GOVERNMENT OF
WESTERN AUSTRALIA

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

Hardy Inlet

Talinup-Goorbilyup

HEALTHY
ESTUARIES
WA

Condition of the estuary 2016–19

#WAestuaries

Acknowledgements

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The department acknowledges the Wadandi Noongar people as the Traditional Owners of the inlet, and pays respect to their Elders past, present and emerging.

Most photos are by Ash Ramsay and Joanna Browne, Department of Water and Environmental Regulation. Photos on p. 35 of microalgae under the microscope are by Sarah Grigo, Department of Water and Environmental Regulation.

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About estuaries

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

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

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

The Regional Estuaries Initiative extended scientific monitoring programs in six estuaries in south-west Western Australia (WA). This provided foundational knowledge on ecosystem health, seasonal variation in water quality and key drivers of estuary dynamics (e.g. river flow, catchment nutrient inputs and marine exchange). This information helps us assess how estuarine health is changing over time.

Insight into the condition of our estuaries enables more effective management. It allows, for example, for the prioritisation of efforts to improve fertiliser practices and helps to pinpoint high-priority stream restoration sites. It also enables the identification of public health risks that can then be communicated to the public if needed and helps us understand where more research is needed.

Report at a glance

This report summarises three years of the Regional Estuaries Initiative Hardy Inlet monitoring program (2016–19) and compares these results with historical data. We report on the main drivers of estuary health – flow and catchment condition, and the estuary response – and the status of water quality indicators and key habitats such as seagrass. Findings from the 2019–23 monitoring period will be summarised in a subsequent report.

The Hardy Inlet provides a beautiful backdrop to the town of Augusta and hamlet of East Augusta, where the mighty Blackwood River joins the sea. The estuary is a playground for residents and visitors, with its protected waters providing a venue for fishing, boating, water skiing and other recreational activities. It provides important habitat for birds, fish and dolphins. Seagrass beds ripple in its shallow waters, and diverse and unique flora line its banks.

The Hardy Inlet basin generally has relatively good water quality. However, the water is occasionally made murky by microalgae, particularly in West Bay. Macroalgal blooms regularly occur near the mouth in the spring and summer.

The catchments of the Hardy Inlet – the Blackwood and the smaller Scott – have been modified through clearing and agriculture. These activities have led to a decline in the health of the estuary which, in future, may be further exacerbated because of the changing climate. The Scott and Blackwood rivers carry nutrients from the catchments, particularly phosphorus from the Scott. Nutrients are released from sediments in the deeper, low-oxygen sections of the lower Blackwood River and areas around Molloy Island. High nutrient concentrations result in high densities of microalgae, subsequently leading to a loss of amenity and ecological function.

A water quality improvement plan (WQIP) was produced for the Scott catchment in 2012 to prioritise actions to reduce nutrients entering the estuary. It was updated through the *Scott River Action Plan*[1] in 2020. Given the poor water quality of the Scott River and area around Molloy Island, implementation of the actions in the plan is critical to improve the condition of the estuary. Actions to reduce nutrients from both the Blackwood and Scott river catchments of the Hardy Inlet are being implemented through Healthy Estuaries WA in partnership with the Lower Blackwood Land Conservation District Committee (Lower Blackwood LCDC).

Key points:

- ⇨ The Hardy Inlet estuary comprises the Hardy Inlet basin (from the mouth to Island Point, including North Bay and West Bay), the area around Molloy Island and the estuarine portions of the Blackwood and Scott rivers.
- ⇨ The Hardy Inlet basin is healthy, except for spring macroalgal blooms and occasional dense microalgae. It is well flushed and well oxygenated.
- ⇨ Surface waters of the lower Blackwood River are mostly healthy, except for occasional high densities of microalgae. Deeper waters are unhealthy, often with low dissolved oxygen, and sediment nutrient release.
- ⇨ The lower Scott River and waters surrounding Molloy Island are unhealthy, with high nutrient concentrations and microalgal densities.
- ⇨ With reduced rainfall and river flow and rising sea levels because of climate change, it is likely that catchment-derived nutrients will further accumulate in the sediments of estuarine portions of the Blackwood and Scott rivers.
- ⇨ Reduced river flows and rising sea levels will change sandbar dynamics, which could possibly lead to reduced marine exchange.
- ⇨ Seagrass habitat and cover increased between 2018 and 2020, with seagrass habitat extending to 61 per cent of the estuary in 2020.

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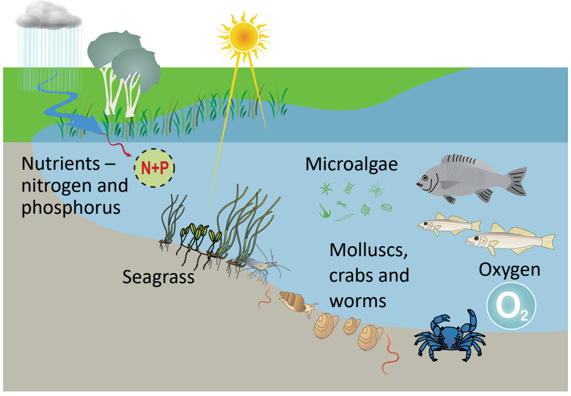
[1] Lower Blackwood Land Conservation District Committee (2020) *Scott River Action Plan*, Lower Blackwood Land Conservation District Committee, Western Australia. Available at: lowerblackwood.com.au/projects/scott-river-action-plan/

What is estuary health?

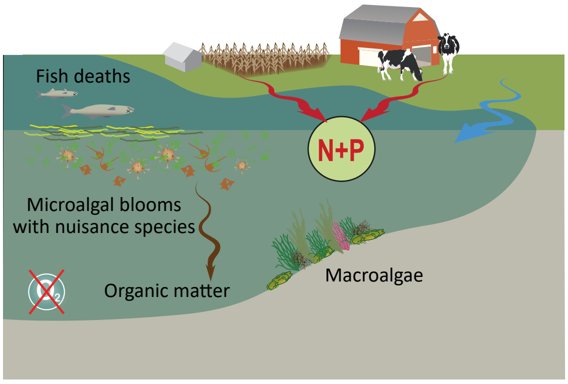


Healthy estuaries

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. They also stabilise sediments, shelter fish, provide food for birds such as swans, and oxygenate bottom waters.

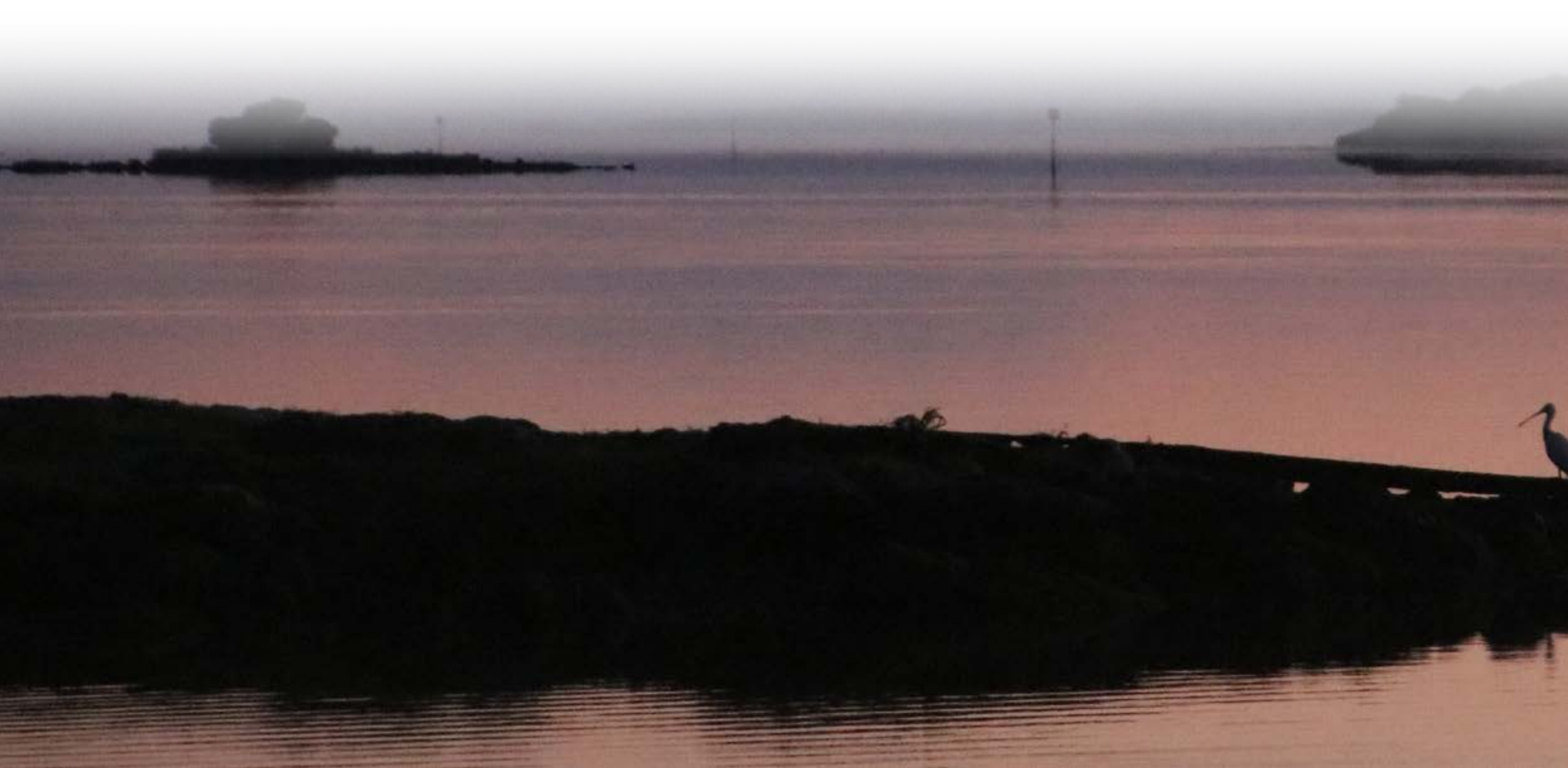


Unhealthy estuaries

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.



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

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 deaths and even lead to an ecosystem shift from a healthy seagrass-dominated system to the less desirable microalgae-dominated system.

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: In river concentrations, when multiplied by flow volume is an estimate of the load that enters the estuary.

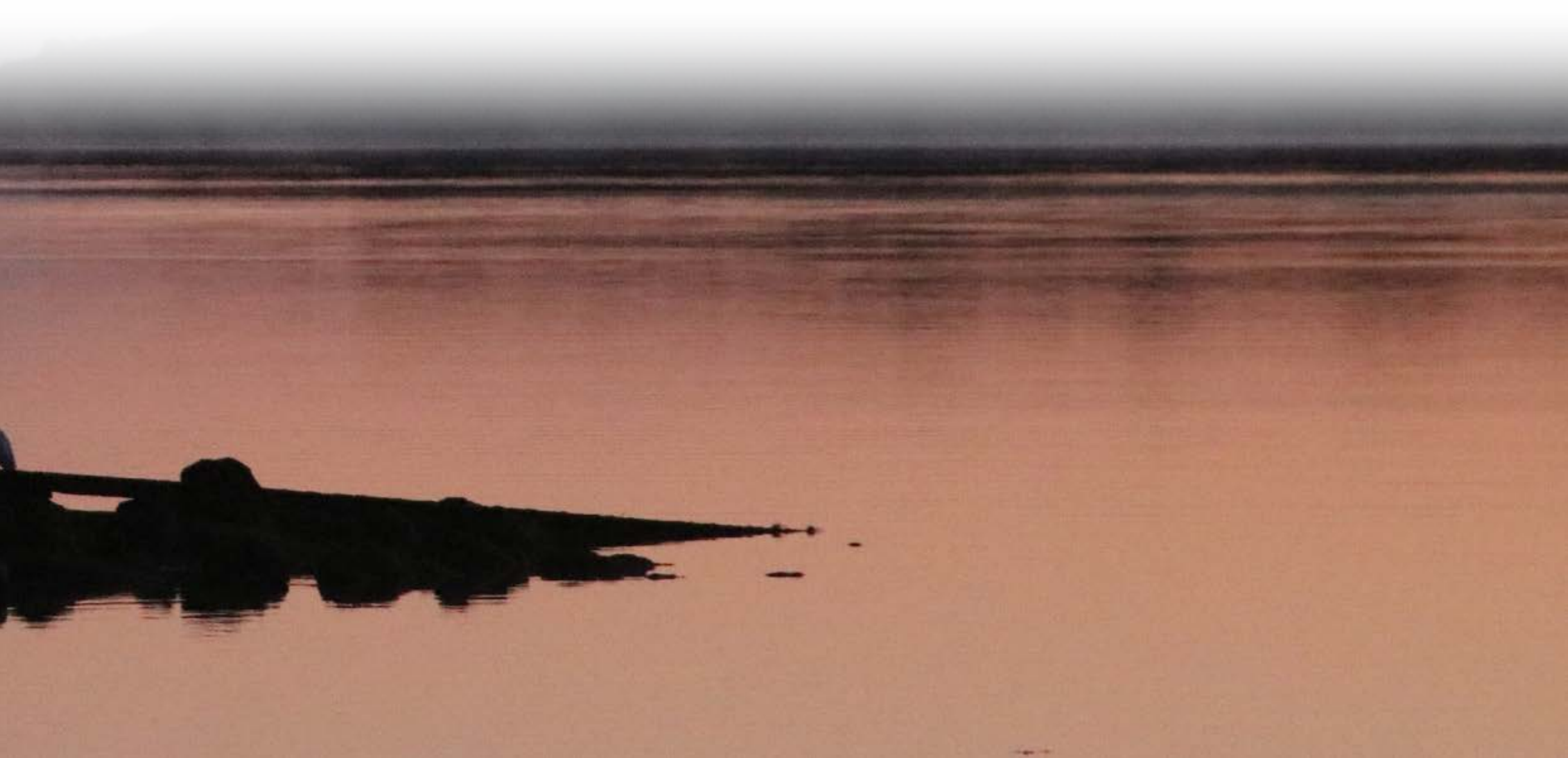
In the estuary

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 total 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 spatial extent and condition assessment.



About Hardy Inlet and its catchments

The Hardy Inlet is on the south-west coast of Australia, just over 300 km south of the city of Perth. It opens to the Southern Ocean near Cape Leeuwin, where the Southern Ocean meets the Indian Ocean. The inlet forms a sheltered backdrop to the town of Augusta, nestled on its western shore and to the hamlet of East Augusta, camouflaged amongst the peppermints on its eastern banks.

The Hardy Inlet includes the estuarine parts of the Blackwood and Scott rivers to the north-east, which flow into the Hardy Inlet basin (which includes North Bay, West Bay and the lower estuary channel). It opens to the ocean at Flinders Bay and forms 'the Deadwater' to the east of the mouth. Marine water travels 42 km up the Blackwood River and 8 km up the Scott River, creating estuarine habitats in the lower rivers. The Blackwood River and Scott River converge around Molloy Island.

The Hardy Inlet basin has an area of 9 km^2 and is shallow (depth < 2 m), with a narrow channel to the ocean at one end and a fluvial delta at the other end where the rivers discharge around the small settlement of Molloy Island. Hardy Inlet supports seagrass, fish, bottom-dwelling fauna and birds. Dolphins and stingrays are often spotted cruising in from the sea. It is a popular tourist area and visitors and residents enjoy fishing, boating, swimming and watersports in its protected waters.

The Blackwood River is the largest river by volume in south-west WA. It flows 330 km from the Lake Grace area, winding down through the Wheatbelt and the Blackwood Valley. It has the longest section of permanent groundwater-fed flow in south-west WA and has an unusual pattern of being more saline during winter than in summer. Throughout the year, fresh groundwater feeds into the Blackwood just downstream of Nannup[2] from the Yarragadee and Leederville aquifers.

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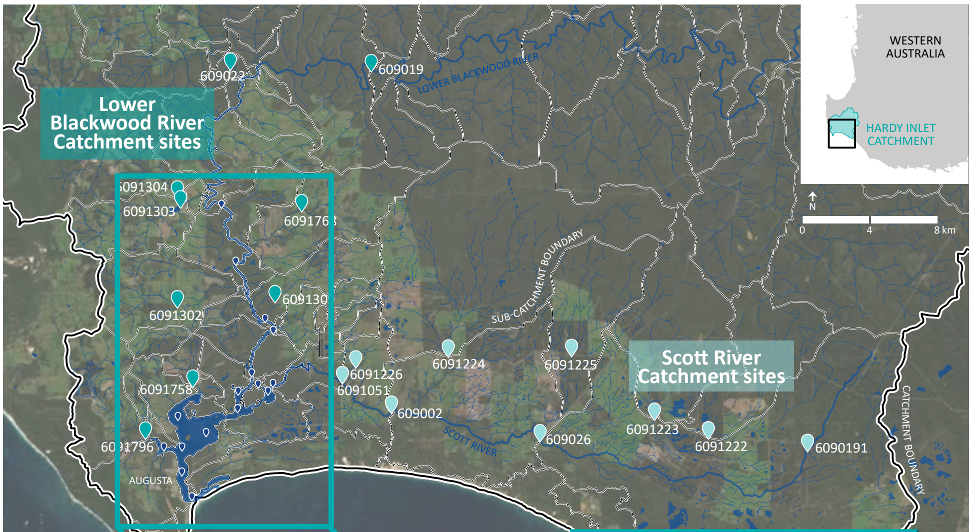
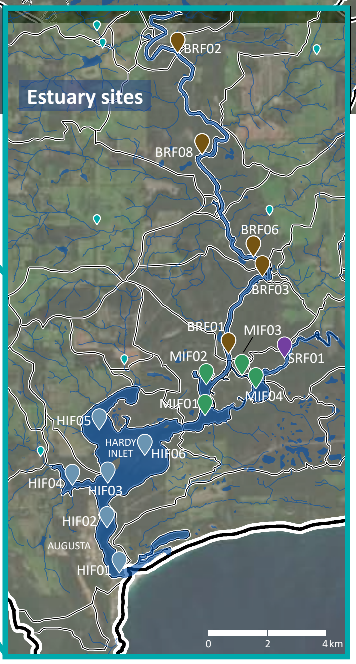
[2] Department of Water (2015) *The importance of groundwater to the Blackwood and other iconic rivers of the south-west,* Department of Water, Government of Western Australia, Perth

In winter, rain falling in the salt-affected Wheatbelt leads to salty water washing downstream. In summer, with very little rainfall, the fresh groundwater has more influence on the river water. Most of the flow of the Blackwood is from the wetter Lower Blackwood catchment, and this section is monitored by the Department of Water and Environmental Regulation (the department).

The Scott River is much shorter than the Blackwood and has a catchment only 3 per cent of the size of the greater Blackwood Catchment. In addition to the main channel, there is a network of drains, tributaries, swamps and wetlands across the catchment. The water from the Scott is darker than that of the Blackwood, stained by humic acid from ironstone deposits and tannins from rotting native vegetation. Many of the soils in the catchment have a low ability to retain phosphorus, and one third of the catchment contains potential acid sulfate soils. The poor nutrient retention by the soils, along with intensive agriculture land uses, contributes to high nutrient concentrations in the Scott River.

Water quality monitoring is undertaken fortnightly at 16 estuary sites, nine sites in the Lower Blackwood catchment and nine sites in the Scott catchment as part of Healthy Estuaries WA (continuing from the Regional Estuaries Initiative).





Hardy inlet in 2010 prior to the new mouth being dredged

Historical context

Hardy Inlet is in the boodjar (Country) of the Wadandi Noongar people. The area where the Blackwood River turns into Hardy Inlet and runs to Flinders Bay is Talinup. It is named after the Talin or Knob Sedge (*Carex inversa*) – a bush/reed that appears on the estuary shores. Goorbilyup is the Wadandi name for the lower Blackwood River entering to the estuary, with Goorbilya meaning the large intestine.[3] The Scott catchment area, and much of the Lower Blackwood catchment south of the Blackwood River, is in the boodjar of the Pibelman Noongar people. The Upper Blackwood catchment extends into the lands of the Kaniyan, Wiilman and Goreng people.

In the 1830s, European developments led to land clearing in the Hardy Inlet catchment for houses and sheep and cattle grazing. Expansion of cattle grazing in the 1850s resulted in increased burning regimes, which slowly started to affect the native vegetation. Landscape modifications subsequently accelerated with the development of milling in the 1870s, tourism in the 1900s, the implementation of the World War I Group Settlement Scheme in the 1920s and the creation of the Flinders Bay railway in 1925.

Development of the Scott River valley for agriculture started in the 1970s for beef, dairy and tree plantations. Intensive potato farming started in the 1990s but was found to be economically unviable, with farms mainly converted to irrigated dairy.

A detailed study of the Hardy Inlet and Blackwood River was conducted in the mid 1970s by Ernest Hodgkin.[4] Despite the development of agricultural activities influencing the estuary through runoff and land clearing, this study reported an overall healthy and resilient ecosystem. These observations, however, were made before the clearing of the Scott River valley for agriculture. Ernest Hodgkin also noted that natural variation in salinity across the system was of high importance because it was influencing the distribution and abundance of flora and fauna.

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[3] Cultural informants Undalup Association/Zac and Wayne Webb

[4] Hodgkin EP (1978) *An environmental study of the Blackwood River estuary Western Australia 1974-1975*, report to the Estuarine and Marine Advisory Committee of the Environmental Protection Authority, Report No. 1, Department of Conservation and Environment, Perth

Subsequent studies,[5,6] revealed that numerous changes had occurred in the Hardy Inlet and its catchment between 1970 and 2012. Water flows had decreased in the Blackwood River and rising salinity negatively affected crops and water use. Nutrient concentrations had risen in the waterways because of sustained land clearing and the application of large amounts of fertilisers. Additional runoff of nutrients from dairy and cattle farms, along with sand bank erosion, further contributed to a decline in water quality. Sedimentation rates had increased, and low dissolved oxygen concentrations in deeper waters led to the release of nutrients from the sediments. Changes in the estuarine biota were reported, including a decrease in fish stocks and more frequent algal blooms.

Aiming to address the numerous issues which had arisen since the 1970s and promote a healthy and sustainable ecosystem, a WQIP[7] was developed in 2012 for the Hardy Inlet. The aim of the plan was to offer a strategic approach to decreasing the nutrient inputs from the Scott River catchment into the Hardy Inlet. Recommendations in this plan were developed to support best management practices and meet nutrient load reduction targets. Many of the recommended on-ground actions (including continued monitoring) were undertaken by the department through the Regional Estuaries Initiative and continue through Healthy Estuaries WA.

Today, the Hardy Inlet and its catchments still support a wide range of activities and cultural, social and economic values. Yet, increasing pressures may lead to a system that is no longer able to sustain these key values. For example, decreasing water flows, associated with climate change, result in greater nutrient accumulation within the inlet. Continuing management effort will be required to combat this and other stresses and prevent any further decline in estuarine health.

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[5] Brearley A (2013) *Revisiting the Blackwood River and the Hardy Inlet, 40 years of change. An environmental review of the Blackwood River estuary Western Australia 1974-2010*. Ernest Hodgkin Trust for Estuary Education and Research, Perth

[6] Department of Water (2013) *Hardy Inlet Estuary Condition Report 1999 to 2010*, Department of Water, Western Australia. Available at: www.wa.gov.au/government/publications/estuary-condition-report-hardy-inlet-1999-2010

[7] White, KS (2012) *Hardy Inlet water quality improvement plan: Stage one – the Scott River catchment*, Department of Water, Government of Western Australia, Perth. Available at: www.wa.gov.au/government/publications/hardy-inlet-water-quality-improvement-plan

Climate change in south-west WA

Lower river flow, higher temperatures and rising sea level are drivers of estuary health.

The south-west of WA has a Mediterranean climate pattern with cold, wet winters and warm, dry summers.

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

Changes in the key climate drivers in south-west WA are already evident and predicted to continue. The region has become warmer and drier.

The decline in rainfall in south-west WA has been greater than anywhere else in Australia, with a marked drying trend in autumn and early winter.[8] Since 2000, May to July rainfall in south-west WA has been about 27 per cent less than the long-term average.[9] There is strong evidence to suggest that rainfall in the region will decline further in the future.[8,10] Despite the drying trend, the intensity of heavy rainfall events will likely increase.[8] Two summer flow events linked to heavy rainfall occurred during the 2016–19 period.

Freshwater flows have also decreased dramatically, up to 70 per cent since the 1970s – a pattern which is expected to continue.[11]

Between 1910 and 2013, the average annual air temperature in south-west WA increased by 1.1°C.[9] By 2030, the average annual warming under potential emission scenarios is projected to range from 0.5 to 1.2°C above the 1986–2005 baseline.[10]

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[8] Department of Water and Environmental Regulation (2021) *Western Australian climate projections, Summary*, Government of Western Australia, Perth. Available at: www.wa.gov.au/government/publications/western-australian-climate-projections-summary

[9] Bureau of Meteorology (2022) *State of the Climate 2022, Australia's changing climate*, Bureau of Meteorology and CSIRO, Australian Government. Available at: www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

[10] Hope, P. et al. (2015) *Southern and south-western flatlands cluster report, Climate change in Australia projections for Australia's natural resource management regions: cluster reports*, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology, Australia. Available at: www.climatechangeinaustralia.gov.au/en/communication-resources/reports/

[11] Petrone, K et al. (2010) Streamflow decline in southwestern Australia, 1950–2008, *Geophysical Research Letters, Hydrology and land surface studies*, 37(11). Available at agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102

How will estuaries be affected?

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

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

Stratification patterns will change as low flows cannot fully flush estuarine waters in winter; rather, smaller freshwater flows sit as a layer above the saline bottom waters and may persist for longer periods of time. This can result in depleted oxygen (known as hypoxia) and the release of sediment-bound nutrients, which can fuel undesirable algal blooms (discussed in more detail later).

Nutrients from catchment inflows could become retained in the estuary rather than being flushed out to sea. This can lead to increased algae and low light conditions for seagrasses. The estuarine river reaches of many south-west WA estuaries (including the Blackwood River) already show these patterns of extended periods of low oxygen because of high nutrient and organic matter loading and persistent stratification.

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

The synergistic impact of these various stressors is difficult to predict, and recent studies show that these effects are happening at rates faster than those predicted by climate change models.[12]

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[12] Scanes E, Scanes PR & Ross PM (2020) *Climate change rapidly warms and acidifies Australian estuaries, Nature Communications* 11(1803). Available at www.nature.com/articles/s41467-020-15550-z

Rainfall

Rainfall has been declining in the Upper Blackwood and Lower Blackwood catchments since the beginning of the 20th century. Across the Blackwood catchment, rainfall in the period 2000–19 was about 13–26 per cent[13] lower than 1909–69 levels.

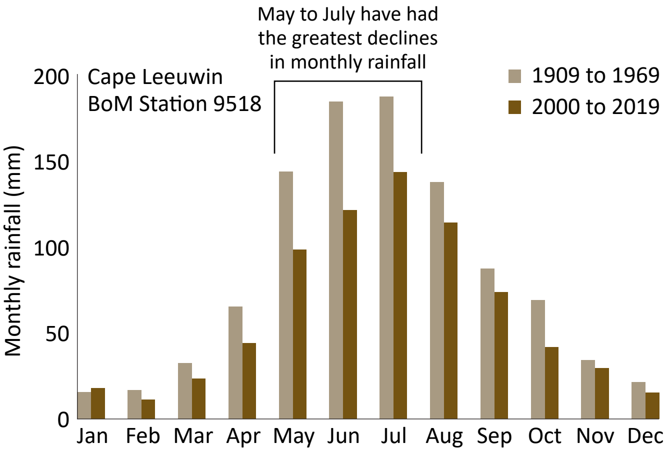
Rainfall data has not been collected for long enough in the Scott catchment to assess whether there has been a similar trend. Consistent with south-west WA as a whole, the greatest declines in rainfall in the Blackwood catchment have been in May to July. There has also been a shift in peak rainfall timing to later in winter.

In the Lower Blackwood catchment, 12 of the lowest 13 rainfall years on record have occurred since 2000. Within the monitoring period, annual rainfall varied significantly with the years 2016 and 2017 being relatively wet (856 mm and 866 mm, respectively) and the years 2018 and 2019 being relatively dry (736 mm and 694 mm, respectively).

Rainfall in the Scott and the Mid and Lower Blackwood catchments is higher than in the Upper Blackwood catchment. Rainfall in the Scott and Blackwood catchments is generally highest in the winter months; however, the Blackwood catchment experienced unusual summer rainfall events in 2016 (in the mid catchment) and 2017 (in the upper catchment). These summer events are discussed on page 40.

Key points:

- Rainfall in the Blackwood catchment decreased by 13–26 per cent in 2000–19 compared with 1909–69.
- The 2016–19 period has shown a continuation of this decline despite summer rainfall events.



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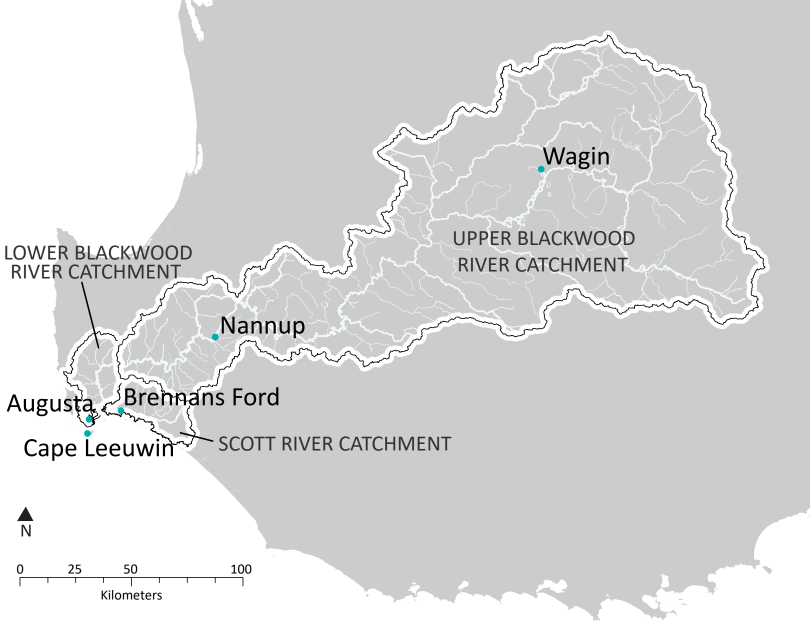
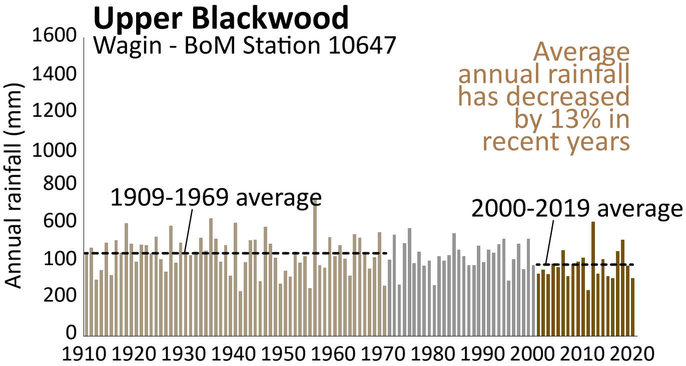
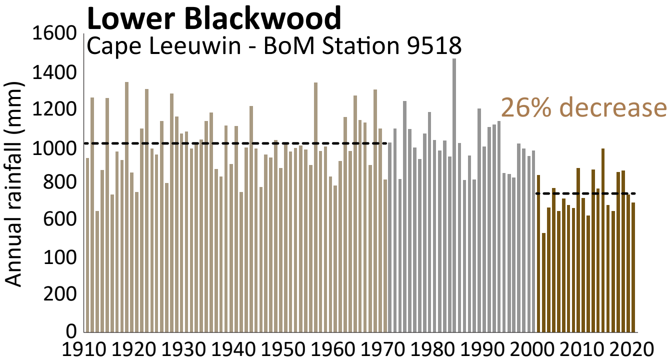
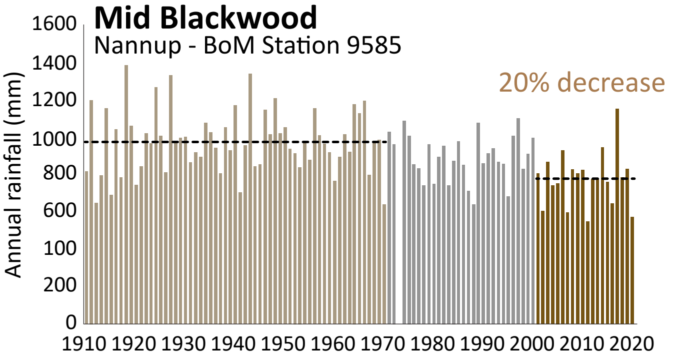
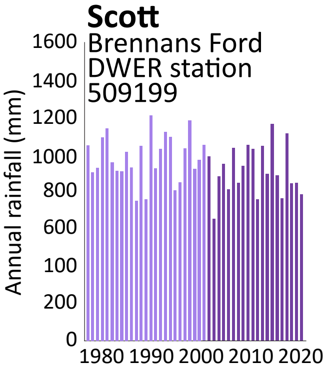
[13] This is the range of rainfall decreases from three representative rainfall stations across the Blackwood catchment


Wagin
UPPER BLACKWOOD RIVER CATCHMENT
LOWER BLACKWOOD RIVER CATCHMENT
Nannup
Augusta
Brennans Ford
Cape Leeuwin
SCOTT RIVER CATCHMENT
N
0
25
50
100
Kilometers


Upper Blackwood
Wagin - BoM Station 10647
Average annual rainfall has decreased by 13% in recent years
1909-1969 average
2000-2019 average
Annual rainfall (mm)
1600
1400
1200
1000
800
600
100
200
0
1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020


Lower Blackwood
Cape Leeuwin - BoM Station 9518
26% decrease
Annual rainfall (mm)
1600
1400
1200
1000
800
600
100
200
0
1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020


Mid Blackwood
Nannup - BoM Station 9585
20% decrease
Annual rainfall (mm)
1600
1400
1200
1000
800
600
100
200
0
1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

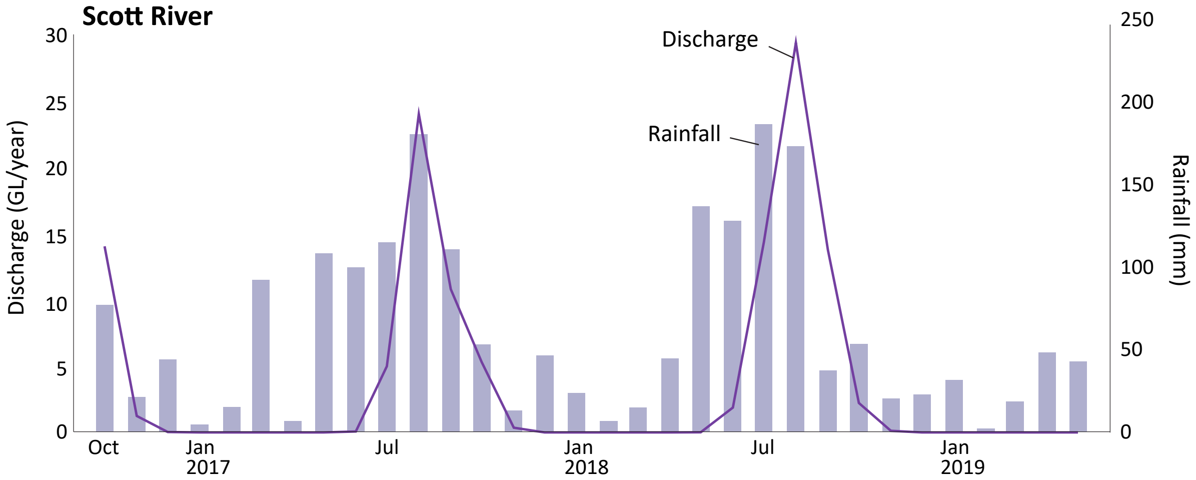

Scott
Brennans Ford DWER station 509199
Annual rainfall (mm)
1600
1400
1200
1000
800
600
100
200
0
1980 1990 2000 2010 2020

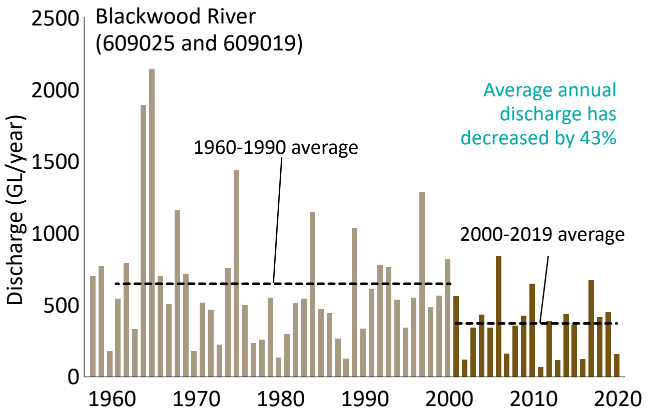
River flows

River flows are important for estuary condition because they directly influence the transport and concentration of nutrients and modify ecological processes. River flows (discharge) and rainfall generally follow a similar pattern; however, flows are also influenced by other factors. Peak river flow often occurs several months after winter rains start. In the Scott River, flow almost stops in the warmer months. The Blackwood River, however, flows year-round, with a strong groundwater component.

Key points:

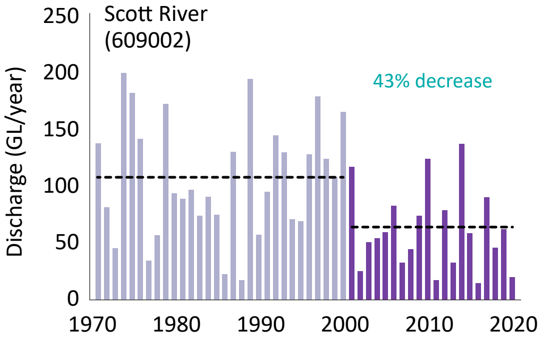
- ⇨ Flow in the Blackwood has declined by 43 per cent.
- ⇨ The decrease in flow is because of a combination of factors including rainfall, evaporation and water use.
- ⇨ The timing of flows has changed.





Average annual discharge has decreased by 43%

Note the different scales, the Scott typically contributes 14% of the flow to the Hardy Inlet, compared to 78% by the Blackwood



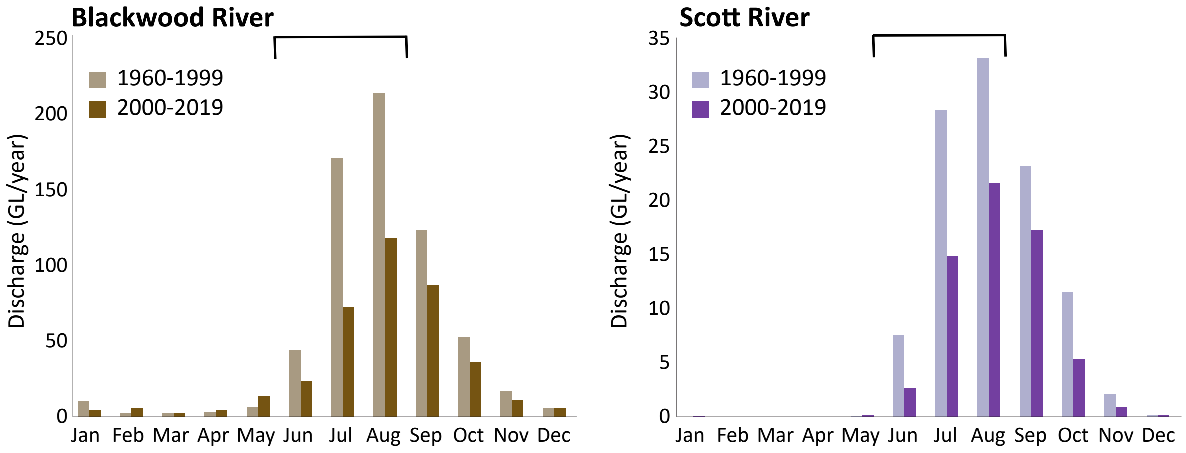
43% decrease

The average flow in the Blackwood declined by 43 per cent in the period 2000–19 compared with 1960–99. This is a greater decrease than the decrease in rainfall (11 per cent in Wagin, 15 per cent in Nannup and 28 per cent in Cape Leeuwin). Similarly, in the Scott River, there has been a disproportionate reduction in flow compared with rainfall.

The relationship between rainfall and flow is complex. Decreases in flow that were greater than decreases in rainfall have been observed throughout south-west WA.[14] Catchment runoff is influenced by both rainfall and evaporation rates. A series of dry years reduces soil moisture and groundwater levels and results in a disproportionate decrease in runoff and associated streamflow. This suggests a hydrological shift that will not be reversed without multiple years of above-average rainfall. In addition to these climate changes, flows to the Blackwood have also decreased because of capture in dams and extraction through bores. The decline in flow of the Scott River is not well understood and further investigation into surface water and groundwater interactions is needed.

The winter period (June to August) showed the greatest reduction in flow since 2000 in both the Scott and the Blackwood. In the Blackwood, there has been an increase in average flows in February because of summer rainfall events. These summer flow events are discussed later in the report.

June to August have had the greatest declines in monthly flow



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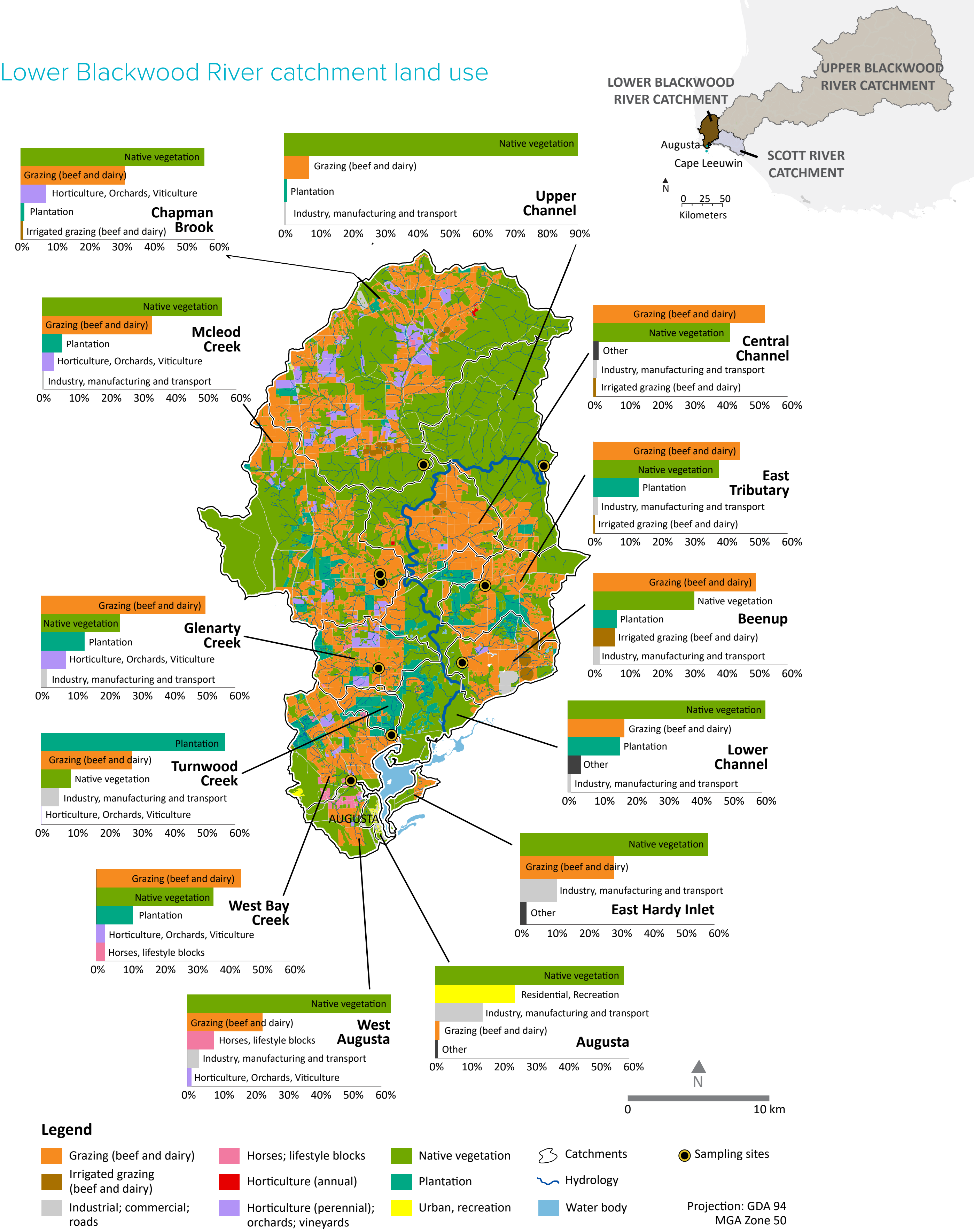
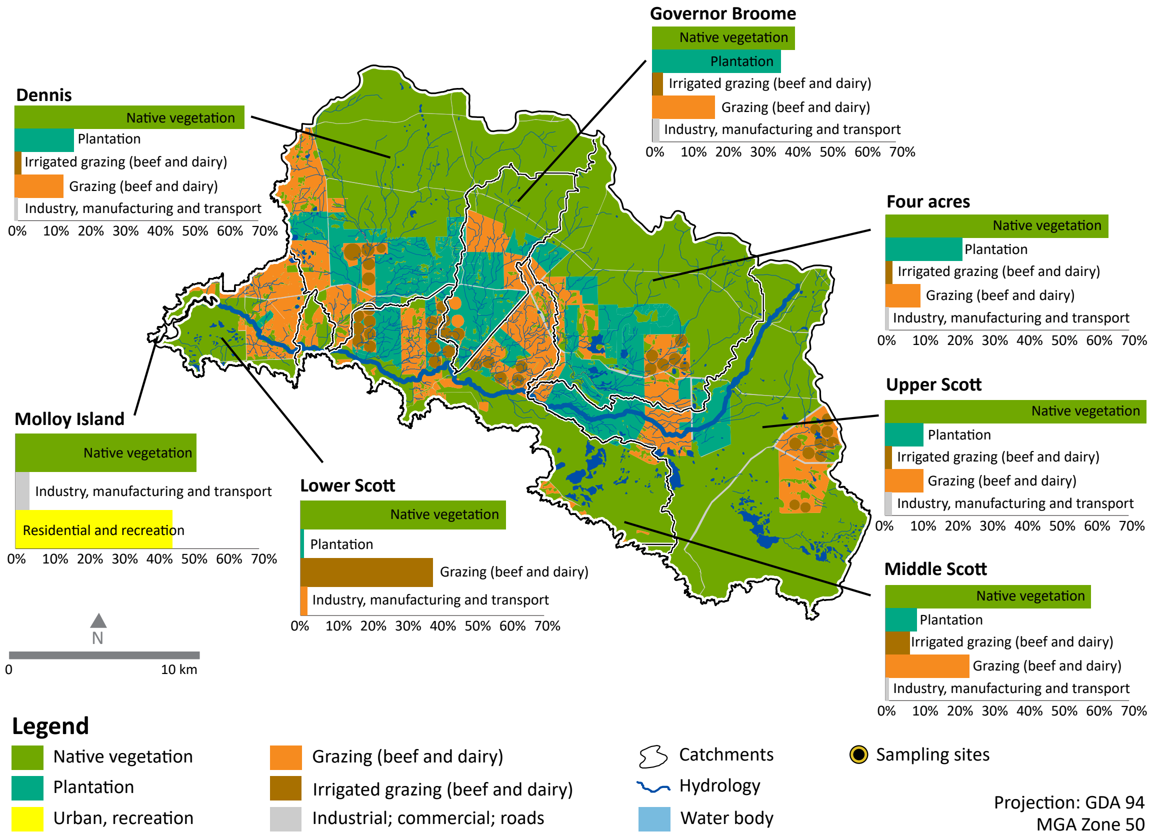
[14] Petrone, K et al. (2010) Streamflow decline in southwestern Australia, 1950–2008, *Geophysical Research Letters, Hydrology and land surface studies*, 37(11). Available at agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102

Catchment land use

Lower Blackwood River catchment land use



Scott River catchment land use



The Blackwood River and Scott River converge around Molloy Island and flow into the Hardy Inlet basin. The greater Blackwood catchment is the second largest in south-west WA and comprises the Upper Blackwood catchment (21,148 km^2) and Lower Blackwood catchment (669 km^2). The Scott River catchment is much smaller (670 km^2) but, despite this, it contributes about 14 per cent of the flow to the Hardy Inlet because of its higher rainfall.

Different land use types vary in the amount of nitrogen and phosphorus they export to receiving waters such as estuaries.

Native vegetation exports the least. Beef and dairy farms tend to have among the highest export of nutrients, which reflects the amount of nutrients applied as well as the total area for this land use. Urban garden fertiliser use, septic tanks and wastewater treatment plant discharges also contribute nutrients. Land use mapping and knowledge of the nutrient sources within the catchment help us to identify areas that currently contribute nutrients to the estuary – or may in the future. This information is used to help guide investment in reducing nutrient loss from large, diverse catchments.

Catchment nutrient sources

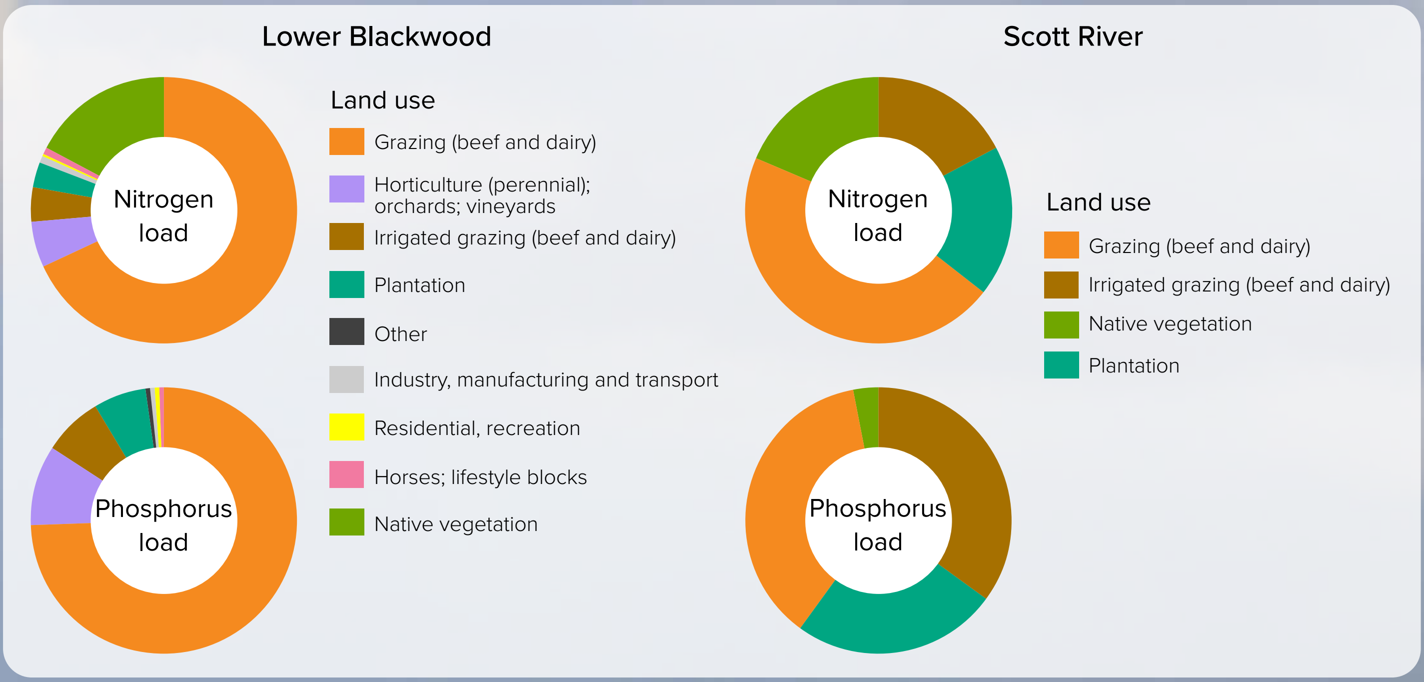
We used catchment modelling to understand the sources of nutrients in the Lower Blackwood catchment. About 30 per cent of the Lower Blackwood catchment has been cleared for beef and dairy grazing. These land uses contribute the most nutrients, accounting for more than 80 per cent of phosphorus and more than 70 per cent of nitrogen. Additional diffuse nutrients are also derived from horticulture, viticulture and plantations. Land use varies between subcatchments, which has flow-on effects on water quality. For instance, more than 50 per cent of the Beenup and Glenarty Creek subcatchments are used for beef and dairy farming, while plantations are largely dominant in the Turnwood Creek subcatchment.

Water quality from the Upper Blackwood catchment is monitored at Hut Pool. The catchment (not shown on land use maps) is very large and 81 per cent of its land has been cleared for agriculture. The catchment extends into the Wheatbelt; hence, the main land use is cropping.

In the Scott River catchment, about 20 per cent of the land has been cleared for beef and dairy farming and 15 per cent for plantations. Modelling highlighted that, like the Lower Blackwood catchment, beef and dairy grazing contributed the largest proportion of nutrients (more than 70 per cent of the phosphorus and more than 60 per cent of the nitrogen). Plantations were also a major source of nutrients, contributing almost 20 per cent of the nitrogen load. Relative nutrient contributions also varied between subcatchments.

Soils vary in their capacity to bind phosphorus. In south-west WA, areas on the coastal plains with grey sands tend to have poor phosphorus-binding capacity. Phosphorus applied as fertiliser to these soils can move relatively quickly to drains, streams and groundwater. Sustainable farming in south-west WA includes improving soil structure, which will help reduce nutrient losses (mostly phosphorus) from farmland.

Much of the Scott catchment lies on the Scott Coastal Plain which has soils of very low phosphorus-binding capacity compared with the heavier soils of most of the Lower Blackwood catchment. The extensive network of drains in the Scott catchment, and runoff from water-logged areas, are also significant pathways for the transport of phosphorus to waterways. These factors, combined with intensive agriculture, are the main reasons why the Scott contributed about 45–60 per cent of the phosphorus load to the Hardy Inlet in 2016–19, even though it comprises only 3 per cent of the catchment area, and 10–12 per cent of the flow.


Lower Blackwood
Nitrogen load
Phosphorus load
Land use
🟧 Grazing (beef and dairy)
🟪 Horticulture (perennial); orchards; vineyards
🟫 Irrigated grazing (beef and dairy)
🟩 Plantation
⬛ Other
⬜ Industry, manufacturing and transport
🟨 Residential, recreation
🟥 Horses; lifestyle blocks
🟩 Native vegetation
Scott River
Nitrogen load
Phosphorus load
Land use
🟧 Grazing (beef and dairy)
🟫 Irrigated grazing (beef and dairy)
🟩 Native vegetation
🟩 Plantation

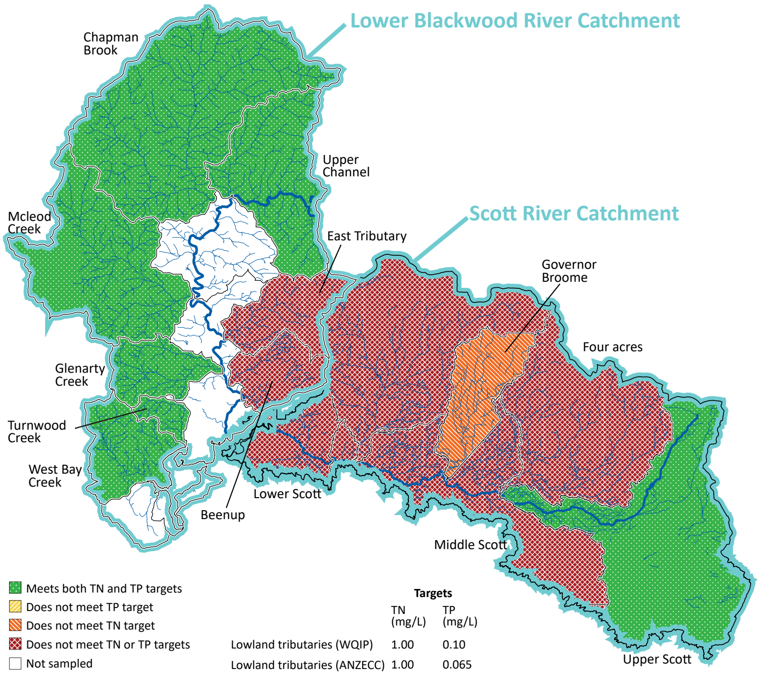
Catchment nutrient concentrations

During the 2016–19 monitoring period, nutrient concentrations in surface water samples were measured fortnightly, mid-channel, in one or more waterways of each subcatchment of the Lower Blackwood and Scott catchments.

In the Scott catchment, winter median nutrient concentrations were compared with the Scott River catchment WQIP targets for total nitrogen concentration (TN, 1.0 mg/L) and total phosphorus concentration (TP, 0.1 mg/L). In the Blackwood catchment, concentrations were compared with the Australian and New Zealand (ANZECC) guidelines for South West lowland rivers[15] (TN, 1.2 mg/L; TP, 0.065 mg/L).

Nutrient concentrations in the Lower Blackwood subcatchments were generally lower than those in the Scott catchment. Phosphorus and nitrogen winter median concentrations were below guideline values in all Lower Blackwood subcatchments, except Beenup and East Tributary. These two subcatchments lie on the sandy soils of the Scott Coastal Plain, which are poor at holding nutrients. The other Lower Blackwood subcatchments lie on the clay rich soils of the Leeuwin Naturaliste Ridge which hold nutrients more readily. Beenup and East Tributary also contain grazing and dryland dairy, and Beenup has irrigated dairy – all land uses associated with high nutrient exports. High proportions of nitrates and phosphates indicate most of the nutrients are likely derived from fertiliser and animal waste.

Winter median compared to targets



In the Scott River, phosphorus concentrations have increased in most subcatchments since the WQIP was published, with the largest increases at Dennis and Four Acres. The 2016–19 winter median total phosphorus concentrations exceeded the target in all Scott subcatchments, except the Upper Scott and Governor Broome. For nitrogen, winter median concentrations were above the target in all subcatchments, except the Upper Scott. The Upper Scott catchment was the only one below the WQIP target for both total phosphorus and total nitrogen, likely because there is mostly native vegetation upstream of the site.

The S-Bend site, in the Four Acres subcatchment, had the highest nutrient concentrations by far, with its 2016–19 winter total phosphorus (1.79 mg/L) and total nitrogen (5.70 mg/L) medians far exceeding their respective 0.1 mg/L (TP) and 1.0 mg/L (TN) WQIP targets. As well as the very high winter concentrations at S-Bend, concentrations were even higher in samples taken during the drier part of the year, for both total nutrients and phosphate and ammonia. These very high concentrations, and the presence of *Escherichia coli* (a bacteria found in mammal faeces) at levels

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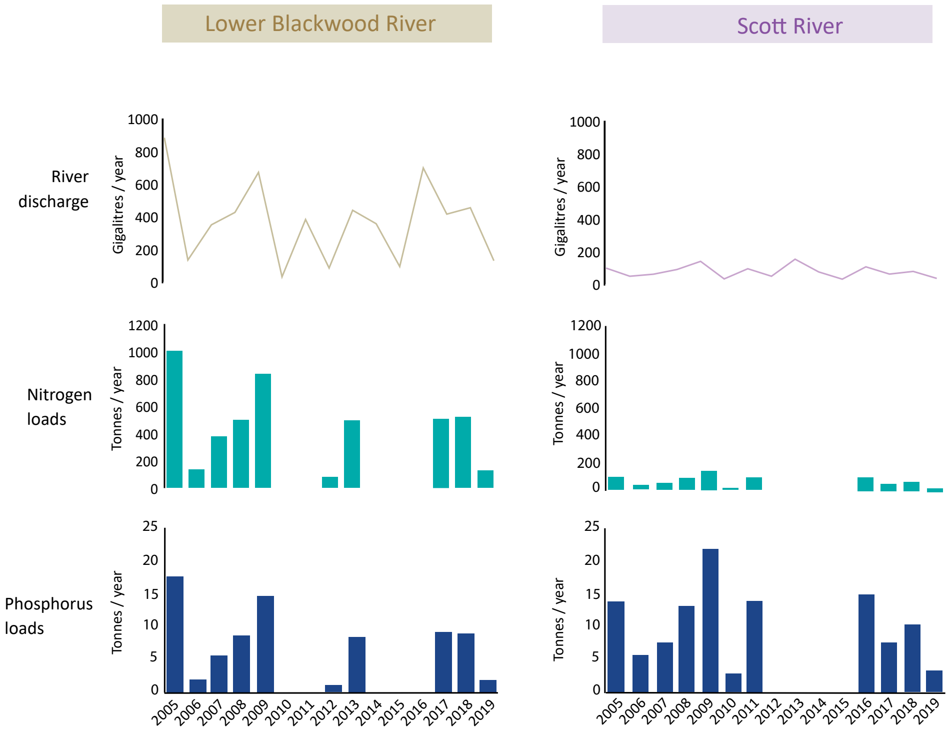
[15] ANZECC & ARMCANZ (2000) Australia and New Zealand Guidelines for fresh and marine water quality, Vol. 1, The Guidelines, Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand. Available at: www.waterquality.gov.au/anz-guidelines/resources/previous-guidelines/anzecc-armcanz-2000

up to 25 times the ANZECC recreational guidelines, suggests that dairy effluent and irrigation runoff from upstream is contributing significant amounts of nutrients at this site. Upstream of S-Bend, there is a dairy shed, dryland and irrigated dairy and bluegum plantations.

Detailed catchment water quality monitoring results are available on the Healthy Estuaries WA website: estuaries.dwer.wa.gov.au/nutrient-reports

Flows and loads to the estuary



The total amount (or load) of nutrients entering the estuary is estimated by multiplying the nutrient concentration by the flow volume (discharge). Therefore, annual nutrient loads follow the same pattern as annual river flows. Given this fluctuation, changes in nutrient concentrations are a more useful measure of nutrients coming from the catchment.

In 2017–19, flow and nutrient loads were within the range recorded in 2004–13. The year 2019 was particularly dry and nutrient loads were lower than in wetter years like 2017 and 2018. For example, the total nitrogen load in 2019 was 27 per cent of the load recorded in 2017 and 51 per cent of the 2018 load. The total phosphorus load in 2019 was 29 per cent of that recorded in 2017 and 26 per cent of the 2018 load.

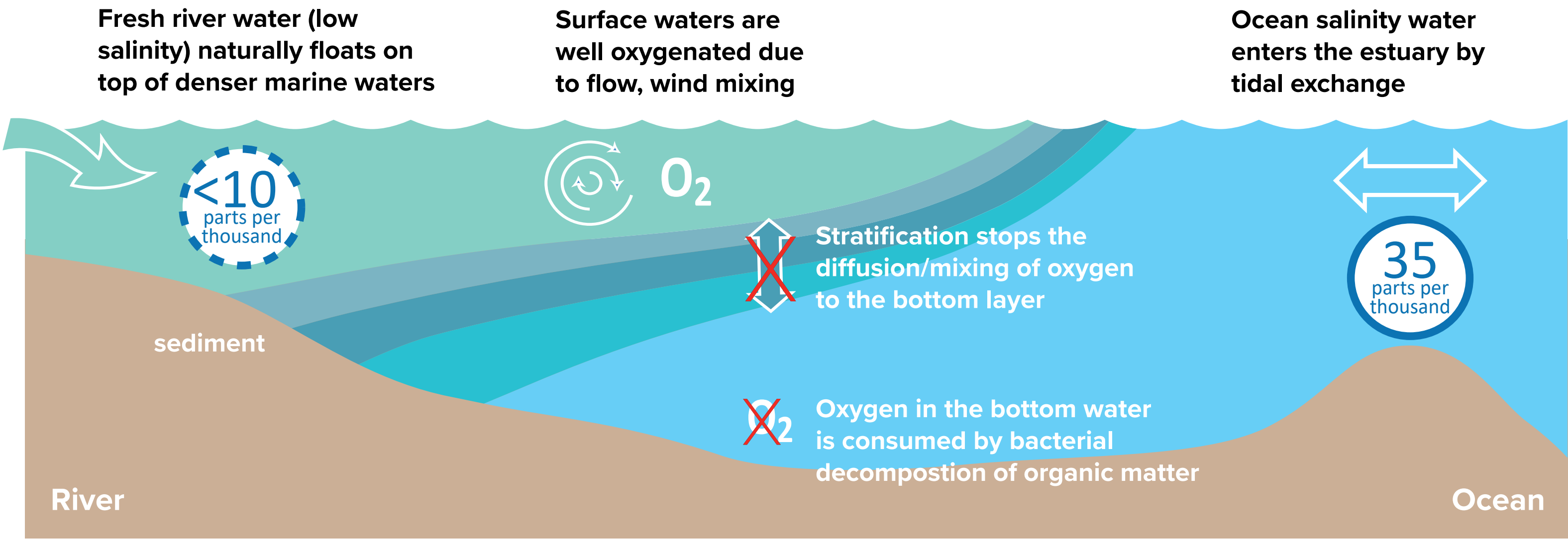
While low flows caused by a drying climate may seem potentially good for estuaries because they can result in smaller nutrient loads, the issue is more complex. For example, a change in the timing of rainfall can increase nutrients in spring when algal blooms are more likely to occur. In the Hardy Inlet, the distribution of loads is also particularly important. In low flow years, the delivered nutrient load may be deposited in the riverine portions of the estuary instead of being flushed to the ocean. Despite the flow from the Blackwood River being consistently larger than the Scott River, the Scott River had the largest phosphorus loads in almost all years because of the very high phosphorus concentrations.

A salt-wedge estuary

The Hardy Inlet is a salt wedge estuary. For much of the year, tidal flows are stronger than river flows, pushing marine water up the Scott and Blackwood rivers. The fresh river water sits above the salty sea water as marine waters are denser than the fresher river flows. This phenomenon is known as stratification. Stratification varies within the estuary depending upon flow, tide and distance from the ocean. It can change seasonally, and even daily and the degree of stratification differs in different areas across the estuary.

One of the greatest impacts of stratification is a reduction of oxygen in the salty bottom waters. Oxygen is unable to mix into these bottom layers, and oxygen is additionally used by the decomposition of organic matter such as algal blooms. Low dissolved oxygen is unhealthy for aquatic animals. Concentrations below 4.8 milligrams per litre (mg/L) are stressful to fish and below 2 mg/L can be deadly. Low oxygen in the bottom waters can also lead to sediments releasing nutrients, which can fuel algal blooms.

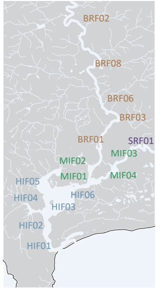
In the Hardy Blackwood system, 42 km of the Blackwood River and the area around Molloy Island, are affected by stratification throughout most of the year.



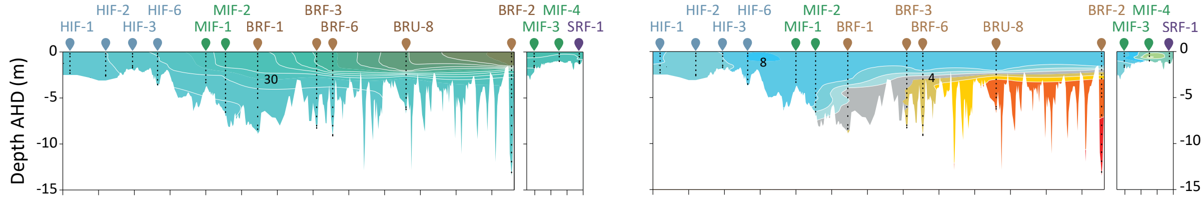
Salinity and dissolved oxygen through the seasons

These contour plots represent typical conditions throughout the seasons. In summer and autumn there is very little flow from the Blackwood River and no or very little flow from the Scott. The Hardy Inlet basin is mostly marine and there is low dissolved oxygen in the deeper waters of the Blackwood. In early winter and spring there is increased stratification with increased river flow, and low dissolved oxygen extends to the waters surrounding Molloy Island. During years with strong winter flows, full mixing occurs throughout the water column and dissolved oxygen is at healthy levels throughout. This may only last for one or two months. In low rainfall years (e.g. 2019), such flushing may not occur.

Fortnightly contour plots of salinity, oxygen and temperature are available on the Healthy Estuaries WA website: estuaries.dwer.wa.gov.au/hardy-profiles



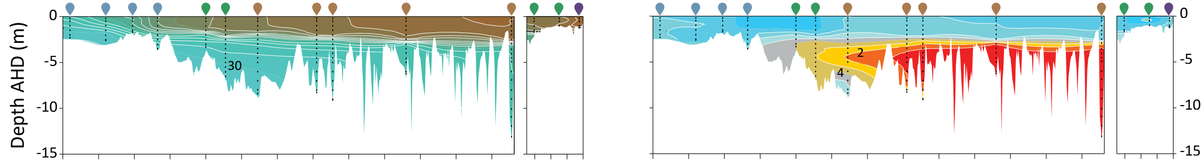
Summer and Autumn (low flow)



Little flow from the Blackwood and none from the Scott Marine water up to Molloy Island, and quite salty as far as Alexandra Bridge Salty near the Scott

Very low dissolved oxygen in deeper waters of the Blackwood Healthy dissolved oxygen in surface waters. In this example the high dissolved oxygen near the Scott River indicates an algal bloom

Early Winter and Spring (moderate flow)

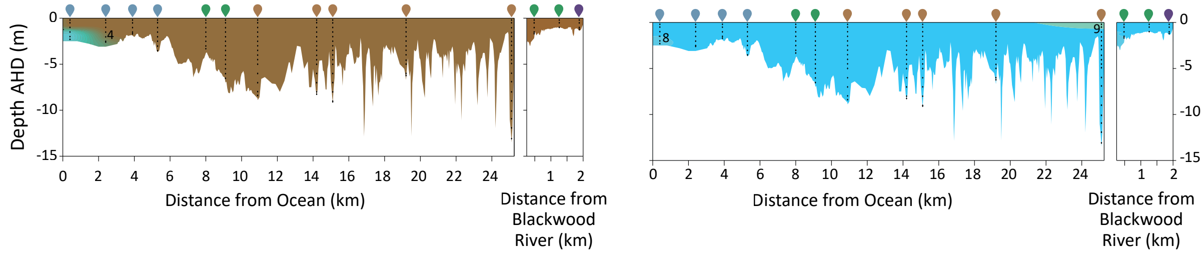


Blackwood and Scott rivers flowing - fresh water in the Scott, surface waters of the Blackwood and around Molloy Island Salty bottom waters in the Blackwood River and around Molloy Island Marine water near the mouth of the estuary

Very low dissolved oxygen in deeper waters of the Blackwood Low dissolved oxygen in deeper waters around Molloy Healthy dissolved oxygen in surface waters

Winter (peak flows)

Note this non-stratified period may only last one (2017) or two months (2018) depending on flow



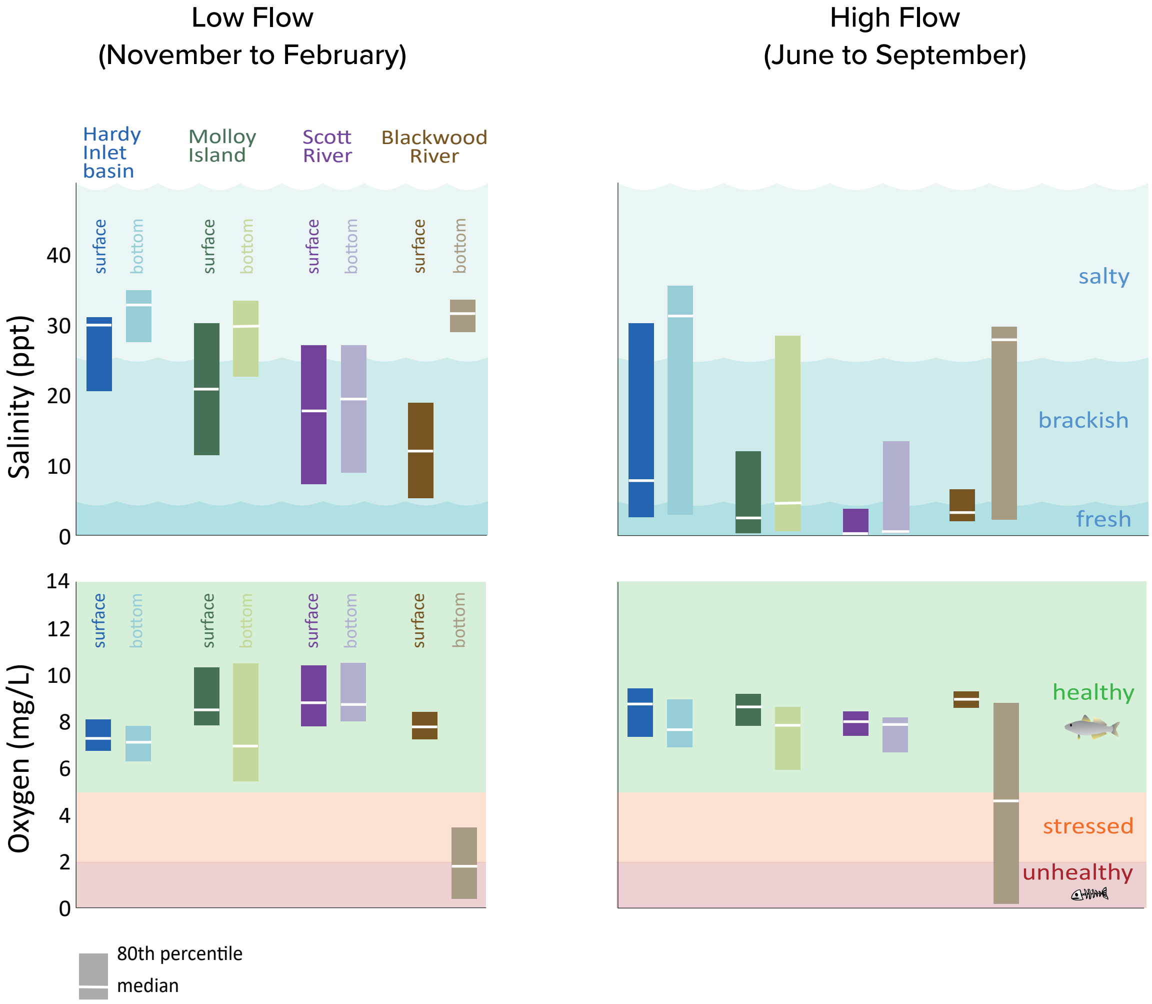
Rivers flowing Fresh water throughout estuary except near estuary mouth (where tide enters)

No stratification caused by salinity so healthy dissolved oxygen throughout the entire estuary

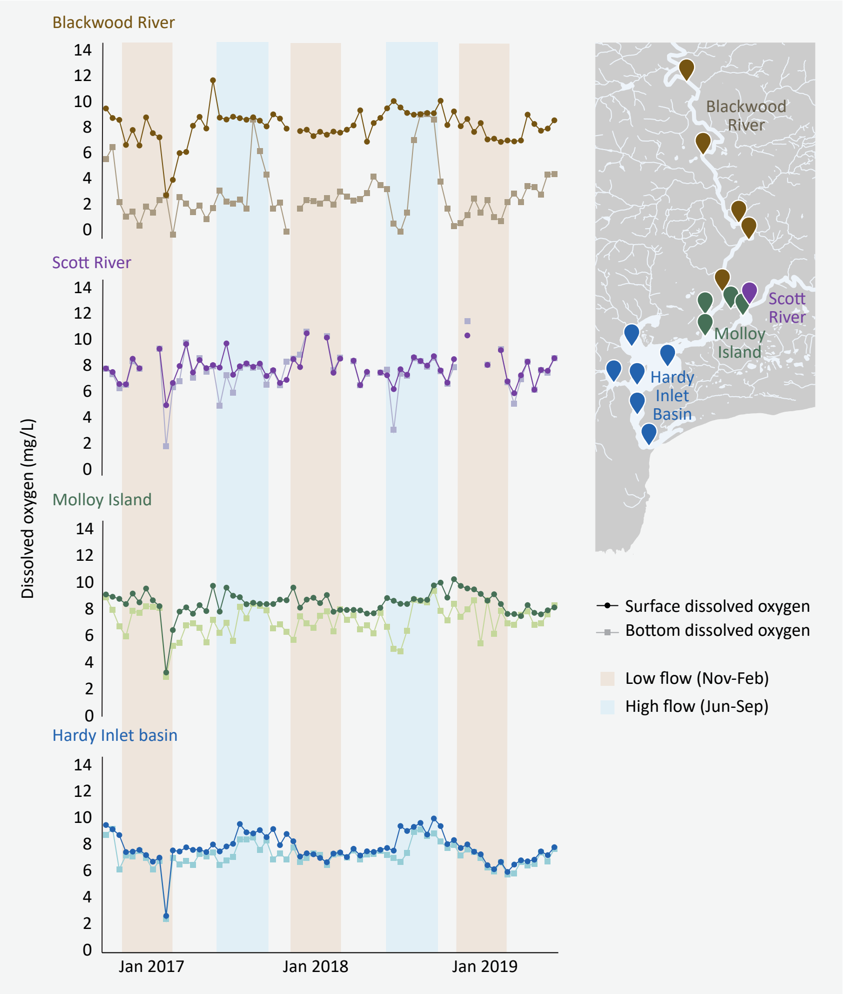
Salinity and dissolved oxygen across the system

The averages of salinity and dissolved oxygen in the Hardy Inlet show that salinity decreases with the distance from the mouth, and bottom waters are more saline than surface waters. On average, dissolved oxygen levels across the system are healthy, except in the bottom waters of the Blackwood River. For much of the year, the surface and bottom waters of the Blackwood are highly salinity stratified and the dissolved oxygen levels are very low in the bottom waters.

Stratification varies across the system and is strongest in the deeper waters. Despite stratification, the surface waters across the entire system had healthy dissolved oxygen levels between 2016 and 2019, except during the February 2017 flow event, when the entire system was low in dissolved oxygen (see page 40). The Hardy Inlet basin and the shallower waters of the Scott River and around Molloy Island were generally well mixed, with healthy dissolved oxygen. However, stratification often contributed to very low dissolved oxygen in the Blackwood River and deeper areas around Molloy Island.



The Molloy Island averages above do not represent the full story, as very high dissolved oxygen waters in the bottom waters of the shallower sites (e.g. at site MIF04 to the west, about 1.5 m deep) were moderated by low dissolved oxygen in the bottom waters of the deeper sites (e.g. at site MIF02 to the east of Molloy Island, about 6 m deep). The high values at MIF04 during the low flow period (average 10.6 mg/L) were because of macroalgal and cyanobacterial blooms, while the lower values at MIF02 (5.2 mg/L) resulted from stratification.



Blackwood River

Salinity stratification in the deeper waters of the river meant bottom waters were low in oxygen much of the time. Bottom waters only had healthy oxygen levels during times of peak flow.

Scott River

As the Scott River is shallow, oxygen could reach the bottom waters much of the time. Low oxygen water which flowed down the Blackwood River during the 2017 summer flow event moved up into the Scott River.

Molloy Island

Salinity stratification in the deeper water of the channels led to lower oxygen in the bottom waters. Oxygen was low in surface and bottom waters during the summer flow event in February 2017.

Hardy Inlet basin

The shallow waters of the inlet are well-oxygenated and well-flushed by the tides. The rainfall event in February 2017 pushed low oxygen water from the upper Blackwood out to sea.

In the estuary:

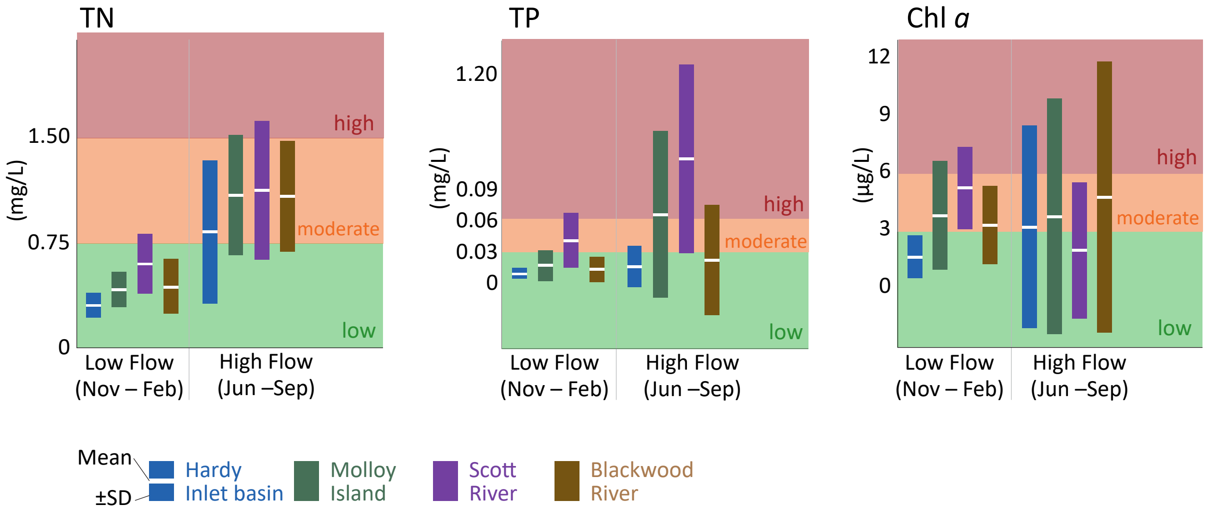
nutrient and chlorophyll concentrations

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

As discussed earlier, catchment inflows are the principal source of nutrients to most estuaries. Where there is persistent stratification and organic matter, sediments can also be a source of dissolved nutrients. By measuring the seasonal pattern of nutrient concentrations in surface and bottom water samples, we can infer whether these nutrients are likely to have come from catchment inflows, bottom sediments or a combination of both. An estuary's first response to higher nutrient concentrations is usually increased microalgal activity. We monitor this by measuring the concentration of chlorophyll *a*, a plant pigment, in water.

Spatial and seasonal patterns

Nutrient concentrations vary spatially and seasonally. Nutrients accumulate in the shallow sediments behind Molloy Island where water from the Scott River slows down because of restriction by the narrow channels on either side of the island. In the deeper areas of the Blackwood and around Molloy Island, stratification and low oxygen leads to sediment nutrient release. The waters of the Hardy Inlet basin are mostly well-mixed and are flushed with the tide. However, even in this region, excess nutrients can lead to algal blooms.



Nitrogen was higher during high flow periods compared with low flow periods. Nitrogen was lowest in the shallow Hardy Inlet basin, a result of mixing with low-nutrient marine waters. In the Scott River, nitrogen was elevated despite the river barely flowing between December and June. This suggests that the sediments are a source of nutrients in the Scott River during low flow periods.

At all sites, total nitrogen concentrations were much higher during the high flow periods than during low flow periods. This is because rains washed nutrients into the rivers. Even during high flow periods, there is a marine influence in the Hardy Inlet basin, which is reflected by its lower average total nitrogen concentration compared with the other areas.

Similarly, **phosphorus** concentrations were generally higher in the high flow period. Total phosphorus in the Hardy Inlet basin was low in both flow periods because of the strong tidal influence. The Scott River, however, showed elevated phosphorus concentrations even in the low flow period, commonly higher than recommended guidelines.

In the high flow periods, the Scott River had excessively high total phosphorus concentrations. The average value (0.116 mg/L) was nearly four times the ANZECC guideline value (0.03 mg/L), three times the Blackwood average concentration, and eight times that in the Hardy Inlet basin. Phosphorus concentrations at the Molloy Island sites were also very high, with the average (mean) double the guideline value. The sandy soils of the heavily cleared Scott catchment allow phosphorus from fertilisers and dairy effluent to run off and enter the river. Soluble phosphate, an indicator of these sources, was often extremely high in the Scott River.

Chlorophyll *a* concentrations showed a similar pattern to that of the nutrients across the four regions in the low flow periods, which coincide with warm temperatures and sunshine. Chlorophyll *a* levels were highest in the Scott River and around Molloy Island.

During high flow periods, colder temperatures and fast-flowing water mean dense patches of microalgae are less likely to occur. However, dense aggregations of microalgae can occur in early winter when rains have started – but before the rivers are fully flowing – and the waters may be stratified. These different conditions explain the highly variable range in Chlorophyll *a* observed across all sites in the high flow period.

Comparison with historical data

Before the Regional Estuaries Initiative, water quality monitoring was inconsistent and did not always occur throughout the entire year for the Hardy Inlet. The five years where monitoring did occur year-round (since 2000) are compared with the 2016–19 period, for 12 of the 16 currently monitored sites.

Nitrogen concentrations were generally similar to historical values. Total nitrogen was higher in the Blackwood River, Molloy Island and Hardy Inlet in the 2016–17 hydrologic year (October to September) than in other years, because of a summer flow event (discussed on page 40 in more detail) which brought nitrogen-rich organic matter down the Blackwood River. The following two years (2018–19) had similar or lower levels of total nitrogen than the previously sampled years.

Average total phosphorus in the Blackwood River was low in 2016–18 but increased in 2018–19. The increase was primarily because of four instances of bottom release of phosphorus from sediments observed at the deep site BRF02, between June and September 2019. On these occasions, phosphorus levels spiked to 12–34 times more than normal levels. In most winters, stratification was disrupted by flow, but in 2019 this did not occur because of very low rainfall.

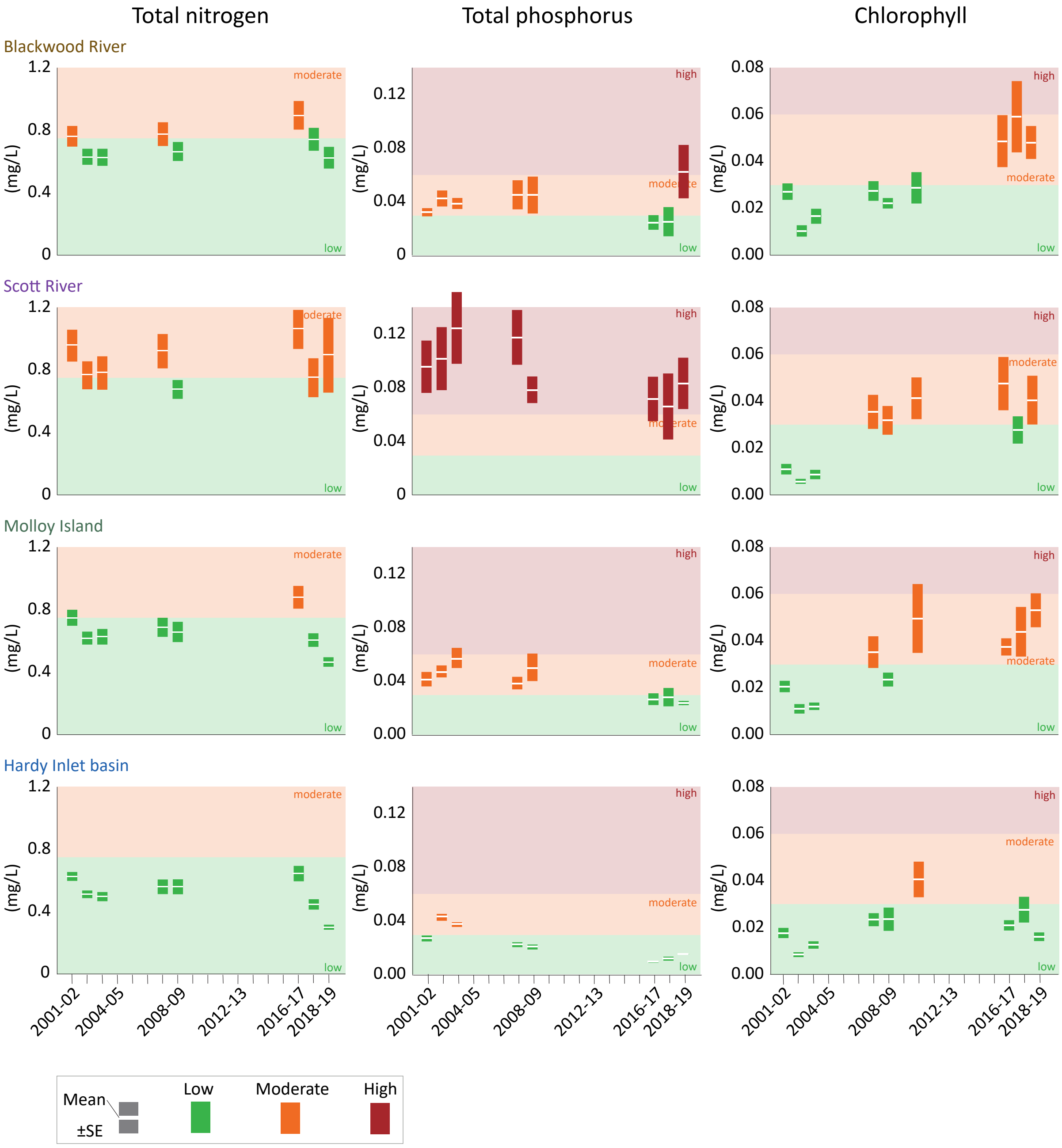
In the Scott River, average total phosphorus appears to have decreased in recent years but remains at very high levels. Average total phosphorus around Molloy Island has dropped from moderate to low levels and has also improved in the Hardy Inlet.

Low concentrations of both nitrogen and phosphorus observed in the Hardy Inlet basin in 2017–19, may indicate a greater marine influence in the basin compared with historical data. This may be because of a combination of lower rainfall, rising sea level and increased marine exchange following the dredging of the new mouth.

In the Blackwood River, average chlorophyll levels increased in the 2016–19 period compared with the previous years. These increases are because of very high peaks in densities of microalgae in May 2017 and in May and July 2018, along with high peaks in July and August 2019.

Both the Scott River and Molloy Island showed a large increase in average chlorophyll levels after 2007 compared with the 2001–04 period. This coincided with increases in phosphorus at Brennans Ford (in the lower Scott River) and a likely increase in nutrient-rich sediments in the Scott-Molloy area. Chlorophyll levels were slightly lower in 2017–18 in the Scott, but still much higher than those in the early 2000s.

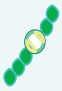
In the Hardy Inlet basin, average chlorophyll levels were low in all sampled years, except 2010–11. The average that year was raised by a diatom bloom in June 2011.


Total nitrogen
Total phosphorus
Chlorophyll
Blackwood River
Scott River
Molloy Island
Hardy Inlet basin
(mg/L)
1.2
0.8
0.4
0
0.12
0.08
0.04
0.00
0.06
0.02
high
moderate
low
2001-02
2004-05
2008-09
2012-13
2016-17
2018-19
Mean
±SE
Low
Moderate
High

Phytoplankton groups

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

Cryptophytes 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.



Cyanophytes, also known as cyanobacteria, are primitive, single-celled organisms that are often blue-green in colour. Cyanobacteria indicate poor water quality when abundant. They can form nuisance blooms and some are toxic. In the Hardy Inlet they include *Oscillatoria, Trichodesmium, Merismopedia,* and *Lyngbya*-like species.

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

Dinophytes use their flagella to move through the water column, and many are also mixotrophic — meaning they can photosynthesise and/or ingest prey for growth. They are nuisance species worldwide and are sometimes toxic.

Raphidophytes are marine and freshwater species, their cells tend to be large with two flagella. *Heterosigma akashiwo* is the most notorious of this group, it can form toxic algal blooms.

Microalgae dynamics

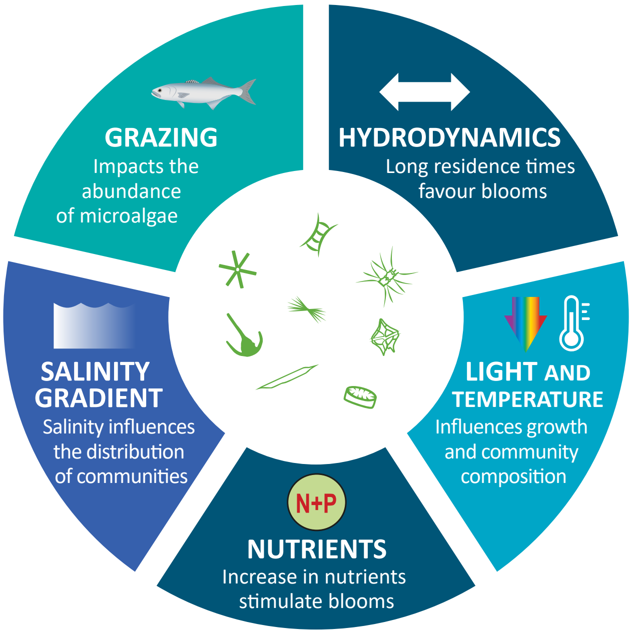
Microalgae, also known as phytoplankton, are tiny photosynthetic organisms which play a huge role in removing carbon dioxide from the atmosphere and generating the oxygen we breathe. As key components of healthy ecosystems, they provide food for invertebrates and fish. During the day, they photosynthesise, which oxygenates the water. However, excessive nutrients, warmer water temperatures and reduced water movement can lead to a rapid increase in the cell numbers of microalgae, promoting the occurrence of blooms. These blooms can be detrimental to aquatic ecosystems because they can:

- clog fish gills
- reduce light availability to seagrasses
- rapidly remove oxygen from the water when they decompose, causing fauna deaths.

Certain species can also produce toxins, which can be harmful to fauna such as fish, crabs and dolphins, as well as to humans.

Chlorophyll *a*, as mentioned, is a universal indicator of microalgal activity. However, to further understand microalgal dynamics in estuaries, we identify and assess the density of each type of microalgae. Like studying plant communities on land, we investigate whether there is a community of desirable and diverse species, or whether it is dominated by undesirable algae, comparable with weeds. This can tell us whether the microalgal community composition is healthy or unhealthy.

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

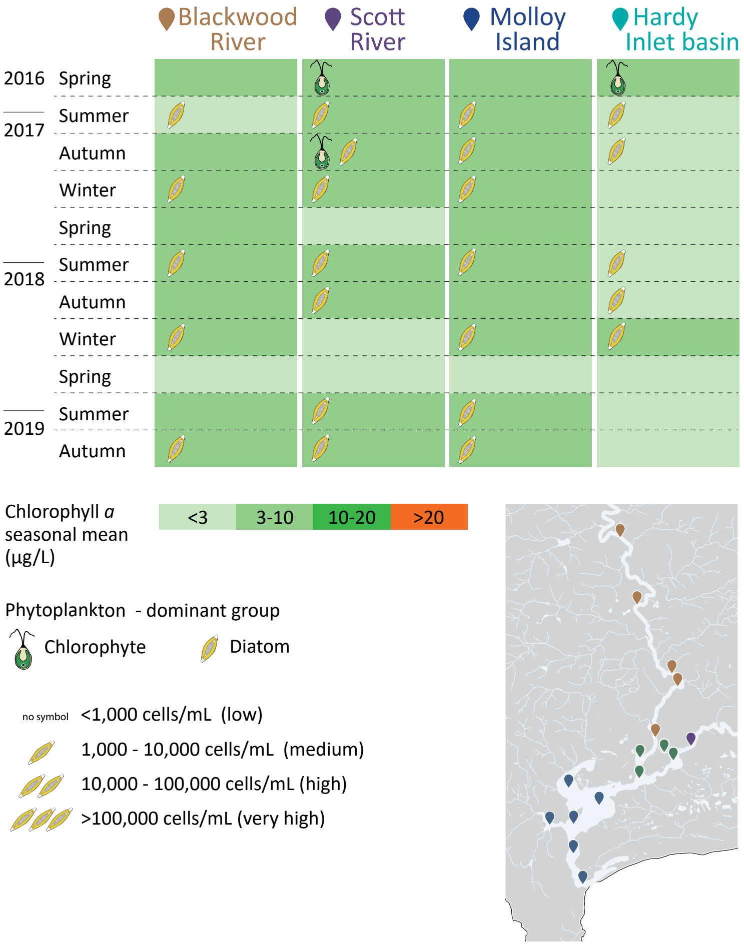


Microalgae:

seasonal and spatial patterns

Key points:

- ⇨ Diatoms were the most abundant group.
- ⇨ High densities of several non-harmful species occurred.
- ⇨ The highest densities occurred in early winter and autumn, when nutrients were high, but before peak flows.



The highest microalgal activity in the Hardy Inlet (2016–19) occurred in March and June 2017 and July and December 2018. Diatoms were the most abundant group, (67 per cent of the total cell count) followed by cryptophytes (10 per cent), then chlorophytes and dinoflagellates (both at 7 per cent).

The only significant microalgal bloom during 2016–19 was that of *Lyngbya*-like species observed during the summer of 2018–19 (see next section). Although high densities of other microalgae were measured, they were below levels of concern.[16] Even so, densities were sufficient at times to cause murky waters, reducing the amenity for humans and altering habitat for flora and fauna.

The Blackwood River and Molloy Island areas had elevated densities of non-harmful marine diatoms *Nitzschia* spp. (22,000 cells/mL in June 2017) and *Cyclotella* spp. (14,000 cells/mL in July 2018). Although cell counts were below levels of concern,[16] chlorophyll concentrations greatly exceeded ANZECC guidelines at these times. Interestingly, during July 2018, densities of *Cyclotella* were very low in the fresher waters of the Scott River and two eastern Molloy Island sites.

The *Nitzschia* spp. found in the Blackwood River and around Molloy Island in June 2017 also extended up to the Scott River (20,000 cells per mL). In February 2017, elevated densities (10,000 cells/mL) of the non-harmful diatoms *Skeletonema* spp. occurred.

Hardy Inlet basin generally had low to medium densities of microalgae. Elevated densities of the non-harmful diatom *Chaetoceros* spp. were observed in the Hardy Inlet basin in March 2017 (9,000 cells/mL) and 2018 (8,000 cells/mL), and December 2017 (14,000 cells/mL). The increased microalgal activity was focused in West Bay. The fine sediments in West Bay have high nutrient concentrations which likely contribute to the higher microalgal concentrations and often murky appearance of the water. In July 2018, *Cyclotella* extended from Alexandra Bridge down to the upstream end of the Hardy Inlet basin, and out to West Bay.

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[16] Interim ecological trigger levels determined by the department's Phytoplankton Ecology Unit

Close up of *Trichodesmium*, 'sea sawdust', on surface of water

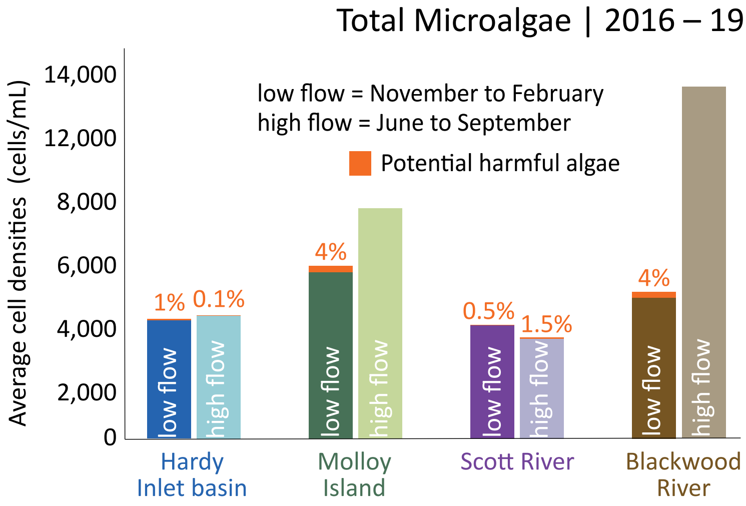
Potentially harmful microalgae

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

To assess the occurrence of potentially harmful microalgae, we compare our data against the department's interim ecological trigger values, which were derived from international and national guidelines, where available, and expert local knowledge.

In the Blackwood River and around Molloy Island, abundances of microalgae were generally higher in the high flow period than in the low flow period. In the Scott River, the opposite was true, with slightly higher abundances in the low flow period. In the Hardy Inlet basin, abundances were similar in both low and high flow periods. The proportions of potential harmful microalgae were low overall, with the highest around Molloy Island and the Blackwood River in low flow months.

The total number of potentially harmful microalgal species identified in the 2016–19 period was 23, with trigger values exceeded 18 times. These exceedances were most common in May, November and December, and recorded at Molloy Island and the Blackwood River. Five potentially harmful species exceeded triggers during the period. These included four dinophytes (*Prorocentrum minimum, Dinophysis acuminata, Alexandrium pseudogonyaulax, Alexandrium* spp.) and one planktonic diatom (*Pseudonitzschia* spp.).



These species can cause poisoning to humans through consumption of affected shellfish. The Department of Health provides health warnings about recreational harvesting when densities of these species are above trigger values.

Other potentially harmful species which did not exceed trigger values, but are of concern, are the cyanophytes *Trichodesmium* and *Lyngbya*-like species.

Trichodesmium is regularly washed into the estuary from the ocean. It was detected twice in sampled water, and visually observed on five other occasions. *Trichodesmium* occurred in the Hardy Inlet basin in late summer through to autumn. It appears as a pink scum (although can also be red, green to brown, or white when decaying) and resembles sawdust, leading to its name ‘sea sawdust’. Some strains have been reported to cause eye, skin and respiratory irritations.[17] It is recommended that people avoid areas that are visibly affected.

Lyngbya-like species are investigated in detail in the next section because these cyanobacterial mats have been of concern in the Hardy Inlet since 2006.

The dinophyte *Karlodinium* spp. and raphidophyte *Heterosigma akashiwo* occurred on four and six occasions respectively. Both these species are known to cause fish deaths, however, during the reporting period they were recorded below trigger levels. In combination with a microalgal bloom collapse and low dissolved oxygen, *Karlodinium* spp. was believed to be a contributing factor in a mass fish death of between 500 and 1,000 bream, mullet, whiting and tarwhine between Molloy Island and Alexandra Bridge in May 2006.

A marine raphidophyte, *Chattonella* spp., was identified during the reporting period. This genus of microalgae had not been previously observed in historical records of the area.

Dinophysis acuminata

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[17] NHMRC (National Health and Medical Research Council) (2008) *Guidelines for managing risks in recreational waters*, NHMRC, Australian Government

Lyngbya-like blooms near Molloy Island

Key points:

- ⇨ A large *Lyngbya*-like bloom occurred in summer 2018–19, identified as *Limnoraphis* sp. and *Neolyngbya* cf. *biscayensis*.
- ⇨ The bloom closed popular swimming areas throughout the summer.
- ⇨ The main drivers for *Lyngbya*-like species are high-nutrient organic loads and high phosphorus concentrations.

Lyngbya-like cyanobacterial blooms (including *Limnorphis* and *Neolyngbya*) have been occurring around Molloy Island since 2006.[18] These blue-green algae form mats on the bottom of shallow waterways and rise to the surface under certain conditions. They usually appear as a black, fuzzy or slimy scum on sediments or macroalgae (acting like bacteria), or as slimy, bubbly mats that photosynthesise at the surface. Floating mats of *Lyngbya*-like species can outcompete and shade seagrasses and macroalgae. These species may be harmful to swimmers causing skin, eye and respiratory irritations.[19]

A particularly large bloom of *Lyngbya*-like species and the free-floating macroalgae species *Ulva* and *Rhizoclonium* was observed around Molloy Island from November 2018 until early February 2019 and continued blooming in the lower Scott River until April 2019. In response to the department's reports, the Department of Health advised people to avoid recreational activities in and on the water including fishing, crabbing and collecting shellfish in the area. Popular swimming areas on and near Molloy Island were closed and warning signs were put in place from December until mid-February.

Lyngbya-like species are difficult to visually identify to species level. Genetic analysis of the 2018–19 bloom identified *Limnoraphis* sp. and *Neolyngbya* cf. *biscayensis*. Some *Lyngbya*-like species have genes allowing them to produce toxins. Toxins were not detected from fresh samples analysed from the 2018–19 bloom. Although not detected on that occasion, the species may still be capable of producing toxins (or toxins in the sample were below the level of detection). The environmental triggers for toxin production by these and other potentially harmful microalgal species are relatively unknown. This is an emerging area for investigation by scientists worldwide.

Lyngbya-type species have a range of characteristics which have enabled them to thrive in degraded waters. These include the ability to grow in low-light, low dissolved oxygen conditions and to 'fix' nitrogen. The area around Molloy Island and the lower part of the Scott River has many qualities which are ideal for *Lyngbya*-type species to thrive. The most important ones are the high organic loads in the area (e.g. from dairy effluent), and high nutrient concentration, particularly phosphorus. Other qualities include:

- dark-coloured, humic and tannin-rich waters
- the availability of iron
- shallow, warm waters
- high dissolved organic carbon
- restricted flushing.

There does not appear to be just one factor which causes *Lyngbya*-like species to bloom. The combination of factors allows *Lyngbya*-like species to dominate at certain times.

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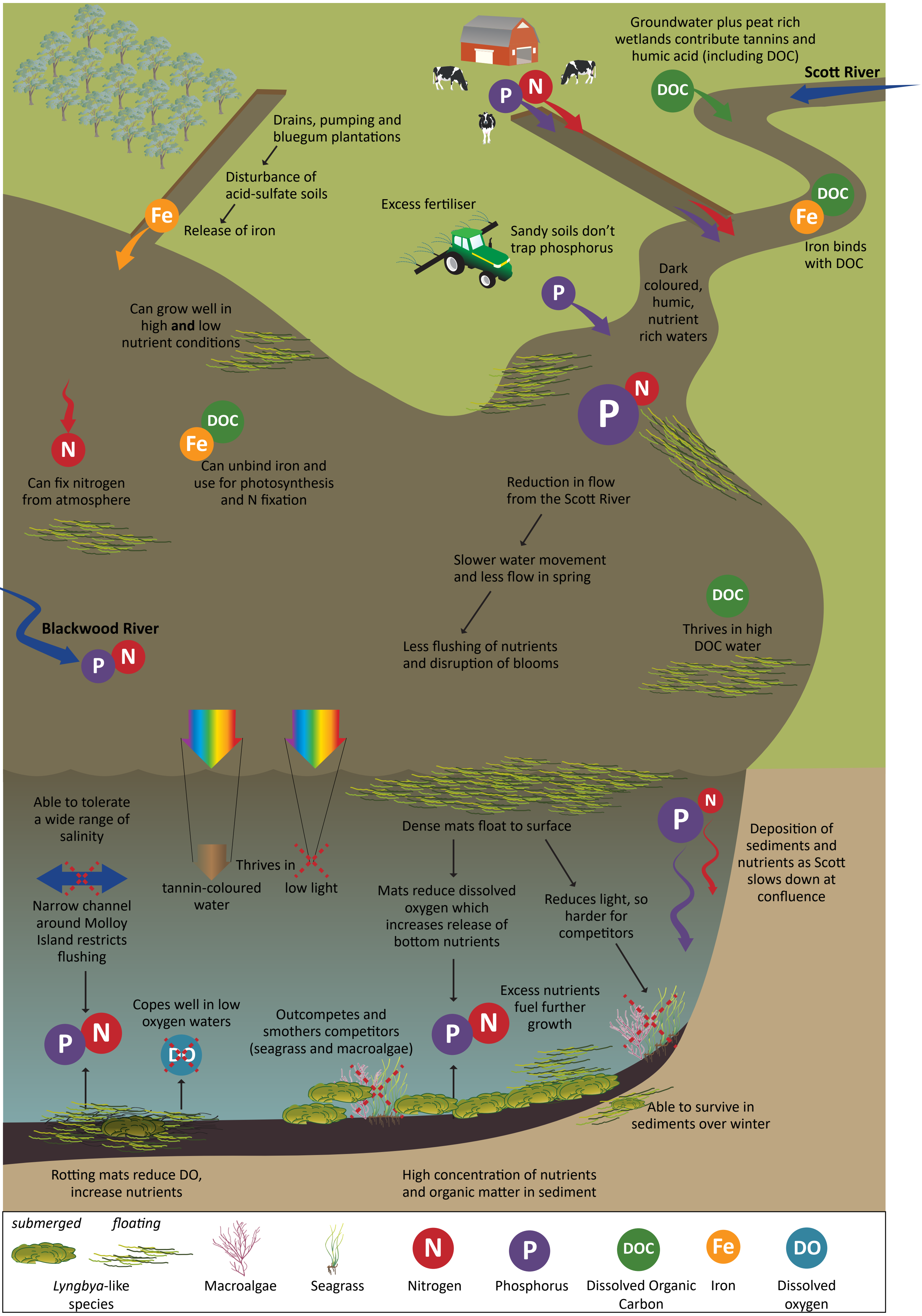
[18] Department of Water (2013) *Hardy Inlet Estuary Condition Report 1999 to 2010*, Department of Water, Western Australia. Available at: www.wa.gov.au/government/publications/estuary-condition-report-hardy-inlet-1999-2010

[19] NHMRC (National Health and Medical Research Council) (2008) *Guidelines for managing risks in recreational waters*, NHMRC, Australian Government


Groundwater plus peat rich wetlands contribute tannins and humic acid (including DOC)
Scott River
DOC
P
N
Drains, pumping and bluegum plantations
Disturbance of acid-sulfate soils
Release of iron
Fe
Excess fertiliser
Sandy soils don't trap phosphorus
P
DOC
Fe
Iron binds with DOC
Dark coloured, humic, nutrient rich waters
Can grow well in high **and** low nutrient conditions
N
Can fix nitrogen from atmosphere
DOC
Fe
Can unbind iron and use for photosynthesis and N fixation
P
N
Reduction in flow from the Scott River
Slower water movement and less flow in spring
Less flushing of nutrients and disruption of blooms
DOC
Thrives in high DOC water
Blackwood River
P
N
Able to tolerate a wide range of salinity
Narrow channel around Molloy Island restricts flushing
Thrives in
tannin-coloured water
low light
Dense mats float to surface
Mats reduce dissolved oxygen which increases release of bottom nutrients
Reduces light, so harder for competitors
P
N
Deposition of sediments and nutrients as Scott slows down at confluence
P
N
Copes well in low oxygen waters
DO
Outcompetes and smothers competitors (seagrass and macroalgae)
P
N
Excess nutrients fuel further growth
Able to survive in sediments over winter
Rotting mats reduce DO, increase nutrients
High concentration of nutrients and organic matter in sediment
submerged
floating
Lyngbya-like species
Macroalgae
Seagrass
N
Nitrogen
P
Phosphorus
DOC
Dissolved Organic Carbon
Fe
Iron
DO
Dissolved oxygen

2010

September – new opening dredged.

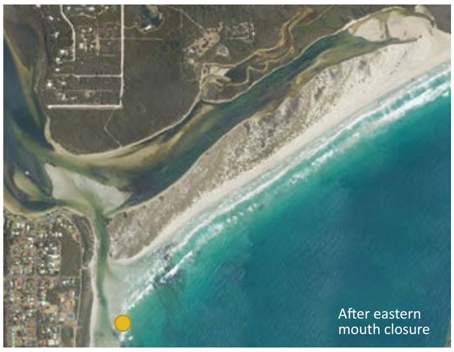
October – new opening closed due to unusually low flows.

2011

August – new opening re-established and remained open until December, then closed.

2013

August – new opening re-dredged. Remained open after this.



2015

November – eastern mouth closed (forming the Deadwater).

Shifting sands – the mouth of the Hardy Inlet

The estuary mouth is naturally dynamic and has had various configurations over the decades. It has moved many times from its current opening near Dukes Head, to up to 2.3 km further northeast, near Swan Lake.[20] The mouth has migrated slowly eastward twice since the 1920s, through a combination of changes to drainage, erosion, sedimentation, long-shore drift, and wind and wave action. On two occasions, once in 1945 and again in 2015, the opening near Dukes Head was reinstated by the successful dredging of a new channel.

In 2010 the mouth was 1.8 km east of its current position, flowing through what is now the Deadwater. In October 2010, a new opening next to Dukes Head was dredged but it closed in September because of unusually low flows. The new opening was re-established for five months in 2011 but closed in December. In 2013, the new opening was re-dredged, and water flowed through both openings until November 2015 when the eastern mouth closed. Since then, the mouth appears to once again be slowly migrating eastward and will likely continue to do so.

Based on routine water quality sampling, there was no discernible difference in water quality between the pre- and post-dredging of the new channel. The Hardy Inlet Estuary condition report of 1999 to 2010 stated:

> Seine Bay west of Dukes head, which is remembered for its clear waters and fringing beaches, is now more estuarine in character. Waters are coloured and aquatic macrophytes and algae grow in the shallows.[21]

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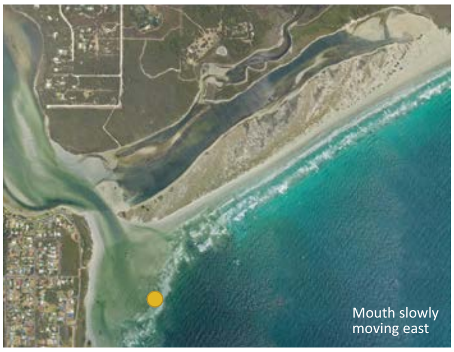
[20] Brearley A (2005) *Ernest Hodgkin's Swanland: estuaries and coastal lagoons of South-western Australia*. Ernest Hodgkin Trust for Estuary Education and Research and National Trust of Australia, Western Australia

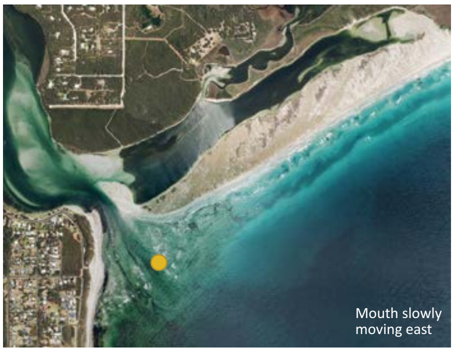
[21] Department of Water (2013) Hardy Inlet Estuary Condition Report 1999 to 2010, Department of Water, Western Australia. Available at: www.wa.gov.au/government/publications/estuary-condition-report-hardy-inlet-1999-2010

2016 2017 2018 2019 2020 2021

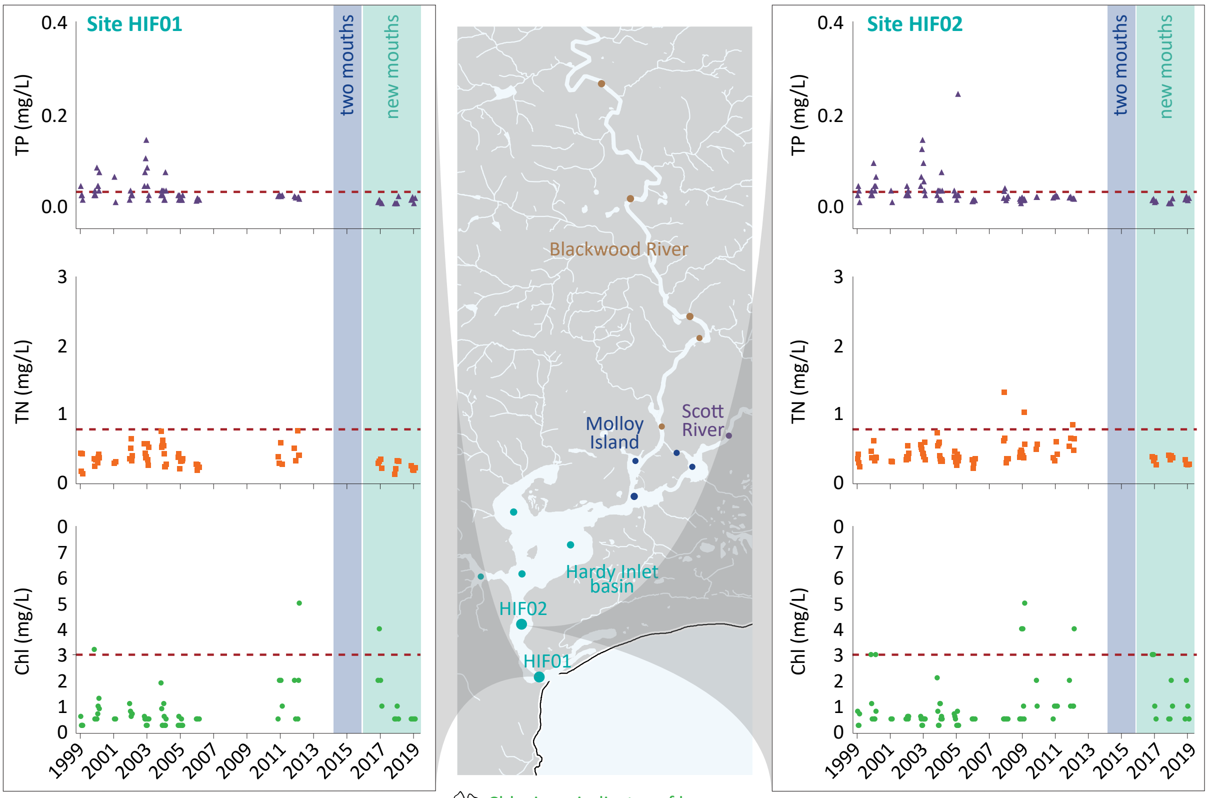
2017



2019



2021



Chl a is an indicator of how much microalgae is in the water

Data from low flow period (Nov–Feb)

Since the opening has moved, the waters at the ‘Colour Patch’ – a small embayment near the mouth – are, anecdotally, clearer in the spring and summer months, and recreational activities are popular in the area. While the fringing beaches of Seine Bay itself have not returned, there is now a sandy spit at Dukes Head which is popular for fishing. However, the ability to access the long stretch of beach along the ocean side of the Deadwater has been considerably restricted. Aquatic macrophytes and algae still grow and form blooms in the shallows of the lower part of the estuary. A large sandbar has formed in the center of the channel within the opening of the estuary, caused by the ocean pushing marine sand into the estuary. The Deadwater has re-formed since the eastern mouth closed and, as predicted, macroalgae has bloomed there.

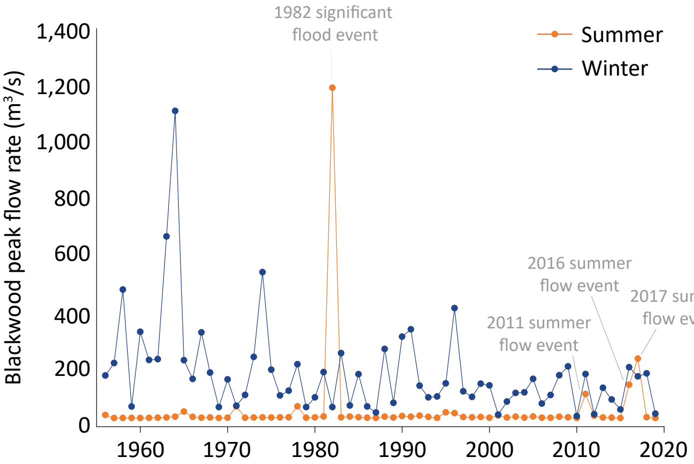
Timing of flows and rainfall

The timing and distribution of flows and nutrients during the year influence how an estuary responds to nutrient inputs. The effects of climate changes – such as increased intense rainfall events, reduced flows and rainfall, a shift in the timing of rainfall and increased temperatures – have affected the Hardy Inlet. These impacts are likely to continue and increase.

Summer flows

In February 2017, a tropical low and associated rainband brought widespread rainfall to WA's south-west. Major flooding occurred in the Blackwood River catchment, particularly in the upper reaches. The floodwaters took two weeks to reach the estuary and contained stormwater, wastewater and organic matter including animal waste, leaf litter, soil and plant debris. The breakdown of all the organic matter decreased the oxygen severely. Oxygen levels remained low for weeks in the inlet, while nutrients and microalgal activity were high. Although the Scott catchment did not flood, the floodwaters in the Blackwood pushed up past Molloy Island and into the Scott River.

An earlier summer flow event in 2016 led to the death of between 100 and 1,000 fish, crabs, octopus and stingrays that were trapped in the Deadwater. A similar event in late December 2011 greatly increased nitrogen in the estuary. No fish kills were recorded at that time. However, a large bloom of *Lyngbya* (143,000 cells/mL) in the Scott River one month later may have been linked to the event. Although rainfall is decreasing in south-west WA, the intensity of heavy rainfall events is likely to increase with our changing climate.[22]



Reduced winter flows

It seems counterintuitive, but the highest chlorophyll values and microalgae cell counts in the Hardy Inlet in 2016–19 occurred in winter (June 2018 and July 2017), rather than in the warmer seasons. These high densities occurred when nutrient levels in the river increased because of rainfall, but the flow was not strong enough to stop microalgae colonies forming or to disrupt stratification (which can increase nutrients in deeper waters and fuel algal blooms).

Reduced winter rainfall also means winter flows no longer continue for as long into spring. Subsequently, spring flows also decreased in the Scott and Blackwood. Like terrestrial flora, microalgae and macroalgae typically bloom in spring as temperatures and light increase. With reduced spring flows there are less tannins in the water to inhibit the growth of algae. Nutrients from spring rains may not be flushed out of the estuary as quickly. As fertiliser is often applied in

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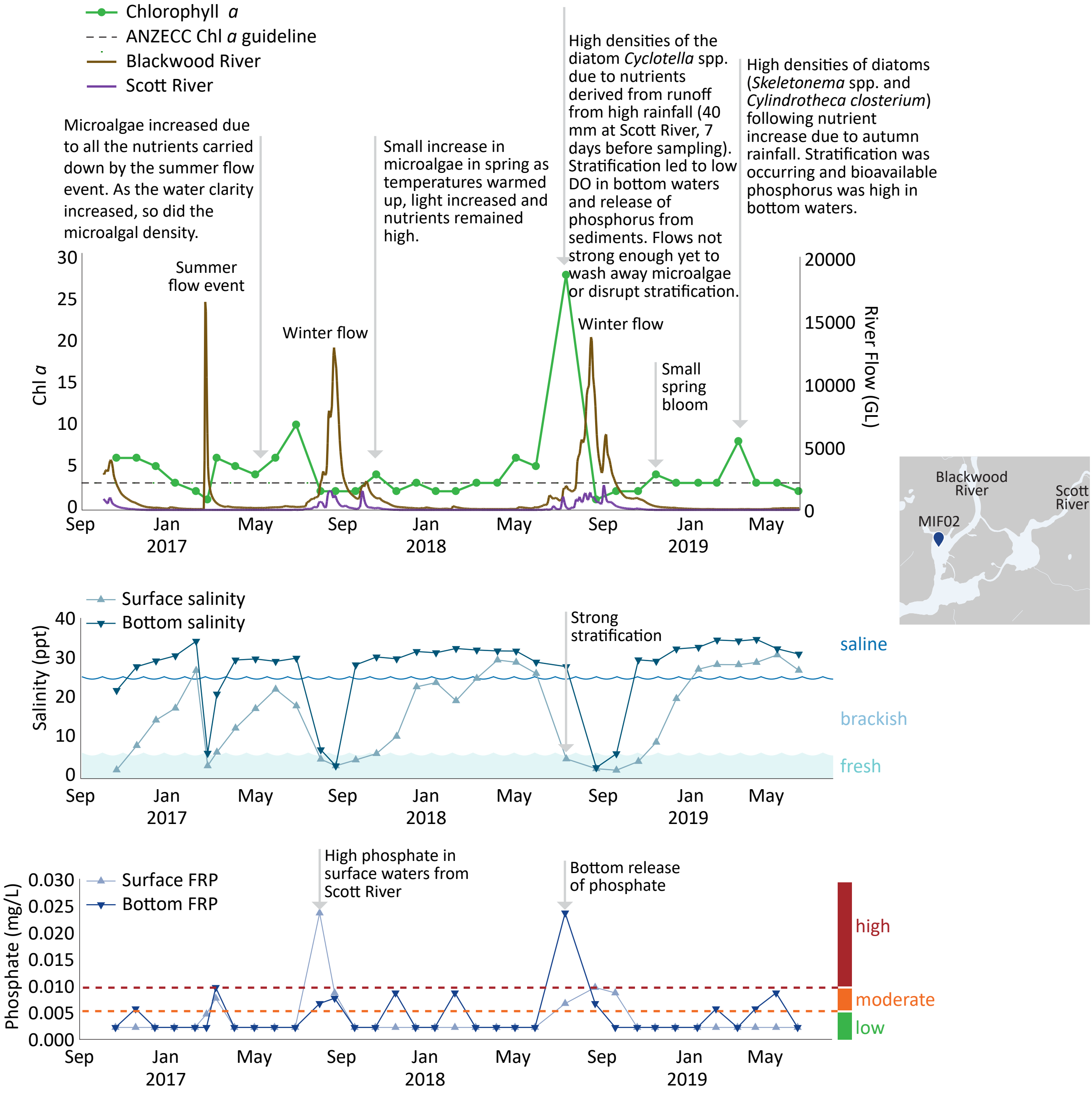
[22] Department of Water and Environmental Regulation (2021) Western Australian climate projections, Summary, Government of Western Australia, Perth. Available at: www.wa.gov.au/government/publications/western-australian-climate-projections-summary

spring, spring rains can wash nutrients into the waterways and flows may not be strong enough to carry them away. In warm and sunny spring seasons macroalgae and *Lyngbya*-like blooms appear to be more prevalent in the Hardy Inlet compared with years with a cooler spring.

Temperature increases

Temperatures have increased across south-west WA and warmer temperatures generally lead to an increase in algae. In autumn this may be particularly relevant because stratification is often strong at this time (leading to the release of nutrients from sediments). Nutrients and organic matter built up over the summer may be washed into waterways by early autumn rain. When this occurs before the river has started flowing, the matter is unlikely to be washed away. If temperatures are warm, these factors can combine to increase microalgae, as occurred in Hardy Inlet in 2019.



Microalgae increased due to all the nutrients carried down by the summer flow event. As the water clarity increased, so did the microalgal density.

Small increase in microalgae in spring as temperatures warmed up, light increased and nutrients remained high.

High densities of the diatom *Cyclotella* spp. due to nutrients derived from runoff from high rainfall (40 mm at Scott River, 7 days before sampling). Stratification led to low DO in bottom waters and release of phosphorus from sediments. Flows not strong enough yet to wash away microalgae or disrupt stratification.

High densities of diatoms (*Skeletonema* spp. and *Cylindrotheca closterium*) following nutrient increase due to autumn rainfall. Stratification was occurring and bioavailable phosphorus was high in bottom waters.

Strong stratification

High phosphate in surface waters from Scott River

Bottom release of phosphate

Seagrasses and macroalgae

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

Seagrasses are flowering plants adapted to live underwater in estuarine or marine environments. They provide habitat and food for fish, birds and crustaceans. Seagrasses contribute to maintaining healthy estuaries with good water and sediment quality.

Macroalgae are also an important and natural part of estuarine and marine ecosystems. However, excess nutrients can cause prolific 'nuisance' algal growth, smothering seagrasses, reducing oxygen in the water and producing foul odours.

We completed two surveys of seagrass and macroalgae during the reporting period, in December 2018 and January 2020.

In the Hardy Inlet, *Ruppia megacarpa* is the dominant seagrass, with *Zostera, Halophila decipiens* and *Halophila ovalis* also present. Seagrass is present in more than half of the main estuary basin.

Seagrass cover was fairly low in December 2018 but 13 months later, in January 2020, both the density and area of seagrass had increased. The areas where seagrass increased between surveys was mainly in the inlet channel area between the town of Augusta and the eastern shoreline, and along the eastern boundary of the central basin. Neither survey observed seagrass in West Bay, where water is likely too turbid to support seagrass. The increase in seagrass cover was paired with an overall decrease in macroalgae. Despite the decrease, macroalgae was very abundant near the mouth in January 2020.

Both *Ruppia megacarpa* and macroalgae can grow quickly when environmental conditions are favourable. Greater river flows and cooler temperatures were recorded in the winter and spring of 2018 than in 2019. Tannin-stained fresh water flowed out through the estuary well into spring in 2018, when seagrass growth typically increases. Macroalgae can grow under low light conditions and could have established earlier in the spring season than the seagrass meadows in 2018–19. In the following spring (preceding the January 2020 survey), very low river flows, combined with warm sunny conditions, increased the light available to seagrass. These warm, clear waters would have promoted healthier seagrass growth and allowed the seagrasses to outcompete the macroalgae. Septic contamination has been repeatedly shown in Seine Bay[23] and the additional nutrient supply likely allowed macroalgae to thrive near the mouth.

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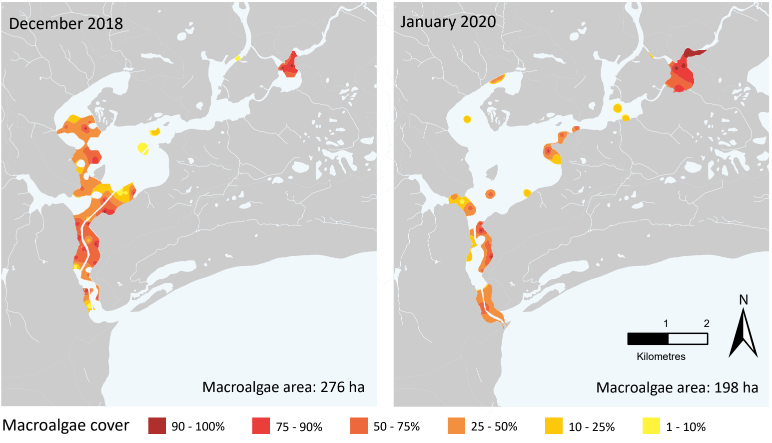
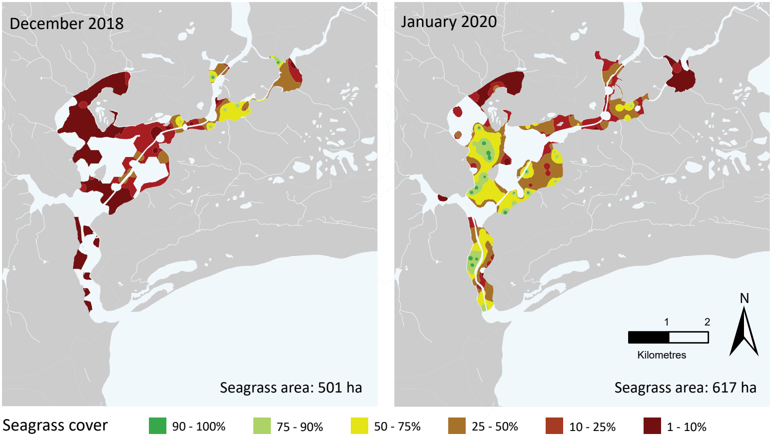
[23] Data supporting this statement provided by Augusta Margaret River Shire





Outlook

Nutrient pollution and climate change are the biggest risks to the health of estuaries in south-west WA, including the Hardy Inlet. We have already observed dramatically reduced river flows. Unseasonal storms in summer and autumn are occurring and are predicted to increase. These storms deliver nutrient loads to the estuary which are not flushed out to the ocean at times when temperatures are warmer, resulting in increased microalgal activity. Increased microalgal activity will reduce the light available to seagrasses and may contribute to their decline.

To maintain the social and ecological values of the Hardy Inlet, management should continue to focus on building resilience and adaptability where possible. Nutrient reduction from all sources is the principal action, combined with the protection of functional ecosystems such as seagrasses. Priority attention should be given to the Four Acres, Dennis and Lower Scott subcatchments which contribute a large proportion of the nutrient load to the Hardy Inlet.

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

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

More information

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

Some key activities include:

- working with farmers and the Lower Blackwood LCDC to restore stream function and move stock away from waterways
- working in partnership with the Department of Primary Industries and Regional Development, farmers, industry, and the Lower Blackwood LCDC to reduce nutrient runoff from farms through improved fertiliser management practices, while supporting farm productivity
- working in partnership with Western Dairy and the dairy industry to support farmers to improve dairy effluent management practices and implement the revised *Code of Practice for Dairy Farm Effluent Management WA* (2021)[24]
- supporting the scientific monitoring of the Hardy Inlet and its catchments
- trialling new materials to treat soil to bind phosphorus and reduce nutrient export to the estuary.

For more information on Healthy Estuaries WA and the Hardy Inlet, visit estuaries.dwer.wa.gov.au/estuary/hardy-inlet

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[24] Western Dairy (2021) *Code of Practice for Dairy Farm Effluent Management Western Australia*. Western Dairy, Western Australia. Available at: www.dairyaustralia.com.au

What you can do

Farmers

Base fertiliser management decisions on soil test results.

Fence streams from livestock and restore native vegetation.

Follow best practice dairy effluent management.

Homeowners

Adopt best fertiliser practice in your gardens.

Plant natives.

Local communities

Stay informed through the estuaries website.

Join your local catchment group.

Report algal blooms and unusual fish deaths.

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

#WAestuaries