Department of **Water and Environmental Regulation**
Department of **Primary Industries and Regional Development**

GOVERNMENT OF WESTERN AUSTRALIA

Wilson Inlet

Nullaki

Condition of the estuary 2019-2023

#WAestuaries

Acknowledgements

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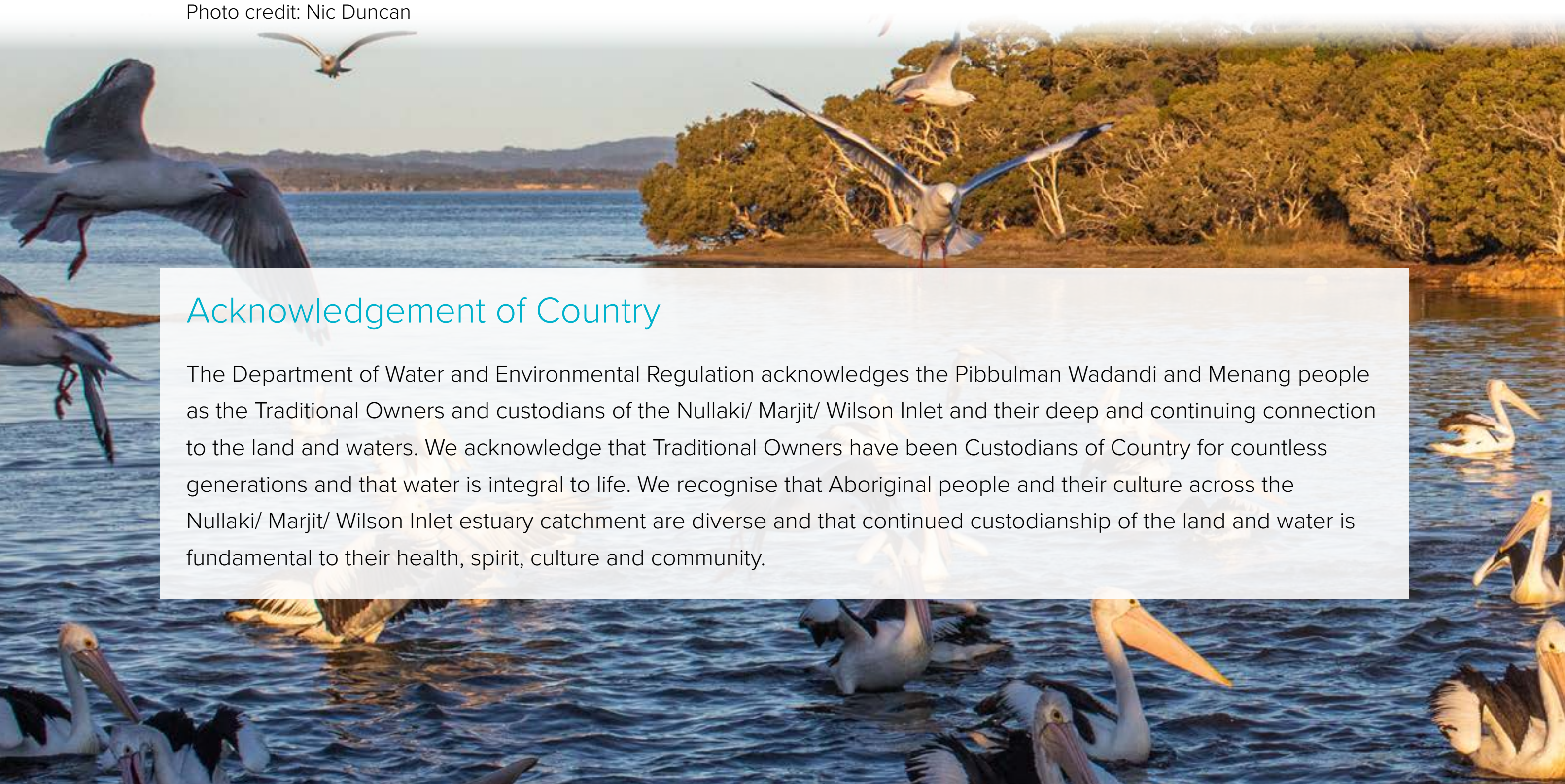
Photo credit: Nic Duncan



Acknowledgement of Country

The Department of Water and Environmental Regulation acknowledges the Pibbulman Wadandi and Menang people as the Traditional Owners and custodians of the Nullaki/ Marjit/ Wilson Inlet and their deep and continuing connection to the land and waters. We acknowledge that Traditional Owners have been Custodians of Country for countless generations and that water is integral to life. We recognise that Aboriginal people and their culture across the Nullaki/ Marjit/ Wilson Inlet estuary catchment are diverse and that continued custodianship of the land and water is fundamental to their health, spirit, culture and community.

About estuaries

Estuaries are biodiverse environments that are economically and ecologically important. Many of our estuaries are under threat due to human activities. Healthy Estuaries WA works to protect these areas by reducing nutrient pollution and promoting collaboration between communities, scientists and governments.

Estuaries are unique and dynamic environments where freshwater and seawater meet. They provide key habitat for birds, fish and crabs, and are among the most diverse and productive environments in the world. They are the heart of recreation for many communities, with over 80 per cent of the Western Australian population living around our estuaries. While estuaries have enormous ecological value, they are also economically important, supporting regional populations through tourism and commercial fishing.

Estuaries face many pressures, primarily from excessive nutrient inputs from agricultural and urban land, and climate-related changes such as reduced river inflows, increased temperatures, ocean acidification and rising sea levels. These pressures are a risk to estuary health and the social, economic and environmental reasons we value estuaries.

We gather scientific information on the health of at-risk estuaries to deliver actions that improve the health of these crucial environments.

Our vision for healthy estuaries requires collaboration with landowners, farmers, nonprofit environmental groups, government agencies and local communities. We have been working to understand at-risk estuaries and implement actions to protect them since 2016 through the Regional Estuaries Initiative (2016–20) and Healthy Estuaries WA (2020–present). Healthy Estuaries WA works to reduce nutrient inputs from priority catchments, use the latest science to monitor and effectively manage waterways, and continue to build collaboration.

Report at a glance

This report summarises four years of the Healthy Estuaries WA Wilson Inlet water quality monitoring program (June 2019–May 2023) and compares these recent results with the previous reporting period (Oct 2016–May 2019). We report on the main drivers of estuary health (rainfall, river flows, catchment condition, nutrient inputs and sandbar dynamics) and on the estuary's response (water quality, seagrass condition).

In the period 2020–23, Wilson Inlet showed large differences in water quality between years. This is because of differences in annual rainfall, and therefore river flow, nutrient input from the land uses in the catchment, and ocean connectivity. With rainfall and other climate parameters predicted to become more variable in the future, it seems likely that water quality in Wilson Inlet will also become more variable between years.

Water quality in Wilson Inlet is currently good, but climate change and the continuing supply of nutrients from the catchment are ongoing threats to the inlet's health.

Rainfall was highly variable between years

River flows were highly variable between years, depending on rainfall

Salinity stratification occurred when the sandbar was open, with at times low oxygen levels

Oxygen levels in the inlet were healthy most of the time, except in deeper waters during stratification

Nutrient concentrations in the inlet were

- generally low, but higher when rivers were flowing
- higher in wetter years

Water quality of Wilson Inlet was highly variable between years, influenced by nutrient loads and sandbar dynamics

Wilson Inlet remains a resilient estuary despite high nutrient loads from the catchment

Nutrient sources: Land uses in the Sleeman River and Cuppup Creek remained the main contributors of phosphorus into the inlet

Sandbar dynamics: The connection between the ocean and the inlet varied each year, including a year when it didn't open and a year with the longest opening on record

Seagrass
A decrease in seagrass extent between 2019 and 2022 was paired with an overall increase in macroalgae

No fish kills reported

Potentially **harmful microalgae** species rarely exceeded harmful levels

Microalgae were dominated by diatoms in most years, a nutritious food source for aquatic fauna

Nutrient sources: The inlet's sediment was also a significant source of nutrients during oxygen depletion

How do we assess water quality?

Estuary year – June to May of the following year. We mostly use estuary years because the health of an estuary is greatly influenced by the winter flows (also called discharge) from the catchment. This report includes data for four estuary years, from June 2019 to May 2023.

We split the estuary year into wet and dry months.

The estuary year

Wet months					Dry months						
Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May

Sandbar status – open or closed. The sandbar status is an important driver of water quality in Wilson Inlet and so included in most analyses in this report.

ANZECC guidelines. Average estuary water quality is assessed against ANZECC water quality guideline values,[1] which identifies likely ecologically acceptable water quality.

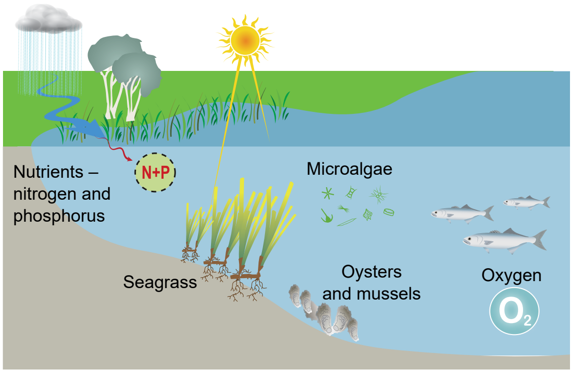
Catchment nutrient concentrations are presented as the **median** (middle value) of the **wet months** (June to October) for the years 2020 to 2022 and are assessed against water quality objectives for Wilson Inlet that are derived from ANZECC guidelines values.[2]

Seagrass and macroalgae assessments were done **annually in summer** over the reporting period, and we present the data that have been collected between 2019 and 2022.

Estuary health refers to the natural balance and functioning of an estuary, including its water quality, habitats and ability to support plant and animal life. Many things can compromise the ecology of an estuary: over fishing, contamination from industrial waste or the invasion of foreign species. However, for south-west Western Australian estuaries, eutrophication is the main threat.

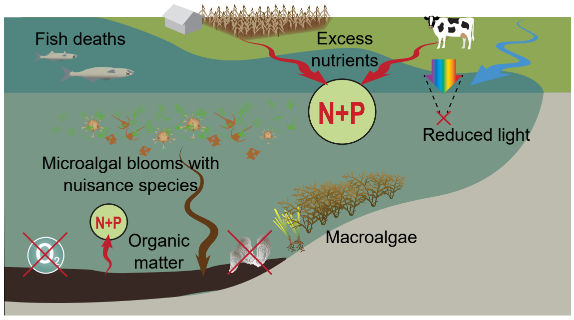
Eutrophication is the overgrowth of aquatic plants (usually micro or macroalgae) caused by excessive nutrients – nitrogen and phosphorus. High algal growth (or algal blooms) leads to high organic matter decomposition rates, which deplete oxygen in the water. Eutrophication can also cause fish and other 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 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.



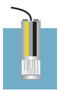
Unhealthy estuaries

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

What we measure

In the catchment

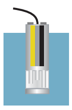
Flow: The volume of water per unit of time determined at hydrological gauging sites.



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

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

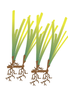
In the estuary



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

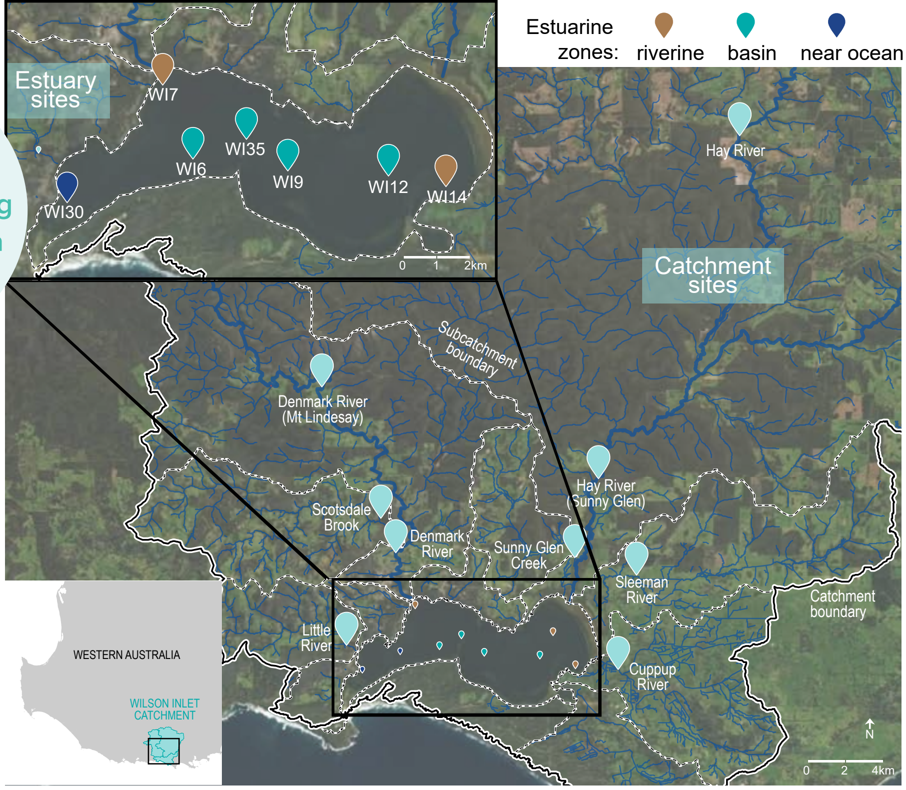
Nitrogen and phosphorus: Concentrations measured in surface and bottom water samples. Analyses include totals and dissolved nutrients (nitrate, ammonium and phosphate).

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



Seagrass: Mapping of extent and health status.

A catchment is the land area where water falling as rain drains to a river or estuary.



About Wilson Inlet and its catchment

Wilson Inlet is located on the south coast of Western Australia near the town of Denmark. It is a seasonally closed estuary. 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, an average depth of 2 m and a maximum depth of about 4.5 m. It is a seasonally closed estuary, that is at times separated from the ocean by a sandbar.

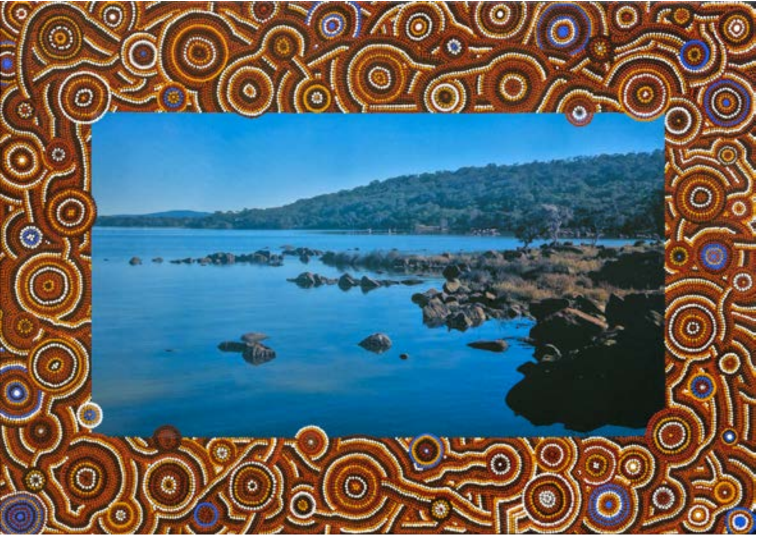
Under the *Water Services Act 2012*, when the water level in the inlet increases following rainfall, the sandbar must be opened to prevent flooding of low-lying land. If the sandbar is not opened, private and public land, including several roads, could be under water. The inlet has been manually opened for more than 100 years and many aspects of the inlet's ecology now rely on regular openings of the sandbar. A recent review of the protocol guiding the opening of the sandbar resulted in an improved framework which takes these ecological factors into account when deciding whether to open the sandbar during dry years where flooding does not occur[3].

The sandbar closes naturally, usually in summer, because ocean waves transport sand into the channel and river flows have declined.

Five main 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 and Denmark rivers, drain 88 per cent of the catchment and deliver on average 60–70 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, respectively, 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 nine catchment sites and seven estuary sites. For this report, we divide the seven estuary sites into three different zones: the *Riverine zone* near the mouths of the four largest rivers entering the inlet; the *Near Ocean zone* closest to the sandbar; and the *Basin zone* covering the largest part of the estuary.



Beetchabup Dreaming © Lynette Knapp

Historical context

Pibbulman Wadandi and Menang people have lived around Nullaki or Marjit, as Wilson Inlet is known to the local traditional custodians, for thousands of years. Nullaki is a Noongar word that refers to seagrass while Marjit is a Noongar word for water snake. 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 burial stand testimony to the continuous use of this area before Europeans arrived through to today.*

Since the colonisation of the area by 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.

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

Public concerns about the health of Wilson Inlet started in the late 1970s when excessive growth of the seagrass *Ruppia megacarpa* was observed. While seagrass is an important part of the estuarine ecosystem, the excessive growth led to very high amounts of rotting seagrass wrack on the shoreline at times. 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 washing into the inlet from the catchment. Actions included streamline fencing, revegetation and soil testing farmland to inform fertiliser use.

Wilson Inlet remains a vulnerable ecosystem. Ongoing management and monitoring efforts continue to contribute to maintaining and improving the health of Wilson Inlet, which 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, tourism attractions and supporting the local economy.

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

Climate change in the South West region

Climate is a key driver of estuary health, with temperature and rainfall affecting both water movement, water quality and the wider ecosystem. The South West region is experiencing significant drying due to climate change, with declines in rainfall greater than in other areas of Australia[4]. As a result, less freshwater is flowing into South West estuaries. Our monitoring and modelling of estuary condition will continue to guide actions to improve water quality as the changing climate continues to exert pressure on estuary health.

The South West region, which has a Mediterranean climate with cool, wet winters and warm, dry summers, is experiencing warmer and drier conditions due to climate change.

Since 1910, the average annual air temperature has risen by 1.1°C, with predictions for an additional increase of 0.5–1.1°C by 2030 (relative to the 1986–2005 baseline). It is expected that the temperature and frequency of very hot days will increase and that heatwaves will be longer and more intense[5].

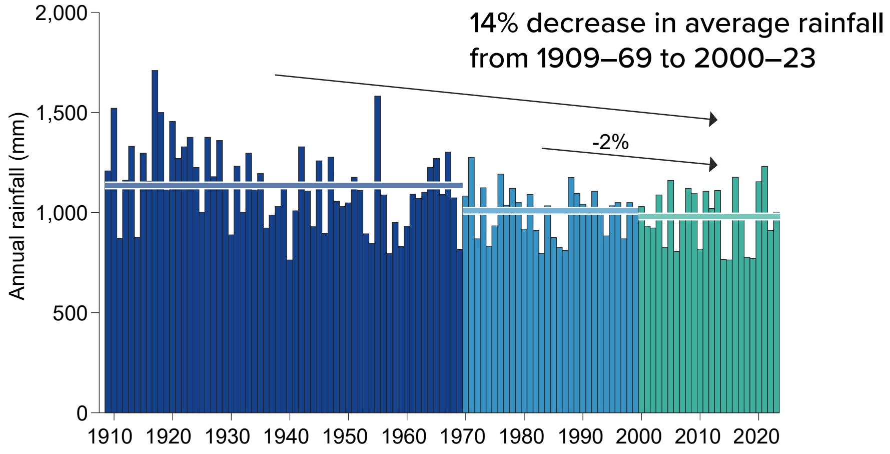
Since 1970, rainfall during May to July has decreased by about 20 per cent compared to the average of 1900–69, while rainfall over the entire cooler period (April to October) has dropped by 16 per cent. There are fewer wet years now compared to the last century[6,7]. There is strong evidence supporting a continuing decline in cool period rainfall in the region[8,9,10,11]. Despite the drying trend, the intensity of heavy rainfall events is likely to increase, as warmer air holds more moisture[12,13].

The decline in rainfall has led to a significant reduction in runoff, with streamflow dropping by up to 70 per cent since the 1970s. Associated declines in soil moisture and groundwater levels lead to broader environmental changes, including changes in vegetation growth, and reduction of wetland habitats and connectivity of streams[14,15].

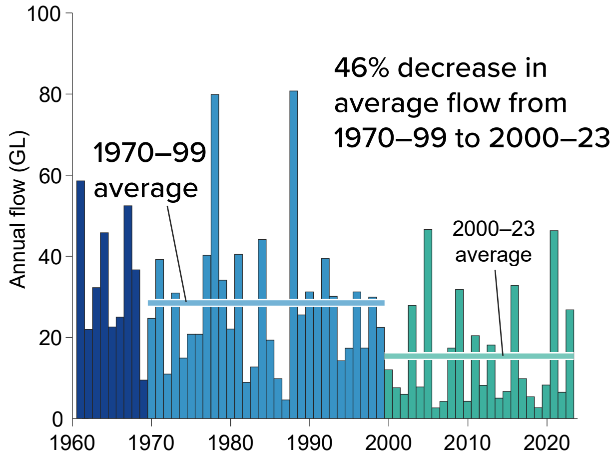
The effects of climate change on rainfall are slightly less pronounced on the south coast than the west coast. In the Wilson catchment, the average annual rainfall over 2000–23 is 14 per cent lower compared to the 1909–69 average and 2 per cent lower than the 1970–99 average (Bureau of Meteorology station 9531). The disproportionate reduction in average streamflow of 46 per cent between 1970–99 and 2000–23 in the Denmark catchment highlights the complex relationship between rainfall and streamflow. Very dry years have become more frequent, for example, since 2000, one in three years had annual rainfall below 850 mm while it was one in eight in the previous period (1970–99). Drier periods reduce soil moisture and groundwater levels, leading to a significant drop in runoff and streamflow. This causes a hydrological shift that cannot be reversed unless there are multiple years of high rainfall.

While the drying trend in the South West region of Western Australia is indisputable, there will always be wetter years within any time period. The period covered in this report (2019–23) was such a period, being wetter than average.

Annual rainfall – Denmark (BOM #9531)



Annual flow – Denmark River



How will Wilson Inlet be affected by future climate trends?

Rainfall plays a key role in estuary dynamics as it determines freshwater inflows.

When the sandbar is closed in Wilson Inlet, freshwater inflows affect the water level and therefore the annual sandbar opening. In drier years when the sandbar remains closed, nutrients from catchment inflows are retained in the estuary rather than being transported to sea. This could lead to increased algal activity and low light conditions for seagrasses.

When the sandbar is open, the interplay between freshwater inflows and ocean water exchange affects the salinity, residence time and stratification patterns (see 'stratification' section).

More frequent summer storm events could increase the occurrence of unseasonal nutrient input.

Temperature is also important, as it strongly influences biological growth rates. During the time when the sandbar is closed, warmer temperature can also lead to very low water levels in the inlet through evaporation, potentially reducing the area where seagrasses can grow.

The effect of climate change on the water quality in Wilson Inlet will be complex, in part because of the complexity of sandbar dynamics.

In a drier and warmer climate, it is likely that the inlet will remain closed for longer periods, and that there will be an increased frequency of years in which the sandbar remains closed throughout the entire year. Impact on the inlet's ecology in years when the sandbar remains closed include a reduction of habitat for migratory birds, foreshore vegetation deaths, reduced fish populations in the inlet and lower salinity[16].

On the other hand, extreme rainfall events in winter can lead to longer opening periods (such as in 2021–23 as described in this report). This shows that the higher variability in rainfall might also lead to a higher variability in the length of the sandbar opening periods.

Key point

- ⇨ In a drier and warmer climate, it is likely that the inlet will remain closed for longer periods, and that there will be an increased frequency of years in which the sandbar remains closed throughout the entire year.

Sea level rise (about 200 mm at the Denmark Coast since the 1990s; see coastadapt.com.au) will also impact the inlet. At higher sea levels it might be harder to achieve long-lasting channels through the sandbar. Ocean exchange might be greater, which may lead to stronger stratification that persists for longer periods of time, in particular in the eastern parts of the inlet. 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). On the other hand, greater ocean exchange might lead to healthier dissolved oxygen conditions in the western part of the inlet due to daily renewal of bottom waters during high tide.

The collective 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[17].

Rainfall and river flow

Rainfall produces river flow (also called discharge), which is an important factor influencing the water quality of estuaries by transporting nutrients and sediments from catchment land uses into the estuary. This directly influences the ecological processes. In Wilson Inlet, river flow also influences the sandbar status (open or closed).

While annual rainfall and river flow is typically reported for calendar years, here we report on estuary years (June to May in the following year). We do this to be able to meaningfully link these environmental factors to estuary health, since winter flows greatly influence estuary water quality in the following spring to autumn months.

The average rainfall for Denmark in the last 40 years is 990 mm (1975–76 to 2015–16). In the current reporting period, the two estuary years 2019–20 and 2022–23 were drier than average (928 and 867 mm). The years 2020–21 and 2021–22 were wet, with above average rainfall of 1,195 and 1,164 mm, respectively.

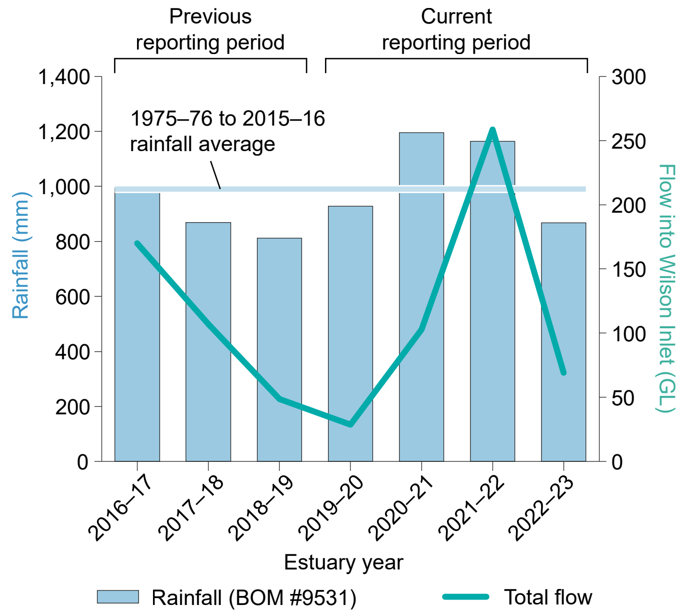
On average, annual rainfall during the current reporting period was higher than in the previous reporting period (1,038 mm compared with 892 mm: 16 per cent higher). This does not contradict the long-term drying trends in South West region that were discussed in the previous section since there will always be drier and wetter periods due to climate variability.

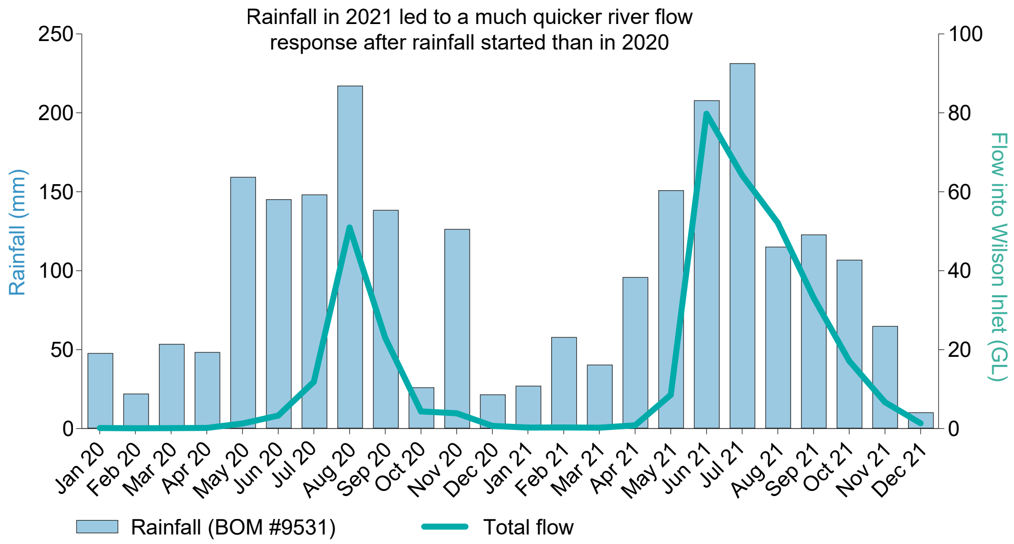
Key points

- Rainfall was variable between estuary years, with two years of low to average rainfall and two wetter than average years.
- June to October rainfall of the wettest year (2020–21) was 25 per cent greater than the long-term average (1975–76 to 2015–16) and the fourth wettest year in the last 40 years.
- Despite having similar rainfall, 2020–21 produced less river flow than 2021–22. This is because the rainfall in 2020–21 followed a drier period, so low soil moisture meant a greater proportion of the rainfall was absorbed by soils in the catchment before reaching the streams and rivers. This means that while 2020–21 had slightly higher rainfall, the inlet received more river flow in 2021–22.

Wet years typically have high river flow. However, this is not always the case, as observed in 2020–21 compared with 2021–22. While both years had very high rainfall, the total river flow* in 2020–21 was much lower than in 2021–22 (103 GL versus 259 GL). This shows that the relationship between rainfall and river flow is complex. Evaporation rates, for instance, also influence catchment runoff. River flow is also affected by the intensity of the rainfall event, the period between events and the location of the rainfall within the catchment. Dry years reduce soil moisture and groundwater levels which results in a disproportionate decrease in runoff and river flow. In 2020–21, because the three preceding estuary years had been relatively dry, soils needed to be wetted sufficiently in winter 2020 before the rivers started to flow. This was different in 2021–22, because the soils were already wet and rainfall led to a much quicker response in river flow after rainfall started.

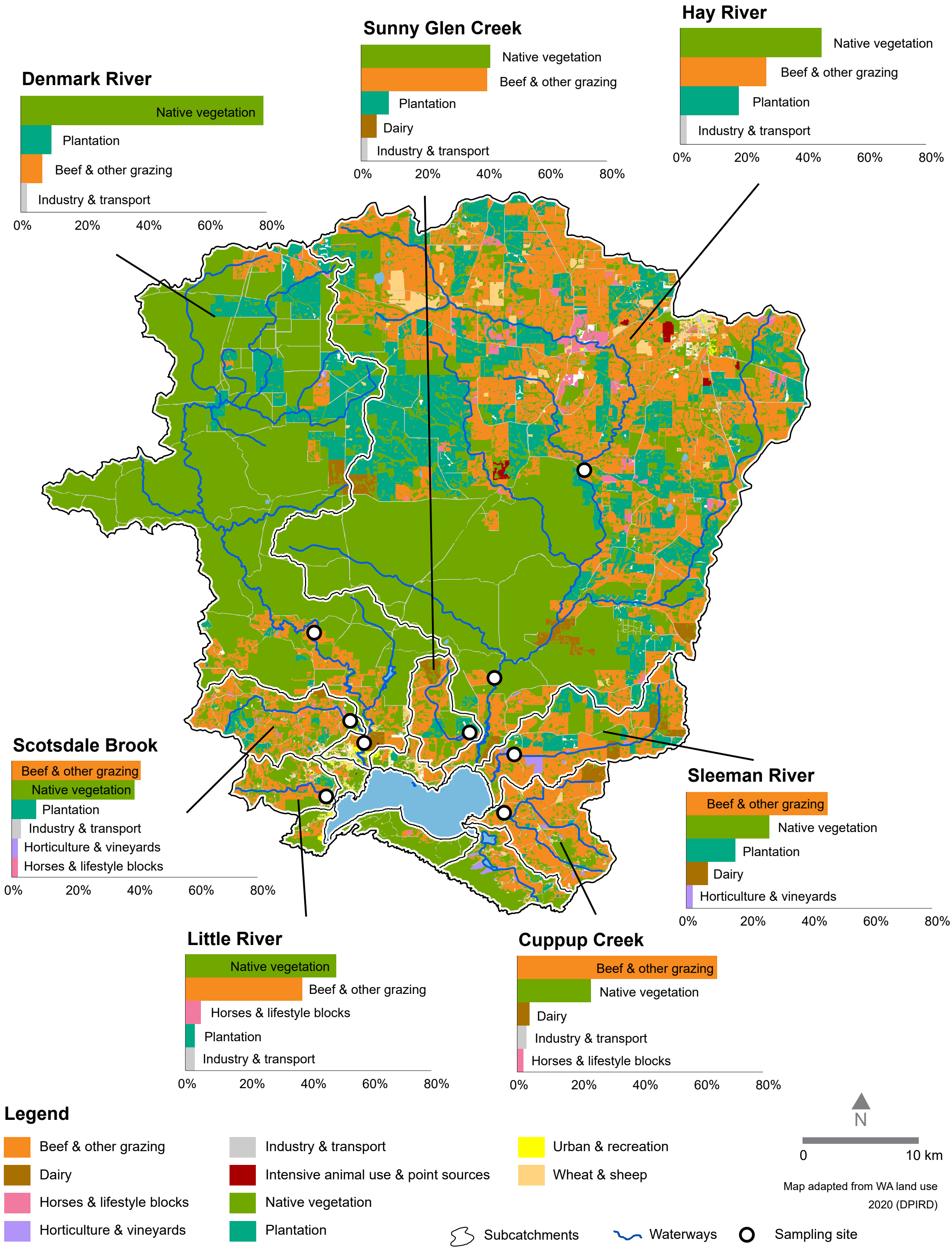
Rainfall and flow into Wilson Inlet - estuary years





* Total river flow is the sum of the flow of Hay River, Denmark River, Scotsdale Brook, Little River, Sunny Glen Creek, Sleeman River and Cuppup Creek.

Catchment land use



The percentage land use graphs show the most common land use in each subcatchment. Graphs have only been prepared for the monitored subcatchments.

Catchment nutrient sources

Different land uses and soil types affect the amount of nitrogen and phosphorus that wash off the land and flow into rivers and estuaries. Native vegetation typically results in the least nutrient runoff, while beef and dairy farms contribute the most. This is due to the higher levels of nutrients used on these farms and the large areas of land they cover, which increases the amount of nutrients that can be carried into waterways through runoff and leaching.

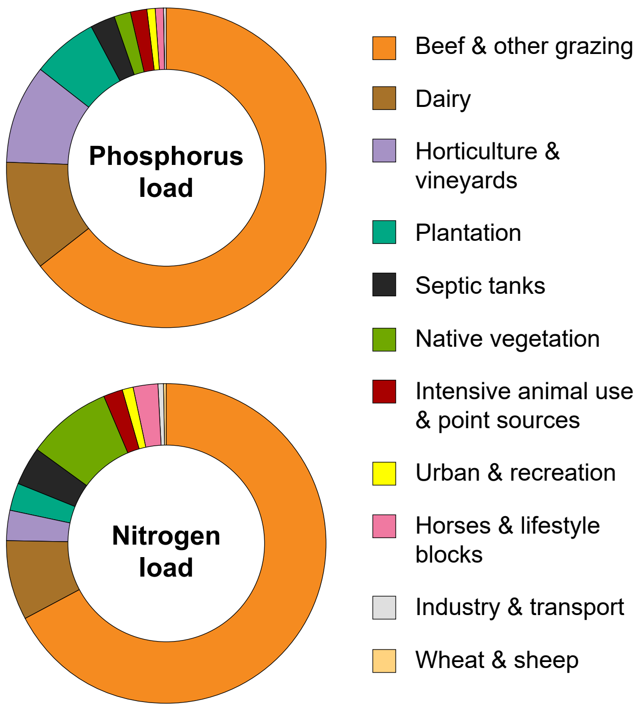
Wilson Inlet catchment is about 2,300 km^2, of which about 47 per cent of the catchment is cleared and used for livestock grazing, plantations, horticulture and residential purposes. Such land uses change hydrological pathways (which determine when and how much water flows into Wilson Inlet), increase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

We used catchment modelling to understand the sources of nutrients in the Wilson Inlet catchment. About 26 per cent of the catchment has been cleared for beef and dairy grazing. These land uses contribute the most nutrients, accounting for more than 75 per cent of phosphorus and nitrogen input into the estuary. Additional nutrients are also derived from diffuse sources such as horticulture, septic tanks and plantations. Horticulture presents a nutrient intensive land use, because it contributes approximately 9 per cent of the total phosphorus discharged into the inlet but only covers around 0.2 per cent of the land area. Urban garden fertiliser use and wastewater treatment plant discharges also contribute nutrients.

Facts and figures

Catchment area	2,250 km^2
Per cent cleared area (2020)	47%
Rivers flowing into Wilson Inlet	Hay River, Denmark River, Sleeman River, Cuppup Creek, Little River
Average annual flow (2019–22)	115 GL
Main land use (2020)	Native vegetation, beef and sheep farming, plantations

Native vegetation, which still covers about 54 per cent of the total Wilson Inlet catchment area, contributes only a small amount of nutrients to the estuary, about 2 per cent of phosphorus and 9 per cent of nitrogen.



Catchment nutrient concentrations

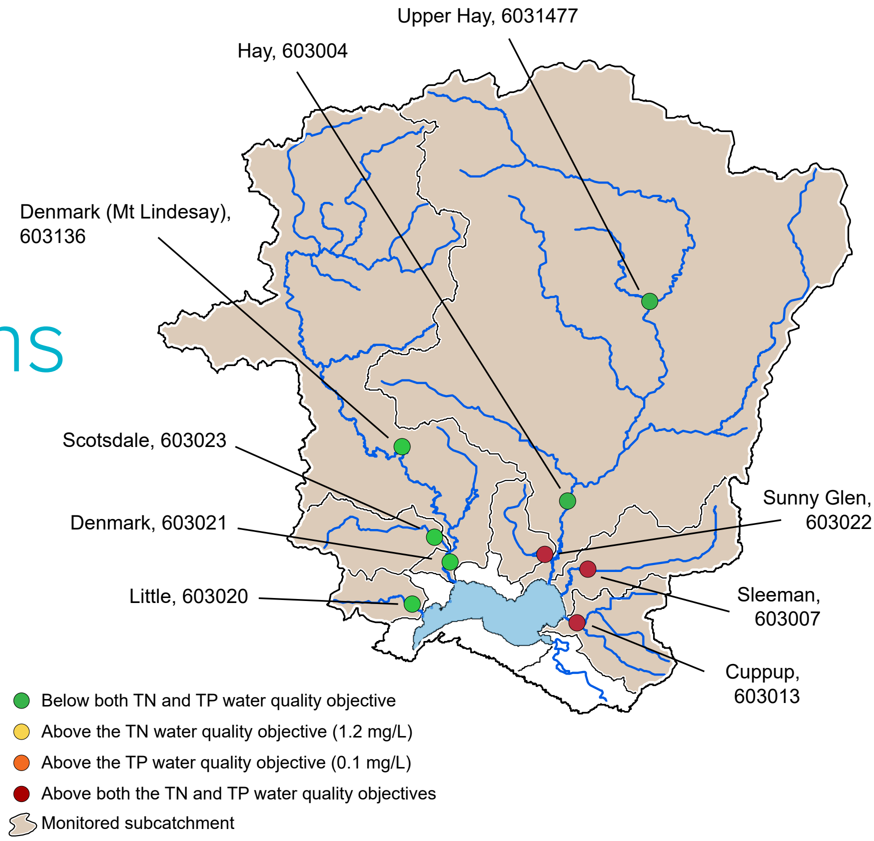
Measuring nutrient concentrations leaving the subcatchments helps us understand how different land uses contribute to nutrient runoff and from where these nutrients are entering the inlet. By identifying which subcatchments have higher concentrations, we can better set water quality objectives. These are nutrient concentrations we aim to achieve for healthier waterways. Having water quality objectives helps prioritise management actions based on the land activities and localities that are having the most impact.

Median wet month (June to October) nutrient concentrations for the three-year period 2020–22 were compared to the relevant water quality objectives. Concentrations above these objectives indicate there may be a risk of eutrophication. We used data from the wet months because rivers have a much greater influence on the estuary during this time than the rest of the year.

River nutrient concentrations reflect the subcatchment land use. Rivers discharging from cleared landscapes have historically had the highest nutrient loads[18].

Wet month median nitrogen and phosphorus concentrations in Cuppup Creek, Sunny Glen Creek and Sleeman River, for instance, exceeded the water quality objectives (nitrogen: 1.2 mg/L; phosphorus: 0.1 mg/L).

Performance against water quality objectives



Detailed catchment water quality monitoring results are published online at https://estuaries. dwer.wa.gov.au/nutrient-reports/

Key points

- Hay River, Denmark River, Little River and Scotsdale Brook had healthy median nitrogen and phosphorus concentrations in the wet months that meet our water quality objectives.
- Cuppup Creek, Sunny Glen Creek and Sleeman River had median nitrogen and phosphorus concentrations in the wet months that exceed our water quality objective, representing poorer water quality.

By contrast, Denmark River, Scotsdale Brook and Hay River had healthy wet month median nutrient concentrations below the water quality objectives. These three subcatchments have the highest proportion of native vegetation.

Flows and nutrient loads to the estuary

Nutrient inputs from land uses in the catchment are one of the biggest threats to the health of many estuaries. The total amount (or load) of nutrients entering the estuary in a year is estimated by multiplying the nutrient concentration by the flow volume (discharge). Flows therefore drive loads, so fluctuations in river flows from one year to the next mean that nutrient loads vary in a similar way.

The annual nutrient load to Wilson Inlet varied greatly between years because of large differences in river flow. Depending on the river flow, the inlet received between 2.3 and 34 tonnes of phosphorus and 34 and 387 tonnes of nitrogen each year. River flow and phosphorus and nitrogen loads to the inlet were 9, 15 and 11 times greater respectively in the high flow year 2021–22 than in the low flow year 2019–20.

River flow in 2019–20 to 2022–23 was 24 per cent higher than the recent long-term average (2005–06 to 2018–19), which resulted in larger annual nutrient loads. Total nitrogen load was about 34 per cent higher than the long-term average, while total phosphorus load was about 78 per cent higher. There are several reasons why the total phosphorus load was disproportionally higher, including a slight increase in total phosphorus concentrations in some of the subcatchments and the fact that in wetter years, the soils are wetted to a deeper depth and are staying wetter for longer, allowing phosphorus from those soils to be transported to waterways.

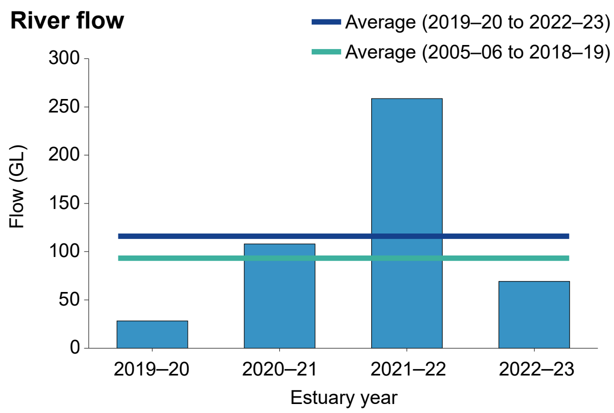
Key points:

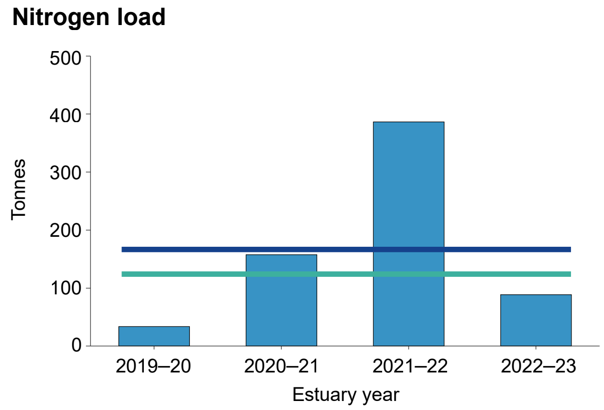
- The year with the highest flow (2021–22) had 15 times greater phosphorus loads and 11 times greater nitrogen than the dry year (2019–20).
- In the driest year, 2.3 tonnes of phosphorus and 34 tonnes of nitrogen were discharged into Wilson Inlet; in the wettest year it was 34 tonnes of phosphorus and 387 tonnes of nitrogen.
- Average river flow, and phosphorus and nitrogen loads (2019–20 to 2022–23) were greater than the recent long-term averages (2005–06 to 2018–19), because the reporting period included higher rainfall years.

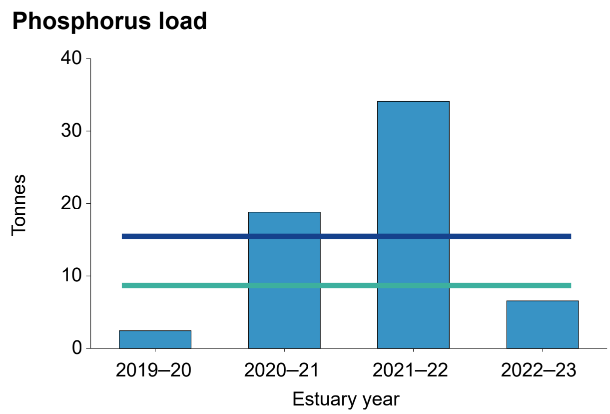
Nitrogen behaves differently in the soils to phosphorus which is why we are not seeing the same increase in nitrogen loads in wet years that we see in phosphorus loads.

While low flows caused by a drying climate may seem potentially good for estuaries because they mean smaller 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 or macroalgal growth response than a winter rainfall event, even when the same amount of nutrients is delivered to the inlet.

It is important to note that our estimates of annual river flow and a river's nutrient load are 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 site, or any nutrients that enter the inlet through 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

Each subcatchment contributes different amounts of nutrients to the estuary, depending on land use, soil type, flow and nutrient concentrations. Understanding which subcatchments deliver most nitrogen or phosphorus to the estuary helps us prioritise management actions to reduce nutrients.

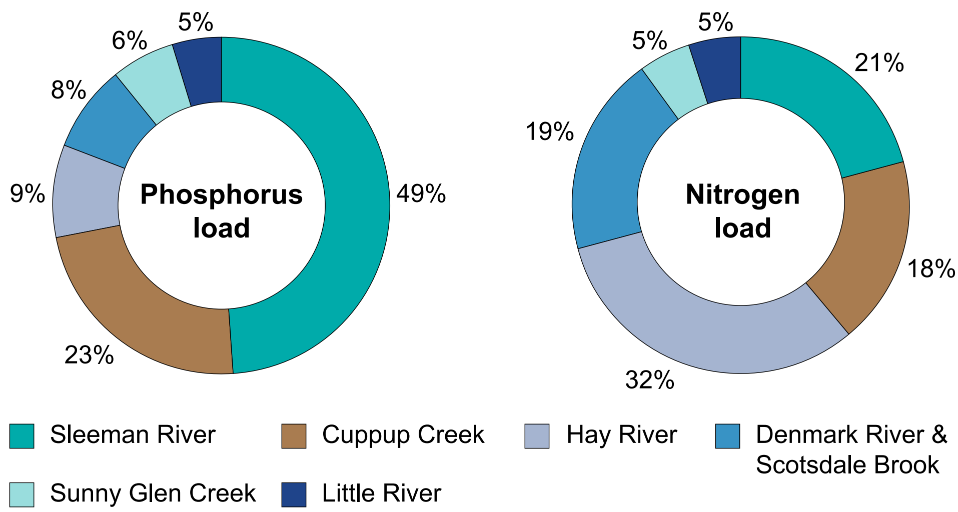
The Sleeman River and Cuppup Creek contributed 72 per cent of the total phosphorus and 39 per cent of the total nitrogen loads to Wilson Inlet in 2019–23 but only drain 7 per cent of the Wilson Inlet catchment area. These large contributions are because they drain mostly cleared, low-lying, flat, waterlogged agricultural land which has a high density of drainage channels. The Sleeman River subcatchment also has large areas of soils that are poor at retaining phosphorus (low phosphorus retention index), contributing to high in-river nutrient concentrations.

Photo credit: Nic Duncan

Key point

- Sleeman River and Cuppup Creek delivered 72 per cent of the phosphorus load to Wilson Inlet.
- Hay River, Sleeman River and Cuppup Creek delivered 71 per cent of the nitrogen load to Wilson Inlet.
- The Denmark River and Scotsdale Brook also contributed a significant nitrogen load to the inlet.
- It is important to continue working with farmers, catchment groups and government to reduce nutrient inputs into Wilson Inlet.

Nutrient loads to Wilson Inlet (average 2019–20 to 2022–23)

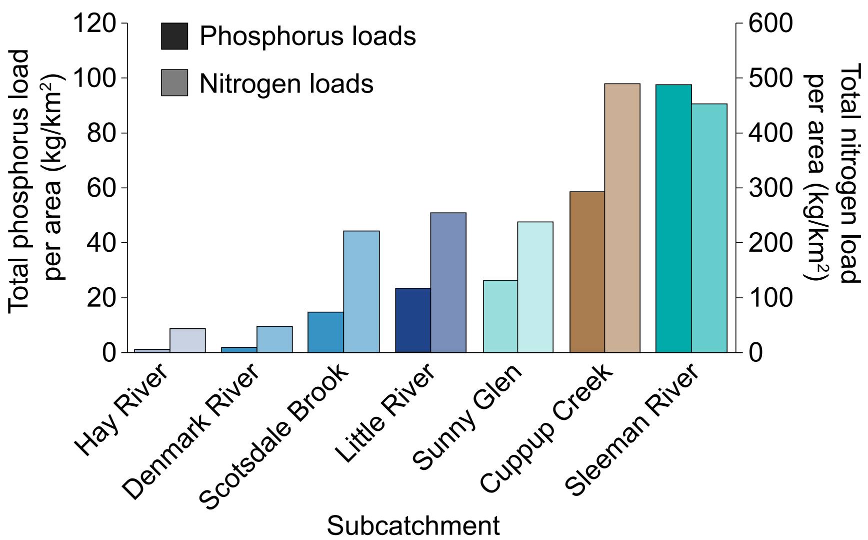


The Hay River, which is the largest subcatchment, delivered 32 per cent of the nitrogen load to Wilson Inlet. This is mostly because of the vast catchment area and associated high flow volumes compared with the other subcatchments. Similarly, the Denmark River and Scotsdale Brook subcatchments also cover a large area and therefore contribute significantly to the nitrogen load.

A way to express how degraded a catchment is is to divide the nitrogen or phosphorus load exported by each subcatchment by the subcatchment's area. This 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 grazing farms, dairy sheds or horticulture). This is perhaps especially important in the Sleeman River and Cuppup Creek subcatchments, as they have the highest nutrient loads for phosphorus.



Estuary water level and sandbar status

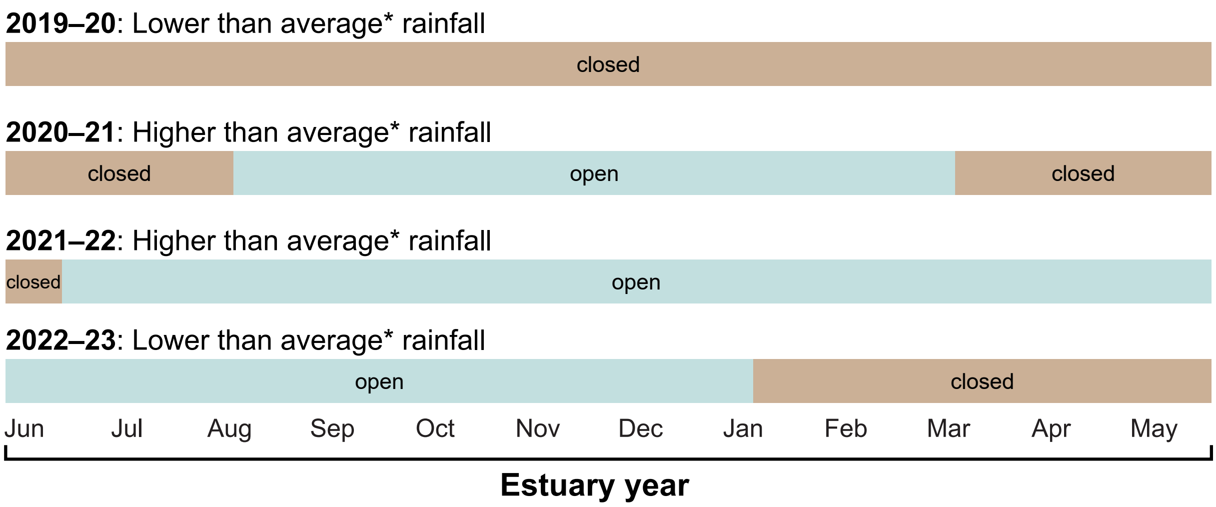
The sandbar of Wilson Inlet is typically closed but manually opened in most winters to relieve flooding of low-lying areas around the inlet.* When the inlet is open and connected to the ocean, the water level in the inlet is influenced by the ocean level and remains fairly stable. The water level can vary greatly from the ocean level when the sandbar is closed.** Together with river flow, the sandbar status (open or closed) affects the water quality in the inlet.

Key point

- The sandbar remained closed in 2019, which was the fourth time the sandbar had not been opened since records began in the 1950s.***
- After the opening in 2021 the sandbar remained open for 563 days – the longest opening on record.

In a typical estuary year (June to May the following year) the sandbar is initially closed at the beginning of winter (June). The sandbar is then opened, typically in mid to end of winter (July to August), before it closes naturally between early summer and autumn (December to March) by deposition of sand from the ocean. The typical sandbar status in an estuary year can therefore be described as "closed – open – closed". The processes driving the sandbar's dynamics have been described in detail in earlier reports[19,20].

The sandbar dynamics in the current reporting period were unusual, with only one of the four estuary years (2020–21) featuring the typical closed – open – closed pattern.



*Average annual rainfall is calculated for 1975–76 to 2015–16

* For more information about the sandbar including videos of sandbar openings, visit https://estuaries.dwer.wa.gov.au/estuary/wilson-inlet/estuary/the-bar/

** To explore water level data for Wilson Inlet, visit https://kumina.water.wa.gov.au/waterinformation/wir/reports/publish/603032/teo.htm

*** There is conflicting information on whether the sandbar also remained closed in 1959

In winter 2019, the sandbar was not opened because the water level did not get high enough to cause a flood risk. This was the fourth time this has happened in recent times (2007, 2010, 2014).

The dry year in 2019 followed a year with one of the shortest openings ever recorded (23 August to 29 November 2018). Consequently, in autumn 2019, we recorded one of the lowest inlet water levels ever (-0.47 m Australian Height Datum (AHD)[*]). The low flows during the dry winter in 2019 meant the water level of the inlet did not rise sufficiently to trigger an opening of the sandbar.

In 2020 the sandbar was opened as usual in winter and the opening lasted for 208 days, before it closed due to sand being deposited by ocean waves and storm activity. The opening duration was slightly above the average of 188 days (1958–2018).

In June 2021 an exceptionally high rainfall event (more than 100 mm within 24 hours) led to widespread flooding and the third earliest opening on record (21 June). For the first time since records began in the 1950s, the sandbar remained open for more than one year, connecting the inlet with the ocean through all of autumn and early winter. The channel was exceptionally wide and deep for a prolonged time and closed after 563 days (5 January 2023).

The winter of 2022 was dry; however, the sandbar was still open from the previous year with a small channel that was slightly re-scoured by winter rains.

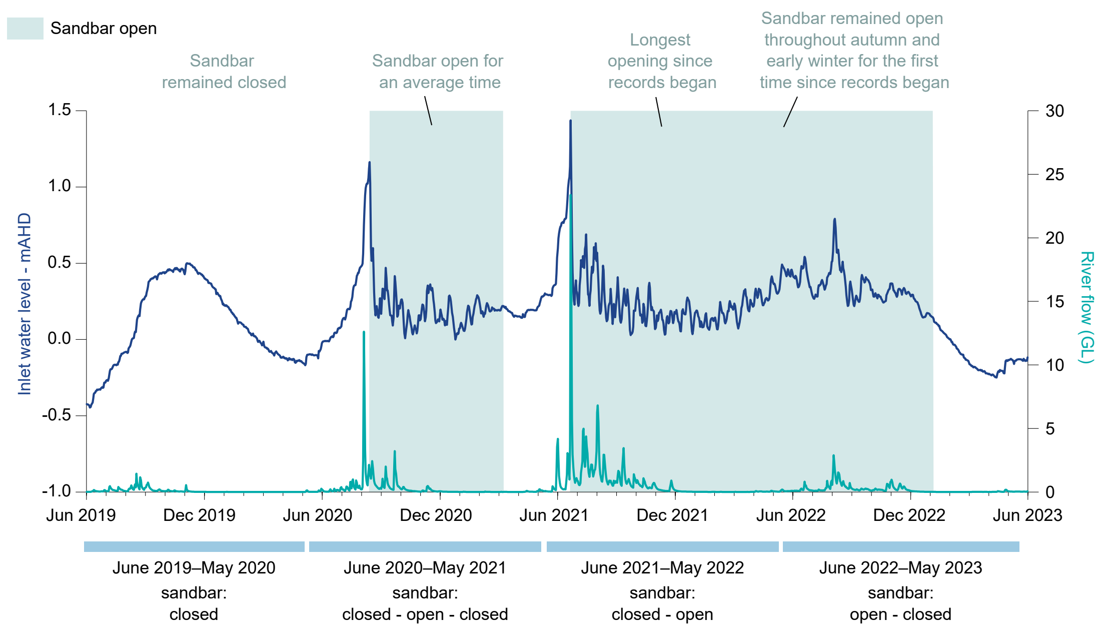
* The Australian Height Datum (AHD) is a geodetic datum used as the reference for elevations (heights) in Australia. It serves as the standard reference for measuring heights above average sea level across the country.

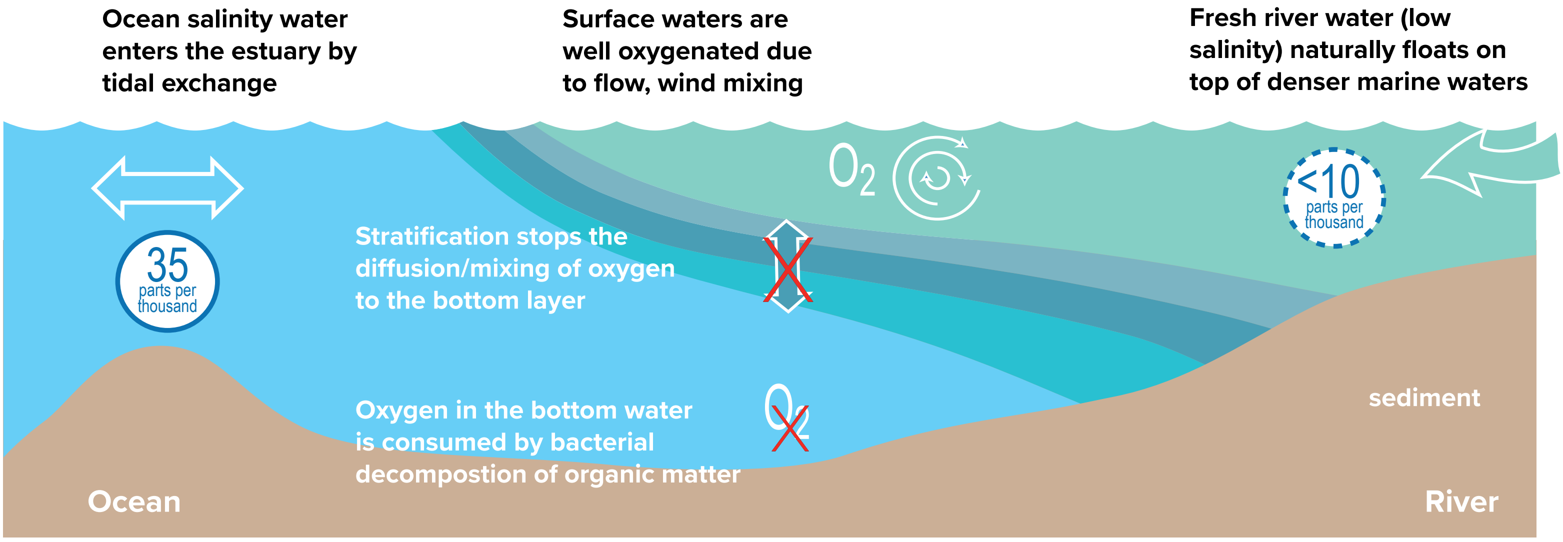
Why did the sandbar remain open for more than 1.5 years after the 2021 opening?

The long opening from June 2021 onwards was because of a combination of factors:

- the higher-than-normal inlet water level at the time of the sandbar breach created a very wide and deep channel
- high winter rainfall after the opening resulted in high and prolonged river flow that continuously scoured the channel
- high sea level and tides during the La Niña period (late 2020 – mid 2022) helped maintain the channel.

More info – see Wilson Inlet snapshot.[21]





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, salinity stratification occurs when the sandbar is open: freshwater from the rivers tends to sit at the surface because of its lower density, while 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 the volume of marine exchange. The latter depends on the channel shape (bathymetry) and on ocean and tidal conditions.[22] The channel through the sandbar is dynamic and usually largest shortly after the opening, when river flow is high. Therefore, the water exchange between ocean and inlet decreases over time during an opening.

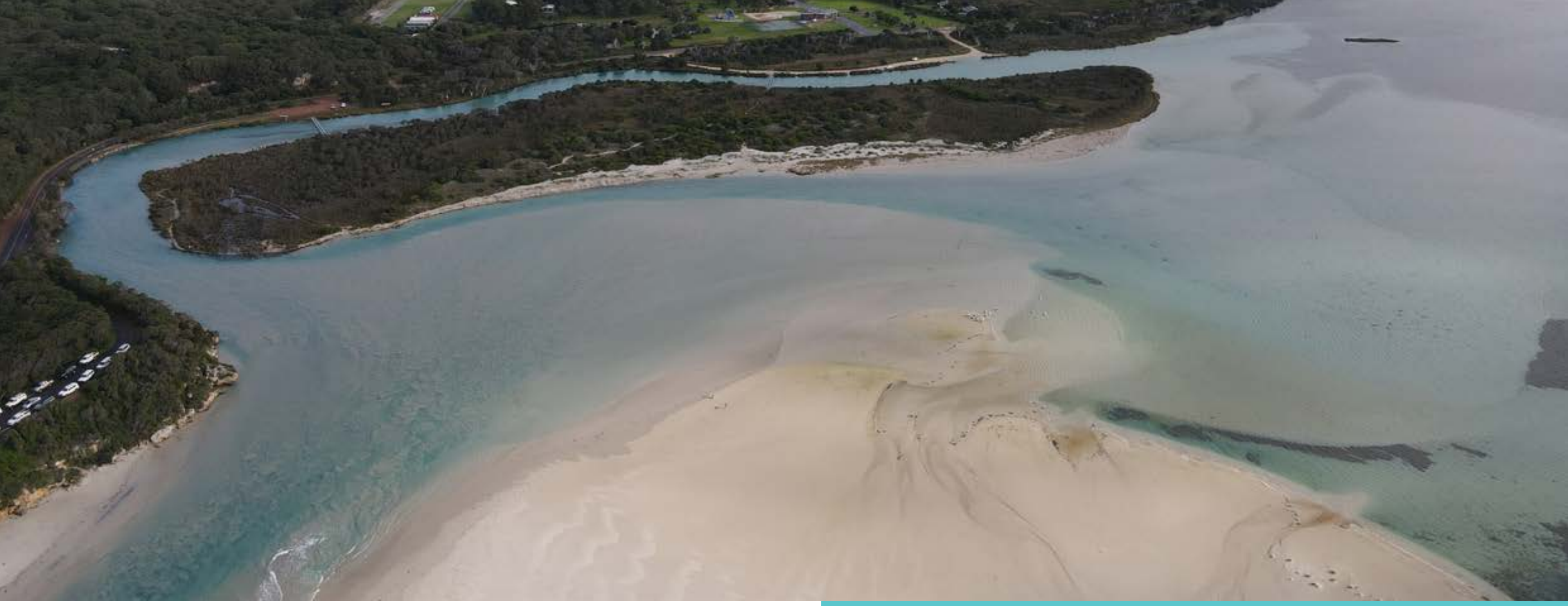
Stratification influences estuarine chemistry and biology, including the oxygen level of bottom waters. Strong stratification causes a physical barrier to the diffusion of oxygen to the bottom waters closest to the sediment.

The bottom layer of Wilson Inlet has large amounts of organic matter which is decomposed by oxygen-consuming bacteria. Oxygen can be depleted rapidly and, when stratification persists, low oxygen (hypoxic) or no oxygen (anoxic) conditions emerge in the bottom layer. These conditions are inhospitable to bottom-dwelling animals and can be harmful to many fish species.

Low oxygen conditions also alter sediment chemistry, potentially resulting in the release of sediment-bound nutrients, which can add to eutrophication problems. In Wilson Inlet, nutrients are released from the sediment at dissolved oxygen concentrations below four milligrams per litre. While nitrogen is quickly released from the sediment under these conditions, phosphorus is only released under prolonged periods of such low oxygen concentrations.[23]

In Wilson Inlet, most of the nutrient release from the sediment occurs during stratification when the sandbar is open. At times nutrient release is also evident without salinity stratification when oxygen demand of the bacteria that biodegrade the organic matter in the sediment is greater than the renewal of oxygen from the water column.

Anoxia also shuts down denitrification – the process where nitrogen is lost from the sediment directly to the atmosphere in the form of nitrogen gas. An important pathway of nitrogen loss from Wilson Inlet.



Stratification and the sandbar

The sandbar status (open or closed) greatly influences water salinity and dissolved oxygen concentrations through stratification. Taking fortnightly profiles of salinity and dissolved oxygen concentrations at the seven estuary sites helps us to understand changes over time and explain water quality patterns.

Key points

- Salinity stratification occurred during times when the sandbar was open and rivers were flowing.
- Stratification lasted longest in the wet year of 2021–22.
- There were regular periods of low oxygen near the sediment in parts of the inlet during stratification.
- Dissolved oxygen concentrations near the sediment were healthy throughout the year in the year the sandbar remained closed.

Wilson Inlet showed salinity stratification during times when the sandbar was open and rivers were flowing. This can be seen most clearly at site WI6 in the western basin, which is also the deepest site we regularly monitor.

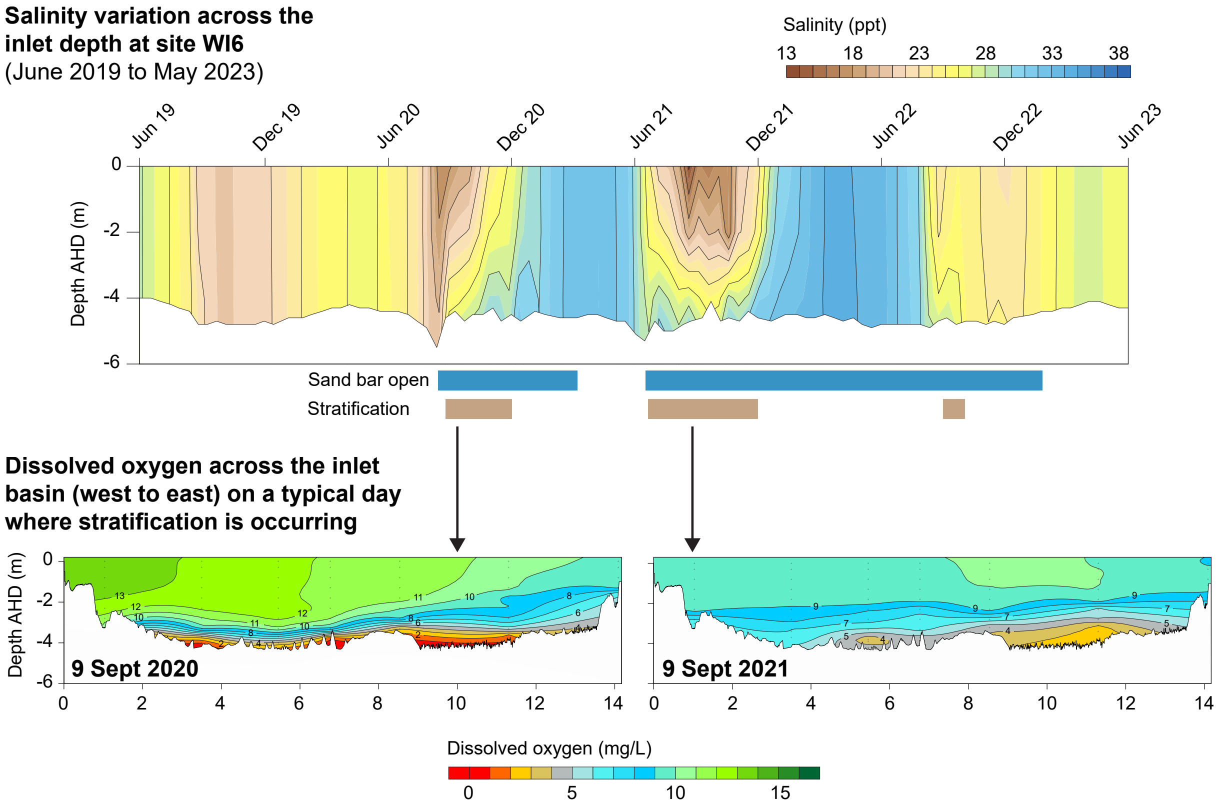
Lower dissolved oxygen concentrations in the bottom water typically co-occurred with salinity stratification. There was not a strong relationship between the strength of stratification and how low the oxygen levels were. This can be seen when looking at west–east transects through the inlet.

In 2019, when the sandbar remained closed, no stratification occurred, as the small volume of river flow into the inlet was quickly mixed by wind with the estuarine water. This meant that dissolved oxygen levels remained at healthy levels (above 5 mg/L) throughout the year in the absence of stratification.

Salinity stratification occurred at times in the other three years. Stratification was strong in 2020. After the sandbar opening in 2020, continuous and widespread low oxygen conditions persisted for about three months throughout the deeper areas of the inlet. Dissolved oxygen concentrations were regularly at unhealthy levels below 2 mg/L.

Stratified conditions lasted the longest (about six months) in the very wet year of 2021. Dissolved oxygen concentrations below 2 mg/L near the sediment occurred at times that year, but concentrations were not continuously low. Oxygen was often higher in the western basin (4-5 mg/L) than the eastern basin (below 2 mg/L at times). This was probably because the larger sandbar channel and higher tides allowed greater ocean exchange in 2021 compared with 2020, allowing oxygenated ocean water to more frequently reach farther into the inlet.

In the dry year of 2022, stratification was less pronounced and lasted only about one month. This is because low river flow and the small channel through the sandbar, allowed only small volumes of ocean water to be pushed into the inlet during high tide. Some areas of dissolved oxygen concentrations below 2 mg/L occurred during the short period of weak stratification.



Salinity and oxygen concentrations

Salinity and dissolved oxygen concentrations can have profound effects on nutrient cycling, water quality and the ecology of the inlet. Here we look at salinity and dissolved oxygen averages during the inlet's four distinct states, which are determined by whether the sandbar is open or closed in the wet or dry months. Comparing averages in the surface and bottom waters between these states provides a high-level understanding of patterns that are connected to river flow and sandbar dynamics.

Wilson Inlet has four distinct states, which are aligned with the annual cycle of hydrodynamic events (wet months/sandbar closed, wet months/sandbar open, dry months/sandbar open, dry months/sandbar closed)[24,25].

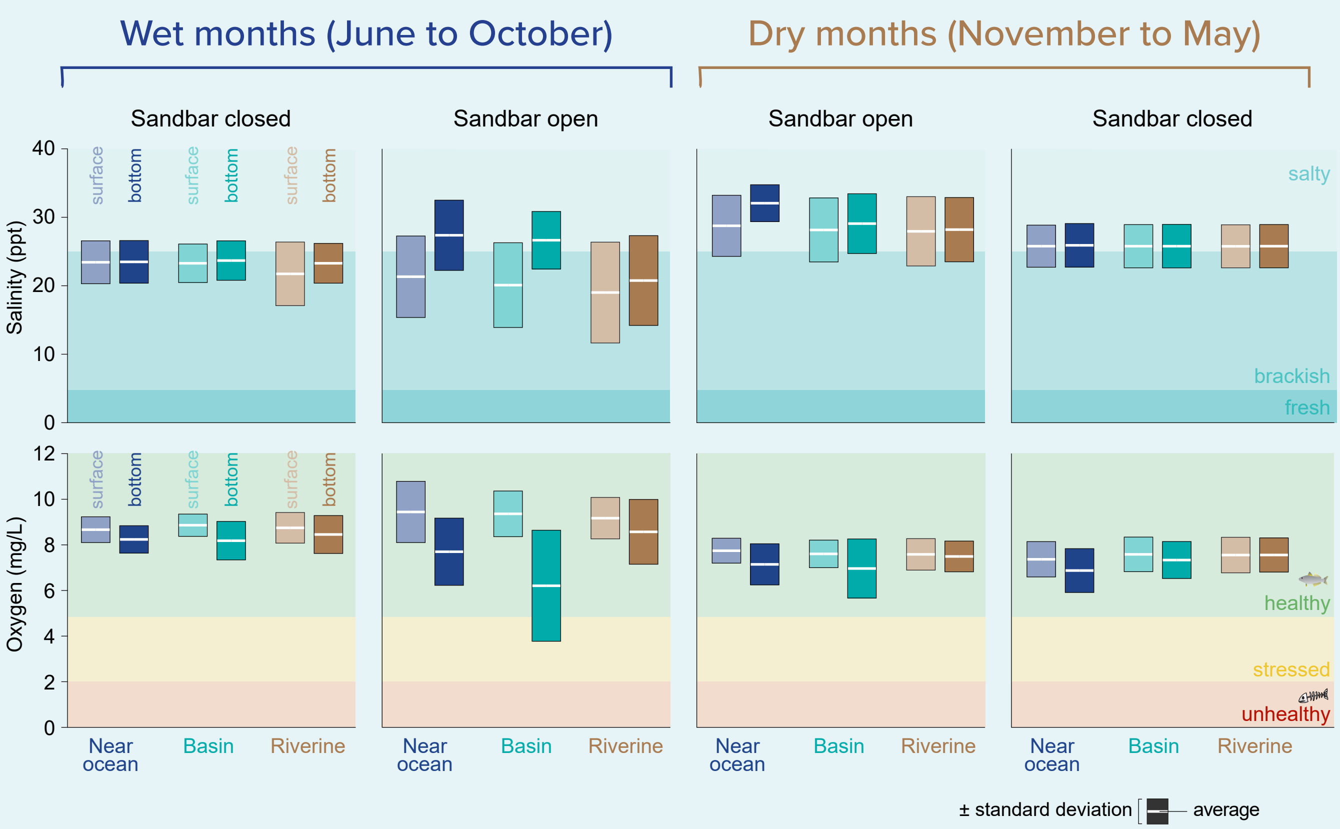
River flow into the inlet is highest in the wet months. The dimension of the channel through the sandbar and therefore the exchange with the ocean changes over time: it is greatest during the wet months, but once river flow decreases during the dry months, the channel starts to silt up, becoming smaller.

Due to the unusual sandbar dynamics in the current reporting period, as described in the *Estuary water level and sandbar status* section, not every year included in this report had all four states.

Key points

- Wilson Inlet has four distinct states which are determined by whether the sandbar is open or closed in the wet or dry months. The four states are: wet months/sandbar closed; wet months/sandbar open; dry months/sandbar open; dry months/ sandbar closed.
- The inlet was well mixed and had healthy oxygen levels most of the time.
- Low oxygen levels near the sediment occurred when the sandbar was open.
- Salinity was highest in the dry months when the sandbar was open, driven by the continuous connection to the ocean in summer and autumn 2022.
- In the past salinity had been highest in the dry months when the sandbar was closed due to evaporation.

Salinity and dissolved oxygen concentrations in Wilson Inlet's four states



The inlet was brackish as rivers started to flow at the beginning of winter. Well mixed conditions, but surface salinity at the riverine sites was slightly lower due to fresher river water.

Healthy oxygen concentrations throughout the inlet. Slightly lower concentrations in the bottom waters even without stratification. This is a sign of high biodegradation rates at the sediment, where oxygen is being consumed by organisms decomposing the organic matter in the sediment.

With the sandbar open, seawater enters the inlet and sits below the brackish inlet water (stratification). This was strongest at sites nearest to the sandbar and in the deeper central basin.

During persistent stratification, oxygen levels decreased at the bottom due to bacterial degradation of organic matter. The high oxygen concentrations in the surface were due to high algae activity.

When river flows slowed in summer, the inlet became more saline due to the continuing ocean exchange. Weak stratification remained, mainly at the site nearest to the ocean.

Mostly healthy oxygen concentrations throughout the inlet, but slightly lower levels near the bottom due to weak stratification.

Without the connection to the ocean and with almost no river flow, wind mixing resulted in similar salinity throughout the estuary.

Oxygen was at healthy levels, although slightly lower concentrations occurred in the bottom water layer at the site closest to the ocean. Oxygen reduction during biodegradation of aquatic plants washed into the inlet while the sandbar had been open, may have contributed to these lower oxygen concentrations.

During this reporting period, average salinity was highest in the dry months when the sandbar was open. This is because the sandbar remained open in summer and autumn 2022 resulting in, on average, marine-like salinity. This is different to the previous report (2016–19), when salinity had been highest in the dry months when the sandbar was closed due to evaporation.

Estuary nutrient and chlorophyll concentrations

Nitrogen and phosphorus are the most important nutrients for plant growth. Estuaries respond to increased availability of nutrients with higher microalgal activity, and too many nutrients can lead to excessive growth and the development of algal blooms. We monitor this by measuring the concentration of chlorophyll *a*, a plant pigment present in microalgae.

Key points

- Nutrient concentrations were low to moderate most of the time.
- Higher nutrient concentrations occurred during times of high river flow, stratification, and during periods of high algal activity.
- Algal activity was very different between the four states* and was highest when dissolved nutrient levels were elevated and temperatures were warmer.
- Nutrient concentrations between 2019–23 were similar to the previous reporting period (2016–19), but algal activity was higher.

Nutrients like nitrogen and phosphorus exist in particulate and dissolved forms. The sum of all forms is called total phosphorus or total nitrogen. Only the dissolved forms – total ammonia, nitrate, and phosphate – are immediately available for plants or microalgae to use.

Total nitrogen and total phosphorus concentrations were low to moderate. The highest concentrations were detected during the wet months near the rivers which suggests input of nutrients from catchment land uses. Nitrogen and phosphorus were also slightly elevated during the dry period when the sandbar was closed, particularly near the ocean.

This was because of higher microalgal activity in this area. The large range of total phosphorus concentrations (shown by a high standard deviation) during the wet months was because of substantial phosphorus input from the catchment.

Concentrations were lowest during the dry months when the sandbar was open, because low river flows were only delivering small catchment inputs and the inlet was diluted over time by ongoing ocean exchange. Although a similar trend was observed in the previous reporting period 2016–19[26], concentrations were notably lower in 2020–23. This is likely because the sandbar remained open in summer and autumn 2022, resulting in an extended period of ocean water exchange.

Concentrations were generally lowest near the ocean when the sandbar was open. In these conditions low-nutrient ocean water was regularly pushed into the inlet during high tide.

* The four states are: wet months/sandbar closed, wet months/sandbar open, dry months/sandbar open, dry months/sandbar closed, and are explained in more detail in the previous section *Salinity and oxygen concentrations*.

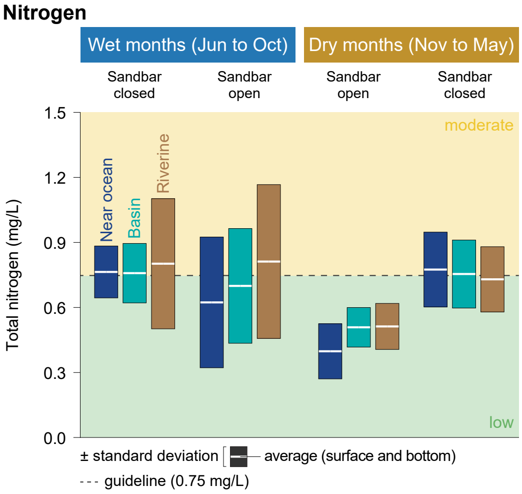
Assessing water quality using guideline values

We use ANZECC water quality guidelines for estuaries in south-west Australia[27] to assess the health of Wilson Inlet in terms of nutrient concentrations and algal activity. Since the guideline values provide a concentration above which there may be a risk of an adverse impact on the ecosystem, we categorise concentrations below the guideline values as low. Above the guideline values there are four more categories.

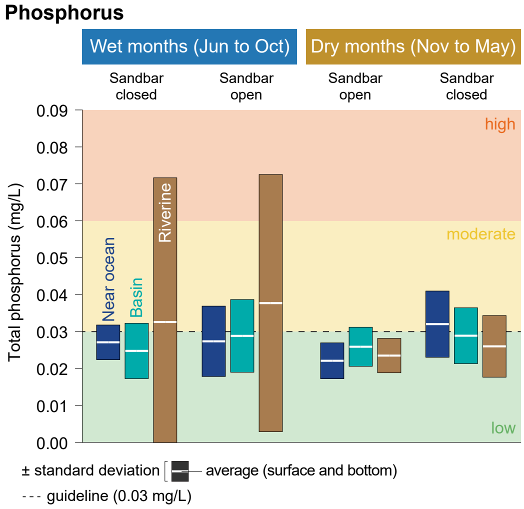
Category	Nutrient concentration
Low	≤ guideline
Moderate	> guideline to ≤ 2x guideline
High	> 2x guideline to ≤ 3x guideline
Very high	> 3x guideline to ≤ 4x guideline
Extreme	> 4x guideline

Parameter	ANZECC guideline value
Total nitrogen	0.75 mg/L
Total phosphorus	0.03 mg/L
Chlorophyll *a*	3 µg/L

Nitrogen



Phosphorus



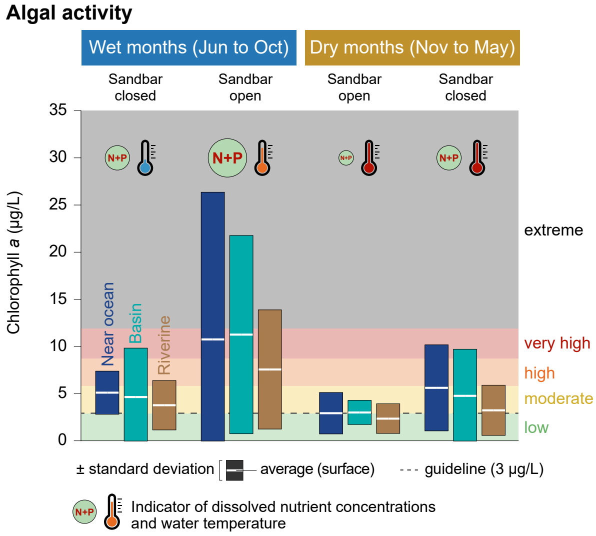
Average algal activity was moderate to very high most of the time. The exception was when the inlet was open during the dry period, in which average concentrations were low.

The highest algal activity occurred during the wet months when the sandbar was open. This is the time when concentrations of dissolved nutrients were highest and when water temperature and light availability started to increase. During this time, periods of extremely high algal activity occurred quickly after dissolved nutrient pulses into the inlet. However, algal activity was generally short-lived (4–6 weeks), which explains the large standard deviations observed during this time.

The zone near the ocean always showed the highest algal activity compared with other zones. This area regularly accumulates organic material like seagrass and macroalgae that is pushed into the inlet from the ocean when the sandbar is open. Therefore, the likely reason for the increased algal activity is that ammonium and phosphate were released from accumulated organic matter by biodegradation and fuelled microalgal growth.

The low algal activity during the dry months when the sandbar was open was because of low nutrient concentrations during this period. This was the only time when algal activity was lower than in the previous reporting period 2016–19[28]. At all other times, in particular during the wet months when the sandbar was open, algal activity was higher than in the previous reporting period.

Algal activity



The impact of rainfall variability and sandbar dynamics on water quality

Climate change contributes to a more variable climate, resulting in an increased occurrence of dry years, more extreme rainfall events and shifts in rainfall timing. As described in the *Rainfall and river flow* **section, rainfall and river flow varied greatly within the 2019–23 reporting period, with two dry years and two wet years. These differences led to three out of the four years having been "unusual" in terms of the sandbar openings (see** *Estuary water level and sandbar status* **section). Here, we compare water quality between the four years to show what climate variability might mean for the inlet's water quality into the future.**

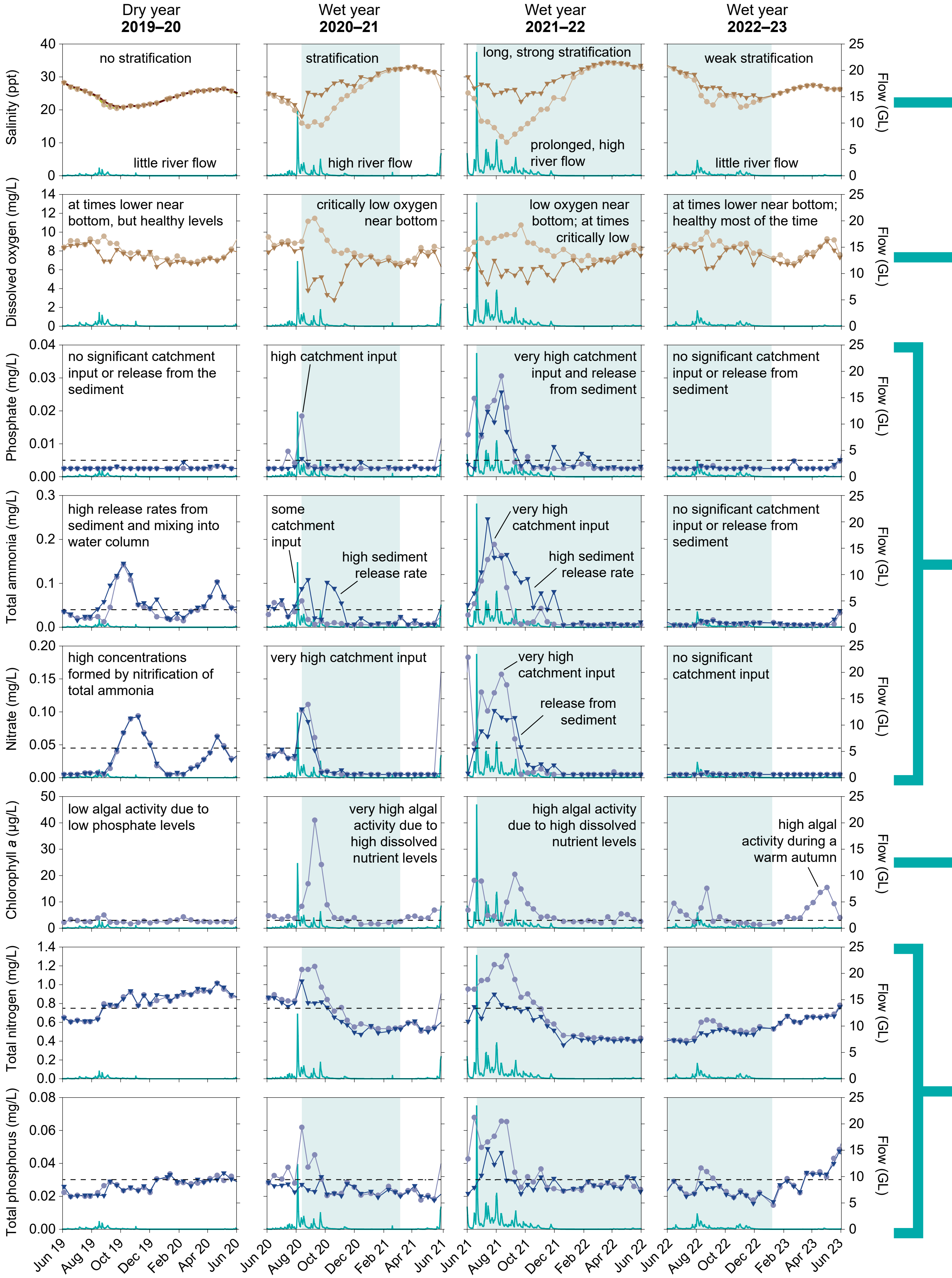
As described previously, only one out of four years within this reporting period (i.e. 2020–21) followed the 'typical', historical opening/closing pattern of the sandbar. In 2019–20, the sandbar remained closed; in 2021–22 the sandbar remained open throughout the entire year; in 2022–23 the sandbar was already open when the rivers started to flow but then closed early due to low river flow in that dry year.

The comparison of water quality in these four strikingly different years highlights the complex interaction of climate and water quality in Wilson Inlet. With rainfall and other climate parameters predicted to become more variable in the future, it seems likely that water quality in Wilson Inlet will also become more variable between years, which will make it harder to detect if water quality is trending better or worse. It is clear though, that with a more extreme climate, it is more likely that water quality in the inlet could be pushed over a critical point, which would result in a radical shift in the ecosystem state (for instance from the healthy to the unhealthy state)[29]. Therefore, it is more important than ever to reduce the amount of nutrients into the inlet.

Photo credit: Angela Rossen

Although the following conclusions are drawn on a limited number of years, we still consider them useful to help us understand how to best manage Wilson Inlet into the future. The key take-away messages are:

- In wet years, nutrient concentrations and algal activity are higher and more variable than in dry years.
- Catchment land uses are the main source of nutrients. This is particularly evident in wet years and highlights that reducing the input of nutrients from the catchment continues to be the most important step for protecting the inlet; at times, the sediment is also a significant contributor of dissolved nutrients.
- In a year when the sandbar remains closed, the sediment can be a significant source of dissolved nitrogen. However, this does not necessarily lead to high microalgal activity, because microalgal growth may be limited by phosphorus availability.
- The inlet might be at risk of eutrophication under a drying climate, given that total nutrient concentrations increased over time when the sandbar remained closed or closed early.
- In addition to improving management practices to reduce nutrient inputs from agricultural land uses to the inlet, careful management of the sandbar is required. In particular, avoiding situations where the inlet remains closed for multiple years in a row – if rainfall allows – will be an important tool to slow the eutrophication of Wilson Inlet.



Dry year
2019–20
Wet year
2020–21
Wet year
2021–22
Wet year
2022–23
Salinity (ppt)
no stratification
little river flow
stratification
high river flow
long, strong stratification
prolonged, high river flow
weak stratification
little river flow
Dissolved oxygen (mg/L)
at times lower near bottom, but healthy levels
critically low oxygen near bottom
low oxygen near bottom; at times critically low
at times lower near bottom; healthy most of the time
Phosphate (mg/L)
no significant catchment input or release from the sediment
high catchment input
very high catchment input and release from sediment
no significant catchment input or release from sediment
Total ammonia (mg/L)
high release rates from sediment and mixing into water column
some catchment input
high sediment release rate
very high catchment input
high sediment release rate
no significant catchment input or release from sediment
Nitrate (mg/L)
high concentrations formed by nitrification of total ammonia
very high catchment input
very high catchment input
release from sediment
no significant catchment input
Chlorophyll a (µg/L)
low algal activity due to low phosphate levels
very high algal activity due to high dissolved nutrient levels
high algal activity due to high dissolved nutrient levels
high algal activity during a warm autumn
Total nitrogen (mg/L)
Total phosphorus (mg/L)
Flow (GL)
Jun 19
Aug 19
Oct 19
Dec 19
Feb 20
Apr 20
Jun 20
Aug 20
Oct 20
Dec 20
Feb 21
Apr 21
Jun 21
Aug 21
Oct 21
Dec 21
Feb 22
Apr 22
Jun 22
Aug 22
Oct 22
Dec 22
Feb 23
Apr 23
Jun 23

In wetter years, **salinity** was more variable over time and between surface and bottom compared to drier years. This is because of the greater exchange with ocean water through the larger channel and the higher volumes of freshwater input from the catchment. In dry years, no significant salinity stratification was observed when the sandbar was closed, while a weak and short-lived stratification occurred in the dry year when the sandbar was open.

Oxygen concentrations were usually healthy. However low concentrations of **dissolved oxygen** in the bottom water occurred, mostly in wetter years during stratification when the sandbar was open. When the sandbar was open, low oxygen concentrations were more pronounced when ocean exchange was too weak for saltwater to be pushed far into the inlet with every tidal cycle. Therefore, low concentrations were more notable in 2020–21 compared with 2021–22. In 2020–21 the channel was smaller and sea level was lower, whereas in 2021–22, the channel was larger and sea level was higher because of La Niña.

Dissolved nutrient concentrations (phosphate, total ammonia, nitrate*) were elevated while rivers were flowing in wetter years because of significant input from the catchment. Ammonium and phosphate were also released from the sediment during times of low oxygen. Dissolved nutrients remained low during the period of river flow in 2022–23, which is typical for a dry year with little catchment input. This was likely further helped by dilution with ocean water as the sandbar was open when the rivers started to flow.

In the drier years, **phosphate** concentrations were low, regardless of whether the sandbar was open or not. In contrast, nitrate and total ammonia concentrations depended on the sandbar status.

Nitrate and total ammonia concentrations were elevated in the dry year when the sandbar remained closed (2019–20) despite very little input from the catchment and healthy dissolved oxygen levels in the bottom water. During this time, oxygen demand by bacteria in the sediment must have been greater than oxygen replenishment into the sediment, resulting in anoxic sediments. This led to high rates of ammonium release. Since the water column was well mixed, concentrations became high throughout the water column. The high nitrate concentrations that appeared shortly after the increase in ammonium concentrations resulted from nitrification of total ammonia to nitrate in the well-oxygenated water column.**

In the dry year when the sandbar was open (2022–23), **nitrate and total ammonia** concentrations were continuously low. This indicates that oxygen in the sediment was high enough to prevent the release of ammonia. The occasional intrusion of ocean water likely helped to replenish oxygen in and near the sediment.

Algal activity (chlorophyll *a*) was highest in wet months when high concentrations of dissolved nutrients were available. Algal activity was very low in the dry year when the sandbar remained closed despite high concentrations of nitrate and total ammonia. However, since phosphate concentrations were very low, it is likely that algae could not grow because of the lack of dissolved phosphorus. In the dry year when the sandbar was open, algal activity in autumn was also significant despite low concentrations of dissolved nutrients. This was a period when solar radiation*** and water temperature were high and indicates that even low nutrient concentrations are sufficient to support algal growth in certain environmental conditions.

Total nitrogen and total phosphorus are the sums of dissolved and particulate nitrogen and phosphorus concentrations. This means that i) concentrations were highest in the wet months of the wet years, ii) concentrations decreased once river flows stopped while the sandbar was still open, iii) concentrations were higher during high algal activity, and iv) total nitrogen concentrations started to slowly increase because of internal input from the sediment during long periods when the sandbar was closed (such as 2019–20 and following the early sandbar closure in early 2023).

Average of all sites

Increased concentrations in the SURFACE water indicate that the catchment is the source; increased concentrations in the BOTTOM water indicate that the inlet's sediment is the source.

Surface (0.5m below surface) / Bottom (0.5m above sediment) — nutrients, chlorophyll *a*
Surface (0.2m below surface) / Bottom (0.2m above sediment) — salinity, dissolved oxygen
sandbar open
flow
guideline

* The measurement for nitrate measures nitrate + nitrite, which is reported as NO_x^-. We still refer to this as nitrate as in most surface waters nitrite is present in very low concentrations.

** Nitrification is the conversion of ammonia to nitrate in the presence of oxygen. (see footnote*)

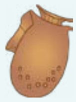
*** Solar radiation is the energy emitted by the sun; it makes photosynthesis of plants, including algae, possible.

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

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*.

Chrysophytes, are known as golden-brown algae due to their pigment. In Wilson Inlet, this group is represented predominantly by the genus *Pseudopedinella*.

Raphidophytes, encompass marine and freshwater species of algae. Their cells tend to be large with two flagella.



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.

Cryptophytes, are occur in freshwater and marine habitats. Their unique characteristic is the presence of ejectosomes, two coiled springs which release under stress and propel the cells in a zig-zag fashion.

Haptophytes are a dominant marine microalgal group in the oceans.

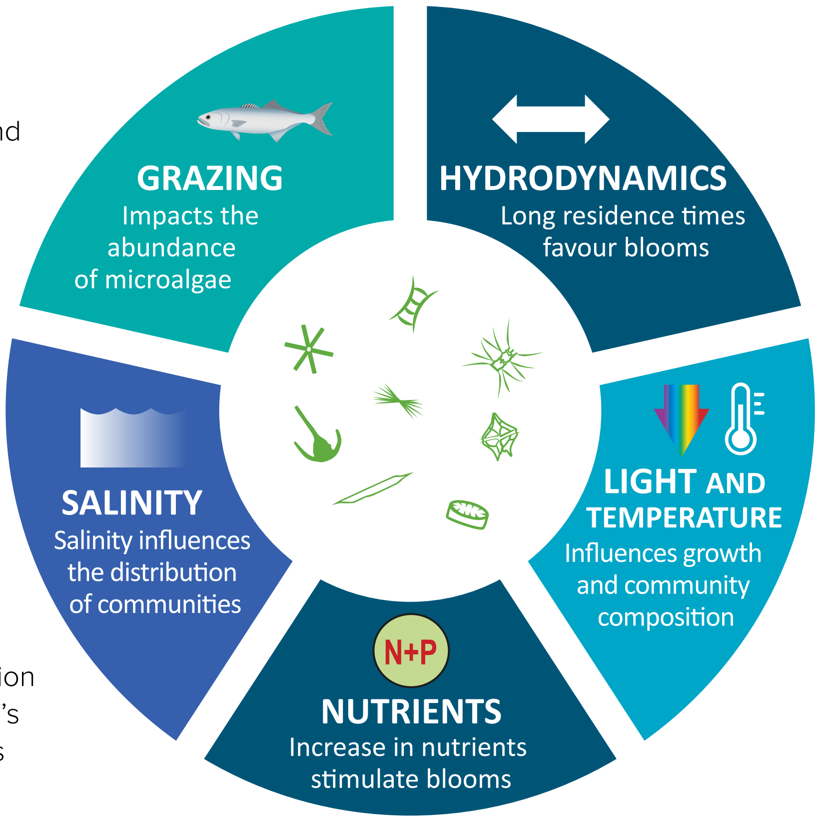
Euglenophytes are single-celled, flagellated mircoorganisms commonly found in nutrient-rich waters. They are mixotrophic feeders (see description in dinophytes). While most are green, some species contain carotenoid pigments, giving them a distinct red colour.

Microalgal dynamics

Microalgae, also known as phytoplankton, are tiny photosynthetic organisms crucial for removing carbon dioxide from the atmosphere and producing oxygen. They form the foundation of the aquatic food chain and enrich water with oxygen through daytime photosynthesis. However, overgrowth of microalgae because of an abundance of nutrients can result in poor water quality and adverse impacts on other aquatic fauna, human health and estuary amenity.

The plant pigment chlorophyll *a* is a universal indicator of microalgal activity. However, to further understand microalgal dynamics in estuaries, we also identify and assess the density of each type of microalgae, by looking at water samples with microscopes. This allows us to assess the diversity of the microalgal community and detect the presence, or even dominance, of potentially harmful microalgae species.* These observations serve as indicators of the estuary's overall health.

The composition of microalgal communities depends on a combination of factors which affect the microalgae's distribution. In estuaries, these factors include hydrodynamics, grazing by



* Our identification of potentially harmful microalgae may range from the species level, such as *Dinophysis acuminata*, to a genus level, like haptophyte spp., which are collectively referred to 'species' in this discussion.

aquatic fauna, light availability, salinity gradient and nutrient availability. The microalgae listed above are some groups present in the Wilson Inlet microalgal community.

Excess nutrients, such as nitrogen and phosphorus, combined with favourable growth conditions – such as warm water temperature, still conditions and ample light – lead to rapid increases in the number of microalgal cells. The term 'algal bloom' commonly describes the resulting dense layers of microalgae on the water surface and within the water column. Algal blooms are often recognised by changes in water colour – green, blue-green, red, or brown – depending upon the type of microalgae. One or more types of microalgae may dominate the community. However, there isn't a specific cell number universally defining a bloom. Blooms vary in duration, ranging from days to weeks and across scales, from ponds to oceans. In estuaries, persistent and widespread blooms can severely disrupt ecological balance, leading to significant economic and social consequences. High densities of potentially harmful microalgae can contribute to this disruption.

We use the term 'potentially harmful' to describe microalgal species that sometimes produce toxins, posing risks to aquatic fauna (such as fish) and human health. Identifying the presence of potentially harmful microalgae goes beyond visual inspection of the waterbody; their impact depends on density thresholds specific to each species of algae. While these microalgae are naturally present in any microalgal community, they pose a potential problem only when exceeding these thresholds.

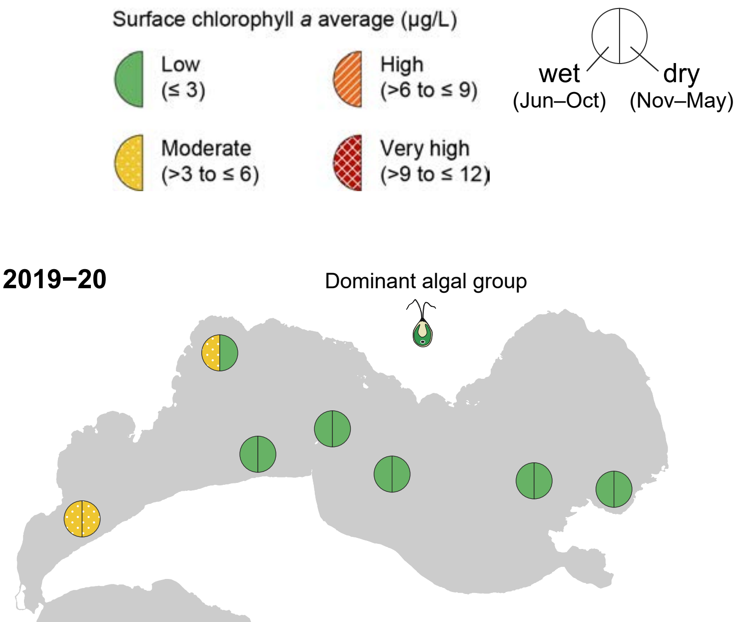
Microalgae that don't produce toxins, but readily attain high numbers are often termed 'nuisance microalgae'. Blooms of these species can discolour water, reduce light availability for seagrasses, contribute to fish kills by depleting oxygen in the water through respiration at night and during decomposition, and may even clog fish gills.

Microalgae: spatial and seasonal patterns

Seasonal and spatial patterns of microalgal densities and activity can reveal how microalgae respond to environmental factors, including rainfall, temperature, solar radiation and sandbar dynamics. Chlorophyll *a* concentrations from the surface waters of all seven monitoring sites indicate where and when microalgae occurred in Wilson Inlet. At four of these sites, microalgae cells were also counted and identified from integrated depth samples (surface to 0.5 m above sediment). These can tell us when and where species and groups were present.

Key points

- Microalgae activity was typically higher in the wet than the dry months, with some interannual differences due to climate and sandbar status.
- Diatoms were the dominant microalgae in most years, except in 2019–20 when the sandbar remained closed and chlorophytes were dominant due to lower salinity.
- Microalgae activity was normally lowest at the eastern site.

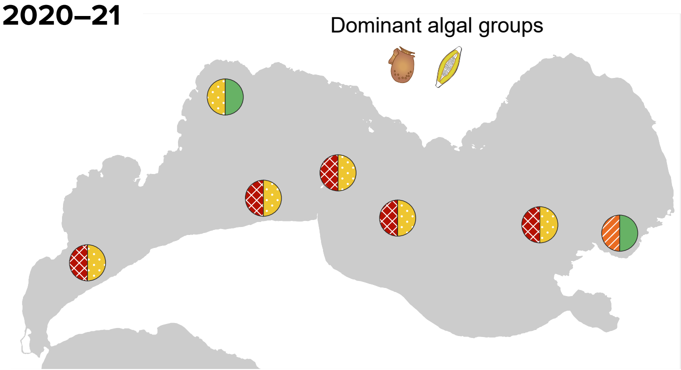


In the dry year of 2019–20, microalgal activity across the inlet was generally low likely linked to the small amounts of nutrients transported into the inlet during this dry year.

Slightly higher activity occurred near the ocean and during the wet months at the site nearest the Denmark River, possibly due to some local input of nutrients.

Chlorophytes were the dominant group for most of the year. This is unusual for Wilson Inlet and is likely linked to the lower-than-normal salinity throughout the inlet in this year due to the sandbar remaining closed.

2020–21

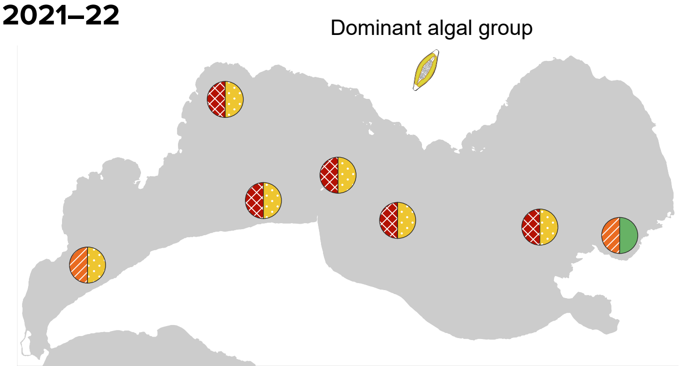


In 2020–21, microalgal activity was high to very high in the wet months when high amounts of nutrients were transported into the inlet and were available for growth.

Activity was slightly lower in the dry months and in the areas where the main rivers flow into the inlet.

Diatoms, a nutritious food source for many aquatic animals, were the dominant microalgae group. In spring, towards the end of the wet months, dinophytes were also abundant.

2021–22

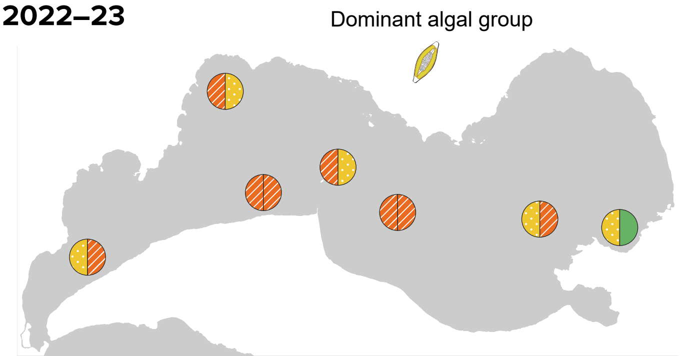


In 2021–22, microalgal activity was high to very high in the wet months when high amounts of nutrients were transported into the inlet and were available for growth.

Algal activity was slightly lower in the dry months, near the ocean and in the shallow eastern bay.

Diatoms were the dominant microalgae group, which is typical for Wilson Inlet.

2022–23

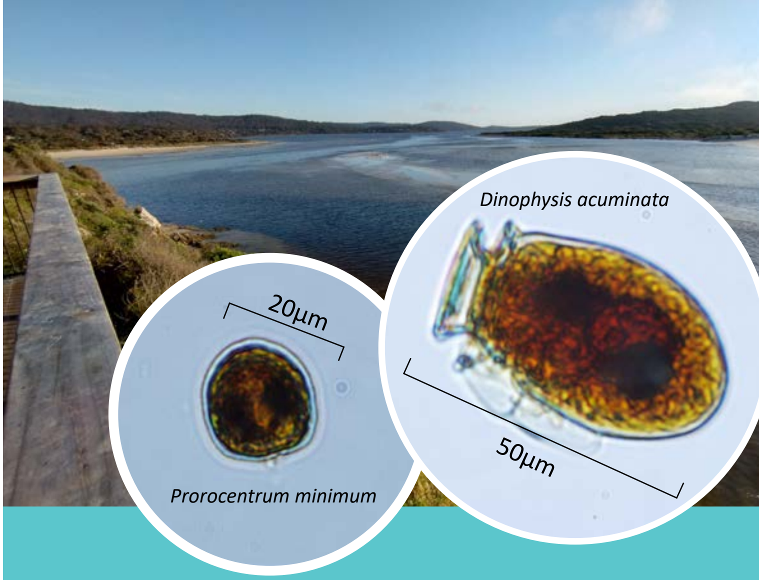


In 2022–23, microalgal activity was mostly moderate to high. The slightly lower values than the previous two years are likely linked to less nutrients transported into the inlet and being available for growth during this slightly drier year.

Algal activity was low in the dry months in the shallow eastern bay.

Diatoms were the dominant microalgae group, which is typical for Wilson Inlet. Interestingly, raphidophytes were seen for the first time in the inlet during an autumn bloom.

Potentially harmful microalgae



Potentially harmful microalgae are naturally occurring in most environmental water bodies. Only when present at densities above the phytoplankton environmental guidelines do they trigger a need for further investigation and potential management responses. We monitor the occurrence and density of potentially harmful microalgae, comparing them to density guideline values for each species. When a guideline is exceeded, it identifies a potential cause for concern that may prompt government authorities to issue health or management advice. By tracking these exceedances, we can assess how the health of the estuary is changing over time.

Occurrences* of potentially harmful microalgal species is evaluated by comparing their cell density (cells/mL) to the department's Phytoplankton Environmental Guidelines (PEG)[30], whose values were derived from an adaptation of published national and international guidelines[31,32] and expert local knowledge. These guidelines identify when microalgae might be contributing to a decline in estuary ecosystem health and suitability for commercial and recreational use.

In Wilson Inlet, 18 potentially harmful species of microalgae occurred during the 2019–23 reporting period. This is a low number compared to other estuaries in Western Australia (Peel–Harvey estuary: 54, Leschenault Estuary: 25, Hardy Inlet: 22, Oyster Harbour: 14).

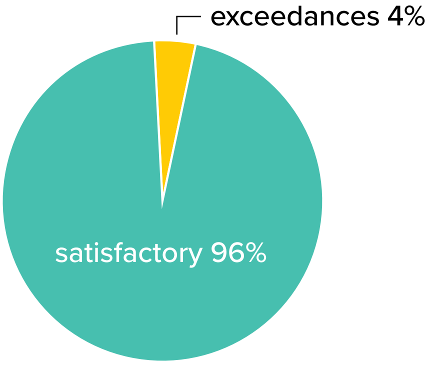
Key points

- 18 potentially harmful microalgal species occurred in Wilson Inlet.
- Only five of the 18 potentially harmful microalgal species exceeded the Phytoplankton Environmental Guideline densities at times. These were three species that can affect human health and two species that can affect fish health.
- Only 4 per cent of the total number of harmful algae occurrences exceeded density guidelines, indicating that these were rare events.
- Whilst we observed potentially harmful algal exceedances in Wilson Inlet, the possibility of presenting a threat to public health or aquatic life were minimal.
- Although potentially harmful algal species were observed in Wilson Inlet, they were short lived and not at a level that required health warnings.

Exceedances of microalgae guideline values

Low densities of potentially harmful microalgae occurred in Wilson Inlet and exceedances of PEG values were rare. Exceedances were observed in just 4 per cent of all potentially harmful algal occurrences during the reporting period.

* Occurrences: the total number of times any potentially harmful species was present in samples during the reporting period.



Of the 18 potentially harmful microalgal species detected in the Wilson Inlet, only five species exceeded the PEG values.* Three of the observed species have the potential to impact human health through wild shellfish consumption and two have the potential to harm fish (see below). While exceedances occurred at all sites in the Wilson Inlet, the number of exceedances was slightly higher at the site near the ocean.

Human health

Human health may be impacted by microalgal species that can cause skin irritation or illness through direct contact, or via the consumption of wild shellfish contaminated with microalgal toxins. The Department of Health may provide specific health warning advice and direct the placement of warning signs in affected areas, when such species exceed guidelines. This is in addition to long-standing advice from the Department of Health not to eat wild shellfish[33]. Since the exceedances of these species were short-lived, isolated events, no warnings signs or health warnings from the Department of Health were required.

Prorocentrum cordatum (previously known as *Prorocentrum minimum*), *Dinophysis acuminata and Alexandrium* spp. were the three species that exceeded the PEG values during the reporting period in isolated events. All are dinophytes, whose toxins can accumulate in shellfish and impact humans after consumption of the affected shellfish.

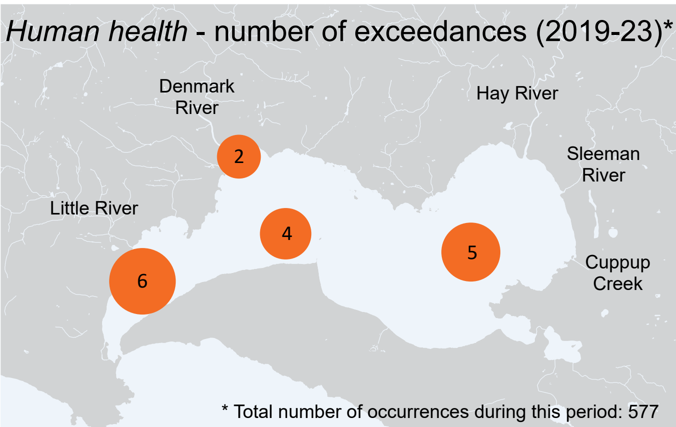
Prorocentrum cordatum was again the most abundant of the potentially harmful microalgae exceeding the guideline values across all sampling locations. This microalgal species has historically contributed to the most exceedances in Wilson Inlet, but the number of exceedances in the 2019–23 reporting period was slightly lower than previously.

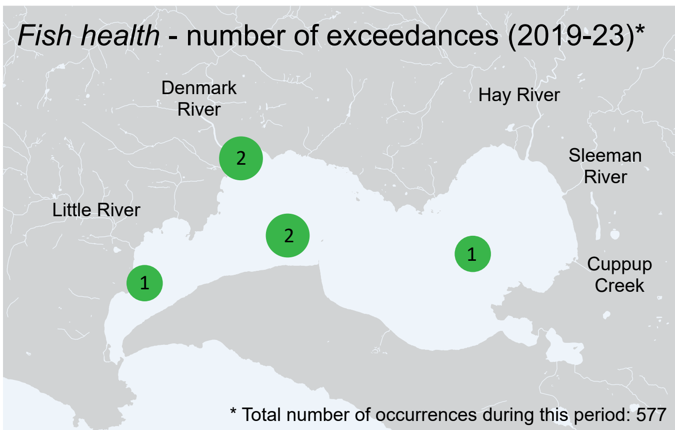
Dinophysis acuminata, which can be toxic in very low numbers, exceeded the guideline values on two occasions and only at levels just above the guideline value for this species.

Alexandrium spp. were above the guideline values at three sites on one sampling date and as such has been an isolated event.

Fish health

Prymnesium spp. and other haptophyes can harm fish through the production of ichthyotoxins. These microalgal species exceeded the guideline value on only one sampling day in 2020 and 2022, respectively. As such these are very rare events. No fish kills were observed.





* Relevant trigger values for Wilson Inlet species: 1,000 cells/mL for *Prorocentrum cordatum*, *Prymnesium spp.*, and *Haptophyte spp.*, and 10 cells/mL for *Dinophysis acuminata* and *Alexandrium spp.*

Seagrass and macroalgae

Seagrass and macroalgae are aquatic plants that are a key part of estuarine ecosystems. Measuring the types and abundance of seagrass and macroalgae can provide valuable insight into estuarine health over time.

Seagrasses are flowering plants that have evolved from land plants and adapted to live underwater in estuarine and 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, improving water and sediment quality by absorbing excess nutrients and producing oxygen through photosynthesis.

While they may look similar, macroalgae (or seaweed) should not be confused with seagrass. 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 clog commercial fishing nets, smother seagrasses, reduce oxygen in the water and produce foul odours when they decompose.

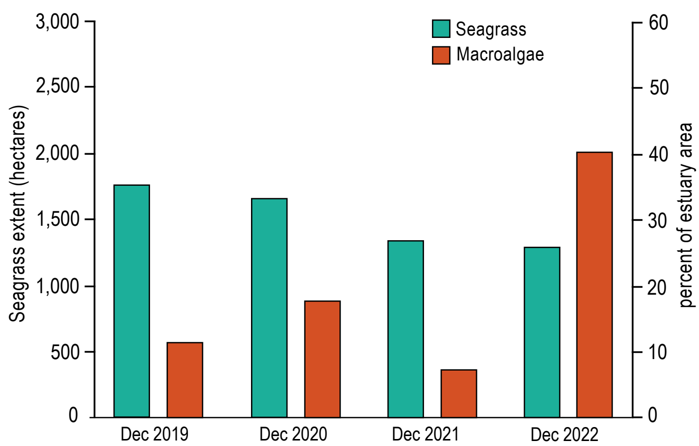
To the local Noongar people, Wilson Inlet is known as *Nullaki*, a Noongar word that refers to seagrass, which could indicate that seagrass has been an integral part of the estuary for a long time.

Maintaining healthy seagrass meadows is crucial for overall estuary health; however, striking a balance is key. In the past, an overabundance of *Ruppia* in the inlet has been problematic, leading to mass die-offs, causing water quality issues and the accumulation of wrack along shorelines. Ongoing monitoring is critical to track estuary health over time.

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 have been declining since 2019, reaching the lowest distribution in December 2022 – about 27 per cent of the total estuary area.
- Macroalgae extent was highest in 2022, covering 42 per cent of the total inlet area.

The department monitored seagrass and macroalgae annually in December during the reporting period (December 2019 – December 2022). These surveys include a snapshot of the distribution and density (or percentage cover) of seagrass and macroalgae across the estuary.



Seagrass was estimated to cover 1,293 hectares in December 2022 – about 27 per cent of the total estuary area*. This indicates a 10 per cent decline in seagrass extent since December 2019, with a notable reduction along Morley Beach and Eden Bank. Seagrass is typically found in shallow areas of the estuary, with about 82 per cent growing in water less than 2 m deep throughout the monitoring periods.

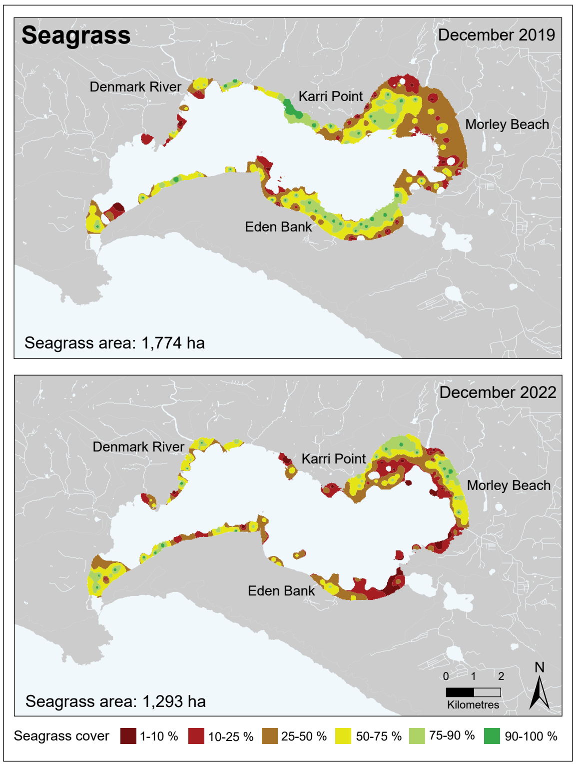
In December 2022, dense meadows were found in several areas of the estuary, including near the mouth of the estuary and at Denmark River, Karri Point and Morley Beach. Seagrass was mostly absent in the area along Eden Bank in December 2022, where meadows had previously been dense in December 2019 and 2020. Areas close to Karri Point consistently had the densest meadows during the reporting period.

The decrease in seagrass extent between 2019 and 2022 was paired with an overall increase in macroalgae. In 2019, macroalgae was estimated to cover 572 hectares, which is about 12 per cent of the estuary area. However, in December 2022, the presence of macroalgae had substantially increased to extend across 2,013 hectares (42 per cent) of the estuary. While the area where macroalgae were present increased over time, the density (or cover) has remained moderate.

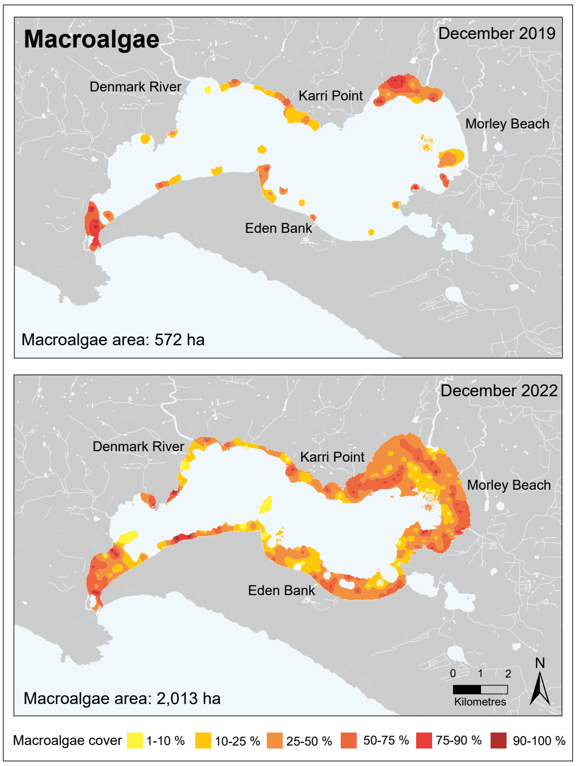
Both *Ruppia megacarpa* and macroalgae can respond quickly to changes in estuary conditions and grow rapidly when environmental conditions are favourable. While some fluctuations are typical in a dynamic estuary, prolific growth of macroalgae can outcompete and smother seagrasses reducing the light available for photosynthesis.

Climate change is influencing estuary dynamics – increasing temperatures and changing the timing and amount of rainfall and river flow, which in turn alters nutrient inputs and sandbar openings. Recent conditions have led to greater nutrient inputs during warmer months, causing rapid macroalgae growth which can outcompete and smother seagrass. Continued efforts to reduce nutrient inputs through the Healthy Estuaries WA program will be essential to keep a healthy balance between seagrass and macroalgae.

Seagrass



Macroalgae



* Total estuary area is approximately 4,828 hectares

Outlook

The outlook for estuaries along the south coast and south-west of Western Australia is increasingly uncertain, with the combined effects of climate change and nutrient pollution posing significant challenges to their health. Our ongoing efforts are an important part of mitigating climate change and preserving the health of our estuaries, ensuring their resilience for future generations.

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 in recent decades which directly impact the sandbar opening. More frequent low rainfall years can lead to more years where the sandbar is not opened to prevent flooding. This could be harmful to the ecology of the inlet. A recent review of the sandbar protocol led to an updated decision framework that now allows opening the sandbar in drier years at lower levels to lessen negative impacts of climate change on the ecosystem[34]. On the other hand, extreme rainfall events like the one that occurred in June 2021 can lead to very long openings and extremely high nutrient inputs from the land uses in the catchment which can be detrimental to the inlet.

And while low flows from a drying climate may seem beneficial for estuaries in terms of nutrient pollution due to smaller nutrient loads, the situation is more complex. For example, 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. This could potentially trigger 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 land uses in the catchment to the estuary. The ongoing work by farmers and the community to reduce the amount of nutrient runoff from farms and properties, including soil testing farmland to inform fertiliser use,

streamline fencing and revegetation, is an important step towards climate resilience, but it requires a sustained effort to combat decades of nutrient pollution. Particular attention should be given to those subcatchments that 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 review management actions which are most likely to decrease nutrient loads to the inlet – an important step in prioritising continued efforts to protect and improve the health of this system.

While the Water Quality Improvement Plan for Wilson Inlet aims to address nutrient loads as a crucial first step, it is also important to consider other environmental changes impacting coastal waters. 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.

The ongoing changes in climate and rainfall contribute to significant variability in water quality, making it more difficult to detect shifts in the system. Consistent and continuous monitoring is the most effective way to identify long-term trends and track improvements or declines in estuary health over time.

Our monitoring and management efforts play a key role in protecting the health of our estuarine ecosystems, helping to build resilience in the face of climate change.

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[32] Department of Health (2022) Environmental quality criteria for toxic algae in marine recreational waters. Government of Western Australia, Perth.

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[34] Department of Water and Environmental Regulation (in prep.) (See 3)

More information

Healthy Estuaries WA works with local partner organisations to improve the health of the Wilson Inlet. Our focus has been on reducing nutrients entering waterways from agricultural sources in the catchment, removing nutrients once they have entered waterways and building scientific understanding of the catchment and estuary to inform management decisions.

Key activities include:

- Working in partnership with the Department of Primary Industries and Regional Development, farmers, industry and Wilson Inlet Catchment Committee to **reduce nutrient runoff** from farms through improved fertiliser management practices.
- Working in partnership with Western Dairy and the dairy industry to support farmers to **improve dairy effluent management practices**.
- Working with farmers and Wilson Inlet Catchment Committee to **restore stream function** and move stock away from waterways.
- Supporting the **scientific monitoring** of Wilson Inlet and its catchments.
- Collaborating with Water Corporation, Shire of Denmark, City of Albany and key stakeholders to **manage the Wilson Inlet Sandbar** amid climate change.

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

Looking for information about fish or birds?

The Department of Primary Industries and Regional Development is responsible for the monitoring and management of our fish. They produce a yearly report on “the state of the fisheries”. Read the latest edition library.dpird.wa.gov.au/an_sofar/

BirdLife Australia uses citizen scientists to collect important data about the birds that live around our estuaries. Contact BirdLife Australia or one of their region-specific groups for more information about local species. birdlife.org.au/groups/

What you can do

Improving the health of our estuaries requires everyone’s involvement – government, industry, farmers, homeowners and local communities all play a key role in protecting these vital ecosystems. Let’s work together by adopting best practices, staying informed and taking action to ensure the long-term health of our estuaries for generations to come.

Visit estuaries.dwer.wa.gov.au/participate/ to find out how you can help.

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