Department of **Water and Environmental Regulation**

Department of **Primary Industries and Regional Development**

GOVERNMENT OF WESTERN AUSTRALIA

Oyster Harbour

Miaritch (Miyaritj)

HEALTHY ESTUARIES WA

Condition of the estuary 2016–19

#WAestuaries

Acknowledgements

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About estuaries

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

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

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

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

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

Report at a glance

This report summarises three years of the Regional Estuaries Initiative Oyster Harbour water quality monitoring program (2016–19) and compares these recent results with historical data. We report on the main drivers of estuary health (flow and catchment condition, and the estuary response), the status of water quality indicators and state of key habitats such as seagrass.

Water quality in Oyster Harbour declined in the late 1970s and '80s due to catchment clearing and excessive nutrient inputs, which also led to extensive loss of seagrass. Seagrass has recovered remarkably in the last 20 years due to significant seagrass transplanting and improved catchment management activities, resulting in better water quality.

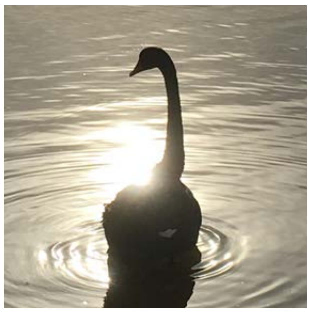
Today, Oyster Harbour generally has very good water quality. It is free from nuisance microalgal blooms, fish kills and concentrations of low oxygen, and is a success story of improved water quality in an estuarine environment.

There are, however, occasional elevated levels of nutrients and microalgal activity in the northern section of Oyster Harbour, and there is some evidence that algal activity in this area has increased in recent years, especially in summer and autumn. Relatively high phosphate concentrations from the King River catchment may be a key contributor to this.

Key points:

- Oyster Harbour is a very healthy estuary
- the estuary has good marine water exchange – it is well mixed and well oxygenated
- nutrient concentrations in the estuary are generally low
- rivers supply nutrients to the northern harbour, which can fuel algal growth
- seagrasses dominate the aquatic flora and have recovered remarkably since significant losses in the 1980s.

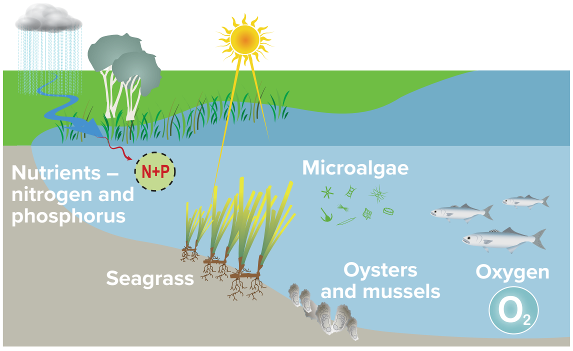
Although the water quality is currently good, climate change may threaten this in future. Sporadic atypical rainfall events could deliver nutrient loads at times of high algal growth activity (in summer, for example). Consequently, efforts to minimise the delivery of excess nutrients from the catchment are as important as ever. The improvements seen in restored seagrass habitat must also be preserved and carefully considered, especially in the context of the expanded aquaculture zone in Oyster Harbour.

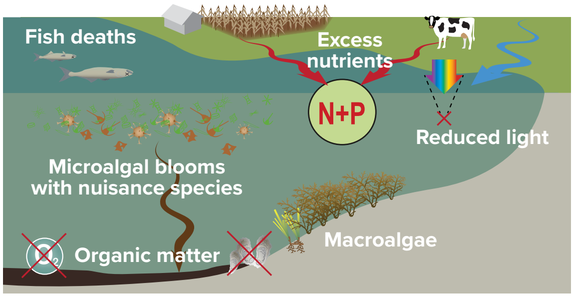


Estuary health refers to the ecological integrity of an estuary. Many things can compromise the ecology of an estuary: over-fishing, contamination from industrial waste or the invasion of foreign species. However, for south-west Western Australian estuaries, eutrophication is the main threat.

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

Unhealthy estuaries

Catchments and foreshores are extensively cleared for agriculture, urban and/or industrial land uses, leading to excessive nutrient concentrations. High nutrients fuel algal growth. Decomposing algae contribute to high levels of organic matter and oxygen consumption. High nutrients also favour macroalgae. Both decomposing algae and macroalgae reduce 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 potentially lead to fish and fauna deaths.

What we measure

In the catchment

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

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

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 insitu 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 extent.

About Oyster Harbour and its catchment

Oyster Harbour, located in the Great Southern region, has an area of 15.6 km^2, is permanently open to King George Sound and is the only south-coast estuary without a sand bar. The estuary has an average depth of two metres and a maximum depth of 10 metres.

Two major rivers (the Kalgan and King) are connected to the northern harbour, and are estuarine (that is, influenced by tidal marine exchange) for approximately nine and seven kilometres, respectively. Yakamia Creek meanders through urban areas of Albany and enters the harbour on the south-western side.

A 200-metre-wide entrance channel at Emu Point connects Oyster Harbour to the Southern Ocean via King George Sound. The channel is dredged to 12 metres. Tides are semi-diurnal, with a range of 0.5–1.2 metres.

The harbour has two operational mussel and oyster farms. Monitoring of these operations for human health associated with shellfish consumption is administered by the Department of Health. An expanded aquaculture development zone now covers an area of 535 ha[1].

The catchment of Oyster Harbour, some 3,000 km^2, extends north to the Porongurup and Stirling ranges.

Water quality monitoring is undertaken monthly in the estuary at seven sites, and fortnightly in the catchment at six sites.

[1] Department of Primary Industries and Regional Development 2020, *Prospective zones*. Available from https://fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Aquaculture%20Zones/Pages/Albany%20Aquaculture%20Development%20Zone.aspx.

Seven-thousand-year-old fish trap of the Menang people.

Historical context

Oyster Harbour is in the traditional lands (boodjar) of the Menang Noongar people and is known as Miaritch (Miyaritj) – which refers to the meeting place of the Warrecoolyup (King) and Kalganup (Kalgan) rivers, and also a meeting place of the Menang people. It is also known as the 'home of all the fishing traps', or mungas, with the land area adjacent to the traps known as Tamungup.[2]

In the 1700s, during the time of early European exploration of the southern coast, Angasi oysters (*Ostrea angasi*) were abundant in Oyster Harbour, hence its name.

The town of Albany, adjacent to Oyster Harbour, was settled in 1826. It was the state's key port during the 1800s, until the opening of the Fremantle Inner Harbour in 1897. By the late 1800s, the native oyster reefs suffered losses of about 90 per cent due to dredge fishing.[3]

In the 1900s, agriculture, timber and later whaling were the dominant industries. Post-World War II saw the rapid expansion of Albany's population and industries, as well as agriculture in the broader catchment. For Albany's harbours, this meant excessive nutrients from wastewater, industry and agricultural fertiliser runoff exceeded the aquatic ecosystem's capacity to absorb them.

Oyster Harbour was considered healthy in 1962 but suffered a deterioration in water quality in the 1980s, culminating in significant seagrass loss by the end of the decade.[4] Detailed scientific studies were undertaken in the 1980s to understand and provide solutions to the problem.

The harbour has been on a 25-year recovery pathway since then, following targeted nutrient management activities for industry and in the catchment. Improvements in water quality allowed for successful seagrass restoration from the mid-1990s, by transplanting individual seagrass plants.[5]

Today, Oyster Harbour is highly valued for its role in tourism, recreation, boating, commercial and recreational fishing, and bird watching. The recent declaration of the expanded aquaculture development zone suggests that harvesting of shellfish will again be an important focus for Oyster Harbour.

Entrance of Oyster Harbour, King George III Sound, interview with the natives, 1825 (Illustration by Phillip Parker King). National Library of Australia, nla.obj-135758345-m

2 Cultural informant Vernice Gillies/Museum of WA (Albany).

3 Warnock, B and Cook, PA 2015. *Historical abundance and distribution of the native flat oyster, Ostrea angasi, in the Great Southern region of Western Australia,* Centre of Excellence in Natural Resource Management, University of Western Australia, Perth.

4 Environmental Protection Authority 1990a, *Albany Harbours Environmental Study* (1988-1989), EPA, Perth.

5 Cambridge, M, Bastyan, G and Walker, D 2002, 'Recovery of Posidonia meadows in Oyster Harbour, southwestern Australia', *Bulletin of Marine Science,* vol. 71, pp 1279–1289.

Climate change in the South West

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

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

Rainfall is a key driver of estuary dynamics as it determines freshwater inflows. The interplay between freshwater inflows and ocean water exchange affects the salinity, flushing rate and stratification patterns in estuaries. Temperature strongly influences biological growth rates.

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

Since 2000, May to July rainfall over the South West was about 28 per cent less than the long-term average.[6] There is strong evidence to suggest that rainfall in the region will decline further in future.[7,8] Rainfall has not only dramatically decreased in autumn and early winter, but there have also been large fluctuations in summer rainfall, which could lead to more frequent and intense storms.[6,7]

Freshwater flows have also decreased significantly, by up to 70 per cent since the 1970s – a pattern which is expected to continue.[9]

Between 1910 and 2013, the average annual air temperature in the South West increased by 1.1 degrees Celsius (°C),[10] and is predicted to increase by a further 0.7 °C by 2030 (relative to the 1961–1990 baseline).[7]

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 phytoplankton diversity and restricted habitat for brackish and freshwater fish species.

Water quality may improve in some areas. For example, the zones closest to permanent openings with good connection to the marine environment will most likely increase in marine biodiversity and decrease in algal activity as they become less influenced by fresh, nutrient-rich catchment inflows. Conversely, intermittently closed estuaries (common on the south coast of Western Australia) 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 this layering may persist for longer periods of time. This can result in depleted oxygen (known as hypoxia) and the release of sediment-bound nutrients, which can fuel undesirable algal blooms (discussed in more detail later). Nutrients from catchment inflows could be retained in the estuary rather than being flushed out to sea. This can lead to adverse impacts such as increased algal activity and low light conditions for seagrasses. The estuarine river reaches of many South West estuaries already show these patterns of extended periods of low oxygen status due to high nutrient loads and persistent stratification.

Shallow estuaries will be particularly vulnerable to warming conditions. Higher temperatures favour algal growth and therefore estuaries may have greater algal productivity, which subsequently affects the overall food web. Extreme heat waves also have negative impacts on some fauna and flora, such as important seagrasses. Sea level rise and increased summer storm events could increase the frequency of coastal inundation events.

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.[11]

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

7 Department of Water 2015, *Selection of future climate projections for Western Australia*, Water Science Technical Series, report no. 72, Department of Water, Perth.

8 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.

9 Petrone, K et al 2010, 'Streamflow decline in southwestern Australia, 1950–2008', Geophysical Research Letters, *Hydrology and Land Surface Studies,* vol. 37, no. 11. Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102

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

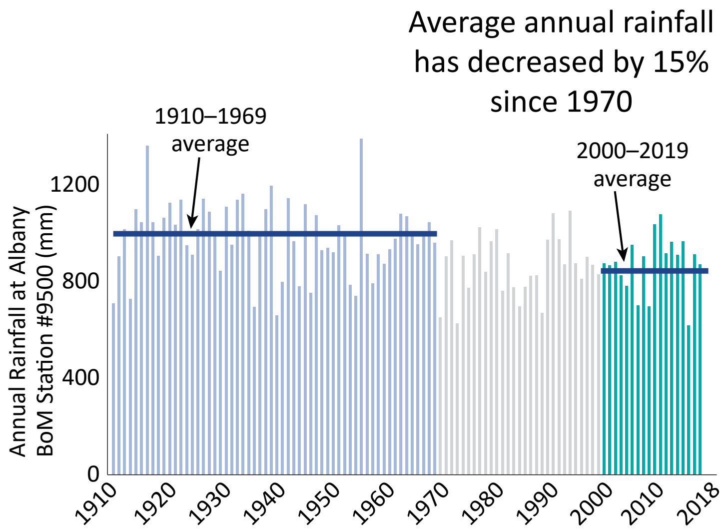
11 Scanes, E, Scanes, PR and Ross, PM 2020, 'Climate change rapidly warms and acidifies Australian estuaries' Nature Communications, vol. 11, no. 1803. Available from: https://doi.org/10.1038/s41467-020-15550-z

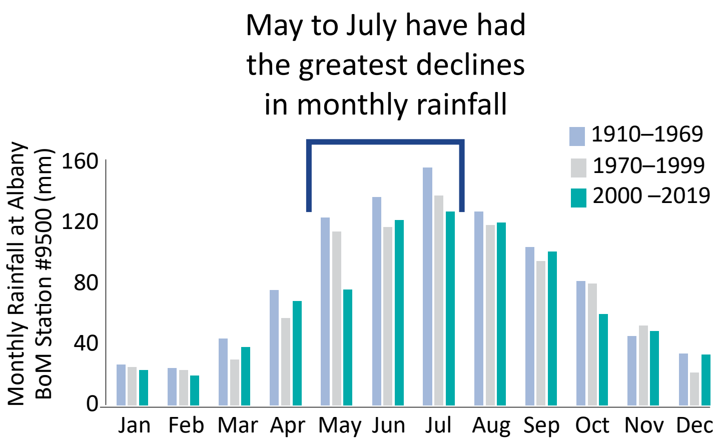
Rainfall and flow

In Albany, the average annual rainfall from 2000–2019 was 834 mm – a 15 per cent decline since the 1910–69 annual average of 984 mm, and a 5 per cent decline since the 1970–99 annual average of 876 mm. Regional climate reports reveal that the greatest decline in rainfall was in early winter: from 2000 to 2019, the autumn-winter average was 20 per cent less than that from 1910–69.[12]

Key points:

- rainfall in Albany has decreased by 15 per cent since 1970
- Kalgan River stream flows have decreased by 25 per cent since 1977
- the greatest declines in rainfall and streamflow were in autumn and early winter.



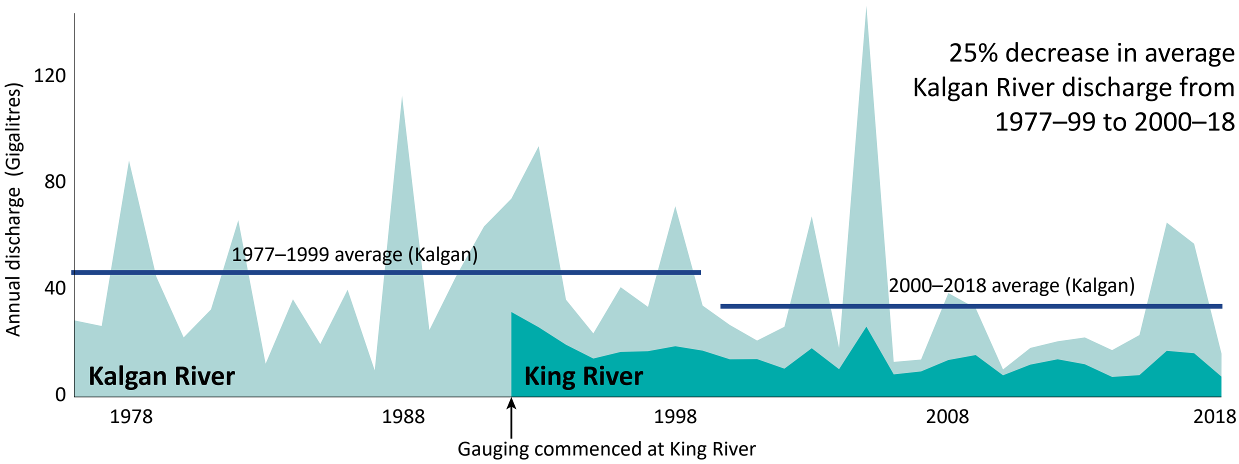


[12] Bureau of Meteorology 2018, *Australia's changing climate.* Available from (http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml)

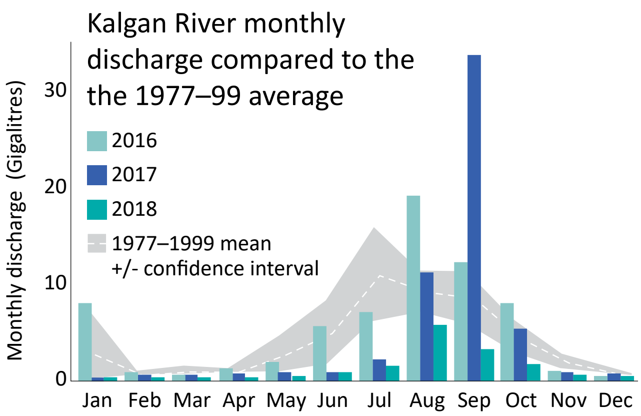
Flow in the Kalgan River has varied widely from year to year since 1977 when stream flow gauging started. The average flow has decreased by 25 per cent, when compared to the 1977–99 average (46.2 GL) and the 2000–18 average (34.7 GL).

Average rainfall, in comparison, decreased by five per cent from 1970–99 to 2000–18. This shows that the relationship between rainfall and flow is complex. Similar patterns have been observed throughout the South West,[13,14] and projections to 2050 show the declines will continue.[15] Catchment runoff is influenced by rainfall, evaporation rates and land use changes. A series of dry years reduces soil moisture and groundwater levels and results in a disproportionate decrease in runoff and streamflow. This suggests a hydrological shift that will not be reversed without multiple years of above-average rainfall.

Significantly less water flows down the King than the Kalgan River. Although records of the flows in the King River only began in 1992, the pattern of decline is still apparent. In the current monitoring period, the 2016 and 2017 annual flows were above average, whilst 2018 was one of the driest years on record.



The recent (2016–19) monthly Kalgan River flows peaked later: in August and September, rather than from July to September (compared to the 1977–99 average monthly flows). Peak monthly flows in 2016 and 2017 were above the 1977–99 averages; and 2018 monthly flows were well below the averages in all months. The King River monthly flows followed a similar pattern.

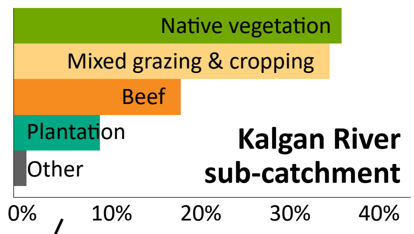


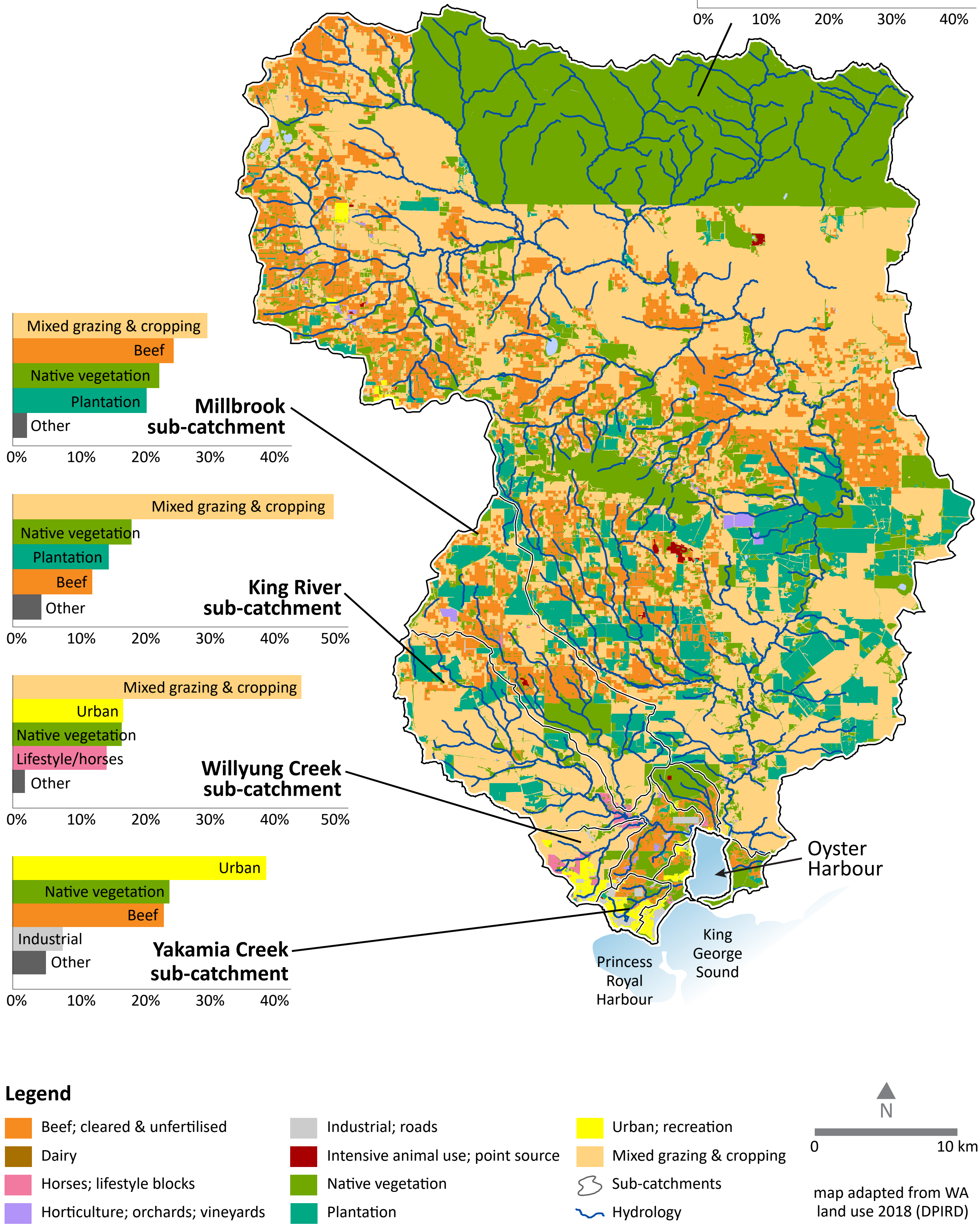
13 Petrone, K et al 2010, 'Streamflow decline in southwestern Australia, 1950–2008', Geophysical Research Letters, *Hydrology and Land Surface Studies*, vol. 37, no. 11. Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL043102

14 Department of Water 2015, *Securing water resources for the South West,* DoW, Perth.

15 Department of Water 2010 *The effects of climate change on streamflow in south-west Western Australia: projections for 2050,* DoW, Perth.

Catchment land use





Catchment nutrient sources

The Kalgan River subcatchment is 2,491 km^2, which makes up more than two-thirds of the Oyster Harbour catchment. Around 12 per cent of the entire Oyster Harbour catchment drains to the King River via three subcatchments: the King, Millbrook and Willyung. To the south-west, the urban areas of Albany dominate the Yakamia Creek subcatchment. Approximately 70 per cent of the entire catchment has been cleared for agriculture — primarily wheat, sheep, and beef farming. Bluegum plantations are a feature of the southern parts of the Kalgan River subcatchment and in the King River subcatchments.

Within the Oyster Harbour catchment, the main sources of nitrogen and phosphorus are fertilisers (such as urea and superphosphate), animal waste, organic matter from soil erosion, wastewater, and sometimes industrial discharges. Nutrients from these sources are delivered to estuaries primarily via runoff to rivers and groundwater discharge.

Soils vary in their capacity to bind phosphorus. In the South West, grey sands on the coastal plains tend to have poor phosphorus-binding capacity. Phosphorus added to soils can move relatively quickly to drains, streams and groundwater. Sustainable farming in the South West means building soil structure which minimises nutrient losses (mostly phosphorus) from farmland.

Facts and figures

Catchment area	3,000 km^2
Area cleared (2018)	70%
River flows	Kalgan and King rivers and Yakamia Creek
Annual flow (2018)	23 GL
Main land use (2018)	Wheat, sheep and beef farming, native vegetation

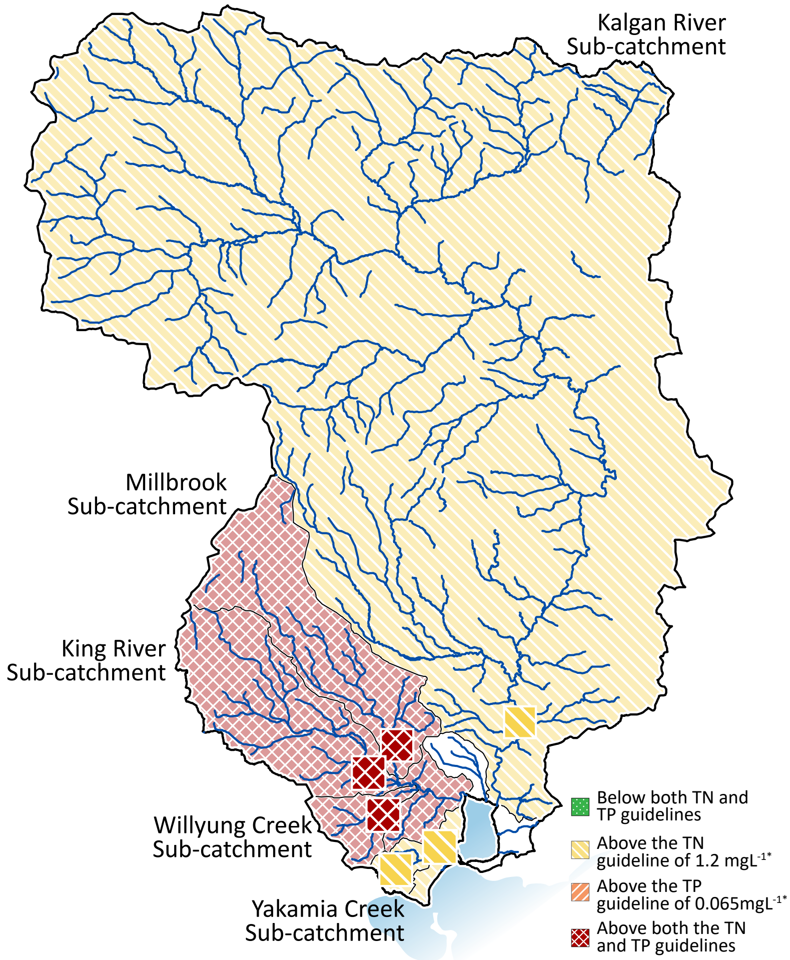
Different land use types vary in the amount of nitrogen and phosphorus they export to receiving waters such as estuaries. Native vegetation exports the least. Pig, beef and dairy farms tend to have among the highest export of nutrients, and this reflects the amount of nutrients applied as well as the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

Catchment nutrient concentrations

During the 2016–19 monitoring period, nutrient concentrations were measured in surface water samples approximately mid-channel every fortnight, in the major river or stream within each subcatchment. Winter median nutrient concentrations were compared to the ANZECC and ARMCANZ guideline values for lowland rivers in south-west Australia.[16] These guidelines provide a value above which there may be a risk of eutrophication.

The map shows where the total nitrogen and phosphorus values were higher than the guideline for the 2016–19 monitoring program. For nitrogen, the winter median concentrations were higher than the guideline value (1.2 mgL^{-1}) in all subcatchments. Winter median total phosphorus concentrations were higher than the guideline value (0.065 mgL^{-1}) in the three King River subcatchments (King, Millbrook and Willyung Creek). There was one site, Upper Yakamia Creek, where the non-winter nitrogen median concentration was also higher than the guideline value.

The King River subcatchment had the highest winter median concentrations of both nitrogen and phosphorus, up to two times the nitrogen guideline value and up to four times the phosphorus guideline. Expansion of peri-urban land and intensive pig farming in the King River subcatchment might lead to further deterioration in water quality in the absence of careful nutrient and effluent management.



* ANZECC guideline values for South West lowland rivers (ANZECC 2000)

Key points:

- ⇨ winter median nitrogen concentrations in all subcatchments were higher than the guideline value
- ⇨ the nitrogen median in the upper Yakamia Creek subcatchment was also higher than the guideline value in non-winter months
- ⇨ winter median phosphorus concentrations were higher than the guideline value only in the King River subcatchment
- ⇨ the highest winter median concentrations (both nitrogen and phosphorus) were observed in the King River subcatchment.

Detailed catchment water quality monitoring results, including trends, will be available soon.

[16] *Australian and New Zealand Environment and Conservation Council (ANZECC) default guideline values for lowland rivers in south-west Australia. These guidelines are used in accordance with the guidance provided in the* Australian and New Zealand Guidelines for Fresh and Marine Water Quality. *ANZECC guideline values provide a concentration above which there may be a risk of an adverse impact on water quality.*

Flows and loads to the estuary

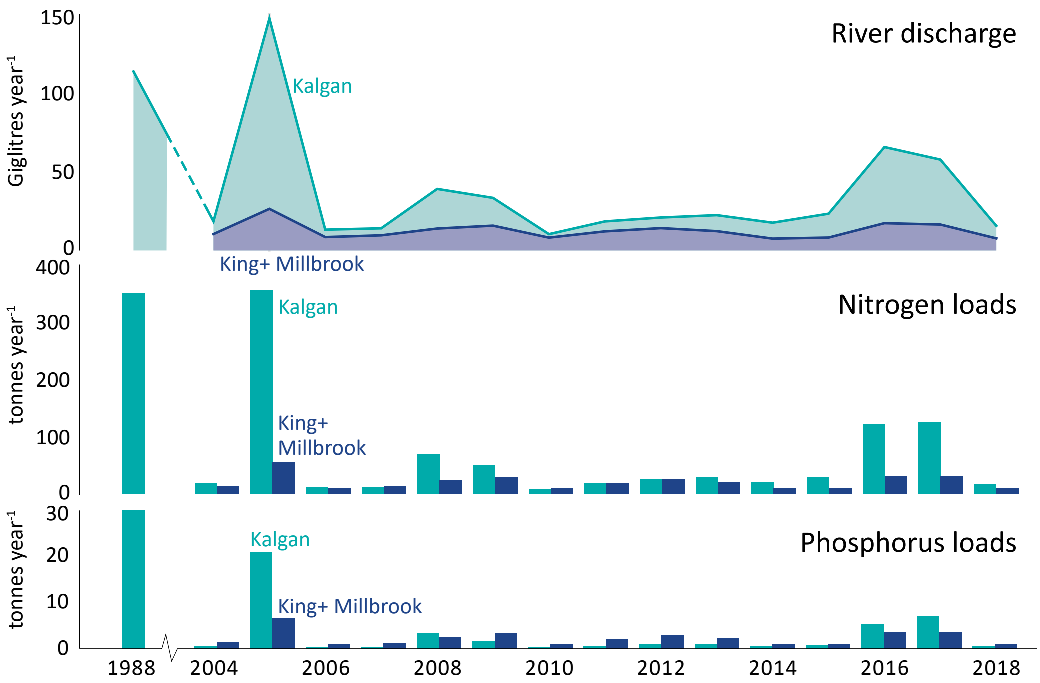
The total amount (or load) of nutrients entering the estuary is estimated by multiplying nutrient concentration by the flow volume. The pattern of high inter-annual variability in annual stream flows is therefore reflected in the annual nutrient loads.

The annual nutrient loads for the 1988 and 2005 flood years were particularly high in the Kalgan River, as flood waters carried nutrients from throughout the catchment to the estuary. In 2016 and 2017, relatively high-flow years, the loads were also above those of the preceding 10 years. In 2018, one of the driest years on record, annual nutrient loads were very low.

While low flows caused by a drying climate may seem potentially good for estuaries, 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. The King River, for instance, is a greater contributor to estuary phosphorus loads in the low-flow years than the Kalgan River. For example, in 2018, a low-flow year, the King-Millbrook Catchment was half the flow (7.7 GL) of the Kalgan (15.7 GL), but the phosphorus load was more than double, 1.02 tonnes, compared to 0.46 tonnes from the Kalgan.

The timing of the nutrient delivery similarly affects nutrient loads. Several small inflows over the year, especially in spring and summer, have much more potential to assimilate into algal growth in the estuary than a large inflow in winter, which would mostly discharge into King George Sound.

These results show us that catchment actions to reduce nutrients to the harbour are important; perhaps especially in the King River subcatchments, as phosphorus inputs are relatively large during low flows.



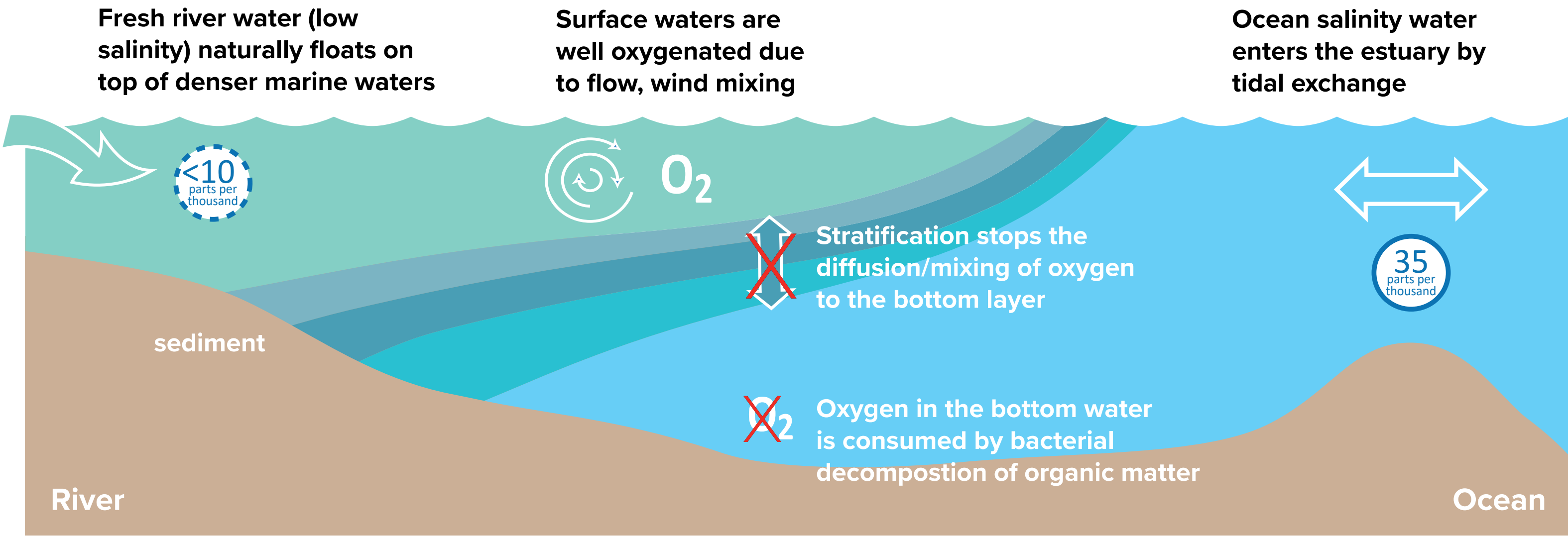
In the estuary:

the importance of stratification

Stratification in water is an important feature of most estuaries. It relates to vertical differences in salinity: freshwater from the rivers tends to sit at the surface because of its lower density, whilst the denser marine water entering from the ocean makes up the bottom layers. These layers require energy to mix – either from wind, currents or shear due to movement between the two layers. The strength and persistence of stratification varies within an estuary, seasonally and even daily, depending on the river flow, tidal conditions and distance from the ocean entrance.

Stratification greatly influences estuarine chemistry and biology, especially the oxygen status of bottom waters. Strong stratification causes a physical barrier preventing the diffusion of oxygen from the surface to the bottom waters.

In estuaries with significant algal productivity, the bottom layer also has a large amount of organic matter which is decomposed by oxygen-consuming bacteria. Oxygen can be depleted rapidly and when stratification persists, low oxygen (hypoxic) or no oxygen (anoxic) conditions emerge. These conditions are inhospitable to bottom-dwelling animals, and no oxygen in the bottom waters gives rise to rotten-egg-smelling hydrogen sulfide gas, which is also toxic. Sediment chemistry is altered by anoxia, releasing sediment-bound nutrients and adding to eutrophication problems.

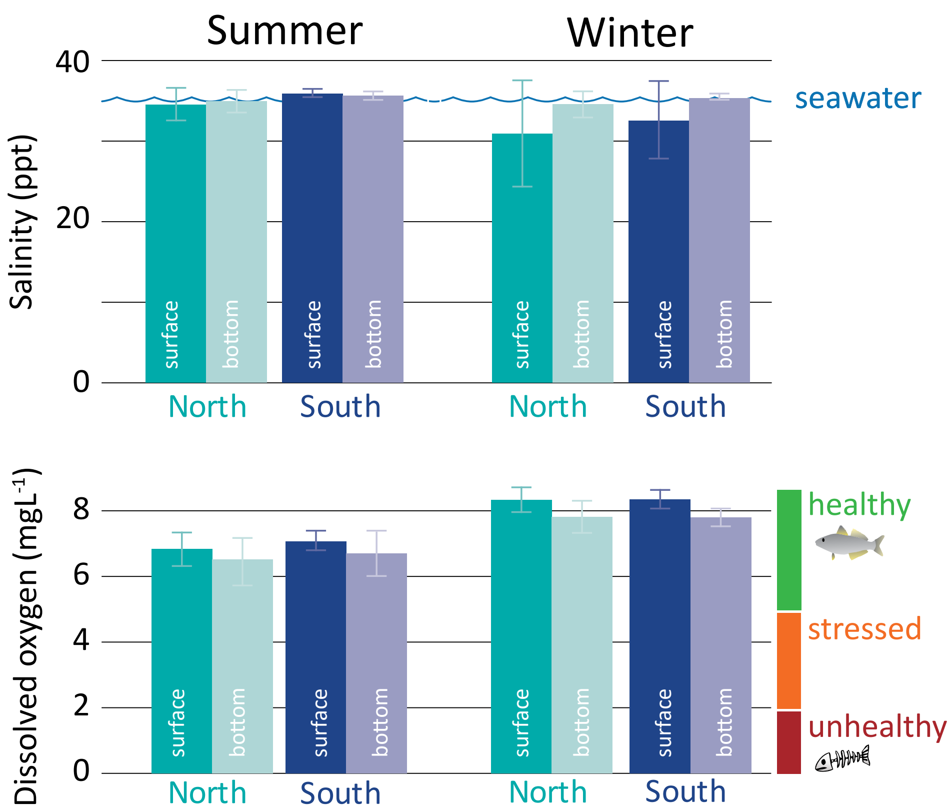


Salinity and oxygen concentrations

Seasonal averages, 2016–19

In summer, the salinity levels of both surface and bottom waters in the north and south of Oyster Harbour are close to being at marine levels. The average dissolved oxygen values were in the healthy range. Bottom dissolved oxygen was slightly lower, particularly in the north of the harbour. This is due to the breakdown of organic matter, which consumes oxygen – a typical process in most estuarine ecosystems.

Winter salinities were slightly lower in the surface waters and varied more, due to the influence of fresher river inflows, yet remained in the 'saline' zone. This indicates river inflows have a relatively small impact on salinity. Average oxygen concentrations were well within the healthy range throughout the period.

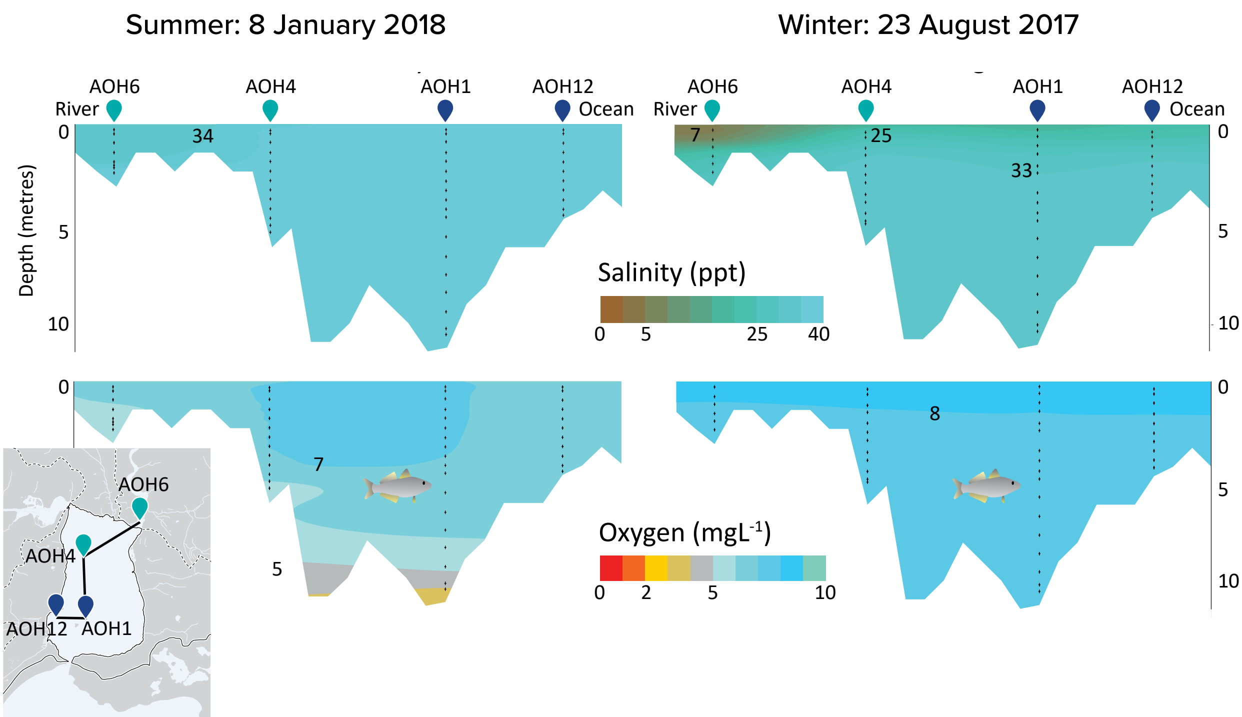


The figures below show a vertical slice through the estuary at one sampling time. The left edge of each plot is the river side, the right is the ocean side and the sediment is at the bottom. These contour plots show us a typical summer condition (for example, 8 January 2018), and the winter condition at the time of maximum freshwater flow (23 August 2017).

In summer, when river flows are very low, the estuary salinity was close to ocean salinity (35 parts per thousand) and uniform throughout the depth.

Oxygen concentrations were mostly good: greater than five mgL-1. However, occasionally oxygen was depleted (<5 mgL-1) in the deepest part of the harbour.

In August 2017, the winter contour plot shows the time of the highest river flow seen during the 2016–19 period. In the north, there is a surface plume of low salinity (nearly fresh) water, less than seven parts per thousand (ppt). The gradient from seven to 33 ppt illustrates a stratified layer extending across the estuary from zero to two metres. Below this, the 'marine' bottom layer is well mixed, as indicated by the absence of contour lines. This stratification was short lived and did not have an impact on oxygen status, with good oxygen concentrations from seven to nine mgL-1 throughout the depth.



In the estuary:

nutrient and chlorophyll concentrations

Nitrogen and phosphorus are the most important nutrients for plant growth. These nutrients 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 (the organic or particulate forms) are not immediately available to plants and algae – they must be remineralised first.

As discussed earlier, catchment inflows are a key source of nutrients for most estuaries. Sediments can also be a significant source of dissolved nutrients where there is persistent stratification and large amounts of organic matter.

By measuring the seasonal pattern of nutrient concentrations in the surface and bottom water samples, we can determine whether these nutrients are coming from the catchment or sediments.

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

Spatial and seasonal patterns

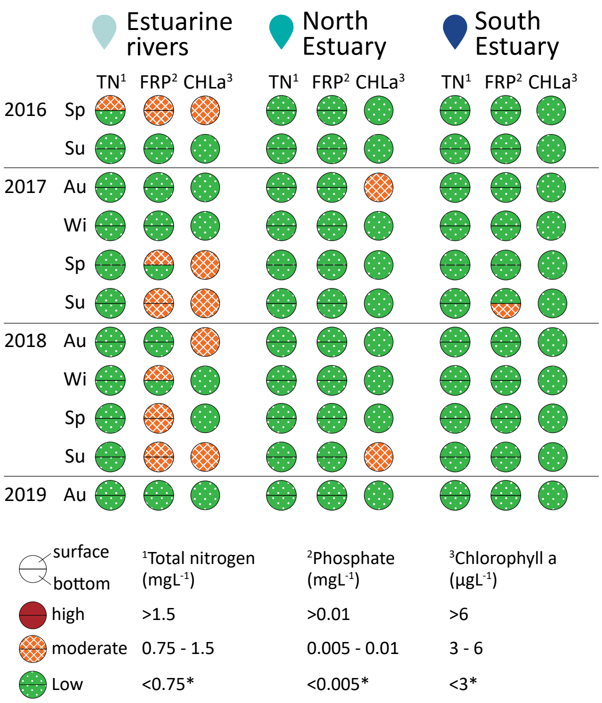
In 2016–19, nutrient and chlorophyll *a* concentrations were generally low, with some exceptions. In the estuarine river sites (Kalgan and King), average (or mean) phosphate and chlorophyll *a* concentrations were often moderate, particularly in spring and summer.

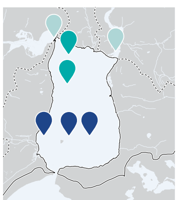
The nutrient and chlorophyll *a* averages in the northern harbour were low most of the time, except on two occasions when chlorophyll *a* was moderate.

The estuarine river sites had the highest nutrient concentrations. Algal activity was moderate in spring, summer, and autumn in the estuarine river sites and in two seasons in the northern harbour.

Other nutrient forms such as nitrate and ammonia are not shown but were all in the low category.

The 2016–19 period demonstrates that sediments are not a major contributor to the estuary nutrient concentrations compared to catchment inputs. We can infer this from the fact that bottom water means were either equal to or below surface water means.





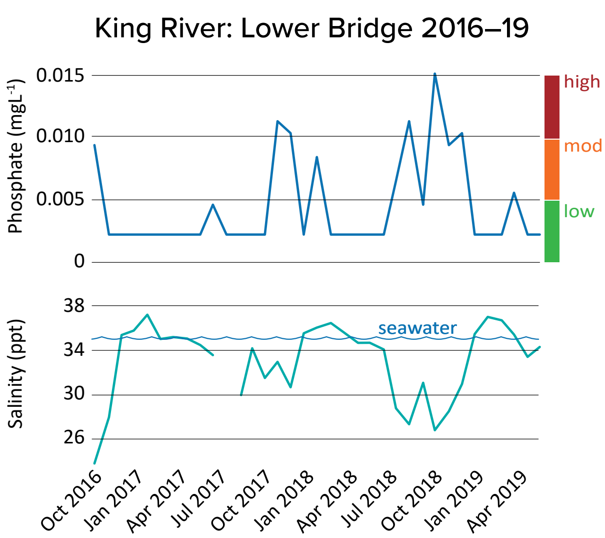
* ANZECC guideline values for southwest estuaries

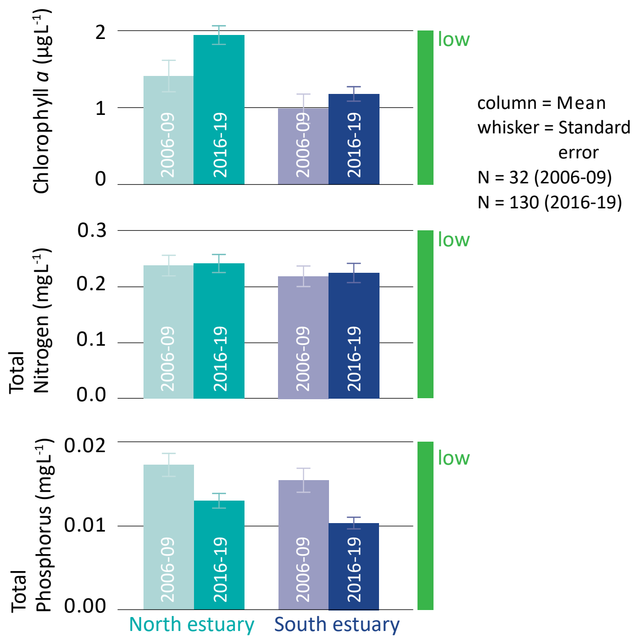
High phosphate in low flows

If we look at the King River Lower Bridge (KRLB) site in more detail, we can see that moderate to high phosphate concentrations occurred when salinities decreased to below seawater levels (35 ppt). This is evidence that the estuary gets its nutrients from the King River, rather than via the breakdown of organic matter or release from sediment. The fact that small flows in spring 2018, a very low-flow year, resulted in high phosphate concentrations could explain the moderate chlorophyll means seen in the summer months. As mentioned earlier, these small nutrient-rich inflows, when delivered to the estuary in the warmer months, can promote algal growth. The predicted increase in the frequency of summer rainfall events will therefore make the northern estuary vulnerable to eutrophication.

Comparison with historical data[17]

The 2016–19 averages of nutrients and chlorophyll were similar to the 2006–09 monitoring period, with some subtle differences. Chlorophyll *a* was slightly higher in recent years especially in the north, but still in the low category. Average nitrogen concentrations were similar between monitoring periods, and slightly higher in the north. Phosphorus means were also slightly higher in north but lower in the 2006–09 period. A more comprehensive comparison with historical data is not possible as the number of sites monitored and samples taken historically were much fewer than the current program.





[17] *The historical data was available for two sites only – one in the north and one in the south – so we cannot compare it directly with the estuarine river sites.*

Recreational water quality:

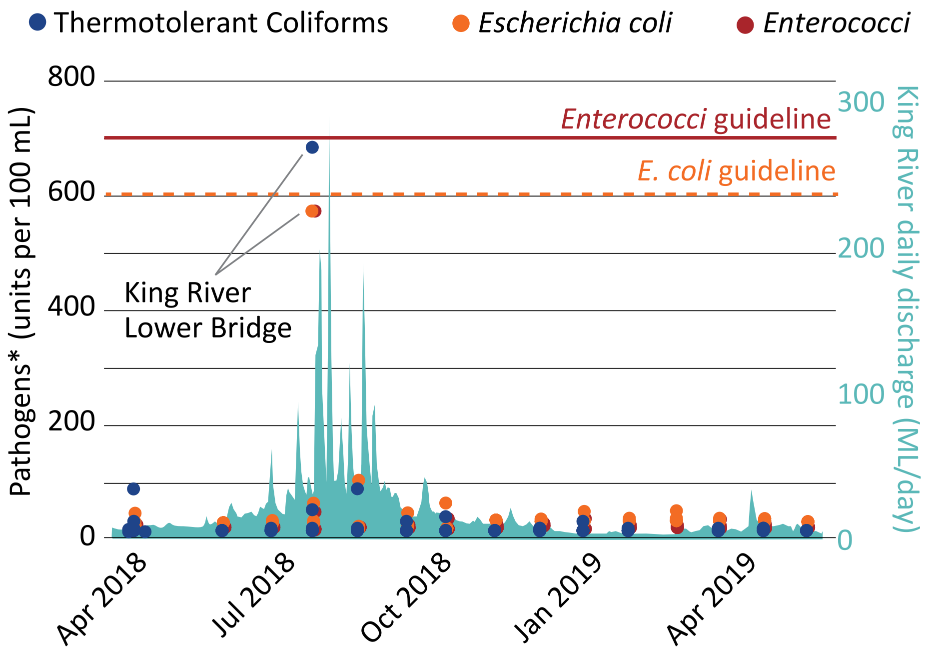
bacteria in water

Recreational water quality is evaluated by bacterial sampling at several sites statewide. Sampling for bacterial analysis was included in the current program from April 2018 in coordination with the Department of Health. Very low levels of pathogens were recorded throughout the estuary, except for one event at the King River Lower Bridge site in August 2018. These elevated results were associated with the start of winter flows.

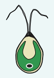
Monthly bacterial sampling indicated that recreational water quality was excellent. We note that monthly sampling might miss some contamination events, but the data provides valuable background information.

Key point:

- ⇨ recreational water quality was excellent more than 90 per cent of the time.



*Analysis courtesy of the Department of Health



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

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

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

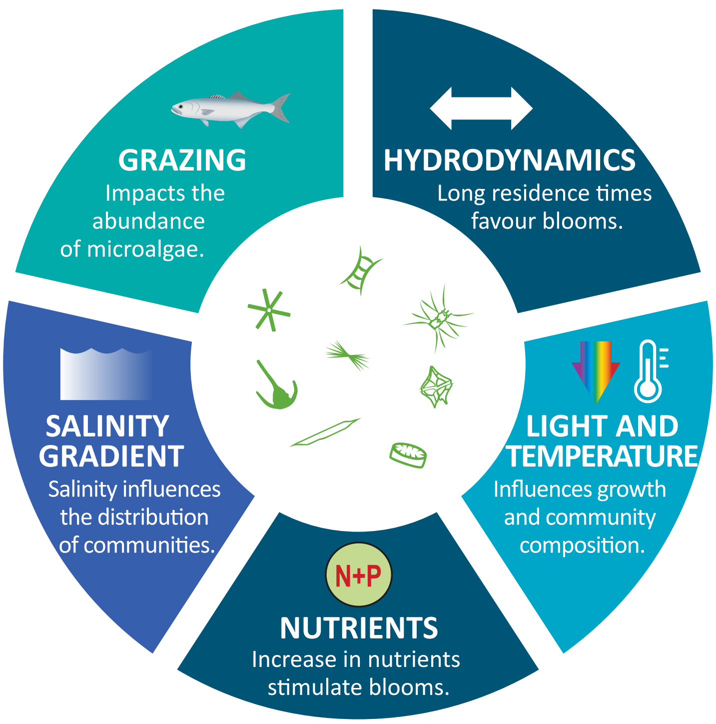
Dinophytes use their flagella to move through the water column, and many are also mixotrophic, meaning they can photosynthesise and/or ingest prey for growth. Dinophytes also contribute to many of the world's nuisance algal species and are sometimes toxic.

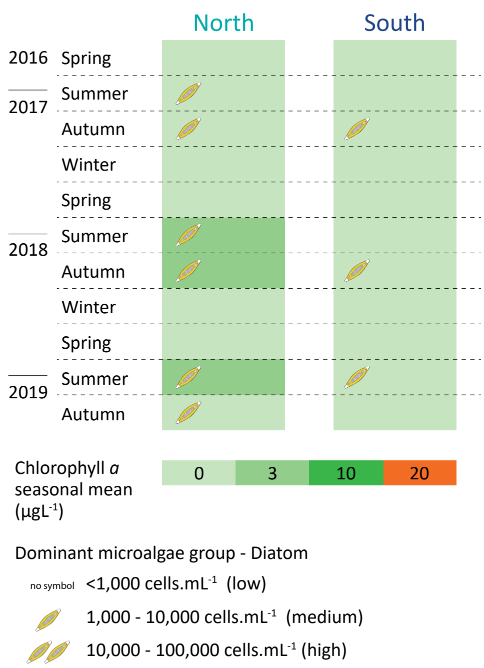
Microalgae dynamics

Microalgae, also known as phytoplankton, are tiny photosynthetic organisms and play a huge role in removing carbon dioxide from the atmosphere and generating the oxygen we breathe. As a key component of healthy ecosystems, they provide food for invertebrates and fish. During the day they photosynthesize, which oxygenates the water. However, excessive nutrients, warmer water temperatures and/or reduction in 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: they can reduce light availability to seagrasses; rapidly remove oxygen from the water when they decompose, causing fauna deaths; and certain species can produce toxins, which can be harmful to aquatic fauna (such as fish, crabs and dolphins) and also 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. Analogous to studying plant communities on land, we investigate whether there is a community of desirable and diverse species, or whether it is dominated by undesirable plants such as weeds. This can tell us if 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 in the table below are just some varieties present in estuarine microalgal communities.





Microalgae:
seasonal patterns

Diatoms were the dominant microalgal group in Oyster Harbour during 2016–19. Diatom cell densities peaked in summer and autumn, like the chlorophyll *a* seasonal pattern. Total microalgal cell densities were almost three times higher in the north compared to the south in the dry months, but comparable in the wet months.

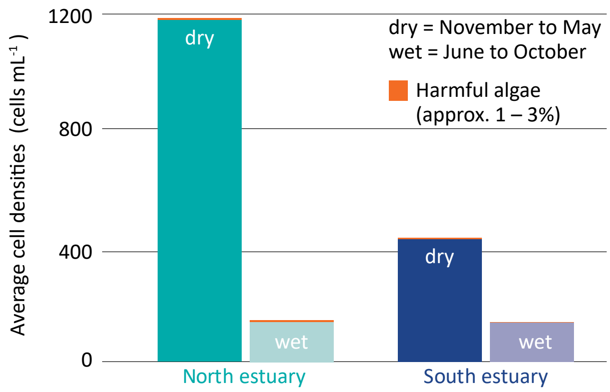
Potentially harmful algal blooms are a response to eutrophication in coastal and inland waters. Our monitoring and analysis program includes the identification and enumeration of all species, including the potentially harmful ones. They can be a threat to human health, fish, marine mammals and sometimes birds, if sufficient toxins are produced or cell numbers are high enough to cause other damage (such as depleting oxygen levels or clogging fish gills).

Overall, in the 2016–19 period, across both seasons and in both the northern and southern estuary zones of Oyster Harbour, harmful algae represented a very small proportion of the average total microalgae densities. Some harmful species, however, can be toxic in very low numbers if they are concentrated in oysters or mussels. Most of the potentially harmful species identified during the three-year period were well below the Department of Water and Environmental Regulation's interim ecological trigger values, with only three exceptions, which were isolated events. Shellfish operations have an independent monitoring program of their aquaculture sites, which is administered by the Department of Health.

Key points:

- peak algal activity occurs in the summer and autumn months and more so in the north
- diatoms were consistently the dominant microalgal group
- numbers of potentially harmful algal species were low, only very occasionally exceeding guidelines in the northern harbour.

Total microalgae 2016–19



When the Department of Water and Environmental Regulation's ecological trigger values are exceeded, the relevant government authorities, such as the Department of Health and City of Albany, are notified. Based on this information, the Department of Health provides advice on human health effects, such as skin irritation or illness associated with shellfish consumption. Sometimes this results in warnings and/or further investigation.

Note: the Department of Water and Environmental Regulation's interim ecological trigger values are adapted from multiple guidelines and local/historical knowledge and are subject to annual review. In the case of Oyster Harbour, as a large area is now an aquaculture development zone, we have applied the WA Shellfish Quality Assurance Program[18] guidelines to relevant species and the Department of Water and Environmental Regulation's interim guidelines for all other species.

[18] Western Australian Shellfish Quality Assurance Program 2016, *Marine Biotoxin Monitoring and Management Plan 2016: Western Australia Shellfish Quality Assurance Program,* Department of Health, Perth.

Seagrass success story

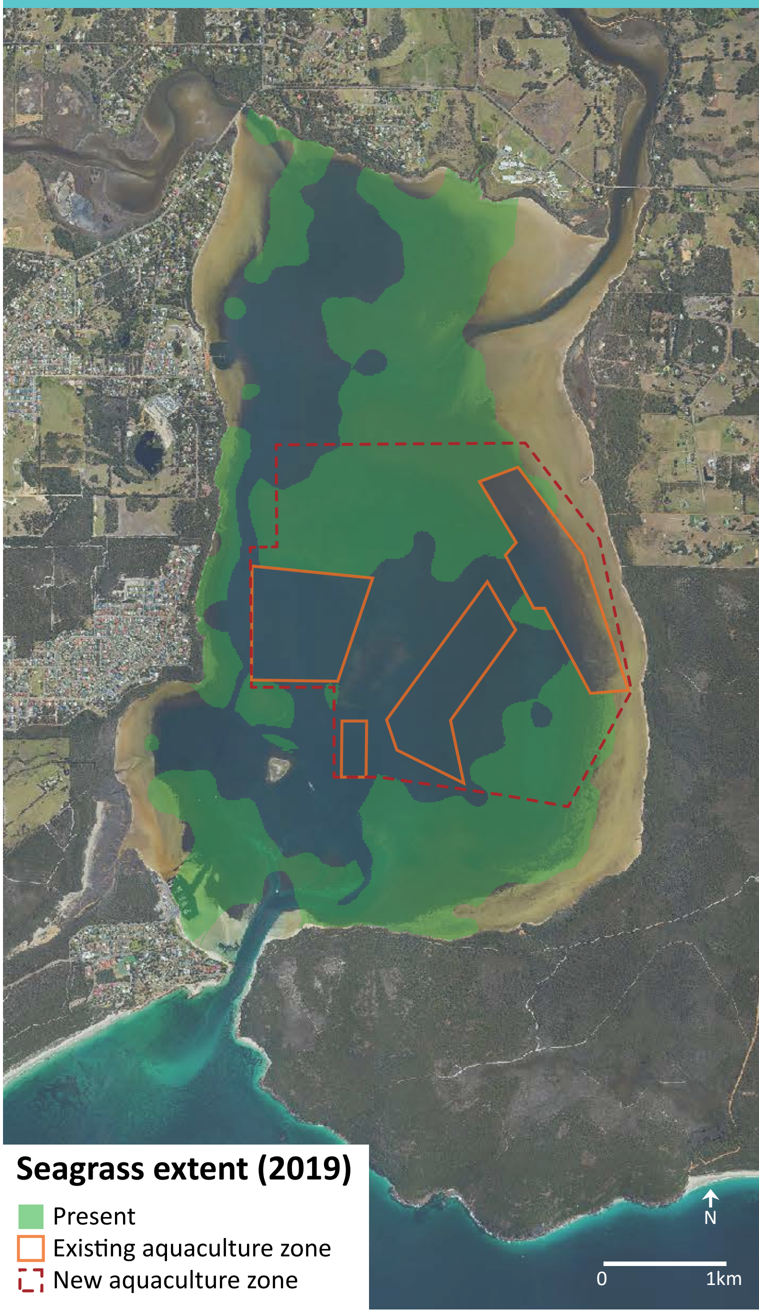
Seagrasses are flowering plants which have evolved from land plants and adapted to live underwater in estuarine or marine environments. They are important components of aquatic ecosystems, providing habitat and food for fish, birds and crustaceans. Seagrasses also contribute to maintaining healthy estuaries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

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

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

Key points:

- seagrass area in 2019 has increased 9 per cent since 1962, despite an 80 per cent loss from 1962 to 1988
- recovery is due to two key actions: improved catchment practices to reduce nutrients, and 20 years of seagrass transplanting.



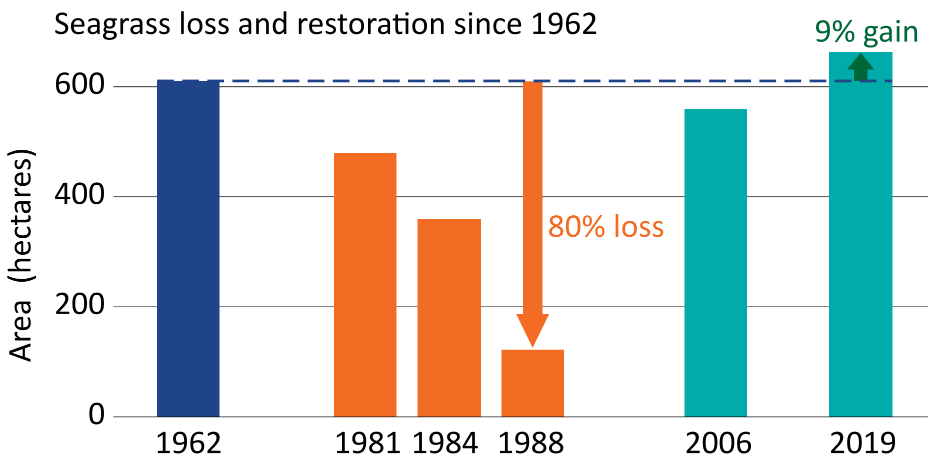
Seagrass habitat in Oyster Harbour is dominated by *Posidonia australis* and *Posidonia sinuosa*. In 1962, these varieties covered an area of 610 hectares.[19] By 1988, 80 per cent of the seagrass cover was lost, mainly due to nutrient enrichment causing excessive epiphyte growth and resultant light reduction.[20] Nutrient enrichment was attributed to extensive catchment clearing and expansion of agricultural activities in the post-war period.

A recent survey of seagrass in Oyster Harbour[21] has shown there has been an incredible recovery of habitat, with seagrass now covering an area of 663 hectares – nine per cent more than in 1962. The recovery is due to the improvement of catchment management practices, and a sustained 20-year seagrass transplanting effort.[22]

The expanded aquaculture development zone covers a significant area of seagrass habitat: 196 hectares. This is 30 per cent of the seagrass area mapped in 2019, and includes meadows of seagrass which were transplanted as part of the restoration effort.

Considering the worldwide decline in seagrass habitat, the seagrass recovery in Oyster Harbour is remarkable. It bodes well for the capacity of estuarine environments to recover from eutrophication when appropriate management actions are undertaken.

Seagrass habitats are one of the most rapidly declining ecosystems on Earth. Since the 1940s, these underwater marine plants have been losing seven per cent of their known habitat areas per year.[23]



[19] McKenzie KG 1962, *Oyster harbour: a marginal Environment,* PhD thesis, The University of Western Australia, Perth.

[20] Environmental Protection Agency 1990, *Albany Harbours Environmental Study 1988 1989*, Bulletin 412, EPA, Perth.

[21] Bennett K, Sanchez-Alarcon M, Forbes V, Thornton H and Kilminster K, *Seagrasses in four estuaries in Western Australia's south-west,* Water Science Technical Series, report no. 86, Department of Water and Environmental Regulation, Perth.

[22] Cambridge M, Bastyan G and Walker D 2002, 'Recovery of Posidonia meadows in Oyster Harbour, southwestern Australia', *Bulletin of Marine Science,* vol. 71, pp 1279–1289.

[23] Waycott, M et al 2009, *Accelerating loss of seagrasses across the globe threatens coastal ecosystems,* Proceedings of the National Academy of Sciences, vol. 106, no. 30, pp 12377-12381.

Restoring lost oyster reefs

Native oysters were abundant in Oyster Harbour at the time of early European settlement. But by the late 1800s, 90 per cent were lost. Similar losses were seen across the world.

Oyster reef habitats are highly valuable for aquatic ecosystems – they support high marine biodiversity, provide nurseries for fish and crustaceans, and improve water quality by filtering out microalgae from the water column.

The Nature Conservancy began restoring the oyster reef habitat in late 2019: 1600 m^2 of limestone substrate seeded with oyster spat was placed in the southern part of Oyster Harbour. Oyster spat was supplied by the Albany shellfish hatchery. The success of this project will further improve water quality and increase biodiversity in Oyster Harbour.

Note that the native oyster reefs are for habitat restoration and not a food source for harvesting.

Text and image courtesy of Alex Hams, The Nature Conservancy

Outlook

Nutrient pollution and climate change are the biggest risks to the health of estuaries along the south coast of Western Australia. We have already observed dramatically reduced river flows. 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, and 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.

Management should continue to focus on building resilience and adaptability where possible. For Oyster Harbour, this means supporting ecosystem activities such as seagrass and native oyster reef restoration, and continuing catchment efforts that minimise the delivery of nutrients and sediments to the estuary. We should pay attention to the King River subcatchments, as these deliver relatively high nutrient loads during low-flows in spring, summer and autumn. Aquaculture in the expanded aquaculture development zone should be managed with sensitivity to ensure protection of the valuable seagrass habitat.

Increasing carbon dioxide concentrations in the atmosphere are leading to acidification in coastal waters across Australia, and especially in the Southern Ocean. The trend in increasing sea surface temperatures will also promote microalgal growth. The combined impact of these events 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 climbing 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 and economic values.

More information

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

This has included:

- **restoring** stream function and moving stock away from waterways in partnership with the Oyster Harbour Catchment Group
- **reducing** nutrient runoff from farms through improved fertiliser management practices in partnership with the Department of Primary Industries and Regional Development, farmers, industry, and the Oyster Harbour Catchment Group
- **supporting** the scientific monitoring of Oyster Harbour and its catchments
- **improving** drainage networks to enhance water quality entering Oyster Harbour from the Yakamia Creek catchment, in partnership with the City of Albany and South Coast Natural Resource Management.

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

What you can do

Farmers

Base fertiliser management decisions on soil test results.

Fence streams from livestock and restore native vegetation.

Homeowners

Adopt best fertiliser practice in your gardens.

Plant natives.

Local communities

Stay informed through the estuaries website.

Join your local catchment group.

Report algal blooms and unusual fish deaths.

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

#WAestuaries

HEALTHY ESTUARIES WA