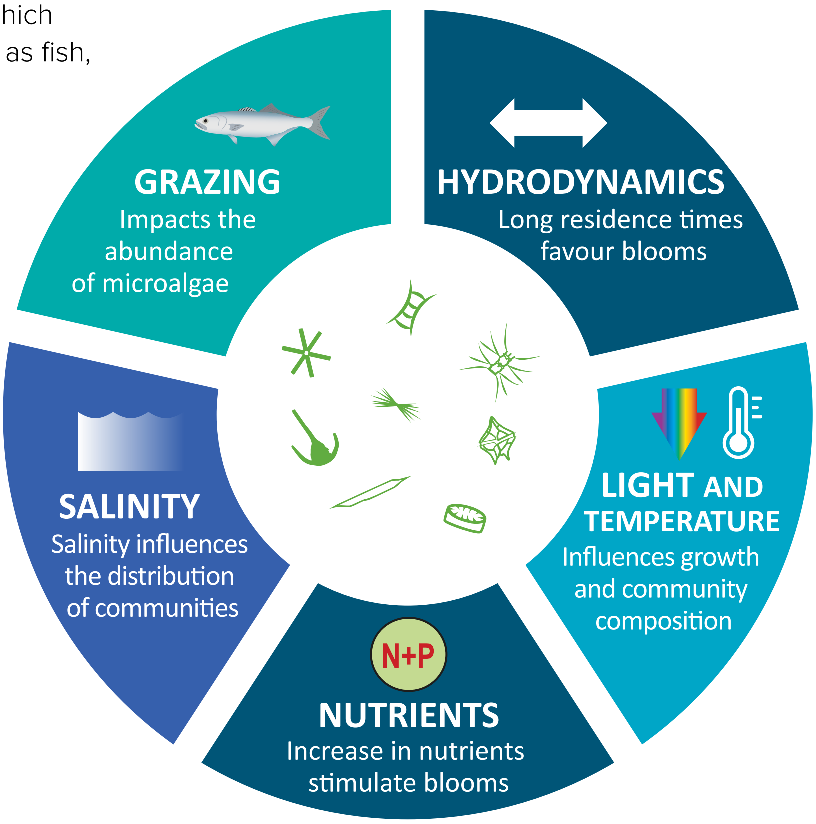
Dinophytes use their flagella to move through the water column, and many are also mixotrophic, meaning they can photosynthesise and/or ingest prey for growth. Dinophytes also contribute to many of the world's nuisance algal species and are sometimes toxic.

Microalgae dynamics

Microalgae, also known as phytoplankton, are tiny photosynthetic organisms which play a huge role in removing carbon dioxide from the atmosphere and generating the oxygen we breathe. As key components of healthy ecosystems, they provide food for invertebrates and fish. During the day they turn sunlight into energy via photosynthesis, which oxygenates the water. However, excessive nutrients, warmer water temperatures and reduced water movement can lead to a rapid increase in the cell numbers of microalgae, also called a bloom. These blooms can be detrimental to aquatic ecosystems: they can reduce light availability to seagrasses; rapidly remove oxygen from the water when they decompose, causing fauna deaths; and certain species can produce toxins, which can be harmful to aquatic fauna (such as fish, crabs and dolphins) and also humans.

Chlorophyll *a*, as mentioned, is a universal indicator of microalgal activity. However, to further understand microalgal dynamics in estuaries, we identify and assess the density of each type of microalgae. This can tell us if potentially harmful microalgae are present and how diverse the community is.

The composition of microalgal communities depends on a combination of factors which affect the algae's distribution. In estuaries, these factors include hydrodynamics, grazing, light availability, salinity gradient and nutrient availability. The groups listed in the table above are just some of the varieties present in estuarine microalgal communities.

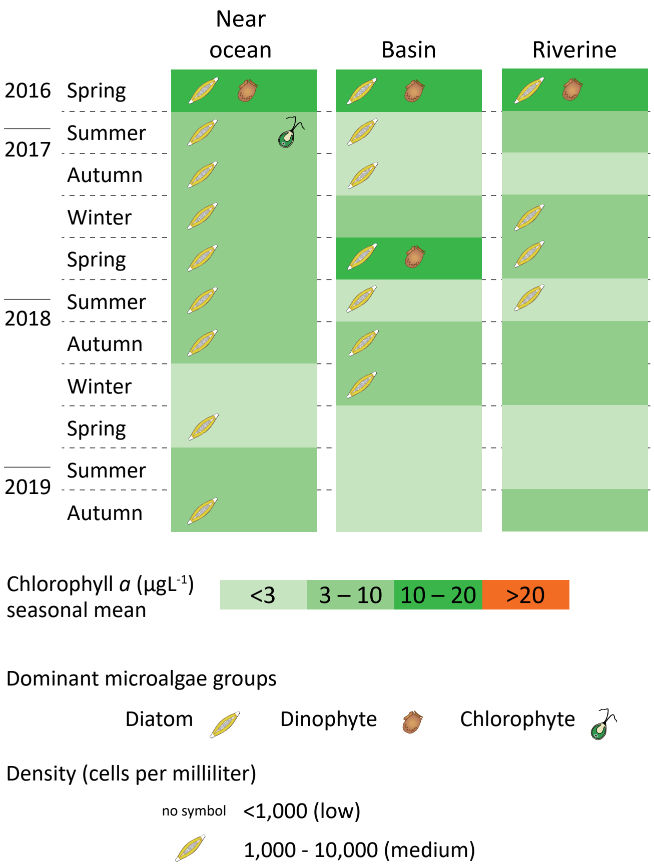


Microalgae:
seasonal patterns

Diatoms were the dominant microalgae group during 2016–19, with *Chaetoceros* and *Cyclotella* being the prevalent genera.

Each year, microalgal cell densities peaked in spring, when the water started to warm and dissolved nutrient levels in the estuary increased, which corresponds with the chlorophyll *a* seasonal pattern. Spring densities in 2019 were much lower than in previous years.

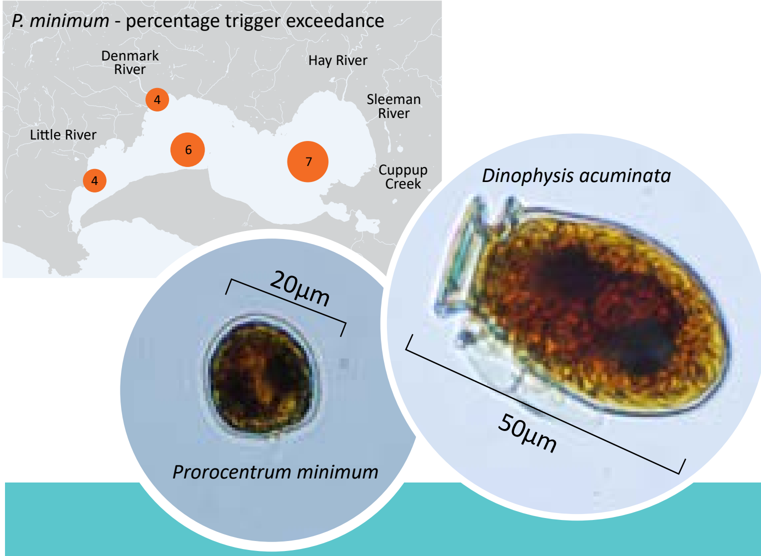
Higher densities of dinophyta, predominantly *Prorocentrum minimum*, occured during spring.



Key points:

- Wilson Inlet is dominated by diatoms, which provide a good food source for many fish species
- microalgal cell density in the inlet is low most of the time, with slightly elevated densities when water temperatures and dissolved nutrient levels are higher.

Potentially harmful microalgae



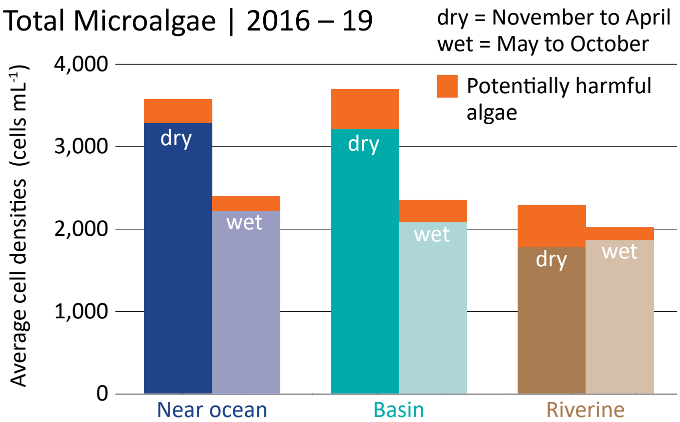
Potentially harmful microalgal blooms are a response to eutrophication in coastal and inland waters worldwide. Blooms can be a threat to human health, fish, marine mammals and sometimes birds. Our monitoring and analysis program includes the identification and enumeration of all species, including the harmful ones.

In Wilson Inlet, 12 potentially harmful microalgal species were identified between 2016 and 2019. This number is low compared to other estuaries in the South West of Western Australia (Peel–Harvey estuary: 57, Leschenault Estuary: 23, Hardy Inlet: 23, Oyster Harbour: 15).

Of these 12 species, only three occasionally exceeded the Department of Water and Environmental Regulation's interim ecological trigger values, which were derived from international and national guidelines, where available, and expert local knowledge.[18] These species were *Dinophysis acuminata, Karenia spp.* and *Prorocentrum minimum*. All three are dinophytes, which can accumulate in shellfish and poison humans after consumption. *Prorocentrum minimum* exceeded the trigger value most frequently: in four to seven per cent of the collected samples, depending on the site (see top map). *Dinophysis acuminata*, which can be toxic in very low numbers if their toxins become concentrated in oysters or mussels, occurred in two per cent of the samples, and only at levels just above the interim ecological trigger value for this species. Importantly, the exceedances of both species were isolated events.

Key points:

- Wilson Inlet has low numbers of potentially harmful algal species
- three of the 12 potentially harmful species detected occasionally exceeded ecological trigger values
- the small dinophyte *Prorocentrum minimum* is the most abundant of the potentially harmful species.



Overall, from 2016–19, potentially harmful algae represented 8–28 per cent of the average total microalgal densities. This proportion was higher from November to April, likely due to better growth conditions.

The high percentage is due to the occurrence of *Prorocentrum minimum*, which was present at high densities at times, but was still below its interim ecological trigger value of 1,000 cells per milliliter. It was detected below the trigger value in 58 per cent of the samples.

[18] Interim ecological trigger values are developed for each potentially harmful microalgal species and can be used to assess the threat they pose to ecological and human health. Relevant trigger values for Wilson Inlet species are 1,000 cells per ml for *Prorocentrum minimum*, 10 cells per ml for *Dinophysis acuminata*, and 5 cells per ml for *Karenia* species.

Seagrass

Seagrasses are flowering plants that have evolved from land plants and adapted to live underwater in estuarine or marine environments. They are important components of aquatic ecosystems, providing habitat and food for fish, birds and crustaceans. Seagrasses also contribute to maintaining healthy estuaries with good water and sediment quality.

Macroalgae, or seaweed, should not be confused with seagrass, even though they can look quite similar. Despite being known as 'weeds', macroalgae are also an important and natural part of estuarine and marine ecosystems. However, an overabundance of macroalgae can be problematic. Excess nutrients in the water can cause prolific 'nuisance' macroalgal growth, which can smother seagrasses, reduce oxygen in the water and produce foul odours when they decompose.

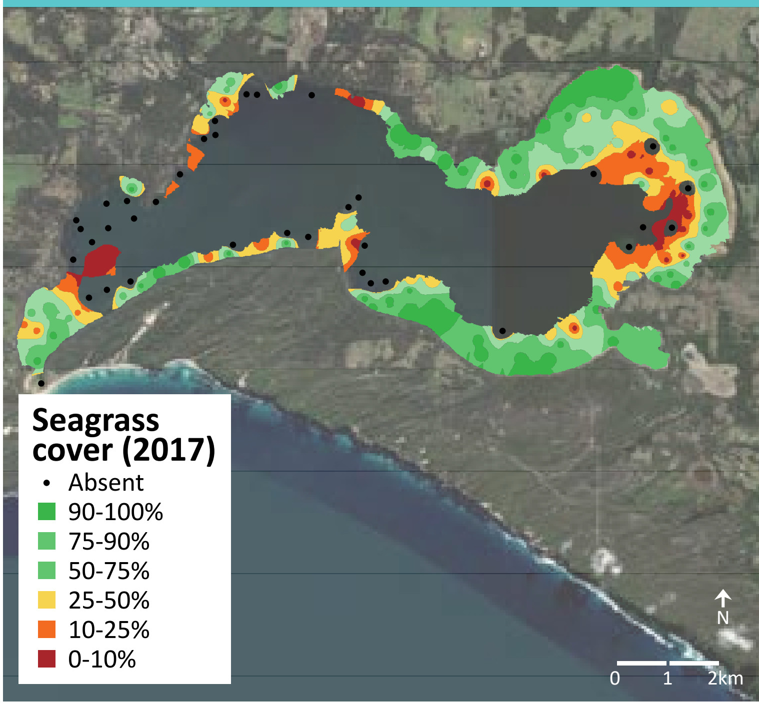
Measuring the abundance and types of seagrasses and macroalgae can provide a valuable insight into estuarine health.

To the local Noongar people, Wilson Inlet is known as *Nullaki*, meaning 'narrow place of seagrass', which could indicate that seagrass has been an integral part of the estuary for a long time.

A large increase in the biomass of the seagrass *Ruppia megacarpa* in Wilson Inlet in the 1970s resulted in numerous studies on the ecological role of *Ruppia*.[19] The studies found that *Ruppia* plays an essential part in maintaining the health of the inlet. It helps to prevent water quality issues by absorbing and buffering nutrients, and by actively transporting oxygen derived from photosynthesis into the sediment, preventing anoxic conditions.

Key points:

- *Ruppia* is the only seagrass species in Wilson Inlet and it plays a critical role in maintaining the inlet's health
- the *Ruppia* meadows in the inlet appear to be in good health, covering 43 per cent of its area
- there has been an 11 per cent decrease in the area covered by seagrass since 2007, mostly around the townsite of Denmark.



A recent survey in 2017–18[20] showed that *Ruppia* was in good health, grew in extended meadows in water depths up to two meters and covered 43 per cent of the inlet's area (2,055 hectares). The covering appeared to have declined by approximately 580 hectares when compared to a survey from 2007, with a notable absence of seagrass in the bay closest to the townsite of Denmark, and in the deeper areas of the eastern portion of Wilson Inlet.

[19] Department of Environment 2003, *Ruppia in Wilson Inlet*, Wilson Inlet 7, report to the community, Government of Western Australia, Perth.

[20] Bennett K et al. 2021, *Seagrasses in four estuaries in Western Australia's south-west*, Water science technical series, report no. 86, Department of Water and Environmental Regulation, Government of Western Australia, Perth.

Outlook

Nutrient pollution and climate change are the biggest risks to the health of estuaries along the south coast of Western Australia.

We have already observed dramatically reduced river flows which directly impact the sandbar opening. Continued lower river flows could make the annual sandbar openings less likely to occur in the future. While estuaries are highly variable ecosystems and many of the organisms living in and around them have adapted to this variability, the ecosystem of Wilson Inlet could change if the sandbar remains closed for consecutive years. *Ruppia*, for example, seems to cope with irregular openings of the sandbar, but the effect of consecutive years without opening is unknown. Similarly, we don't know the consequences successive closed years could have for fish species which rely on marine recruitment, such as King George whiting, snapper or Australian Herring. Their populations may see a drastic decline if the sandbar remains closed for too many years in a row. Water and migratory bird populations could also be affected, as they rely on particular water levels at the time of breeding and feeding.

The predicted sea level rise and increase in storm surges could make successful sandbar openings more difficult. Consequently, the sandbar may close earlier, leading to very low water levels during summer and autumn, making it even harder to reach a water level that would allow a successful opening in the next year.

The frequency of summer and autumn storm events is predicted to increase. These storms will deliver nutrient loads to the inlet when it is closed to the ocean and at times when temperatures are warmer, potentially triggering increased microalgal activity and macroalgal growth. Both would reduce the light available to seagrasses, causing a decrease in the extent of their meadows, which would have flow-on effects for water quality and the ecosystem.

To maintain the social and ecological values of Wilson Inlet, management should continue to focus on building resilience and adaptability where possible. This means continuing to minimise the delivery of nutrients and sediments from the catchment to the estuary. Particular attention should be given to the subcatchments which contribute most to the nutrient loads, such as Cuppup Creek and Sleeman River. The Water Quality Improvement Plan currently being developed for Wilson Inlet will suggest management actions which are most likely to decrease nutrient loads to the inlet – an important initial step towards effective ongoing management of this system.

Increasing carbon dioxide concentration in the atmosphere is leading to acidification in coastal waters across Australia, and especially in the Southern Ocean. The trend in increasing sea surface temperatures will promote microalgal growth. The combined impact is difficult to predict.

More broadly, national and international efforts to reduce carbon emissions will continue to be critical to mitigating the decreasing rainfall, rising air and sea surface temperatures, increasing ocean acidification and rising sea levels. As well as having other negative impacts, such shifts have the potential to degrade the health of estuarine ecosystems and their associated social values.

More information

The Regional Estuaries Initiative started in 2016 and continues as the Healthy Estuaries WA program. We work with local partner organisations to improve the health of Wilson Inlet. Our focus has been on reducing nutrients entering waterways from their source in the catchment, removing nutrients once they have entered waterways and building scientific understanding of the catchment and estuary to inform management decisions.

This has included:

- **restoring** stream function, moving stock away from waterways and implementing river action plans in partnership with the Wilson Inlet Catchment Committee
- **reducing** nutrient runoff from farms through improved fertiliser and dairy effluent management practices in partnership with Department of Primary Industries and Regional Development, farmers, industry and the Wilson Inlet Catchment Committee
- **supporting** the scientific monitoring of Wilson Inlet and its catchments.

For more information on Healthy Estuaries WA and Wilson Inlet visit estuaries.dwer.wa.gov.au/estuary/projects/.

What you can do

Farmers

Base fertiliser management decisions on soil test results.

Fence streams from livestock and restore native vegetation.

Homeowners

Adopt best fertiliser practice in your gardens.

Plant natives.

Local communities

Stay informed through the estuaries website.

Join your local catchment group.

Report algal blooms and unusual fish deaths.

Find out how at estuaries.dwer.wa.gov.au/participate/

#WAestuaries

HEALTHY ESTUARIES WA