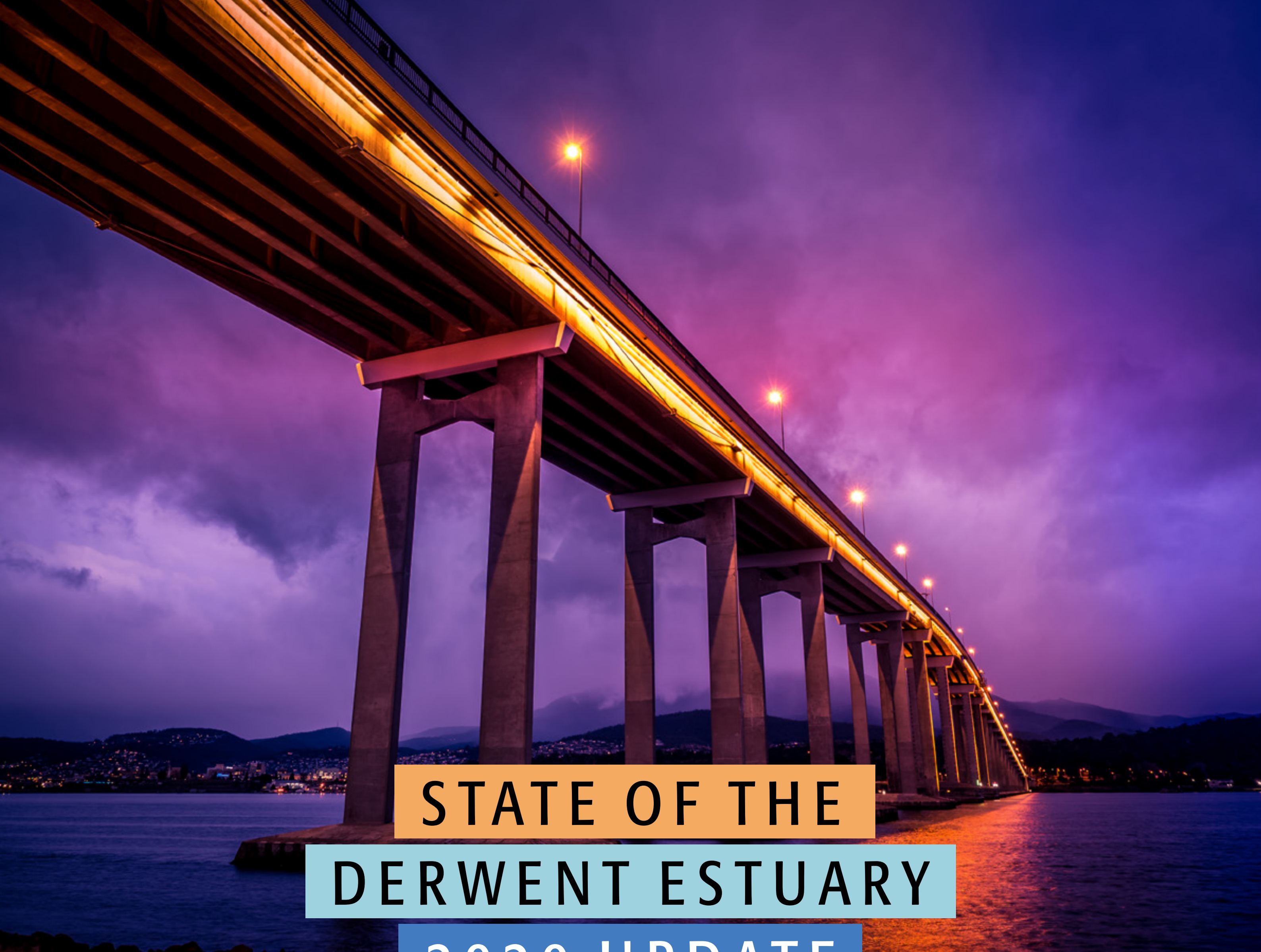

STATE OF THE DERWENT ESTUARY
2020 UPDATE

An update and review of environmental data and activities

Derwent Estuary Program

STATE OF THE DERWENT ESTUARY 2020 UPDATE

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Derwent Estuary Program

The Derwent Estuary Program pays respect to the traditional and original owners of this land and acknowledges today's Tasmanian Aboriginal people as the continuing custodians.

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The Derwent Estuary Program

The Derwent Estuary Program (DEP) is a regional not-for-profit partnership between local governments, the Tasmanian state government, businesses, scientists and the community to share science for the benefit of our estuary. The DEP was established in 1999 and has been nationally recognised for excellence in coordinating initiatives to reduce water pollution, conserve habitats and species, monitor river health and promote greater use and enjoyment of the foreshore. Our major sponsors include: Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough councils, the Tasmanian State Government, TasWater, Tasmanian Ports Corporation, Norske Skog Boyer, Hydro Tasmania and Nyrstar Hobart. We also work collaboratively on projects with the CSIRO Marine and Atmospheric Research, University of Tasmania, Institute of Marine and Antarctic Studies, Derwent Catchment Project and NRM South.

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Executive Summary

The Derwent estuary defines the City of Hobart. It is at the heart of our community and integral to our way of life. We rely on the river for our drinking water and the estuary for our industry, and our wellbeing. Rivers and estuaries worldwide, including the Derwent are under pressure and maintaining their environmental health can be difficult. Issues that affect the Derwent include:

- Metal contamination of water, sediments and seafood.
- Loss and pollution of estuarine habitats and species through urbanisation.
- Introduced marine pests and weeds.
- Altered river flow regimes and blocked fish migration routes.
- Elevated levels of nutrients and low dissolved oxygen levels in localised areas.
- Climate change.

The Derwent Estuary Program (DEP) was established in 1999 to fill gaps in our understanding about the health of the estuary. Specifically, the DEP manages a comprehensive, integrated monitoring program that documents environmental conditions and trends that supports scientific research and informs environmental management. Cooperative monitoring arrangements with the State Government, industries, local governments and the scientific community have generated a wealth of new information on water and sediment quality, seafood safety and estuarine habitats and species, which have been analysed and interpreted in this new report.

Whilst all human actions have an impact, the Derwent estuary is fortunate to have industrial managers who collaborate and work together to manage this shared asset. By taking responsibility for their environmental impacts and repairing past damage we are seeing improvements in the Derwent's environment to the benefit of all the lives it supports and enriches.

State of the Derwent estuary – 2020 update

The new State of the Derwent estuary report reviews environmental quality data collected by the DEP and other stakeholders to give an overview of current estuary health and to highlight environmental trends. **Section 1** reviews Derwent estuary values and uses and provides an overview of the estuary's physical setting. **Section 2** reviews pollutants associated with point and diffuse sources and documents trends. **Section 3** and **Section 4** provide updates on the Derwent estuary habitats and iconic species, including introduced pests and weeds.

For background details about DEP sampling methods, Quality Assurance and Control, data management, nutrient definitions and map references please see Appendices A-F.

Highlights

Catchment (Section 2.2)

The Derwent estuary's catchment covers an area of approximately 9000 km^2 in central and southeastern Tasmania (approximately one-fifth of Tasmania's land mass) and comprises the River Derwent catchment (7500 km^2), the Jordan River catchment (1250 km^2) and other areas immediately adjacent to the estuary (375 km^2).

The River Derwent contributes the majority of freshwater input to the estuary, and both flow and water quality are vital for the health of the estuary (e.g. **Section 2.5**). Key findings from investigations in the catchment:

- River Derwent water allocations have steadily increased in the past 20 years but actual water use in terms of volume and timing is currently impossible to evaluate due to the lack of metering in the catchment and Tasmania in general.
- Nutrient levels from agriculture-dominated catchments were at a maximum during winter months, while fish-hatchery-dominated tributaries showed maximum levels during summer months.

Metals (Section 2.3)

The main sources of metal contamination to the Derwent estuary are principally historical, and while modern environmental management practices have markedly improved, the legacy of former practice still affects the Derwent estuary and will most likely persist for many decades. Current owners of the zinc smelter site have embarked on significant remediation projects to reduce ongoing sources of metal contamination to the estuary, and there are good signs that metals are declining. Key findings:

- Metals have declined in ambient water and surface sediments.
- Metals in fish and shellfish from the estuary still exceed health guidelines or generally expected levels, so the advice from the Department of Health advice about their consumption remains unchanged:
  - Do not eat any shellfish or bream from the Derwent, including from Ralphs Bay.
  - Do not eat other fish from the Derwent more than twice a week and the following people should further limit their consumption to once a week:
    - Pregnant and breastfeeding women
    - Women who are planning to become pregnant
    - Children aged six years and younger
  - When eating fish from the Derwent, it is best to avoid eating fish from other sources in the same week.

Nutrient enrichment (Section 2.4)

Human population growth and industrialisation such as the disposal of wastewater treatment plant effluent, agriculture, aquaculture, paper and fertiliser production, and urban runoff have increased nutrient inputs to many times their natural levels in the estuary. Key results include:

- The upper estuary experiences stress because of high nutrients and low dissolved oxygen, particularly in summer and early autumn.
- Nutrients in the middle estuary have increased over time.
- Improvements to wastewater treatment plants have reduced nutrients from some point sources, particularly at Blackmans Bay, Cameron Bay and Prince of Wales Bay.

Hypoxia (Section 2.5)

Dissolved oxygen is essential for the survival of higher-order organisms including benthic invertebrates and fish. Severe oxygen depletion (hypoxia) is a global problem typically driven by human activities including excessive supply of organic matter and flow modification. Key findings in the Derwent include:

- Approximately 100 hectares of the upper Derwent estuary experiences severe oxygen depletion each summer and autumn.
- Hypoxia dynamics are influenced by river discharge and organic matter loads to the hypoxic zone. Potentially influential human sources of organic matter are the various activities in the River Derwent catchment, the Boyer paper mill and the New Norfolk wastewater treatment plant.

Pathogens (Section 2.6)

Recreational water quality (RWQ) monitoring of beaches and bays in the Derwent estuary throughout each summer (December-March) is coordinated by the DEP in collaboration with DoH (Department of Health), EPA (Environmental Protection Authority) and the six councils that border the estuary (Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough). The primary objectives of the RWQ program are to coordinate the monitoring program; provide the public with up to date information about where they can safely swim; and assist councils and the DoH in managing human health risks associated with poor water quality. Key findings include:

- No swimming sites were rated as 'Poor' at the conclusion of the 2019-2020 season for the first time in over a decade.
- The Nutgrove Beach (west) swimming site improved to a 'Fair' rating at the conclusion of the 2018-2019 season, after a decade of being rated 'Poor'.

Stormwater (Section 2.7)

Increased urbanisation in catchments draining to the Derwent estuary has resulted in many impervious surfaces. The impacts of stormwater pollution pose a significant threat to ecosystem and human health in the Derwent estuary. Urban stormwater is contaminated with many pollutants, including suspended solids, metals, nutrients, litter, hydrocarbons, oxygen-demanding waste (decomposing organic matter), and pathogens. Key projects include:

- Support for councils in managing stormwater quality, by developing a voluntary policy that will guide planning permit conditions.
- A *Source Tracking Tool Kit* developed by DEP is available to councils to help them identify faecal contamination sources in the stormwater network and this is having positive results across the estuary, particularly in reducing pollution reaching beaches.

Habitats (Section 3)

There are numerous habitats in and beside the estuary, including seagrass, wetlands, rocky reefs and terrestrial foreshore. Key findings and actions include:

- Seagrass health is vulnerable to low river discharge and excessive nutrient enrichment. Its condition in the last five years has fluctuated, but it has generally improved since 2015-2016 when large algal blooms smothered this habitat. Conditions for optimal seagrass health continue to be investigated.
- Work has begun on a Foreshore Strategic Weed Assessment and Prioritisation Plan by DEP and its partners.
- No rice grass (*Spartina anglica*) has been observed in the Derwent estuary since spring 2016.
- The condition of a representative cross section of saltmarsh patches in the estuary has been documented, and DEP and UTAS will work with public and private landowners to implement management recommendations.
- The seabed in the mid-estuary is dominated by invasive species.
- Rocky reefs in the mid-estuary are dominated by invasive species, but in the lower estuary, where waters are more stable and less affected by human impacts, they support a diverse ecosystem.

Iconic species (Section 4)

Little penguins and the endangered spotted handfish are a focus for the DEP. Key findings include:

- While still in low numbers, surveying suggests that the Little Penguin population in the estuary remains steady.
- Surveying confirms that there is year-round breeding in the Little Penguin colonies, though primarily during spring/summer.
- A new captive breeding project for the endangered spotted handfish is proving successful with 30 juveniles released so far. The wild population is still at critically low levels.
- Spotted handfish survey techniques have been revised; artificial spawning habitats continue to be refined; new knowledge has been gained about handfish biological parameters and its preferred habitat; and environmentally friendly boat moorings have been installed in some locations to prevent damage to spotted handfish habitat.

Recent and ongoing management

A number of initiatives have been implemented by industries and councils to further improve water quality in the Derwent since the last State of the Derwent estuary report was published in 2015, including:

- Continuing site works at Nyrstar Hobart Smelter, with the completion of the site-wide stormwater catchment program, catching and treating all contaminated stormwater from the site, and the construction of a 700 m long pressure-injected grout curtain, installed in early 2020 through the centre of the site that interrupts the groundwater pathways, enabling a higher volume of groundwater to be extracted and treated through their on-site effluent treatment plant. Upon completion of an additional upgradient horizontal drain, the new grout curtain and associated groundwater extraction system will increase the volume of treated groundwater from the current 10 m^3/day to an estimated total of 94 m^3/day.
- The Blackmans Bay Wastewater Treatment Plant (WWTP) was upgraded by TasWater in 2019 to accept waste from Snug, Electrona and Margate whilst improving plant performance such that reduced loads were discharged to the Derwent. TasWater's campaign to improve the treatment of wastewater resulted in improved effluent quality from Cameron Bay and Prince of Wales Bay WWTPs.
- Local councils have helped improved stormwater quality by constructing eight 'Water Sensitive Urban Design' systems, including rain gardens on streetscapes and large treatment wetlands. Fourteen gross pollutant traps were installed around the estuary to capture litter and treat pollutants.

Major DEP initiatives since 2015 have included establishing the DEP as a not-for-profit company limited by guarantee in 2017, the development and endorsement of the *DEP Business Plan 2019 – 2024* and signing of a new five-year partnership agreement in 2019. Other key projects include:

- continued monitoring and reporting on recreational and ambient water quality, rivulets, and seafood safety.
- initiatives to improve regional stormwater management (e.g. 'Water Sensitive Urban Design' training, preparation of a stormwater policy for planners and developers).
- planning, monitoring and investigations, and providing recommendations for management of key habitats (e.g. baseline surveys of wetlands, saltmarshes, macrophytes and seagrasses, and rocky reefs).
- facilitation of monitoring and management of iconic and protected species (e.g. Little Penguins, spotted handfish).
- continued management and control of rice grass and support of karamu management.
- initiatives to better understand community values, raise awareness, and increase enjoyment of the estuary (e.g. community survey, educational projects and communicating our science to the public via report cards and media avenues).

Acknowledgement

This report was produced with financial and technical support from the Derwent Estuary Program's major partners:

- Tasmanian State Government (including the Environment Protection Authority, Department of Primary Industries, Parks, Water, and Environment and the Department of Health)
- Brighton Council
- Clarence City Council
- Derwent Valley Council
- Glenorchy City Council
- City of Hobart
- Kingborough Council
- Nyrstar Hobart
- Norske Skog Boyer
- TasWater
- Tasmanian Ports Corporation
- Hydro Tasmania

In addition to the partners listed, many people provided information, editorial review and other input to this document. Specific references are provided in the text of the report, so rather than listing individuals here, we wish to acknowledge their respective organisations, which include the following:

- University of Tasmania, including the Institute of Marine and Antarctic Studies
- Commonwealth Scientific and Industrial Research Organisation
- Agriculture and Water Division, DPIPWE
- Aquenal
- Derwent Catchment Project
- Aboriginal Heritage Tasmania
- Tasmanian Aboriginal Centre
- Marine and Safety Tasmania
- Local Government Association Tasmania

A special thanks to our colleagues at EPA Tasmania, Norske Skog, Nyrstar, local governments, Splashback, Myriad Research, Analytical Services Tasmania and the Public Health Laboratory, who assisted in the collection and analysis of the thousands of samples that form the basis of much of this report.

Many thanks also to Ed Butler for scientific review and editorial assistance and Kelly Eijdenberg for report design and layout.

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1

Setting the scene

1 Setting the scene

The Derwent estuary lies at the heart of the Hobart metropolitan area and is an asset of great natural beauty and diversity (**Figure 1.1**). It is an integral part of Tasmania's cultural, economic and natural heritage. The estuary is an important and productive ecosystem and was once a major breeding ground for the southern right whale.

Areas of wetlands, seagrasses, tidal flats and rocky reefs support a wide range of species, including black swans, wading birds, penguins, dolphins, platypus and seadragons, as well as the endangered spotted handfish.

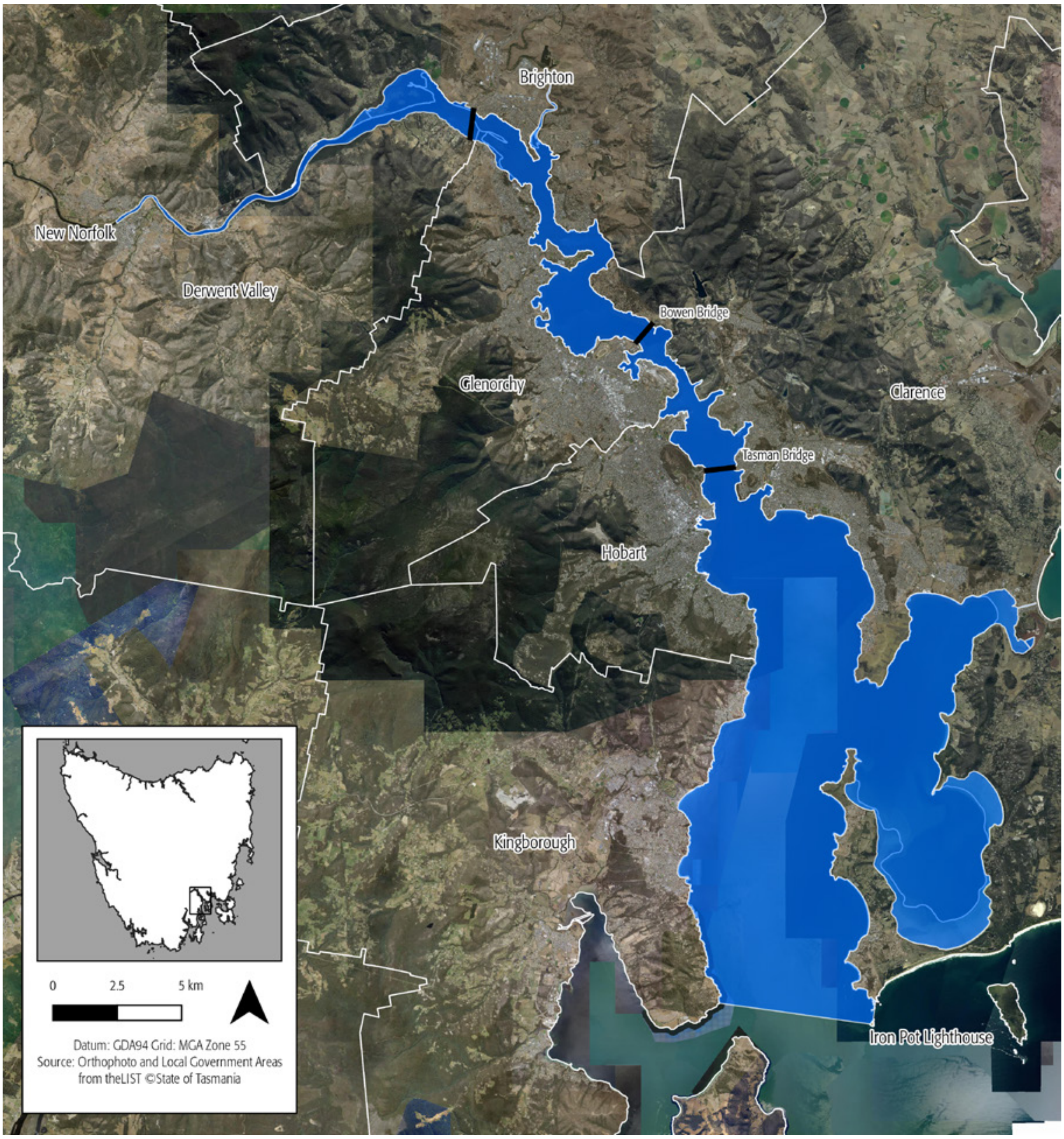


Figure 1.1 Derwent estuary extent and surrounding local government areas.

Approximately 226,800 people–40% of Tasmania's population–live around the estuary's margins (ABS, 2019). The Derwent is widely used for recreation, boating, fishing and marine transportation, and is internationally known as the home of MONA (the Museum of Old and New Art), the finish-line for the Sydney–Hobart Yacht Race and a gateway to the Antarctic. The Derwent estuary supports several large industries, including paper and zinc production, boat-building and chocolate manufacturing. Upstream, the Derwent supplies most of Hobart's drinking water, supports irrigation in southern Tasmania and is an important source of hydro-electric power.

Many pressures affect the Derwent estuary, in particular:

- Metal contamination of water, sediments and seafood.
- Loss and pollution of estuarine habitats and species through urbanisation.
- Introduced marine pests and weeds.
- Altered river flow regimes and blocked fish migration routes.
- Elevated levels of nutrients and low dissolved oxygen levels in localised areas.
- Climate change.

Key stressors are discussed in detail in **Section 2**.

1.1 Derwent Estuary Program

The Derwent Estuary Program (DEP) is a regional not-for-profit partnership between the Tasmanian Government, local governments, industry, scientists and the community. The DEP shares science to enable decisions for sound environmental management, and to guide the public in their choices around recreation and community activities. The DEP was established in 1999 and has been nationally recognised for excellence in reducing water pollution, conserving habitats and species, monitoring river health and promoting greater use and enjoyment of the foreshore (https://www.derwentestuary.org.au/).

In 2017, the DEP registered as a not-for-profit company limited by guarantee. In 2019 a new, voluntary partnership agreement was signed by the DEP partners to continue the collaborative arrangements for another five years (2020–2025). Guiding the DEP's project priorities is a Business Plan 2019-2024.

During the period from 2015 to 2020, the DEP's partners and supporters have included:

- Tasmanian State Government
- Brighton Council
- Clarence City Council
- Derwent Valley Council
- Glenorchy City Council
- City of Hobart
- Kingborough Council
- TasWater
- Norske Skog Boyer
- Nyrstar Hobart
- Tasmanian Ports Corporation
- Hydro Tasmania
- Institute of Marine and Antarctic Studies/University of Tasmania
- Commonwealth Scientific and Industrial Research Organisation
- NRM South
- Derwent Catchment Project

The DEP is underpinned by a comprehensive integrated monitoring program that documents environmental conditions and trends, and that supports scientific research into key issues, such as metals and nutrient processing. Cooperative monitoring arrangements with the State Government, industries, local governments and the scientific community have generated a wealth of new information on water and sediment quality, seafood safety and estuarine habitats and species, which have been analysed and interpreted in this new report.

The DEP uses the Derwent Estuary Conservation Action Plan (CAP), which was developed in 2013, to guide and prioritise activities to protect and improve key habitats and species (DEP, 2012). The CAP was developed using a framework devised by the Nature Conservancy in the US (DEP, 2015). Since 2015, the DEP has implemented several recommendations in the CAP, including saltmarsh monitoring, mapping and restoration; foreshore weed surveys, control and strategic planning; monitoring and management of Little Penguins and spotted handfish; and seagrass surveys in the upper estuary.

1.2 Derwent estuary uses

The Derwent estuary is surrounded by Tasmania's largest population centre, and the estuary is widely used for recreation both on and off the water. The estuary is also very much a working waterfront. The Derwent is Tasmania's fourth largest port and is an important regional centre for the shipping of goods. Antarctic support vessels, commercial fishing vessels and, increasingly, cruise ships and visiting military vessels use the Derwent. There are several major water-dependent industries situated on the foreshore, including the Norske Skog paper-mill, the Nyrstar Hobart zinc smelter, Impact Fertilisers and Incat Catamarans, as well as a host of smaller commercial enterprises. The Derwent estuary is an important tourism resource for Hobart, which is the most visited place in Tasmania. These various uses are indicated in **Figure 1.2**, and described in the following sections.

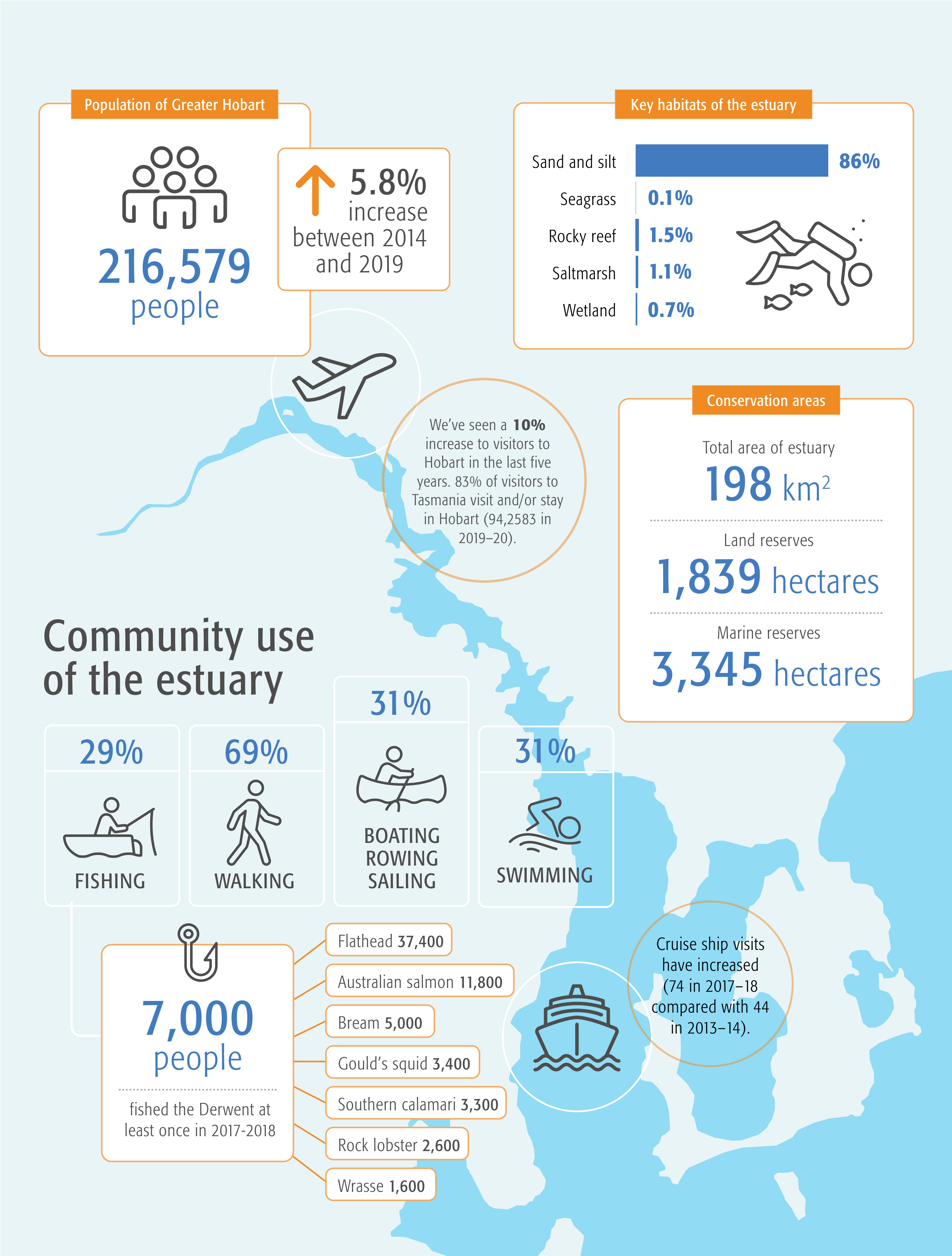


Figure 1.2 Features and uses of the Derwent estuary.

1.2.1 Industry and commerce

Commercial and industrial access to the estuary and river were critical to the early economic development of the region for local transportation, shipping, water supply and wastewater discharge. This dependence has declined over the past 50 years as other forms of transport have predominated; however, a number of water-dependent commercial activities are still situated along the foreshore. These include:

- Prince of Wales Bay maritime industries precinct (construction, maintenance industries), including Incat, which relies on the estuary for construction and maintenance of vessels.
- Nyrstar Hobart Smelter, which relies on the estuary for shipping, water supply and wastewater discharge.
- Norske Skog Paper mill, which relies on the estuary for water supply and wastewater discharge.
- Selfs Point fuel storage facilities, which rely on the estuary for shipping and refuelling of vessels.
- Impact Fertilisers, which relies on the estuary for shipping.
- Domain slipway and other slipway facilities (boat maintenance and some construction).
- Hobart docks / TasPorts Corporation (commercial, tourism and research shipping).
- Sullivans Cove (commercial fishing and tourism).

In addition to these major industries, there are numerous commercial facilities that support recreational and tourism needs, such as:

- marinas and yacht clubs.
- restaurants and cafes.
- ferry cruises, cycle and boat rentals.

1.2.2 Fishing

The Derwent estuary supports an extensive recreational fishing industry throughout its length. In the 12 months prior to October 2017, an estimated 106,200 Tasmanian residents aged 5 years or older fished at least once, representing a 24% participation rate in recreational fishing. (Lyle *et al*., 2019). For recreational fishing, there is an emerging interest in Yellowtail Kingfish and Snapper. There are public health warnings stating that shellfish and bream (due to its long lifespan) should not be consumed, and only limited consumption of other species because of high concentrations of zinc, cadmium and other metals.

Commercial fishing activity is limited in the Derwent, with the area upstream of Dennes Point to Cape Direction a no rock lobster potting area, no gillnetting area and Shark Nursery Area. Commercial fishers may only take scalefish with a special endorsement, with one Danish seine operator endorsed for a whiting "cod-end" net in the Derwent. An average of 19 tonnes of fish was taken for commercial purposes between 2014 to 2019, almost entirely composed of school whiting (Lyle *et al*., 2019).

The Derwent is an important regional home port and unloading area for many fishing vessels, including those catching rock lobster, abalone and scalefish.

There are presently no shellfish or finfish farming operations in the Derwent, nor should shellfish collected from any part of the Derwent (including Ralphs Bay) be consumed because of high concentrations of zinc, cadmium and other metals (**Section 2.3**).

1.2.3 Tourism

In 2019-2020, 1,126,235 interstate visitors came to Tasmania with 942583 (83%) visiting or staying overnight in Hobart (a 10% increase compared with 2013-2014) (Tourism Tasmania, 2020).

Cruise ships and visiting naval vessels are also important contributors to the local economy and tourism industry. Cruise ship visits have steadily increased in the last five years with 74 cruise ships booked to visit Hobart in 2019. In comparison, Hobart received 44 cruise ship visits during 2012-2013. The passengers and crew from these vessels radiate out from the port of Hobart, visiting all regions of southern Tasmania (Tourism Tasmania, 2013; 2019).

1.2.4 Transportation

Shipping and other marine transportation operations on the Derwent are jointly managed by the Tasmanian Ports Corporation (TasPorts) and the Marine and Safety Authority of Tasmania (MAST). The Port of Hobart is Tasmania's southern-most port which supports a diverse range of operations including forestry, bulk minerals, fuel, research vessels, tourism, fishing and recreational activities.

The River Derwent has often been described as one of the world's best harbours, with few rocks, reefs or other hazards. The river has a stable and well-defined channel with a small tidal range and minor to moderate tidal currents. Furthermore, the Derwent has few sedimentation problems that impede navigation, and has many safe anchorages with shelter from prevailing winds. As a result, the River Derwent rarely requires dredging to maintain shipping passages to the critical port facilities. Alongside this however, the River Derwent does possess a navigational challenge – the Tasman Bridge.

On January 10th 1975, the bulk carrier *Lake Illawarra* collided with Hobart's Tasman Bridge, bringing three unsupported spans and a 127-m section of roadway crashing into the River Derwent, where they remain to this day. This event has gone on to shape many of TasPorts' critical pilotage and maritime practices today at the Port of Hobart.

During 2018-2019, 349 vessels visited TasPorts facilities at the Port of Hobart including forestry, bulk commodity, cargo, research, military and cruise vessels. More than 1.9 million tonnes of freight moved through the port, of which, more than 925,000 tonnes were exported and 1 million tonnes were imported. Between October and April, Hobart welcomed 106 cruise ships carrying more than 190,000 passengers and 84,000 crew, providing a critical boost to tourism and the local economy. Alongside this, a number of international Antarctic programs visited the southern port for re-supply operations (pers. comm. S. McLeod, TasPorts, Aug 2020).

1.2.5 Research, education and Antarctic gateway

Hobart is an important centre for research and education, particularly for marine and Antarctic studies. The following research and education centres are located in the area:

- CSIRO Division of Marine Research (Hobart)
- Institute of Marine and Antarctic Studies (Hobart and Taroona)
- University of Tasmania, including the Antarctic Cooperative Research Centre (Sandy Bay)
- Australian Antarctic Division (Kingston)

Several Antarctic icebreakers and other large research vessels are based in Hobart, including the *Aurora Australis*, *L'Astrolabe* and *Investigator*, and a number of other research vessels visit Hobart on a regular basis.

Antarctic tourism is a rapidly growing area. During the Southern Hemisphere summer, a number of ships depart Hobart for Macquarie Island and the Antarctic continent, carrying scientists and tourists to visit and explore these relatively untouched wildernesses. Operators to Antarctica see Hobart as a very important and attractive port, being close to the city and having well-developed infrastructure and suppliers.

1.3 Derwent estuary values

Values of the Derwent estuary include intrinsic natural values associated with land, water and biota, cultural and historical values, and socio-economic values reflected in our current uses. The Derwent estuary is widely used for a diverse range of commercial, industrial, social and recreational purposes. An important regional management goal is to maximise these benefits, while minimising potential environmental damage and conflicts between users.

1.3.1 Natural values

Estuaries are partially enclosed bodies of water formed where freshwater from rivers and streams flows into the ocean, mixing with seawater. These transitional areas between land and sea are typically protected from the full force of ocean waves, winds and storms by the promontories, islands, reefs and sandy spits that mark an estuary's seaward boundary. The sheltered, tidal waters of estuaries support unique communities of plants and animals, specially adapted for life at the margin of the sea. Estuarine environments are among the most productive on earth, producing more organic matter per year than equivalent areas of forest, grassland or agricultural land. The wetlands that fringe many estuaries also provide a number of valuable services. Water draining from the catchment to the estuary carries sediments, nutrients and other pollutants. As this water flows through marshes and other wetlands, pollutants are filtered out creating cleaner and clearer water – a benefit to both people and marine life. Wetlands also act as natural buffers between the land and the sea, absorbing flood waters and dissipating storm surges.

A wide range of habitat types are found in and around estuaries. In the Derwent, these include beaches and dunes, rocky foreshores, saltmarshes and other wetlands, mud and sand flats, seagrass meadows, kelp forests, and rocky reefs. Details about these habitats are given in **Section 3**.

Innumerable birds, mammals, fish, invertebrates and other animals depend on the estuarine habitats of the Derwent as places to live, feed and reproduce. The Derwent is particularly important for migratory birds, which rely on the estuary as a resting and feeding ground during their long journeys. Information about some of our iconic species is provided in **Section 4**.

The estuary's natural values are closely integrated with the social fabric of the region. People are attracted to the region for many of the opportunities that the estuary offers, including aesthetics, recreational pursuits – such as water sports, yachting, fishing and bird watching – and simply being able to connect with the natural environment.

1.3.2 Human heritage values

The Derwent river valley was a major route for Tasmanian Aborigines between the coast and-hinterland for around 40,000 years. The Oyster Bay Tribe on the eastern shore and the South East Tribe on the western shore inhabited the region surrounding the Derwent estuary. Both tribes utilised the Derwent as a source of food, with shellfish, such as oysters and mussels, being a major part of their diet (Ryan, 1996). The Derwent estuary shoreline contains a very high density of Aboriginal sites. These sites include shell middens, stone artefact scatters, rock shelters and quarries, which continue to be destroyed by modern development (Aboriginal Heritage Tasmania, 2017). For further information see **Section 3.2.1.1**.

The Tasmanian Aboriginal Centre's (TAC) Language Program has undertaken both linguistics and historical research on the original languages of Tasmania to retrieve and revive Aboriginal language in Tasmania – *palawa kani* (TAC, 2020a). The name of the River Derwent in *palawa kani*, is timtumili minanya (Milligan, 1859), and in 2015 the TAC, who owns Risdon Cove, chose the name piyura kitina for this site, meaning "little native hen"(TAC, 2020b). Previously, the Aboriginal names for the River Derwent came from G.A. Robinson's records from the 1830s, where he attempted to give his idea of their sound by dividing words into syllables. The names for the Derwent were noted as: TEETOOMELE MENENNYE, RAY. GHE.PY.ER.REN.NE and NIB.BER.LIN (Plomley, 1990).

In 1793, Captain Willaumez of the d'Entrecasteaux/ Kermadec expedition entered and surveyed the river, naming it 'Riviere du Nord'. One year later, Commodore Sir John Hayes of the East India Company explored the river further and renamed it Derwent, after the Derwent River in Cumberland, England (Land Tasmania, 2020). The name 'Derwent' is thought to be derived from the Celtic word for 'clear water'.

Risdon Cove was selected as Tasmania's first European settlement in 1803. Due to unfavourable conditions, the settlement was moved to Sullivans Cove in 1804, where it prospered and grew into the City of Hobart. Some of the sites around the estuary with important European heritage values include, Sullivans Cove/Battery Point, Queens Domain, Royal Botanical Gardens, Government House, Mount Nelson Signal Station, Mulgrave and Alexandra batteries, Kangaroo Bluff Battery, the Shot Tower and Batchelors Grave Historic Sites, and the Iron Pot Lighthouse.

1.3.3 Community values

1.3.3.1 Community survey

In 2019, the DEP repeated a community survey (the first occurring in 2007) of 400 Tasmanians to measure the degree of community engagement with the Derwent estuary and to test awareness of the communications strategies that the DEP had in place at the time (Myriad Research, 2019). The results of these surveys inform the DEPs program planning and assist us in tailoring our communications.

The 2019 Community Survey revealed that the Derwent estuary and its health are very important to the majority of people living here (83% of respondents). However, the perception of 44% of respondents was that the health of the Derwent was much the same as it was five years ago. In 2013, the majority of respondents felt the health of the Derwent had improved. Younger respondents were more likely to be critical of the present health of the Derwent estuary compared with older (60 plus) respondents.

People use the estuary regularly for swimming (31%), boating/rowing/sailing (31%) and fishing (29%). Walking beside the estuary was by far the most popular activity (69%). Levels of engagement with the estuary were comparable with 2013 results.

One in four respondents had heard of the DEP with informed awareness well up on previous surveys in 2007 and 2013 but there was an overall decrease in awareness in the advice provided by the DEP highlighting that continued communication is essential.

The newspaper was again the main source of information (approx. 45%) followed by signage (approx. 29%). The internet as a source of information has doubled since 2013 (from 10% to 20%). Radio and television as sources of DEP advice remained steady at approximately 20%.

Reflecting earlier responses relating to environmental issues, **pollution** was seen as the greatest environmental threat to the Derwent estuary, with **industry** and **sewerage** also seen as significant threats (Myriad Research, 2019).

1.3.3.2 Art and science

Glenorchy Art and Science Project – GASP developed the *Swimmable! Reading the River Project* in 2015 involving artists and scientists to interpret the site at Elwick Bay, with a view to making this part of the river swimmable again. This program was a multi-disciplinary collaboration between artists, scientists, educators, environmentalists, industry and community. It was conceived by GASP with Melbourne-based environmental arts organisation, Carbon Arts, as a three-year project to "deliver temporary and permanent, internationally resonant art in all forms, connecting the local community and visitors to the health of the River Derwent" (Glenorchy Art and Scupture Park (GASP), 2018). Creative projects shone a spotlight on water quality using real-time sensors providing text updates to subscribers. Artists walked the length of the Derwent expressing the experience of the journey in poetry and readings. GASP still offers a place for people to connect with the estuary and art, particularly the walkway along the edge of Elwick Bay and the nodes where people can meet for barbeques and picnics.

The *Metal at MONA* project in 2016 brought together local, interstate and international artists and scientists to address pollution in the estuary from multiple creative angles. The collaboration between art and science students resulted in an increased profile of the issue of metals in the estuary.

1.3.3.3 Volunteers and education

Overwhelmingly the response to the question about participating in cleaning up the estuary in the Community Survey, was that people would, and do, actively participate in improving the condition of the Derwent and the surrounding environment. There are numerous Landcare and Coastcare groups that regularly remove weeds, revegetate degraded foreshores, collect litter or conduct wildlife surveys.

School education opportunities have been provided by the DEP since 2015 through a two-year partnership with Parks and Wildlife Discovery Rangers, where DEP resources and activities supporting classroom and outdoor activities on wetlands, saltmarshes and rocky reefs were provided to primary schools around the estuary. The DEP also sponsored the *Cirque 2 Sea* adventure in 2016 where Andrew Hughes, teacher with the Bookend Trust, travelled the length of the Derwent from Lake St Clair to the mouth of the estuary, engaging over 3000 primary school students with his online blog and lessons (https://expeditionclass.com/contentPage.php?id=3). DEP's online educational resources for teachers and students are regularly accessed, particularly during Covid-19 lockdown. The resources can be found on the DEP website https://www.derwentestuary.org.au/educational-resources/.

Support of tertiary students is also important, and the DEP has provided supervision, field assistance and data to numerous University of Tasmania students, which has resulted in many scientific studies. These studies have furthered our understanding of the complex environment of the River Derwent and estuary.

1.3.3.4 Access

As the condition of the estuary improves, the more interest there is in the estuary for recreation. Walking is by far the most popular way for people to engage with the estuary (Myriad Research, 2019), and the Greater Hobart Trails website provides information and directions to over 90 tracks in and around Hobart (https://www.greaterhobarttrails.com.au/). This website continues to be popular, and over the summer the website receives up to 30,000 visits per month (Google Analytics, accessed January 2020). The Greater Hobart Trails website is an initiative of the DEP in cooperation with DEP's six member councils, Parks and Wildlife Services and the Wellington Park Management Trust. The addition of tracks to the GHT website will continue to be a focus of the DEP's Tracks Working Group.

Clarence City Council established a kayak trail in 2019, reflecting the increasing popularity of this sport https://www.ccc.tas.gov.au/living/parks-trails-roads/clarence-kayak-trail/.

1.4 Physical setting

1.4.1 Estuarine dynamics and zonation

Estuaries represent a continuum of water chemistry from freshwater to saltwater. For the purposes of discussion, it is useful to separate the Derwent estuary into broad zones based on key water quality indicators and geography.

The five estuarine zones – upper, middle, mid-estuary bays, lower and Ralphs Bay – are each characterised by different physical, chemical and biological conditions. The allocation of ambient water quality monitoring sites to estuarine zones is as follows (**Figure 1.3**):

- Upper estuary including sites (NN, U19, U16/17, U14 and U12)
- Mid-estuary channel including sites (U2, U3, U4, U5 and U7)
- Mid-estuary bays including sites (CB, GB, LB, NTB 1, NTB 2, NTB 5, NTB 13 and PWB)
- Lower estuary including sites (SC, KB, G2, E, C, B1, B3 and B5)
- Ralphs Bay including sites (RBN, RB and RBS)

1.4.2 Morphology and geology

The Derwent estuary extends about 55 km from New Norfolk at its northern end to the Iron Pot Light at its mouth, and covers an area of 198 km^2. The morphology of the estuary is that of a drowned river valley, which was formed between 6,500 and 13,000 years ago when sea level rose around 60 m to near its current level.

Estuarine bathymetry is illustrated in **Figure 1.4**. The upper estuary extends from New Norfolk to the Bridgewater causeway, and is characterised by a narrow channel 3-6 m deep, flanked by extensive wetlands and shallow subtidal macrophyte meadows that provide valuable nutrient filtration services to the Derwent estuary (Wild-Allen *et al*., 2010, 2013; Wild-Allen and Skerratt, 2011). The middle part of the estuary – between the Bridgewater Causeway and Bowen Bridge – is 1–2 km wide, with a more convoluted shoreline with some rocky headlands and numerous small embayments. South of the Tasman Bridge the lower estuary widens and is characterised by relatively straight western and eastern shorelines, and a large (> 50 km^2), shallow embayment – Ralphs Bay – on the eastern shoreline.

Average water depths in the lower and middle estuary are in the order of 10 to 20 m, with a maximum depth of 44 m observed immediately south of the Tasman Bridge. The regional geology of the Derwent estuary (also referred to as the Derwent Graben) is complex, dominated by Jurassic dolerites and Cambrian basalts, with smaller areas of Triassic and Recent sedimentary deposits (Department of Mines, 2012). High resolution geophysical

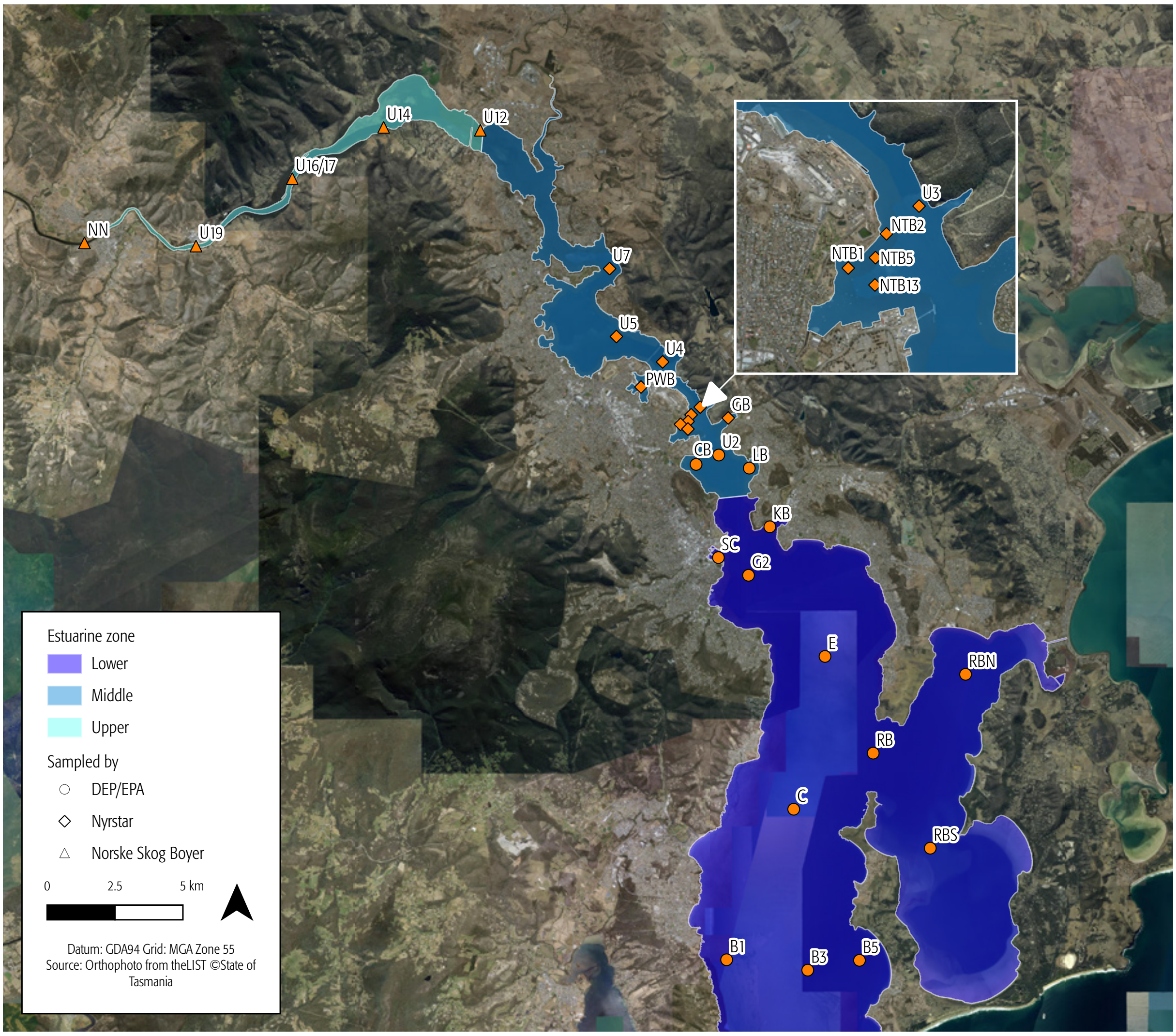


Figure 1.3 Ambient water quality monitoring sites in the Derwent estuary

and bathymetric surveys were conducted across the lower Derwent estuary in 2000 and 2001 to investigate the distribution of Cainozoic sediments and Tertiary volcanic rocks. Magnetic data indicated the location of several previously unknown Tertiary volcanic centres. Seismic reflection profiles recorded a complex sedimentary history aged from late Tertiary to Holocene.

Coastal landforms along the Derwent foreshore are highly varied and include sandy or muddy intertidal flats, sand and pebble beaches, dunes, rocky shorelines and platforms, steep bluffs and sea cliffs. These landforms have predominantly been shaped by erosional processes as sea level continues to rise. Mapping of the foreshore has been conducted as part of an assessment of coastal vulnerability to erosion from changes in sea level (Sharples, 2006). This information can be accessed via theLIST (https://maps.thelist.tas.gov.au/).

1.4.3 Estuary circulation and coastal oceanography

The mid- to upper-estuary is generally stratified with fresh water overlying a salt-wedge, the toe of which is generally located near New Norfolk but may be pushed downstream as far as Bridgewater when flow exceeds 150 cubic meters per second (cumec) or 13,000 megalitre per day (Davies and Kalish, 1994; Wild-Allen and Andrewartha, 2016). The mid- to lower estuary is classified as partially to well-mixed due principally to wind-driven and tidal mixing, and relatively large vertical mass movements occur within the water column.

The average tidal range of the Derwent is slightly greater than one metre, ranging from a minimum of 0.3 m to a maximum of 1.6 m. Tides in the Derwent tend to be asymmetric, in that the diurnal (daily) tide has a slightly greater range than the semidiurnal (twice daily) tide. Hence, Hobart frequently has large variations in the heights of successive tides and occasionally has only daily tide. Tidal currents are relatively weak, typically in the order of 0.1 to 0.2 m/sec. Westerly winds and the Coriolis force deflect the main flow of fresh water from the River Derwent along the estuary's eastern shoreline, while saline bottom water travels slowly up-river. The average flushing period for the estuary is estimated to be about 11 days (Herzfeld *et al*., 2005), but bottom waters of the upper estuary may be retained for between 20 to 35 days, particularly during low flow (Davies and Kalish, 1994). Flushing times may vary considerably, depending on river flow, wind stress and other variables.

More detailed circulation modelling has been done in specific areas of the estuary, such as the area downstream from Norske Skog Boyer's outfall (DEP, 2015) and around existing or proposed sewage treatment plant outfalls. A range of scenario simulations exploring plausible future conditions under contrasting levels of urban development and wastewater discharge have also been completed (Skerratt *et al*., 2013).

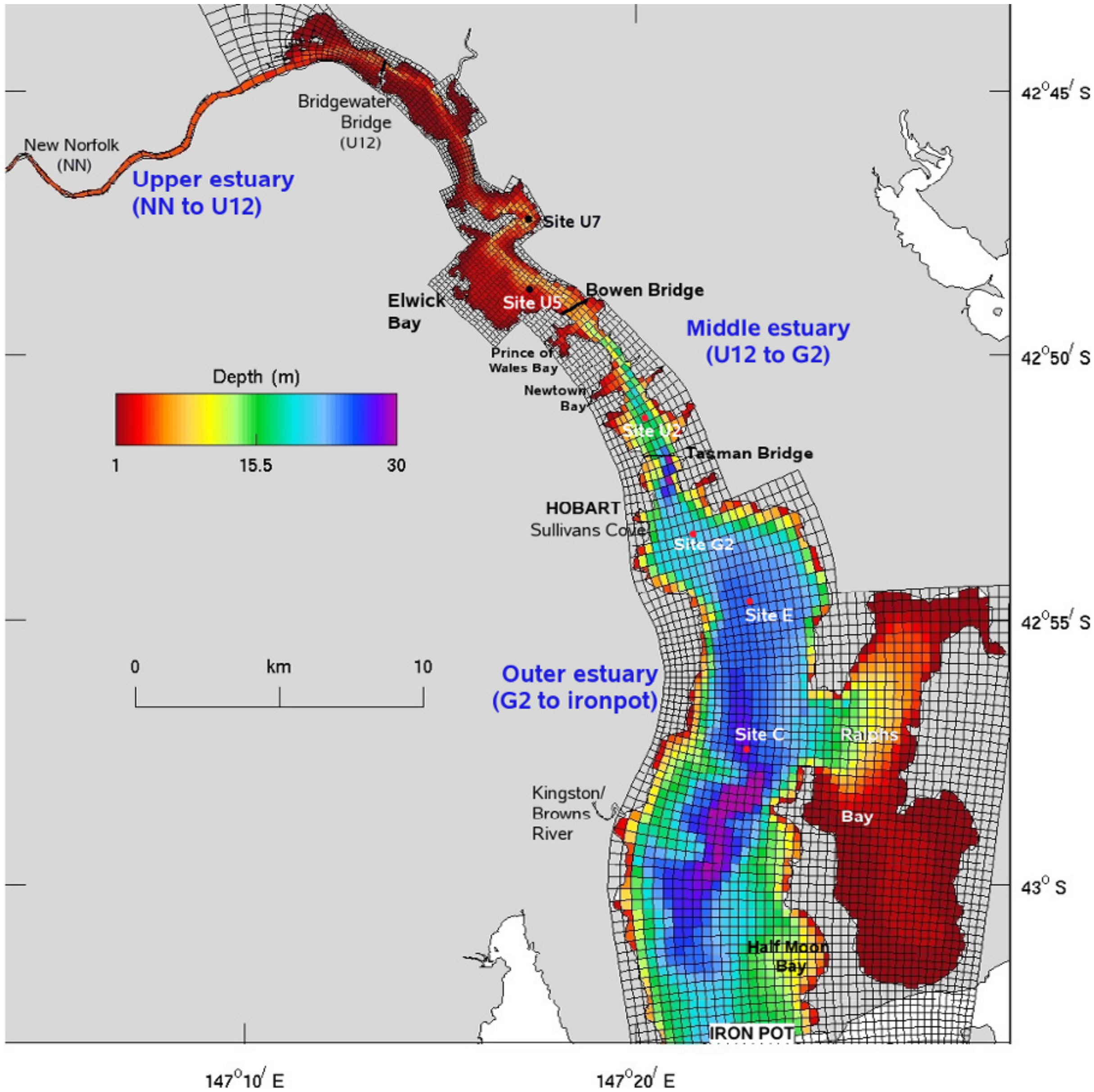


Figure 1.4 Derwent estuary bathymetry, with superimposed mesh for estuarine models; modified from Skerratt *et al*. (2013).

1.4.4 Climate

The Derwent estuary region has a cool temperate climate, with a mean maximum temperature range of 12°C in July to 22°C in February. In general, due to topographic influences and the northwest-southeast orientation of the River Derwent valley, katabatic (downslope) winds prevail, blowing from the northwest. However, southerly sea breezes tend to dominate in summer afternoons. Precipitation is monitored by the Bureau of Meteorology at several sites throughout the Derwent. Mean annual rainfall varies across the estuary, with approximately 611 mm a year around Hobart, and about 690 mm further south at Kingston.

Rainfall in Hobart is relatively evenly distributed throughout the year at between 39 mm in February and 60.8 mm in October (**Figure 1.5** and **Figure 1.6**).

Environmental conditions in the Derwent estuary are strongly affected by climate and winds (Thomson and Godfrey, 1985). Warm, dry years are often marked by poor estuarine mixing, resulting in low dissolved oxygen, while wet weather brings high surface runoff containing litter, silt, faecal bacteria and oil to the estuary. Climate change is discussed as a principal stressor in **Section 2**.

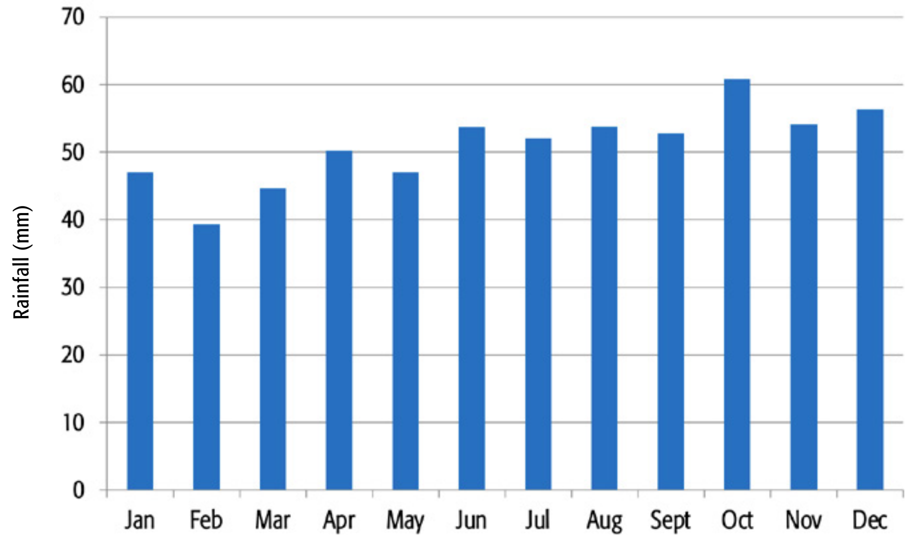


Figure 1.5 Monthly average rainfall from 1882 to 2019 for Hobart at Ellerslie Road (BoM, 2020a)

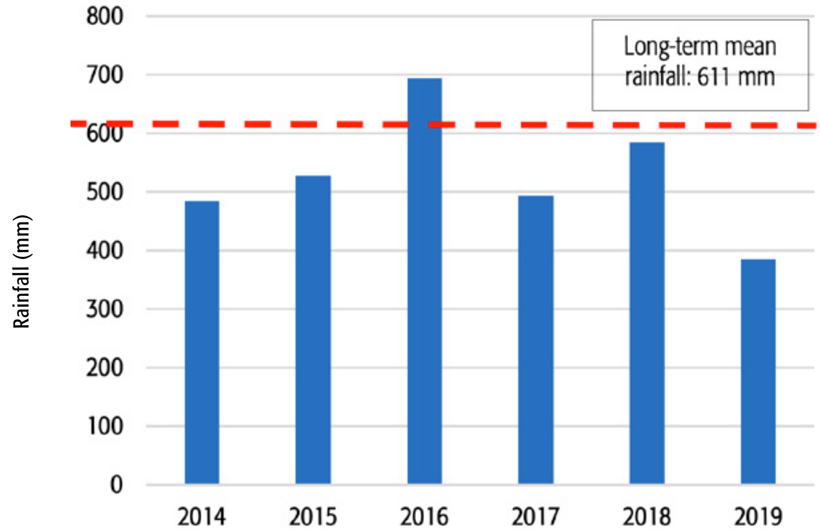


Figure 1.6 Annual rainfall 2014 to 2019 for Hobart at Ellerslie Road (BoM, 2020a)

1.5 Regional context

The marine waters off southeast Tasmania are known to be an area of convergence between subtropical and sub-Antarctic water masses. Nutrient-poor, subtropical waters are carried along the east coast of Tasmania in summer (extension of the East Australian Current) and the west coast of Tasmania in winter (Zeehan Current), whilst nutrient-rich sub-Antarctic waters lie to the south of Tasmania. These water masses enter outer Storm Bay and the D'Entrecasteaux Channel throughout the year and provide nutrients and plankton that fuels primary production in inshore waters (Harris *et al*., 1987; Buchanan *et al.*, 2013). In the D'Entrecasteaux Channel, the marine nutrient supply is augmented by nutrients in rivers (including the Huon, Esperance, Kermandie, Snug, and Nichols Rivulet), sewerage treatment plants and industrial discharge (including fish-farm waste).

Storm Bay and the D'Entrecasteaux Channel and play an important role with respect to the overall circulation and water quality in the Derwent estuary. Marine water from Storm Bay and the D'Entrecasteaux Channel travel up the bottom of the estuary as far as New Norfolk and gradually mix with overlying freshwater from the River Derwent. Recent modelling suggests that the influx of nutrients from the D'Entrecasteaux Channel into the Derwent is relatively small, as elevated concentrations found in surface waters are typically transported south into Storm Bay (Wild-Allen and Andrewartha, 2016). Wild-Allen and Andrewartha (2016) found that bottom water from Storm Bay entering the Derwent estuary had relatively low nutrient content; however, should aquaculture expansion in Storm Bay result in elevated nutrient and/or reduced dissolved oxygen concentrations in bottom waters, then some decline in Derwent estuary water quality might occur.

1.5.1 The D'Entrecasteaux Channel

The D'Entrecasteux and Channel Collaboration was established in 2013 and has been supported by the DEP, NRM South, Tassal, HAC, TasWater and Huon Valley Council. The partners agreed to work together to facilitate and report on actions to sustain a healthy waterway, track waterway conditions, trends and inputs, and increase public awareness and engagement in caring for the waterway. The DEP helped set up the collaboration as a Twinning Project, using prize money from the National Riverprize, which the DEP received in 2010.

Recent outputs have included the 2017 State of the Channel Report, a Joint Action Plan and a number of community engagement activities, including marine debris clean-ups (http://www.ourwaterway.com.au/).

The State of the D'Entrecasteaux Channel and the lower Huon Estuary (D'Entrecasteaux and Huon Collaboration, 2017) reviews and updates available scientific data from 2013 to 2016, and includes a general overview, anthropogenic inputs, water and sediment quality, seafood safety, nutrient sources and modelled impacts, foreshore environment, natural values, habitats and species, introduced species and climate change. The report also identifies several key management issues and data gaps for further investigation.

Another major report completed during the current reporting period was the *Broad Scale Environmental Monitoring Annual Report 2018 – 2019*. This report includes an assessment of water and sediment quality data collected at 15 sites within the D'Entrecasteaux Channel and Huon River/Port Esperance Marine Farm Development Plan (MFDP) areas. There was a no evidence of major broad-scale changes in sediment condition or water quality based on results from 2018-2019. Small increases in ammonia concentration for lower channel locations recorded since 2014-15 appeared to have stabilised during the 2016-2019 period (Aquenal Pty Ltd, 2020).

1.5.2 Storm Bay

Salmon farming exists in several locations in Storm Bay and there are plans to expand the industry. Based on suggested production levels, there is the potential for impacts on the Derwent as water from Storm Bay enter the estuary (Wild-Allen and Andrewartha, 2016). The DEP made a submission to the Marine Farm Review Panel in 2018 outlining concerns about nutrients and their potential impact (DEP, 2018a).

There are several research projects underway in Storm Bay to better understand and characterise water quality in this area. The research is centred around three core projects that aim to: strengthen understanding of the spatial extent of aquaculture inputs to Storm Bay, the capacity of the environment to assimilate nutrient loads associated with aquaculture operations; develop a biogeochemical model for Storm Bay; and develop decision support tools for use by regulators and industry to monitor and manage nutrient loads and environmental management.

The broad-scale environmental monitoring program is a collaboration between scientists at CSIRO, Australia's national science agency, the Institute of Marine and Antarctic Studies (IMAS), the Department of Primary Industries, Parks, Water and the Environment (DPIPWE) and the Environment Protection Authority (EPA). It is funded by the Fisheries Research and Development Corporation (FRDC) with co-investment from CSIRO and IMAS. The DEP is a member of the Steering Committee and Technical Advisory Group (FRDC, 2018). Details of these projects will be provided by the FRDC later in 2020, after the industry review of these programs.

2

Principal stressors

2 Principal stressors

2.1 Climate Change

A less predictable climate and increased frequency and intensity of extreme events, such as storms, droughts, fire and floods, characterise climate change. We will all be impacted in some way as these changes increase the risk to the operation of industries including agriculture, aquaculture, hydroelectric power generation, transport and shipping. Urban infrastructure will also be compromised, for example in flooding events or damage due to drying and cracking soils (ACE CRC, 2010).

Climate change also affects species other than humans, exerting additional pressure on the ability of flora and fauna to grow and reproduce leading to changes in abundance and distribution. Changes to many species combine to affect the composition, structure and function of ecosystems. These impact on the existence of species and ecosystem services, e.g. pollination and carbon storage (Resource Management and Conservation, 2008).

Given the geographical scope and nature of climate change, it is a pressure that applies to all Derwent estuary ecology, in different ways. The following are the priority habitats and species identified in the Derwent Estuary Conservation Action Plan with forecast risks from climate change:

- Upper Derwent Wetlands – vulnerable to climate-driven sea level rise, droughts and floods.
- Saltmarsh – vulnerable to habitat squeeze resulting from sea level rise, increased foreshore hardening to protect human assets.

Climate-change impacts are well studied and documented in Tasmania. A summary of impacts on southern Tasmania, developed by the University of Tasmania's climate modelling team, outlined that:

- The greatest projected increase in temperature in southern Tasmania, over 3 °C, is in the west of the region, around the western half of the Derwent Valley, Huon and the Central Highlands.
- The frequency and duration of high temperature events across the region will increase, and warm spells that are currently 4–8 days in length are projected to increase by 2–6 days.
- The average annual rainfall is projected to increase moderately on the East Coast, Tasman and Greater Hobart regions but decrease by 6–10% in the Central Highlands.
- Global sea level is projected to increase, on average, by 0.82 metres by 2100.
- The current 100-year, storm-tide event is around 0.9 to 1.4 m above average sea level and is projected to increase to 1.87 metres by 2090 (and this increased inundation will also apply to the Derwent estuary).

Also, the current 100-year coastal inundation event may become a 50-year event by 2030 and a 2 – 6 year event by 2090 (ACE CRC, 2010; Southern Tasmanian Councils Authority, 2020).

2.1.1 Climate change management

Councils in southern Tasmania are preparing climate profiles to help them make operational and strategic decisions about climate impacts, particularly actions that are practical and targeted to improve sustainability and biodiversity (Graham *et al*., 2013). Challenges that local governments are grappling with due to climate change include bushfires, increased rainfall intensity and flooding, heatwaves, rising sea levels and storm-tide events (Glenorchy City Council, 2013; City of Hobart, 2017).

The State Government climate-change initiatives are similar in focus to that of local government, but also include an emphasis on renewable energy and supporting business and agricultural producers adapt to a changing climate (Tasmanian Department of Premier and Cabinet, 2017).

The existing natural environment has an important role in mitigating the impacts of climate change. It is known that saltmarsh, seagrass and mangroves are 30– 50 times more efficient at storing carbon than forests (Blue Carbon Lab Deakin University, 2020a). Healthy saltmarshes and seagrass meadows in Tasmania have multiple environmental benefits, including storing carbon and reducing ocean acidity. This led to the protection and rehabilitation of the Derwent's remaining saltmarsh and seagrass becoming a priority for the DEP (DEP, 2012). Initiatives the DEP have been involved in to maintain and improve habitats include saltmarsh mapping, management and restoration (**Section 3.3.2.1**), analysis of litter decomposition within wetlands using teabags, as part of a global scale project (**Section 3.3.3**), understanding drivers of seagrass health to inform estuary management and the assessment of rocky-reef condition (**Section 3.1.3**). Further investigations of hypoxia and the response of the estuary to changing rainfall patterns and river flow will also be a focus (see **Section 2.5**). Changes in rainfall intensity will put a strain on stormwater and sewerage infrastructure in Greater Hobart leading to increased pollution discharge. **Section 2.6.4** outlines DEP initiatives assisting councils with stormwater management.

2.1.1.1 Future Coastal Refugia Area overlay

A previous study of impact of sea level rise in the Derwent helped identify coastal habitats at risk of inundation, and also areas where habitats, such as saltmarsh, could potentially retreat to (Prahalad *et al.*, 2009). Building on this research, a planning overlay was developed by DEP and UTAS (Prahalad, Whitehead, *et al.*, 2019). The Future Coastal Refugia Area planning overlay is an open source online map application maintained by Land Information System Tasmania (LIST)–available through LISTmap (https://maps.thelist.tas.gov.au/listmap/app/list/map). The refugia overlay shows the retreat paths of coastal habitats when natural processes are allowed to occur, including landward migration due to sea level rise and increased storm surges. The overlay is based on flood-inundation modelling and shows the area that is vulnerable to a 1% AEP (annual exceedance probability) storm event by the year 2100.

Result categories were developed upon advice from the Tasmanian Planning Commission as to which refugia areas were compatible with land use zoning under the Tasmanian Interim Planning Scheme. The refugia overlay has now been integrated into the Tasmanian Planning Scheme's Natural Assets Code. **Figure 2.1** shows the compatibility categories, separated into modelling of areas where LiDAR DEM (Digital Elevation Model) coverage was available or absent (Prahalad, Whitehead, *et al.*, 2019), and an example of its use at Old Beach, highlighting that if given the opportunity, this particular patch of saltmarsh would in the future occupy a large part of what is currently a growing suburban area. See **Section 3.3.2.1** for details of a recent DEP/UTAS saltmarsh monitoring program that examined saltmarsh refugia areas, including at Old Beach, across the estuary.

- Case by Case Consideration Zone (LiDAR)
- Case by Case Consideration Zone (no LiDAR)
- Compatible Zone (LiDAR)
- Compatible Zone (no LiDAR)
- Incompatible Zone (LiDAR)
- Incompatible Zone (no LiDAR)
- Special Consideration Zone (LiDAR)
- Special Consideration Zone (no LiDAR)

Figure 2.1 Left: Categories for Future Coastal Refugia Area data (The LIST), divided into compatibility zones according to how modelling of future retreat areas fit in with the Tasmanian Interim Planning Scheme. Right: yellow line is the current extent of the Old Beach saltmarsh. The coloured in-fill is the refugia overlay showing that if the marsh was allowed to migrate inland over time, a large area would be in the Incompatible zone (bright green) due to its current General Residential zoning. The pink line is the survey area used in a saltmarsh monitoring project

2.1.2 Future Projects

Stream temperature under changing climate

Water temperature is an important physical property of rivers and streams, and certain temperature ranges are vital for aquatic plants, animals and other organisms. Under a changing climate, increasing water temperatures may result in a loss of biodiversity or habitat shift, and may also affect other water quality parameters, such as dissolved oxygen concentrations. In order to better understand summertime temperatures in rivers in the Derwent catchment, the DEP is collaborating with DPIPWE to monitor water temperatures. Temperature loggers were deployed at four sites in the Derwent catchment (Clyde, Styx, Florentine, and Tyenna), in addition to 15 sites monitored by DPIPWE. Monitoring river temperatures in future summers will help to detect shifts induced by climate change.

Warming estuaries

A recent study has revealed that waters in Australian estuaries are warming and acidifying (Scanes *et al.*, 2020). Data suggests that temperatures increase faster than current models predict. With sea-surface temperatures of the Tasman sea warming, we may already experience warming water temperatures in the Derwent estuary (BoM, 2020b). In order to test this hypothesis, the Derwent estuary is analysing its 20-year-long data record of surface-water temperatures for the estuary. Results will reveal if current models are potentially inadequate in predicting climate-change impacts relevant to the health of the estuary.

2.2 Catchment

The Derwent estuary's catchment covers an area of approximately 9000 km^2 in central and south-eastern Tasmania (approximately one-fifth of Tasmania's land mass) and comprises the River Derwent catchment (7500 km^2), the Jordan River catchment (1250 km^2) and other areas immediately adjacent to the estuary (375 km^2). For further information about catchment physical setting and uses, see State of the Derwent estuary 2015 (DEP, 2015).

The River Derwent contributes the majority of freshwater input defining the estuary, and both flow and water quality are vital for the health of the estuary (e.g. **Section 2.5**). The following sections report on river flow, water use and water quality in the River Derwent catchment.

2.2.1 River flow

The River Derwent is one of the largest rivers in Tasmania and its flow is highly modified by extensive regulation of tributaries and the River Derwent itself due to hydro-electric power generation, irrigation, and extraction for municipal, industrial and aquaculture purposes (**Section 2.2.2**). Historically, the volume and seasonality of flows in the catchment has been strongly affected by diverse anthropogenic factors (including the diversion of headwater flows from the Ouse/Shannon to Great Lake) and climatic dry periods (DEP, 2015). These flow modifications have affected hydrodynamics in the estuary, dilution and flushing of effluent discharges, oxygen replenishment, displacement of saline water, delivery of silt, primary production, and the seasonal cycles of migratory fish (DEP, 2015). There is currently no holistic catchment management and regulatory environmental flow regime for the River Derwent, and the last investigations into environmental flows in the lower river and upper estuary were conducted in the early 2000s (Davies *et al*., 2002; Davies, 2005). Environmental flow assessments and eco-hydrological studies have also been undertaken for the River Clyde (Davies and Pinto, 2000; Davies *et al*., 2005; DPIPWE, 2016) and Shannon River (DPIPWE, 2013), and the findings of these studies have informed flow management in these rivers. Water Management Plans only exist for the River Clyde Catchment, which was updated in 2017 (DPIPWE, 2017) in accordance with objectives of the *Water Management Act 1999*, and the *Lakes Sorell and Crescent Water Management Plan 2005* (DPIWE, 2005), which is currently under review by DPIPWE.

The long-term average discharge (1974-2019) from Meadowbank Power Station is 91 m^3/s and was slightly lower at 88 m^3/s in recent years (2014-2019). Higher discharge occurs during winter and spring with lowest flow during summer (**Figure 2.2**). The short-term (daily and hourly) flow is highly variable associated with the on/off operation of power stations and flow patterns differ from those in unregulated tributaries such as the Tyenna and Florentine (Eriksen *et al*., 2011). For a more detailed assessment of flow patterns, see Eriksen *et al*. (2011).

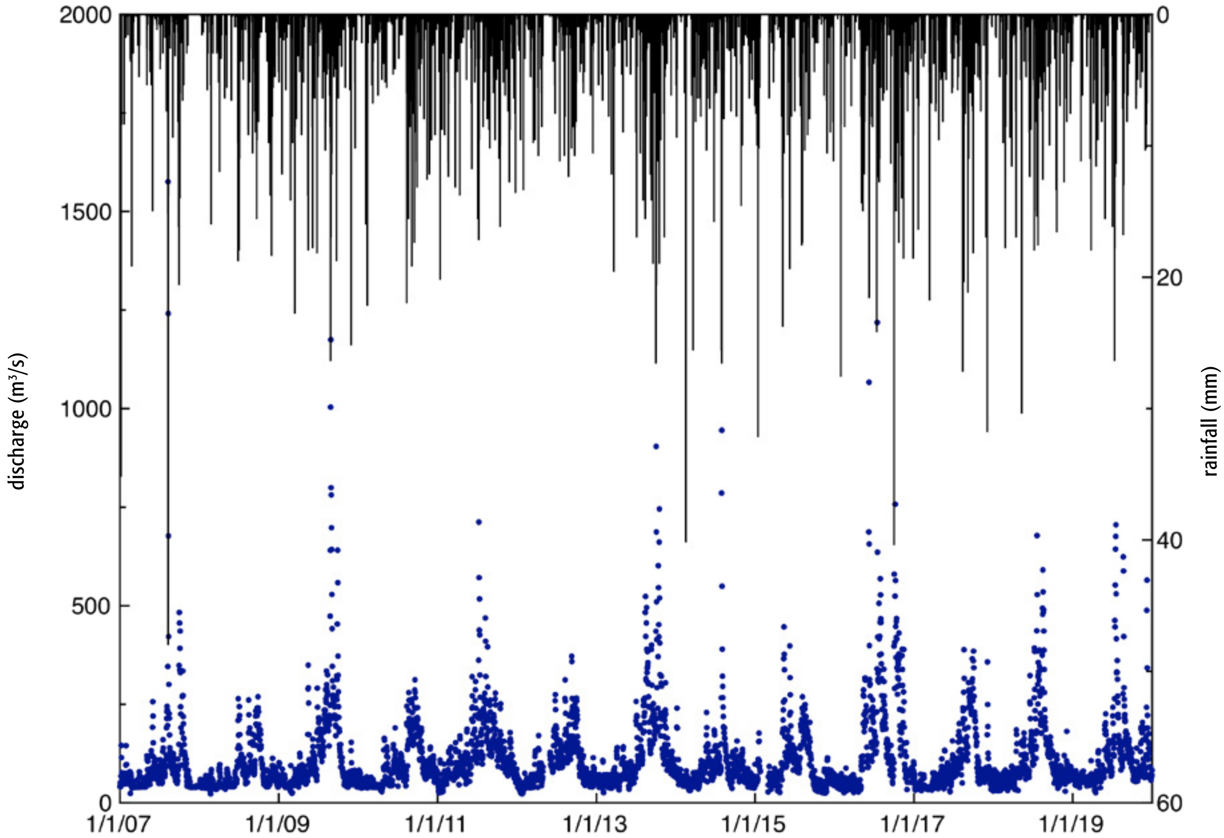


Figure 2.2 Daily flow below Meadowbank Dam (–) and daily rainfall (•) as recorded at Ouse Fire Station (BoM, 2020a)

Despite little change in the long-term average discharge over the past five years, the 2014–2019 period was marked by a number of extreme events. Low winter and spring rainfall in 2015 resulted in low water storage levels followed by a dry summer, coinciding with the Basslink cable outage in December 2015 causing Tasmania's energy crisis. 2016 experienced flooding in early June (BoM, 2016), and 2018 experienced flooding in May causing considerable damage in Hobart and River Derwent sub-catchments, including damage to infrastructure and bank erosion. Following the May 2018 record rain and flood event, the Derwent Catchment Project has developed Flood Resilience Plans for the Glen Dhu Rivulet, Lachlan River and Sorell Creek, summarising observed environmental impacts including weed invasion (DCP, 2020a). The Derwent and Jordan catchments are covered by the Bureau of Meteorology Flood Warning Service (BoM, 2013).

2.2.2 Water use

The River Derwent catchment upstream of New Norfolk has multiple water users (abstractive and non-abstractive) with water allocations for irrigation, aquaculture, hydropower, town and drinking water supplies, and stock and domestic supplies. There are eight different surety levels that water is allocated at, with Surety 1 providing the highest security of water supply at > 95% reliability (DPIPWE, 2020a).

A thorough analysis of water allocations in the greater Derwent catchment carried out in 2011 documented a total of 376 allocations resulting in 395,805 ML/year allocated (Eriksen *et al*., 2011).

According to the Water Information System of Tasmania (WIST, DPIPWE) database, this compares to a total of 496 water entitlements in the greater Derwent catchment in 2020, totaling 456,035 ML/year (DPIPWE, 2020b). This represents approximately 15% of the annual river flow, depending on climate (21% in a dry year) if all allocations are fully used. Water used for hydropower and the Jordan catchment water allocations are excluded from these calculations. Water allocations in the Jordan currently total 15,463 ML/yr. Overall, water demand as reflected by approved water entitlements (in terms of water volume) has increased by 23% over the past decade (**Figure 2.3**). The timing of the water usage is crucial given generally lower summer flows. Some allocations, specifically Surety Level 7 and 8 entitlements, have conditions regarding timing and flow (e.g. Clyde River Catchment). However, the actual water use in terms of volume and timing is currently impossible to evaluate due to the lack of metering in the catchment and Tasmania in general.

Including the Jordan, the majority of water allocations (in water volume) in the River Derwent catchment is located directly along the River Derwent (**Figure 2.4**), accounting for 54%, followed by the Clyde (16%) and Tyenna (12%), not including hydropower water entitlements (**Figure 2.5**). Irrigation and aquaculture accounted for 47% and 27% of the allocations, respectively, followed by town water (17%) and industrial supplies (9%, primarily Norske Skog) (**Figure 2.6**). Most of the water is allocated at Surety Level 5 (62%).

Groundwater extraction is not currently licensed in the catchment and most of the State. There are more than 70 functioning groundwater bores in the catchment registered with DPIPWE (DPIPWE, 2020c), but no data exists on water volumes used. With increasing water demands across the catchment there is a need for integrated catchment management considering both surface and groundwater resources.

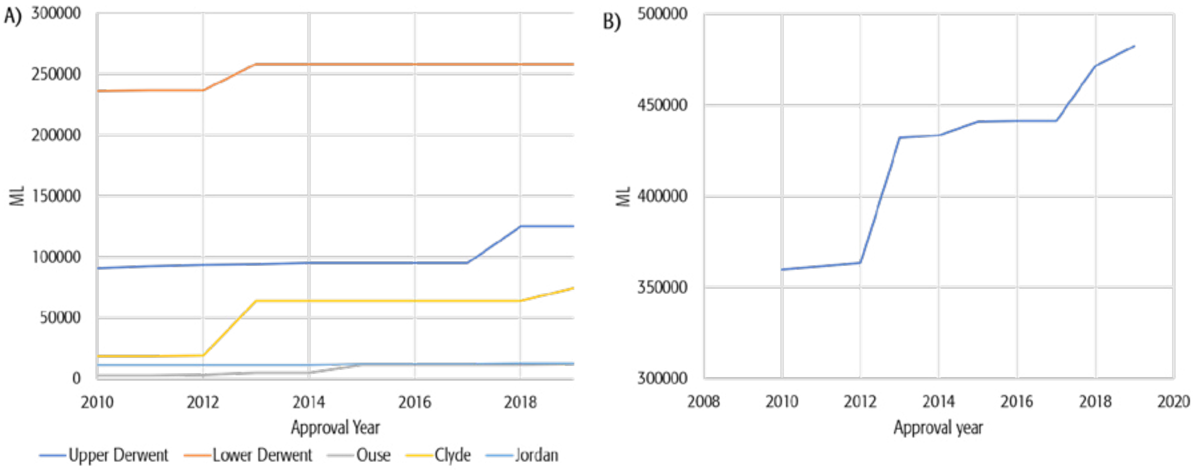


Figure 2.3 Water entitlements (in ML) per sub-catchment (A) and the entire Derwent catchment including the Jordan (B) according to approval year (DPIPWE, 2020b)

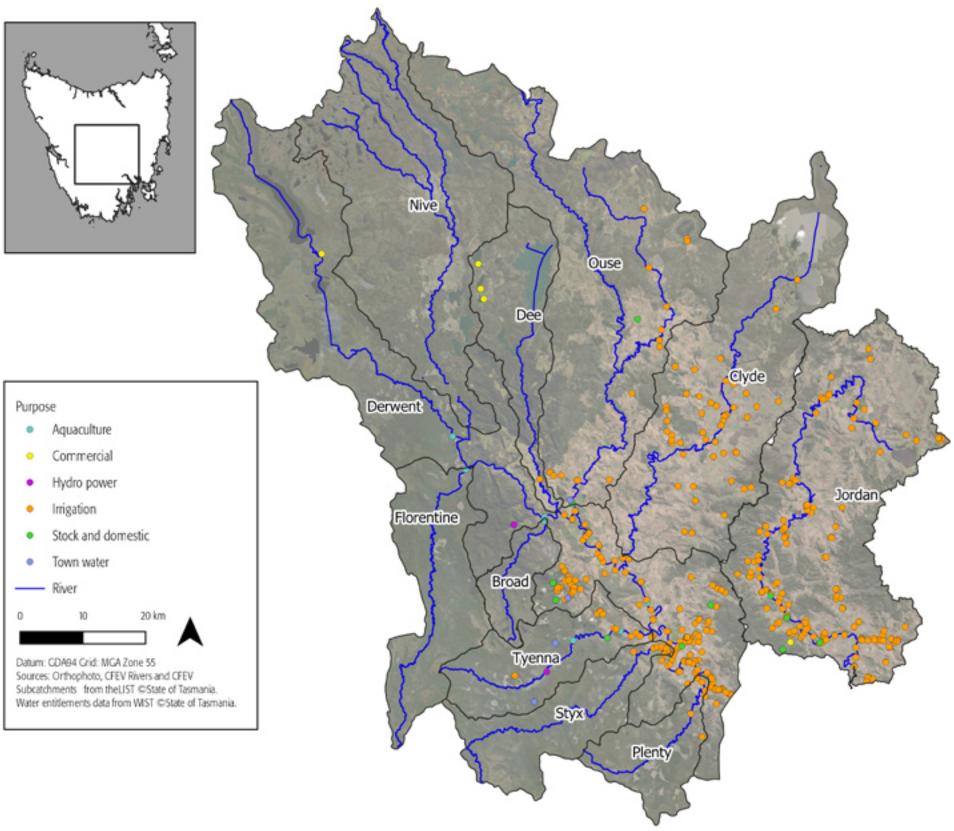


Figure 2.4 Locations and purposes of registered water entitlements in the River Derwent catchment. Water allocations are predominantly situated along the River Derwent main stem and for irrigation supply. Data from WIST (DPIPWE, 2020b)

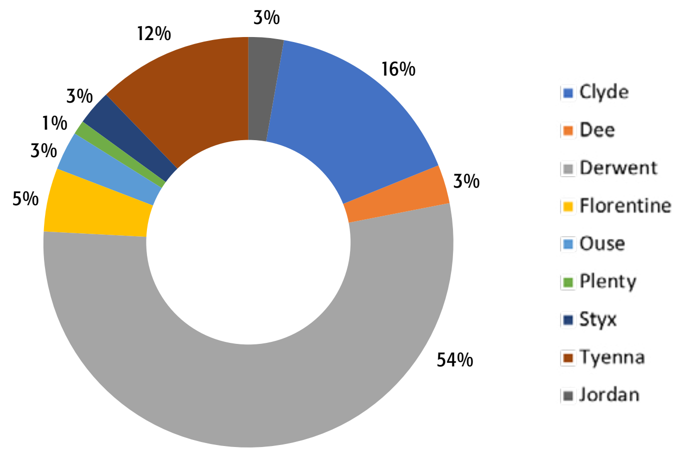


Figure 2.5 Water allocations (in terms of water volume) per catchment, including the Jordan (data from DPIPWE (2020b))

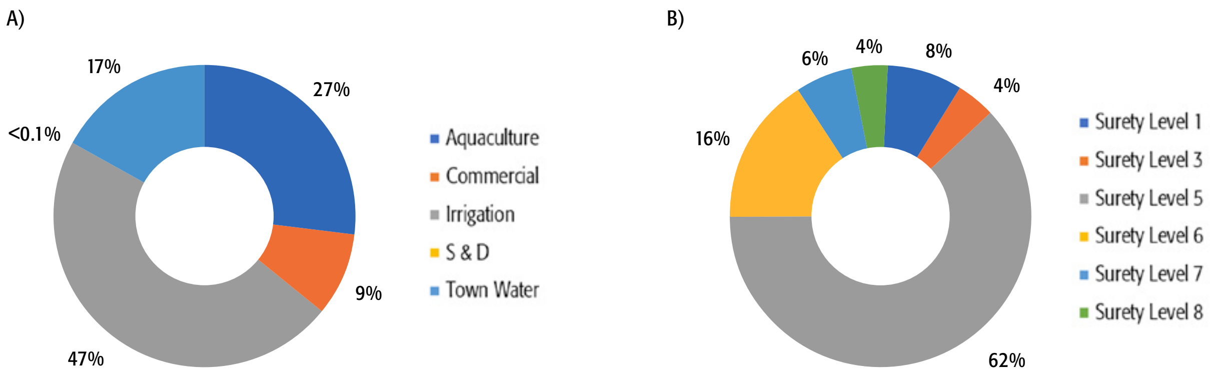


Figure 2.6 Water allocations per purpose (A) and per Surety Level (B) (data from DPIPWE (2020b))

Major recent developments regarding water use in the catchment are the following:

- DPIPWE is developing a Rural Water Use Strategy (RWUS) and released a Position Paper for public comment in April 2020. The Strategy is significant because it will guide Tasmania's water management for the next few decades. The DEP lodged a submission during the public comment period.
- The EPA approved Tassal's Recirculatory Aquaculture System (RAS) Hatchery near Hamilton (Ouse), adding the eighth land-based fish hatchery to the catchment (https://epa.tas.gov.au/assessment/assessments/tassal-operations-pty-ltd-hamilton-recirculatory-aquaculture-system-hatchery-ouse). Extracting water from Meadowbank Lake, water use of this hatchery will be consumptive (irrigation of pastures), in contrast to the already existing flow-through hatcheries (see State of the Derwent 2015 for more details). The new hatchery will have a biomass capacity of 750 tonnes with a maximum annual production of 1,400 tonnes.
- Following a review in 2019 due to dry conditions and increased water demand at Bryn Estyn, Tasmanian Irrigation has developed a 5-year South East Interim Solution (SEIS) to cover deficits. SEIS will take raw water from the River Derwent at Lawitta (rather than drinking water via Bryn Estyn), connecting into the Sorell main line. This line is currently providing 7,650 ML and is planned to provide 20,000 ML to 160 farms in the future, potentially sourcing additional water from Meadowbank Lake and Lake Echo via Craigbourne Dam.

2.2.3 Water quality

2.2.3.1 Water quality monitoring

To better document changes in catchment water quality conditions, a two-year monitoring program was undertaken with a focus on nutrients, sediments and other standard physical and chemical parameters. Samples were collected monthly at five sites along the main stem of the River Derwent and at the lower end of eight major tributaries, between September 2015 and August 2017 (**Figure 2.7**) (DEP, 2018b).

Most of these sites replicated a similar monitoring program carried out in 1996-1997 (Coughanowr, 2001), although different flow conditions between monitoring programs and years make a direct comparison more difficult.

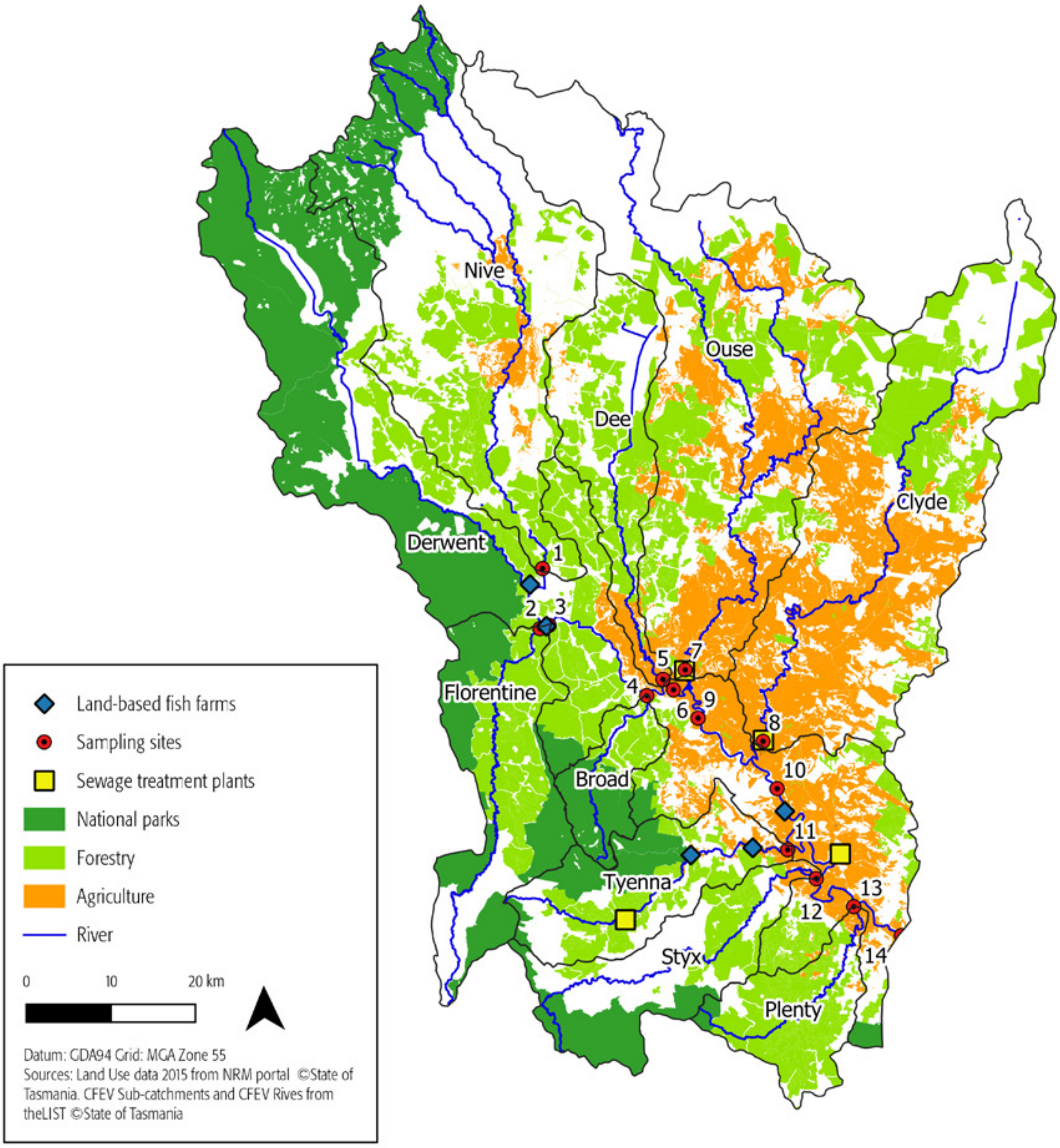


Figure 2.7 River Derwent catchment and sub-catchments, showing sampling sites of the 2015–2017 monitoring program (DEP, 2018b), point sources and general land use upstream of Bryn Estyn (site 14).

Water quality across the catchment varied considerably over the two-year sampling period, with lowest nutrient concentrations (for details on nutrient analysis see Appendix C) typically observed in the upper part of the monitoring area (below Wayatinah) and Broad River, both of which receive run-off from largely natural, forested catchments. Elevated dissolved inorganic nitrogen and dissolved reactive phosphorus levels were observed in both agriculture-dominated catchments (e.g. the Ouse, Clyde) and those receiving effluent from large fish hatcheries (e.g. Florentine and Tyenna, **Figure 2.8**). The highest total nitrogen and total phosphorus loads were calculated for the part of the River Derwent catchment directly adjacent to the river that is not part of any other sub-catchment, followed by Florentine, Clyde and Ouse. The highest phosphate and total ammonia nitrogen (TAN) concentrations were observed at the Tyenna and Florentine during the later summer months. Both these catchments have fish hatcheries. The Rivers Clyde and Ouse appeared to be a source of dissolved nitrate, but predominantly during winter months when rainfall is high. Both these catchments are dominated by agriculture.

Of particular interest was the timing of maximum nutrient levels, with levels from agriculture-dominated catchments at a maximum during winter months, while fish-hatchery-dominated tributaries showed maximum levels during summer months. This seasonality of nutrients is an important factor, as elevated bioavailable nutrients during spring and summer months are of much greater concern than during winter, when water temperatures and light levels are low.

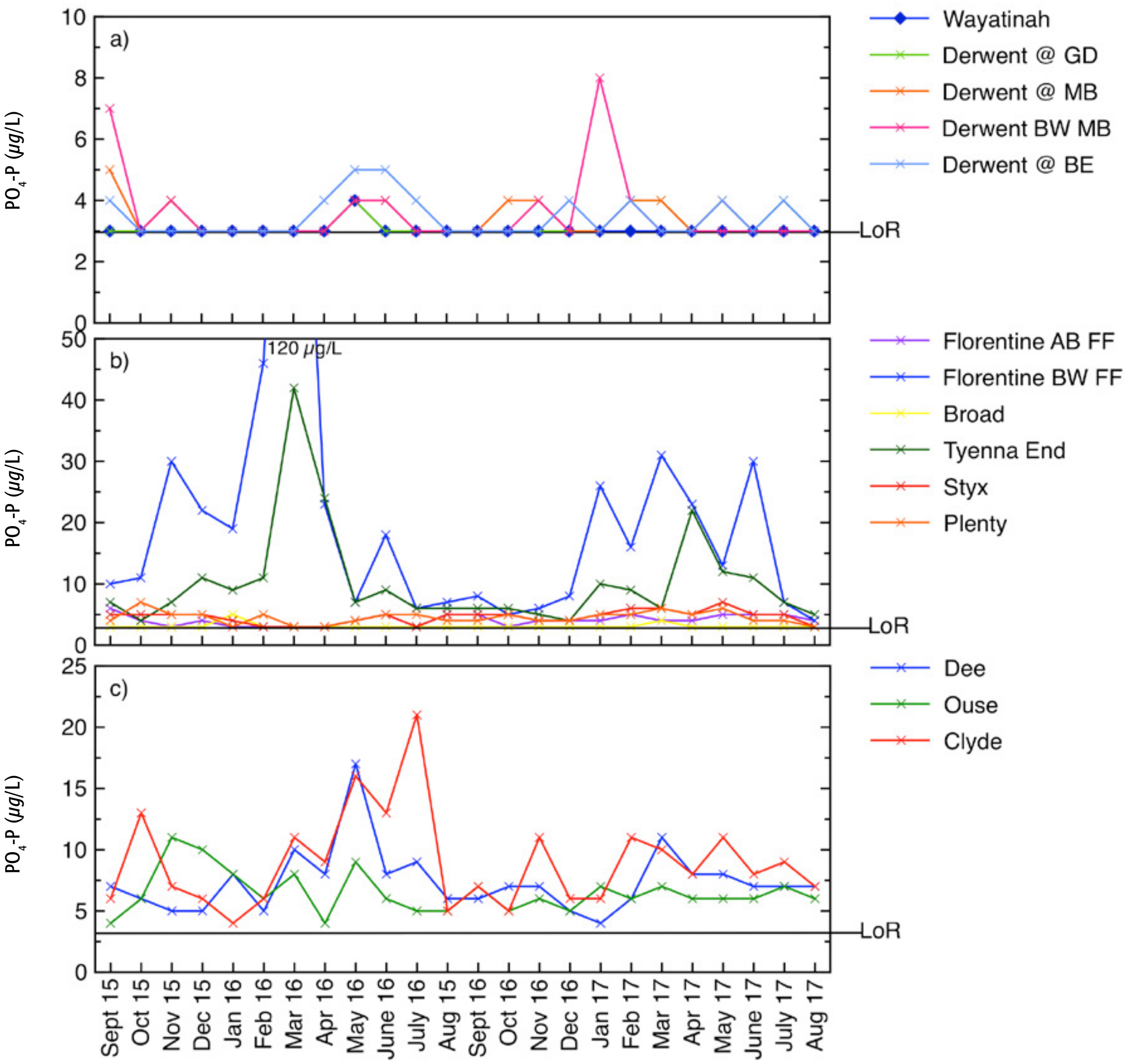


Figure 2.8 Phosphate concentrations for Derwent sites (a), western (b) and eastern (c) tributaries over the 2-year monitoring program (GD=Glen Dhu, MB=Meadowbank dam, AB FF=above fish farm, BW FF=below fish farm). Note the different scales and timing of increased concentrations (DEP, 2018b)

2.2.3.2 A nutrient budget for the catchment

In collaboration with TasWater and the EPA, a nutrient budget to refine our understanding of nutrient sources to the estuary was developed with the help of UTAS seed funding in the area of *Data Knowledge and Decision* (Proemse *et al*., 2020). Using point-source data for 2017 and 2015 land use data (DPIPWE, 2015) in combination with nutrient generation rates for each land use, it was identified that aquaculture is the largest point source of nutrients in the catchment (ending at Bryn Estyn), since only a few smaller WWTP are operating in the catchment. Aquaculture, therefore, contributed 99% of total phosphorus (TP) and total nitrogen (TN) loads when compared to WWTP. However, when compared to diffuse sources, agriculture and forestry were the largest contributors of TP and TN loads overall, agriculture accounting for 47% of TP and forestry accounting for 38% of the TN catchment loads (**Figure 2.9**). The largest areal contributor to TP and TN loads is the part of the River Derwent catchment that is directly located along the river (Derwent stem), followed by the Florentine, Clyde and Ouse (**Figure 2.10**). Some limitations apply given the nature of available data for this project, highlighting the need for continuous, high-frequency, long-term monitoring of water quality parameters in the catchment, specifically given the pressure of changing land use in the catchment.

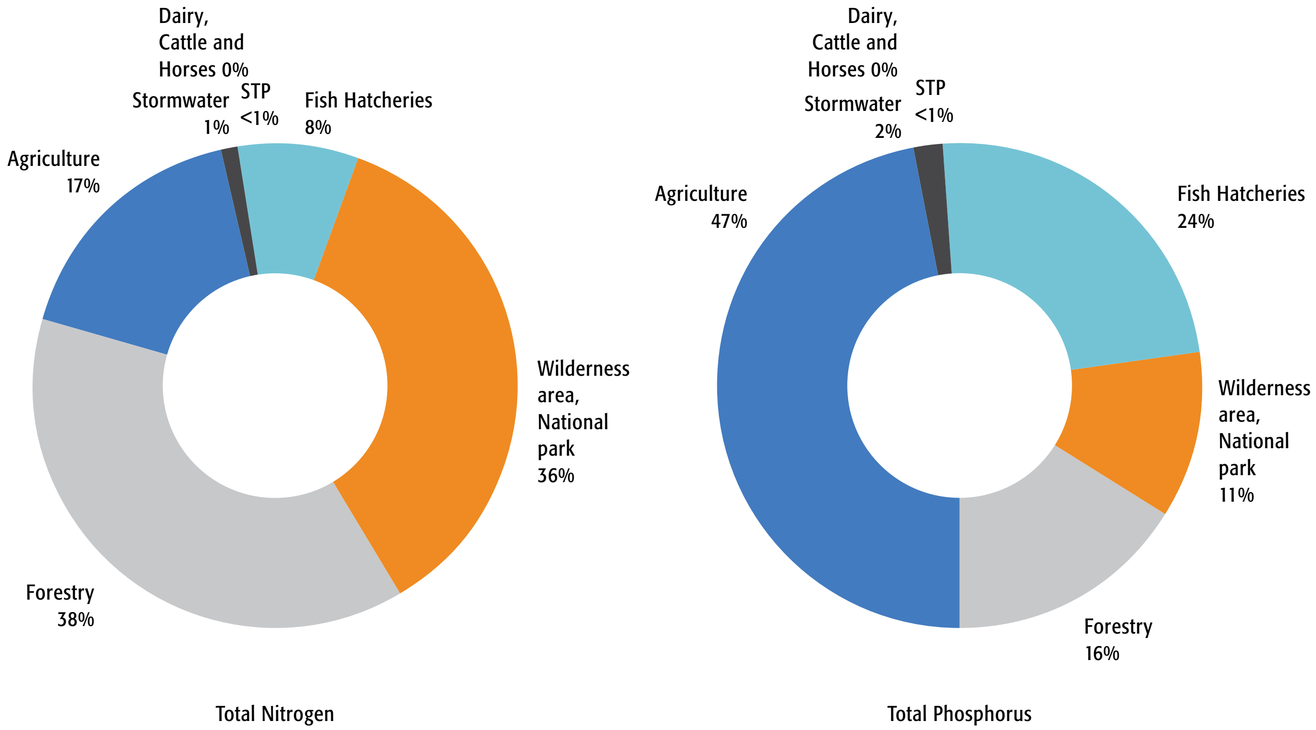


Figure 2.9 Nutrient sources and their contribution to total nitrogen (left) and total phosphorus (right) loads in the catchment

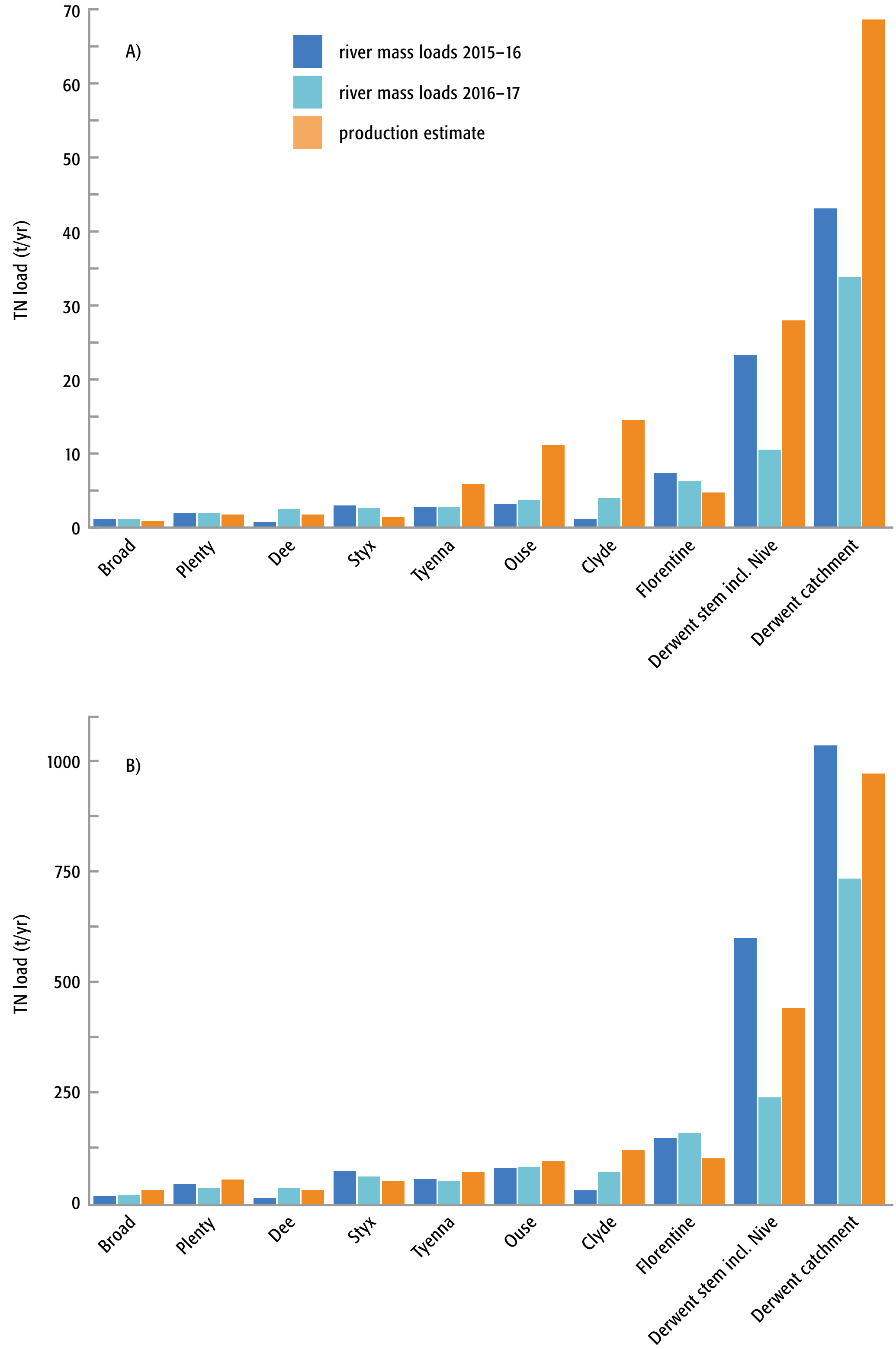


Figure 2.10 Total phosphorus (TP) loads (A) and total nitrogen (TN) loads (B) for tributaries, the river main stem and the entire Derwent catchment. The dark and light blue columns are calculated loads from the two year monitoring program, the orange column are estimated production loads based on point source and land use data

2.2.3.3 River health monitoring

River health monitoring in the Derwent catchment occurs as part of DPIPWE's state-wide River Health Monitoring Program (RHMP), and the following update has been provided by Dr Scott Hardie (Agriculture and Water Division, DPIPWE).

"River health monitoring was undertaken in spring and autumn at eight sites in the River Derwent catchment between 1998 and 2017 (DPIPWE, 2018). These sites were located on the Pine River (upstream of Pine Tier Lagoon), Nive River (at Lyell Highway), Florentine River (at Florentine Road), River Ouse (at Ouse), Styx River (upstream of River Derwent confluence), Stony Creek (at Plenty Valley Road), River Clyde (at Hamilton) and Jordan River (at Mauriceton). This monitoring employed Australian River Assessment System (AusRivAS) protocols and focused on benthic macroinvertebrates and habitat quality (both instream and riparian habitats).

The results of long-term monitoring at the eight sites indicates that the condition of rivers across the River Derwent catchment varies (**Figure 2.11**), with on average the River Ouse, River Clyde and Jordan River being impacted (bands C and B), and the Pine River, Nive River, Florentine River (upstream of fish hatchery), Styx River and Stony Creek being in good condition (equal to or above reference condition, bands A and X).

DPIPWE completed a review of the RHMP in 2018 (DPIPWE, 2018). In accordance with this review, from autumn 2018 onwards, DPIPWE will monitor four sites in the River Derwent catchment during alternate spring and autumn periods (i.e. biennial monitoring). The sites being monitored are the Styx River (upstream of River Derwent confluence), Tyenna River (at Gordon River Road), River Clyde (at Hamilton) and Jordan River (at Mauriceton). This monitoring will continue to employ AusRivAS protocols and focus on benthic macroinvertebrates and habitat quality, and also include more rigorous measures of benthic sediment and benthic algae."

Hydro Tasmania has also undertaken river health monitoring in the Derwent catchment during the period 2014-2019. Spring sampling was undertaken in 2014 for the Ouse and Shannon rivers. Comparative post-flood sampling was undertaken in spring 2016, spring 2017 and autumn 2018 to assess the impacts of the June 2016 flood on river habitats and macroinvertebrate communities.

River health patterns in the Derwent catchment were generally consistent; with the lowest scores occurring at the sites in the middle and bottom reaches of the catchment. Any immediate impacts from regulated flow in the upper catchment are typically ameliorated by tributary inflows downstream. The 2016 flood changed the instream and riparian habitats at sites in the middle (Ouse River at Staffhouse Creek) and lower catchment (Ouse River at Ashton). As a result, macroinvertebrate abundance and diversity were temporarily impacted, however improved river health scores have since been maintained at some of the most flood impacted sites.

Hydro Tasmania will continue to conduct river health assessments using AusRivAS protocols in accordance with their recently revised River Baseline Monitoring Program. Hydro Tasmania will aim to monitor Derwent sites on rotation every 3-4 years in the Derwent/Nive and Shannon/Ouse catchments.

2.2.4 Future projects

Reconstructing hydrological regimes of shallow lakes and their littoral wetlands

In collaboration with the Water Management Branch and Assessment Branch at DPIPWE, this project aims to unravel the history of two shallow lakes and their associated wetlands on the Central Plateau, Tasmania. Lake Crescent and Lake Sorell were dammed in the 1830s, but preliminary data and archival investigations suggest that the lakes and associated wetlands (one of which is Ramsar-listed, two of which are listed on the Directory of Important Wetlands in Australia) are much older. The lakes are used to supply water to the town of Bothwell and for agricultural irrigation in the River Clyde valley downstream of the lakes, as outlined in the lakes' statutory Water Management Plan 2005 (under the Tasmanian *Water Management Act 1999*). A review of this plan by DPIPWE recently commenced and aims to ensure the water resources in these lakes are managed sustainably. It is therefore vitally important to understand the hydrological history of the lakes and their wetlands so that these ecosystems can be managed appropriately. Therefore, the objectives of this study are to (a) identify the age of the lakes and wetlands to examine their history; (b) track water level fluctuations (i.e. wetting/drying phases of wetlands and potentially the lakes) over time, and (c) identify any hydrological changes that have occurred since damming, using sediment cores (**Figure 2.12**). The results will inform management of these unique lakes. This project is supported by a grant from the Australian Nuclear Science and Technology Organisation (ANSTO).

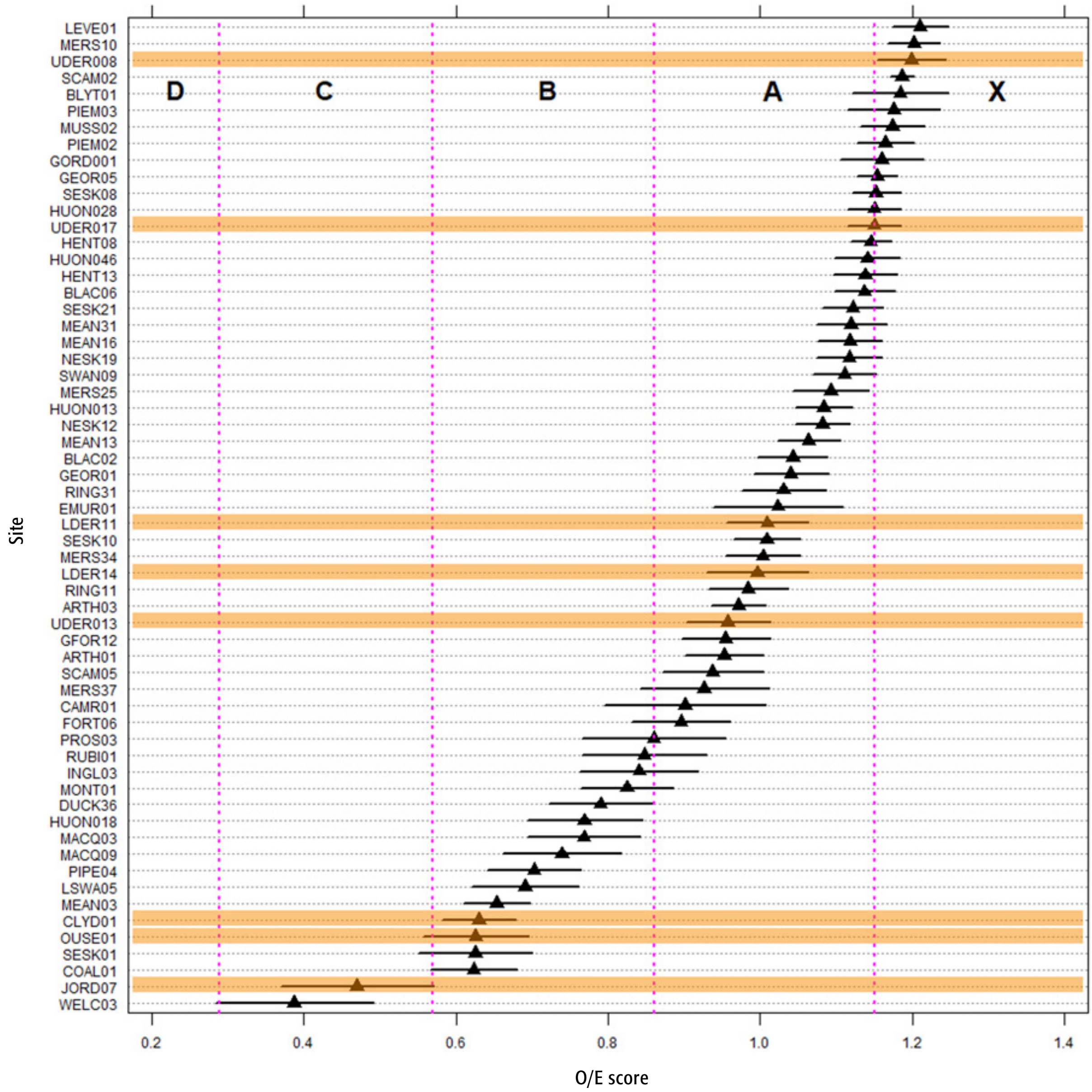


Figure 2.11 Mean ± 95% confidence interval (closed black triangle and black lines, respectively) of river health (Observed/Expected, O/E) scores from long-term sampling in riffle habitat at the RHMP sites, 1994–2016. Sites are ordered according to their long-term mean O/E scores, with the most impaired sites (i.e. low O/E scores) at the bottom and sites that are in good condition (i.e. high O/E scores) at the top. AusRivAS impairment band ratings are shown and are as follows: X = above reference condition, A = equivalent to reference condition, B = significantly impaired, C = severely impaired and D = impoverished. Sites in the River Derwent catchment are highlighted and their details are as follows: Pine River (upstream of Pine Tier Lagoon, UDER017), Nive River (at Lyell Highway, UDER013), Florentine River (at Florentine Road, UDER008), River Ouse (at Ouse, OUSE01), Styx River (upstream of River Derwent confluence, LDER14), Stony Creek (at Plenty Valley Road, LDER11), River Clyde (at Hamilton, CLYD01) and Jordan River (at Mauriceton, JORD07). Figure modified from DPIPWE (2018)

Figure 2.12 Sediment coring of wetlands associated with Lake Crescent and Lake Sorell will help to reconstruct their past hydrological regimes (photo credit: Sara Naylor, DPIPWE)

Reconstructing atmospheric deposition, nutrient cycling, and history of Tasmanian highland lakes

The water level regimes of several lakes on the Central Plateau of Tasmania, Australia, are manipulated for power generation and irrigation supply. This has led to concerns regarding the ecological stability of these lakes under varying water levels, especially during droughts. Lake sediments have the potential to record fluxes of nutrients, pollutants and particulates that can be identified both qualitatively (geochemical and biological proxies) and quantitatively (burial rates). Dammed Central Highland lakes have the advantage of high sedimentation rates compared to other lake systems in Tasmania (typically < 0.5 mm), making it possible to reconstruct the past approximately 150 years of sediment accumulation. In this PhD project (Harrison Stevens, School of Natural Sciences, UTAS), geochemical indicators as well as isotopic dating techniques will be applied to trace changes in lake habitats, sediment and nutrient fluxes as they may have been altered by damming, water level fluctuations and land use change. At remote locations, analysis of trace metals and nutrients in sediment cores will also reveal history of long-range transport of atmospheric contaminants, including bushfire emissions and anthropogenic sources. This project will draw on existing data sets and archived sediment cores, as well as new sediment cores. Results will identify changes that may have occurred due to anthropogenic and natural influences, such as water level manipulation, bushfire disturbances and land use change.

Healthy Rivers Action Plan

In collaboration with the Derwent Catchment Project, the DEP is developing a Derwent Catchment Healthy Rivers Action Plan for the catchment upstream of New Norfolk. The plan is based on existing knowledge of water quality, land use and land management in the catchment, and will include stakeholder engagement. The purpose of the document is to outline a set of priority actions for the catchment with the aim of integrated catchment management. A first draft of the Plan will finalised by the end of 2020.

In-situ online water quality technology

A UTAS team led by Prof. M. Breadmore (Australian Centre for Research on Separation Science) has been developing, in collaboration with Eco Detection, online in-situ analysers for the determination of cations and anions, with a focus on nutrients (nitrite, nitrate, ammonium, phosphate). The systems are based on capillary electrophoresis and sample every 15 minutes with data submitted to the cloud. The DEP is partnering with UTAS to test these systems in the Derwent catchment, with first deployments in late 2020. The collection of high frequency nutrient data will allow for the determination of more accurate nutrient loads in the catchment and entering the estuary.

Source tracking of dissolved organic matter

Dissolved organic matter (DOM) plays a major role in driving both abiotic and biotic processes within aquatic ecosystems (Holland *et al*., 2019), including oxygen removal in hypoxic zones (**Section 2.5**). In collaboration with Dr Aleicia Holland (La Trobe University), the temporal and spatial variability of DOM within the Derwent catchment is currently being investigated on sub-samples of the two-year monitoring program (2015–2017). Fluorescent Excitation Emission Scans can reveal DOM characteristics that identify the source of DOM, revealing whether it is derived from allochthonous (terrestrial) or more autochthonous (microbial, in river) sources. Results will shed light on dissolved organic carbon dynamics (sources and cycling) in the catchment and may help identify potential risks to the hypoxic zone (Holland and Proemse, 2020).

Tyenna River Restoration Program

The Derwent Catchment Project (DCP) has developed a Tyenna River Recovery Plan (funded and supported by the Fisheries Habitat Improvement Fund) for the next 10 years with aims to reduce willow infestations, restore river banks and buffer zones, and mitigate impacts on river water quality from various land and water users (DCP, 2020b). The DEP is working together with the DCP on implementing water quality monitoring for this program to better understand nutrient and sediment loads to the Tyenna and to capture changes in water quality relating to the on-ground restoration activities outlined in the Plan. The DCP is currently seeking funding from various stakeholders and catchment users to implement the plan.

2.3 Metals

Metals in aquatic systems are derived from both natural and human sources, although industrial processes with poor environmental management practices can be a significant anthropogenic source of metal contamination (Bloom and Ayling, 1977). Metals are persistent in the environment and can be toxic. As metals are readily adsorbed to the surface of fine particulate matter, they tend to accumulate in the bottom sediments of aquatic ecosystems, particularly in areas where water moves slowly, allowing particles to concentrate and settle, known as accretion zones. Aquatic organisms can accumulate metals directly from surrounding water and sediments or in their food and a human health risk is posed by ingestion of, particularly, mercury, cadmium, lead and arsenic. Exposure in adult humans can cause sensory, visual, auditory and kidney functional impairment and there may be neurotoxic effects in infants or developing foetuses (World Health Organization, 1976; Hutton, 1987; Ullrich *et al*., 2001). An approximate order of decreasing toxicity of common metals is: mercury>cadmium>copper> zinc>nickel>lead>chromium>aluminum>cobalt;

however, toxicity can vary significantly between different organisms and the chemical species in which metals occur is particularly important when considering toxicity (Kennish, 1996). The different chemical species in which metals occurs is influenced by biological, physical and chemical properties of the environment, principally the composition and activity of bacterial communities, temperature, salinity, pH and the concentration of DO and organic matter (Ullrich *et al*., 2001). Inorganic species of mercury have relatively low toxicity to biota but are readily converted to more toxic forms, such as methylmercury. Methylmercury is rapidly absorbed by aquatic organisms and exerts a toxic effect at low concentrations (Koos and Longo, 1976; Ullrich *et al*., 2001).

The main sources of metal contamination to the Derwent estuary are principally historical, and while modern environmental management practices have markedly improved, the legacy of former practice still affects the Derwent estuary today, and will most likely persist for many decades. The zinc smelter at Lutana began discharging metallurgical liquid effluent containing metals to the Derwent estuary when it was established in 1917. A huge amount of work has been conducted by current and former owners of the zinc smelter to reduce ongoing sources of contamination and to remediate onsite legacy contamination. Currently, contaminated groundwater is the most significant source of metal contamination to the estuary, with smaller contributions from the outfall on site and air emissions (**Figure 2.13**). The paper mill at Boyer also discharged metals to the estuary in the past, especially mercury, which was historically used as a slimicide and in the chlor-alkali plant, which closed in 1993. Zinc was also discharged from this site due to the former use of zinc hydrosulphite as a brightening agent.

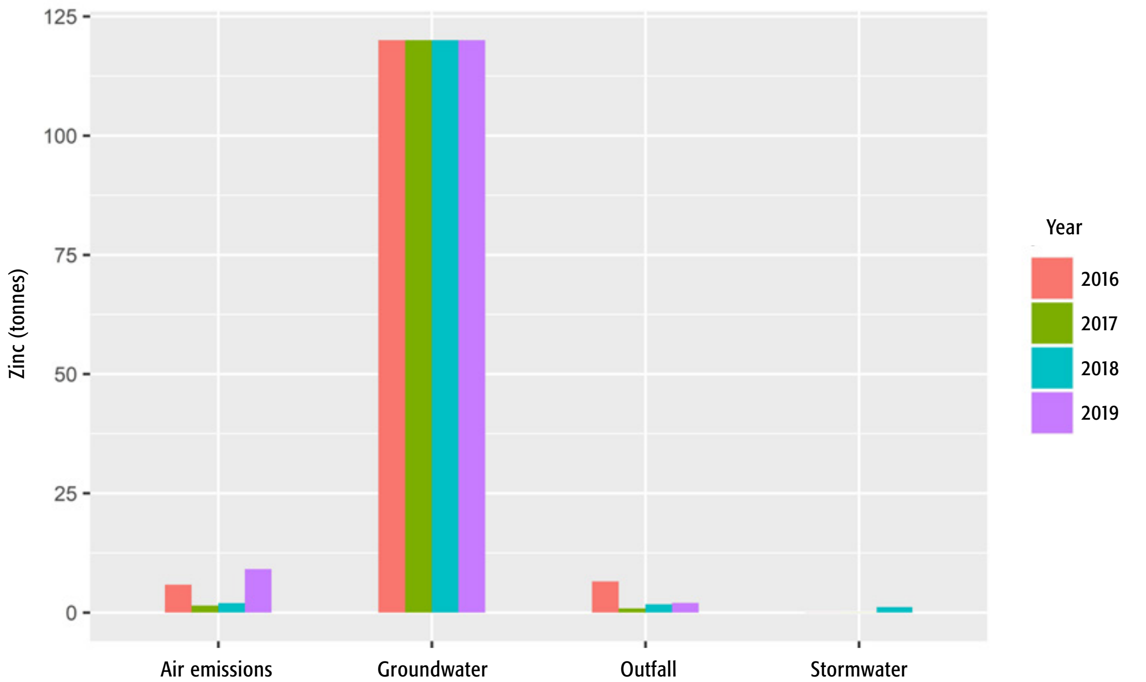


Figure 2.13 Comparison of zinc sources at the Lutana zinc smelter at Lutana is the most significant ongoing source of metal contamination to the estuary, with metals principally originating from contaminated groundwater which is subject to ongoing management by Nyrstar Hobart, the current site owners. Groundwater loads are estimates. All data courtesy of Nyrstar Hobart

2.3.1 Status and trends

Metals have been periodically monitored in Derwent estuary waters since the early 1970s. Metals have been monitored as part of the DEP's ambient water quality monitoring program since 2000, and various monitoring programs have assessed metal concentrations in human-targeted seafood. A wide range of metals is sampled in seafood, but in ambient waters the initially broad spectrum of analytes was reduced to total zinc, because the concentration of most other metals was principally below the laboratory reporting limit. Zinc serves as a good proxy for those metals that are residues in zinc ores (e.g. Cd, Hg, Pb and to a lesser extent Cu), but a poor proxy for metals with other sources (e.g. Ni, Co, Cr).

2.3.1.1 Ambient waters

Zinc concentration maps clearly illustrate dominant zinc sources and estuarine hydrodynamics. The zone where zinc is highest in surface waters is in New Town Bay and throughout the mid-estuary. This distribution of zinc is expected given proximity of these sites to the principal ongoing source of metal contamination to the estuary, which is contaminated groundwater at the Nyrstar Hobart zinc smelter at Lutana (**Figure 2.14**).

In benthic zone waters, there are two zones where zinc concentration is highest; Prince of Wales Bay located immediately north-west of the zinc smelter, and around the submerged aquatic macrophyte meadows near U12 (**Figure 2.15**). The U12 maximum zinc zone may be due to estuarine hydrodynamics, most important of which may be the broad, shallow and slower-moving waters around Bridgewater, resulting in an accretion zone where metals originating in the mid-estuary accumulate. Similarly, the enormous surface area of macrophyte roots and fine sediments in this accretion zone, coupled with high concentrations of organic matter, are likely to be an effective sponge for metals and other contaminants. Another explanation for high zinc concentrations in ambient waters of this area may be metal leachate from the highly sulfidic local sediment when they are exposed to air on spring low tides. This occasional exposure to air may result in partial oxygenation of acid sulphide soils resulting in metal mobilisation from a formerly sediment-bound and relatively biologically unavailable state (Dent and Pons, 1995; Du Laing *et al*., 2009). The DEP does not have a research proposal for this topic at this point and would collaborate with partners if this met their research goals.

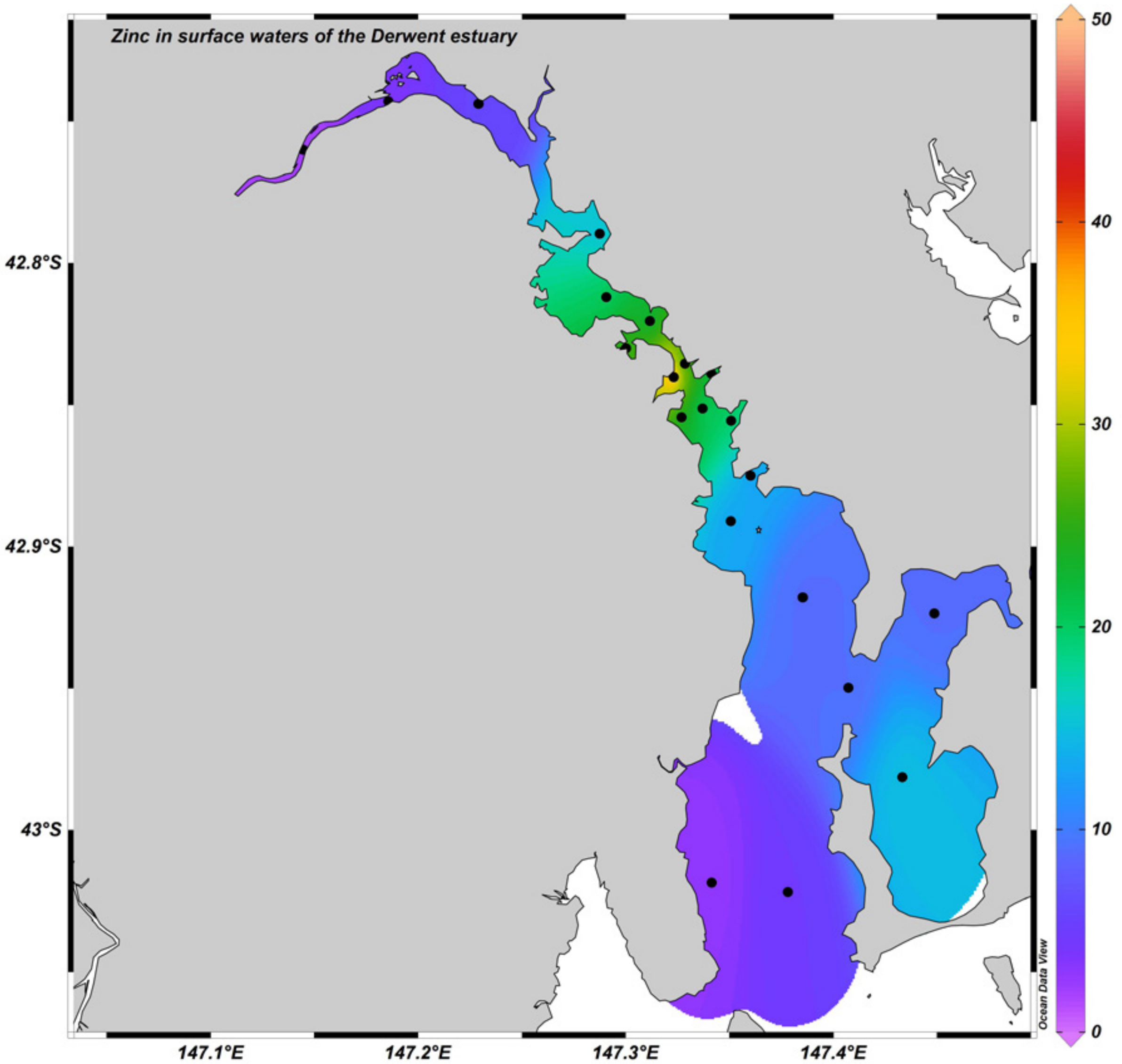


Figure 2.14 Median zinc concentration (µg/L) in surface waters for the period 2007–2020

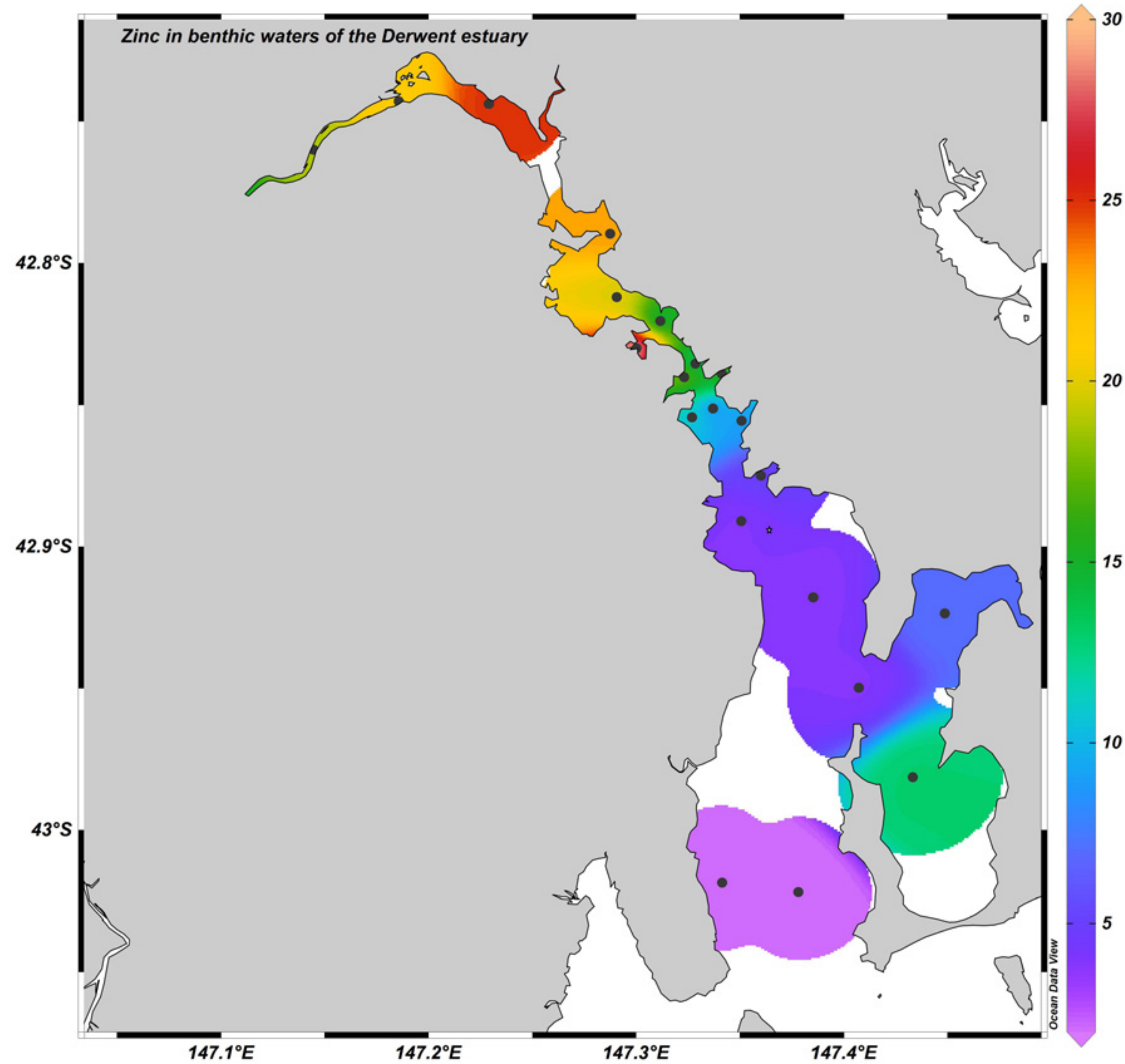


Figure 2.15 Median zinc concentration (µg/L) in benthic-zone waters for the period 2007–2020

Zinc in ambient water declined at 17 of 22 (77%) ambient water quality monitoring sites between January 2007 and December 2019 (**Figure 2.16**, **Figure 2.17**, **Figure 2.18**). We analysed trends in waters at the entry points to the estuary to help understand whether these changes might be due to processes within the estuary, or changes outside the estuary. Surface waters at New Norfolk (site NN) are the entry point for riverine water from the catchment, while underlying salt water enters the estuary from bottom waters near Tinderbox and moves northerly from sampling sites B1 and B3 (Wild-Allen *et al.*, 2013). Zinc did not change at the entry points to the estuary sites where zinc is consistently low, that is the surface waters at New Norfolk and bottom waters at B1 and B3. A further possibility may be that zinc concentrations decreased due to increased riverine discharge and associated dilution. We assessed river discharge trends, and although discharge increased between 2007 and 2010, discharge remained relatively stable thereafter and no significant trend was detected for the full period from 2007 to 2020. While a relationship between ambient water zinc concentration and river discharge is apparent, this is not statistically significant, likely due to the multiple factors influencing estuarine water quality (**Figure 2.19**, **Figure 2.20**). Although river discharge overall did not significantly increase, summer river discharge did increase between and including 2018 and 2020 (**Figure 2.21**) which may have increased flushing or dilution of zinc from ambient waters of the upper Derwent. Thus, we suggest that the widespread decreasing zinc concentration in estuarine ambient waters was most likely due to a combination of three factors:

- Proactive site remediation by Nyrstar Hobart including interception and treatment of both stormwater and groundwater and improving plant operations by reducing ongoing metal contamination (Nyrstar Hobart, 2017).
- Higher summer discharge between 2018 and 2020 flushing and diluting zinc from benthic waters of the upper Derwent (**Figure 2.19**, **Figure 2.20**, **Figure 2.21**).
- Gradual burial of the most heavily metal-contaminated sediments under cleaner overlying sediment (Hughes, 2014; DEP, 2015; Stevens *et al.*, 2020) due to natural sediment accumulation processes. This reduces the potential for the most heavily metal-contaminated sediments to be mobilised into ambient waters and estuarine food webs.

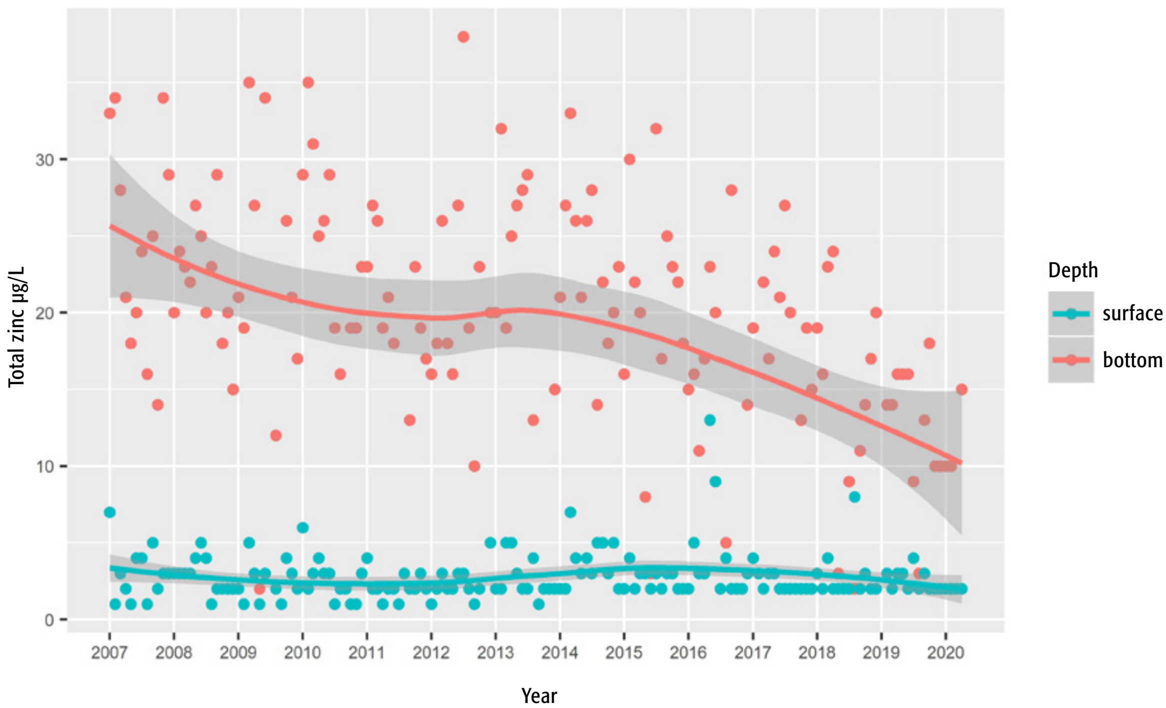


Figure 2.16 Zinc concentration in ambient waters of upper estuary site U16/17 with local regression lines and standard error bands

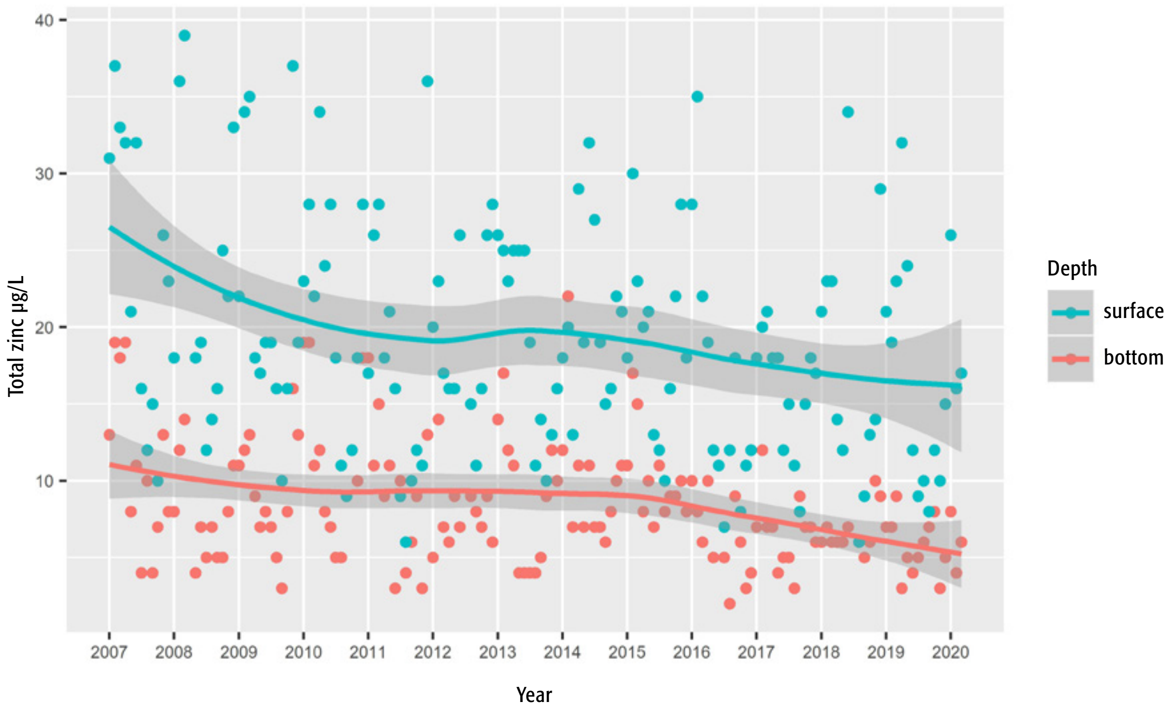


Figure 2.17 Zinc concentration in ambient waters of mid-estuary site U2 (north of the Tasman Bridge) with local regression lines and standard error bands

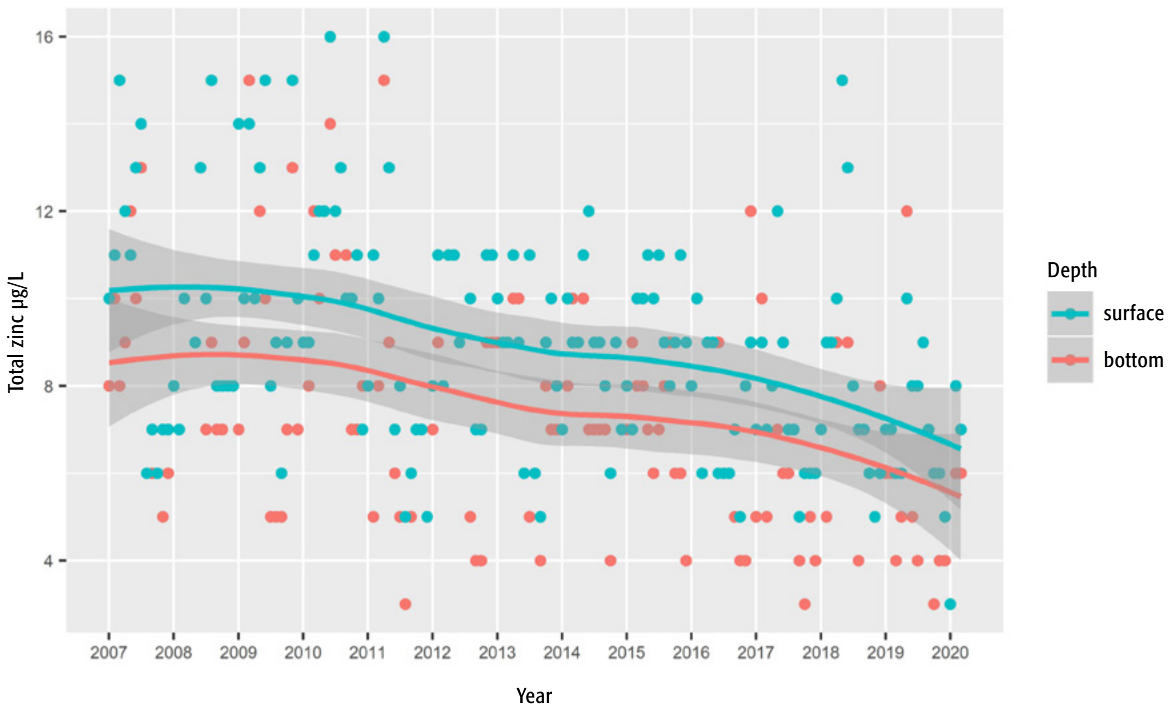


Figure 2.18 Zinc concentration in ambient waters of lower estuary site RBN (northern Ralphs Bay) with local regression lines and standard error bands

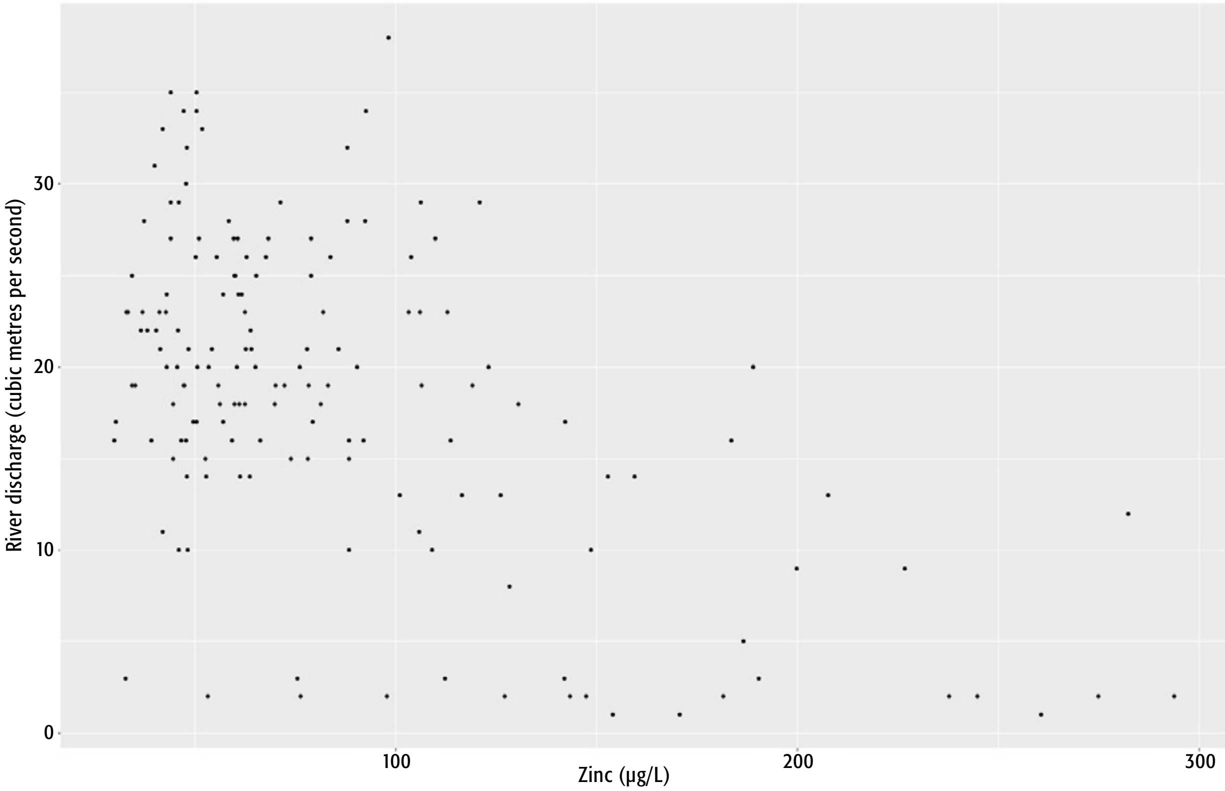


Figure 2.19 Zinc concentration in ambient waters of upper estuary site U16/17 (near the motorboat club) plotted with monthly mean river discharge below Meadowbank Dam

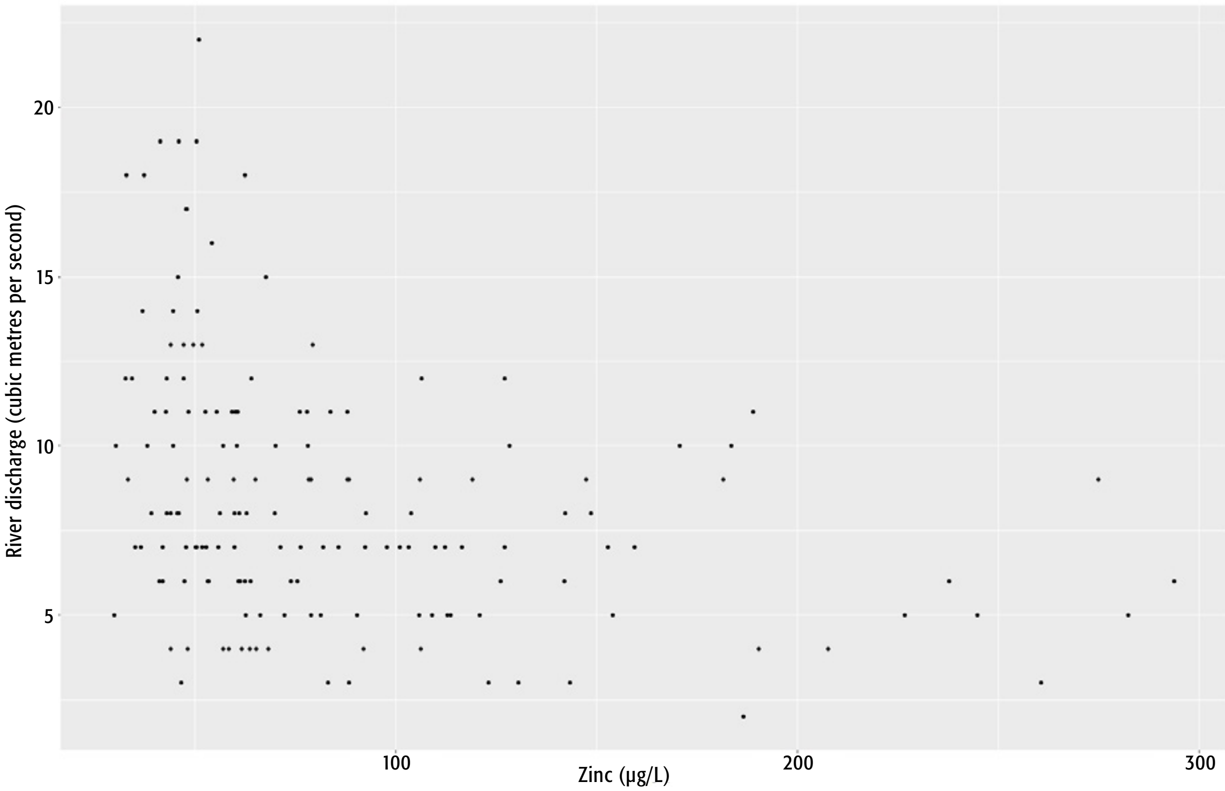


Figure 2.20 Zinc concentration in ambient waters of mid-estuary site U2 plotted with monthly mean river discharge below Meadowbank Dam

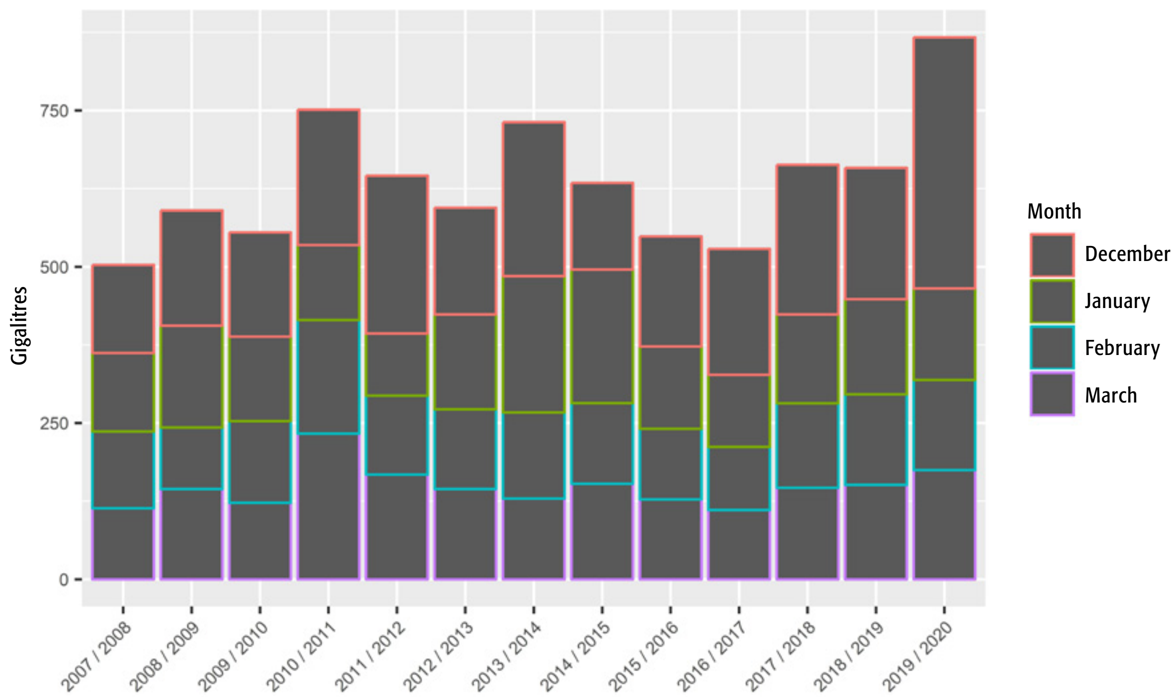


Figure 2.21 Seasonal mean river discharge below Meadowbank Dam

2.3.1.2 Sediment

Metals can accumulate in sediment and be released under some circumstances, such as during hypoxic events or during oxidisation of acid sulphate soils (Dent and Pons, 1995; Banks and Ross, 2009; Botting *et al*., 2009; Banks *et al*., 2012) (**Section 2.5**). Upper Derwent sediment is characterised by anoxic, organic- and sulphide-rich silt, likely derived from a combination of organic matter loads from the River Derwent naturally coupled with loads discharged from the Norske Skog paper mill at Boyer (NSR Environmental Consultants Pty Ltd, 2001).

After zinc and lead contamination was found to be extremely high in the Derwent estuary in the 1970s (Bloom, 1975), action was gradually taken to try to reduce input loads, particularly so in recent years. This progressive metal load reduction is evident in sediment cores, identifying lower concentrations of metals in surface layers (Hughes, 2014).

More recently, an honours study was conducted revisiting metal levels in sediment, in addition to nutrient levels (**Section 2.3.1.2**), with eight cores collected in summer 2019-2020 (**Figure 2.22**). Core U2 was taken from a site adjacent to the zinc smelter, and zinc concentrations in the surface sediment have decreased to just 13% of the recorded historical maximum at this location (2927 mg/kg at 0.5 cm depth compared to 21840 mg/kg at 38.5 cm depth). Metals in core G2 and E had not decreased as rapidly as at U2 but declines were evident. The zinc and lead concentrations are not back to background levels at any middle estuary site, but the steady decreases demonstrate the successful reduction in metal-contaminated effluent into the estuary since the 1970s (**Figure 2.23**). Background levels were not observed for core U2 because sediment was not collected to a sufficient depth.

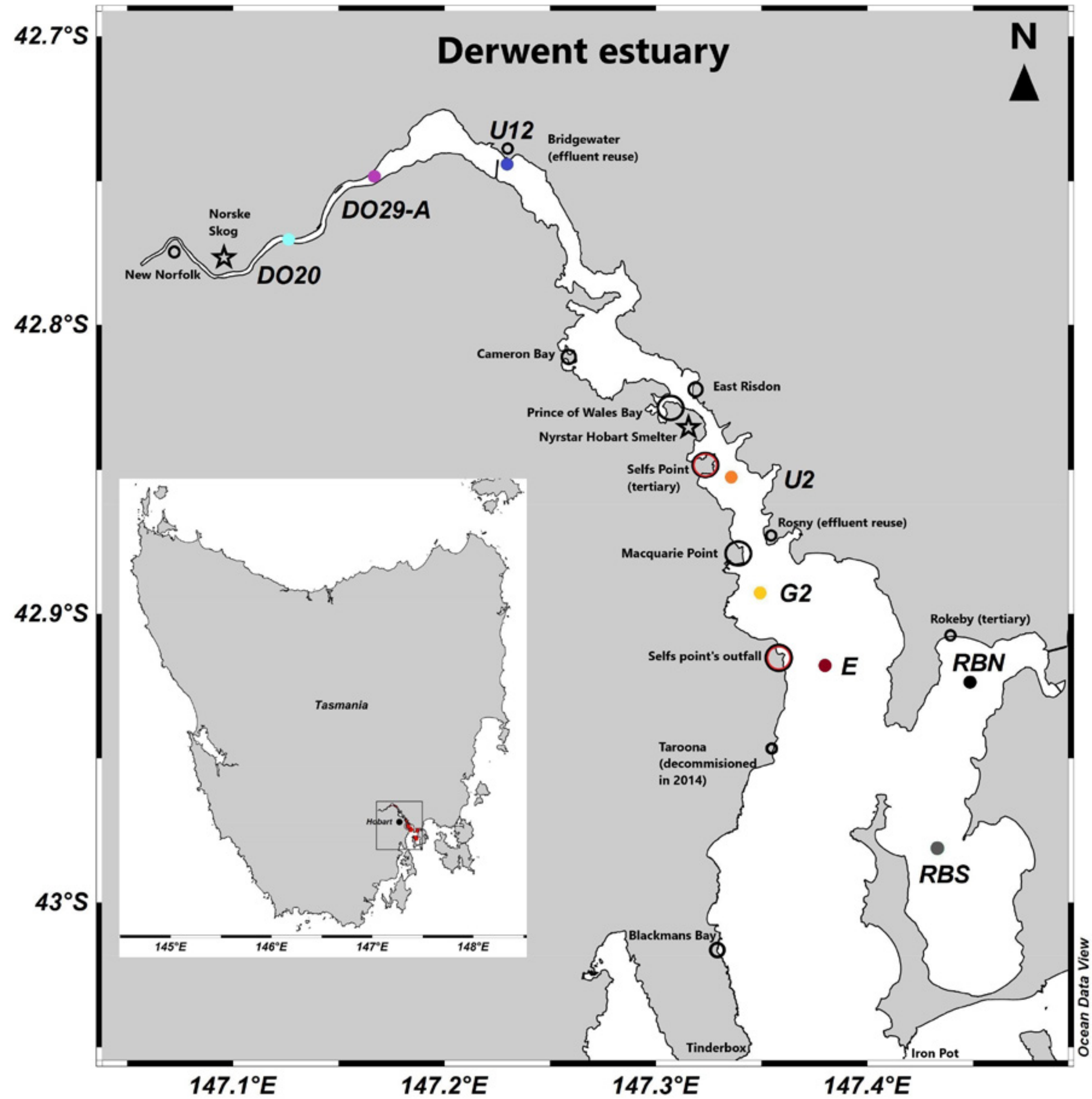


Figure 2.22 Locations of collected sediment cores in summer 2019-2020 (Stevens *et al*., 2020)

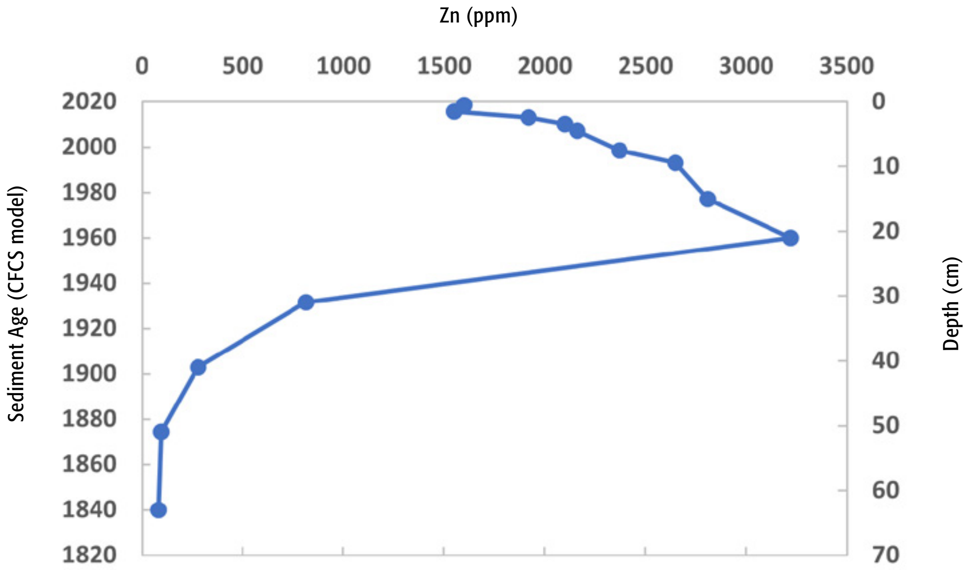


Figure 2.23 Zinc concentrations (measured by ICP-AES) in sediment core G2 versus sediment depth and age. Initial zinc concentration increase above background levels around 1910, and zinc concentration peak around 1970 (Stevens *et al.*, 2020)

2.3.1.2.1 Derwent Estuary Resistome

The following update has been provided by CSIRO Hobart Environmental Genomics team:

"Impacts of anthropogenic pollution, such as eutrophication, biodiversity and habitat loss, and disruption of ecological function, are widely recognised public and environmental health concerns, but there are also indirect impacts that are lesser known. As a survival strategy, some microbes acquire genes to "resist" environmental stressors. The presence of metals in the environment, for example, may select for metal resistance genes. The Derwent estuary is recognised as one of the most highly metal-polluted estuaries in the world with levels of metals (zinc, mercury, lead, cadmium, copper and arsenic) in mid-estuary sediments exceeding national guidelines (Australian and New Zealand Guidelines for Fresh and Marine Water Quality ANZECC Sediment Quality Guidelines SQGs; Simpson *et al*., 2013). Recent studies have demonstrated a link between the presence of metal resistance genes and antimicrobial resistance (AMR) genes in the environment. The development of AMR represents a major global health threat.

Co-selection has heightened the rate of spread and dissemination of AMR genes in the environment, which, in turn has increased the emergence of multi-drug resistance clinical pathogens (Salam 2020). We used another genomics technique, "shotgun metagenomics", to determine the "resistome" of Derwent estuary surface sediment samples collected in June and November 2019. Resistance genes (to antimicrobials, metals, and biocides) were identified at all sites sampled from the lower estuary to Site U12 at Bridgewater, including at sites where metal concentrations are low (**Figure 2.24**, **Figure 2.25**). AMR genes do occur naturally in the environment at low levels. While the numbers we see in samples from the Derwent estuary are within the range we have detected in other Australian estuaries, we do see an increase in all types of resistance genes where metal loads increase in the mid-estuary (**Figure 2.26**). Surprisingly, it is the furthest site upstream, U12 at Bridgewater, where metal concentrations are low, that we see the greatest abundance of resistance genes. Why we see this increase at Site U12 is currently unknown but understanding the persistence of AMR genes in the environment is important for controlling AMR and better health outcomes. This work is ongoing."

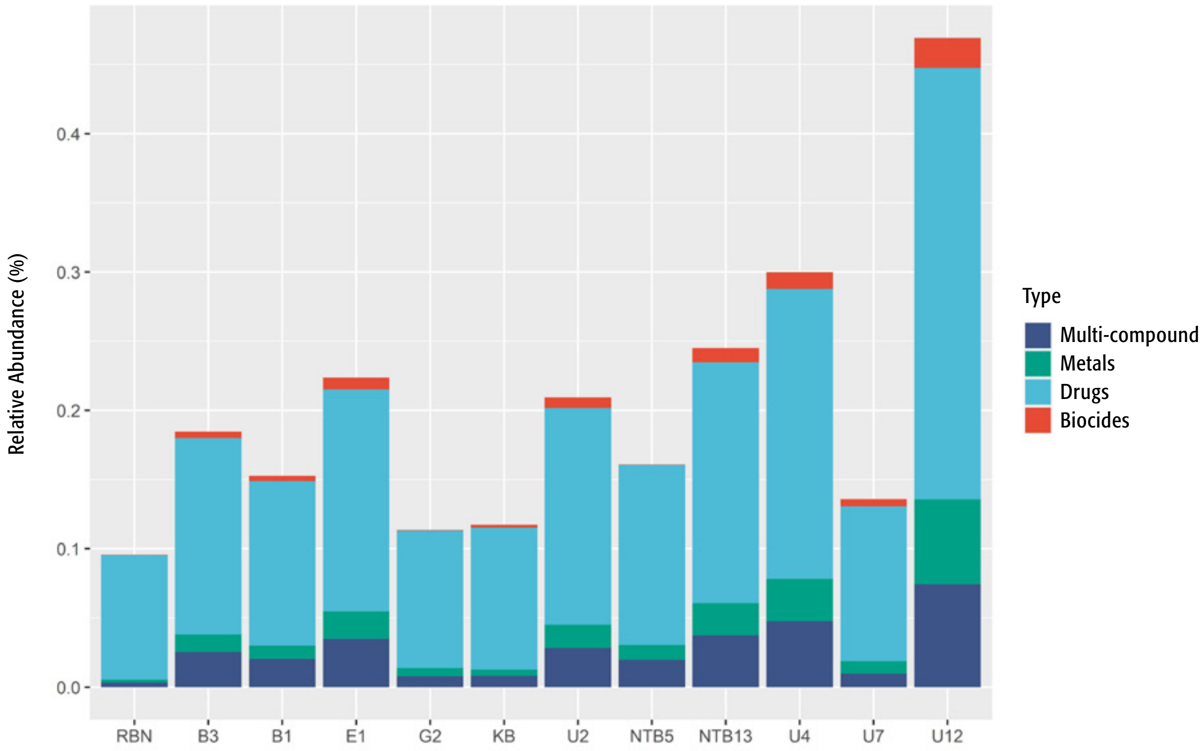


Figure 2.24 Derwent Estuary Resistome – Relative abundance of microbial resistance genes in Derwent estuary sediments showing antimicrobial, metal, biocide, and multi-compound resistance genes in the sediments at most sites

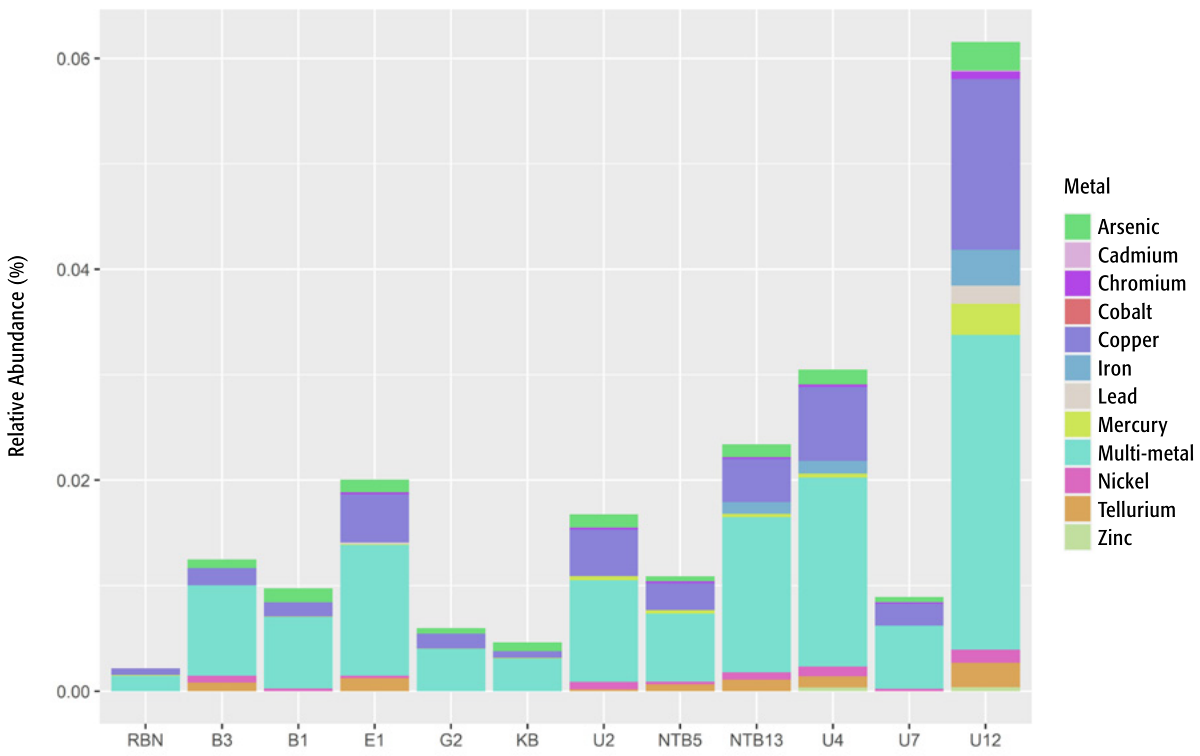


Figure 2.25 Derwent Estuary Resistome – Relative abundance of microbial resistance genes in Derwent estuary sediments showing that the most abundant metal resistance genes detected were those that function against multiple metalloids and copper. eDNA was isolated from sediment samples collected in November 2019 and data displayed was derived from metagenomic sequencing

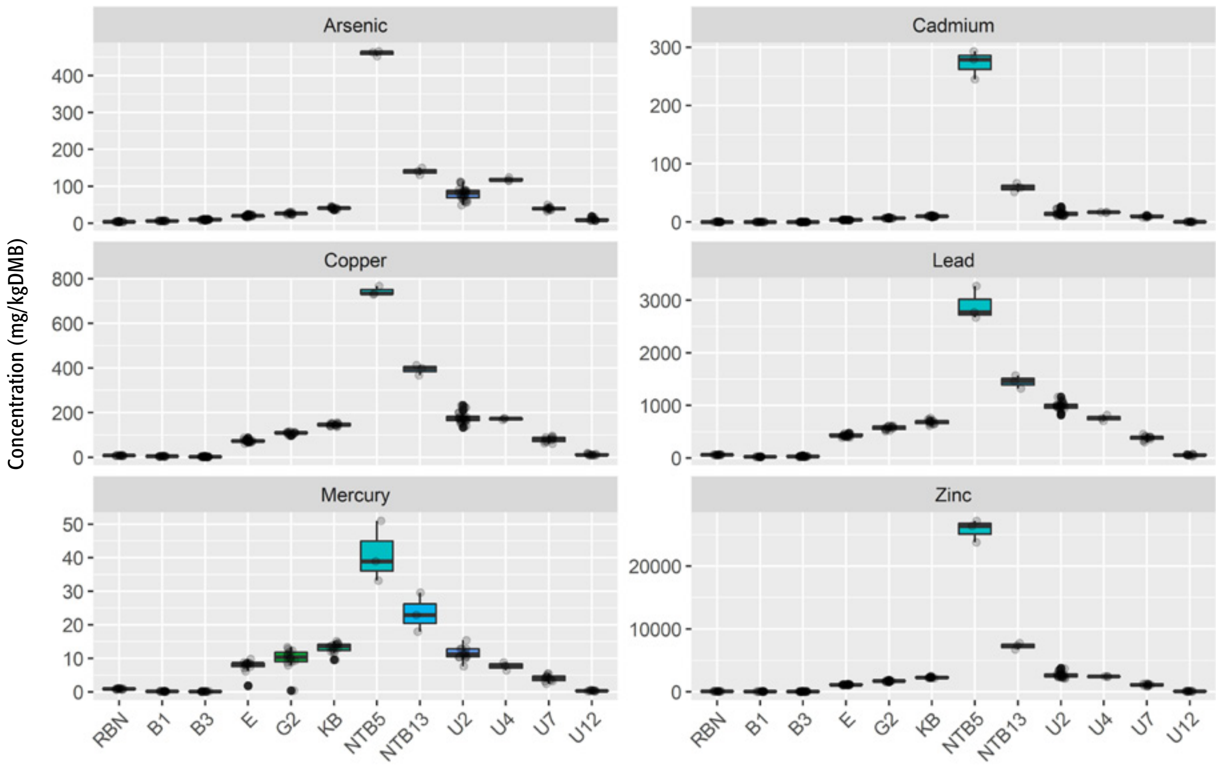


Figure 2.26 Metalloid concentrations collected from surface sediments throughout the Derwent estuary

2.3.1.3 Fish

Seafood species that recreational fishers commonly target in the Derwent estuary are contaminated with toxic metals derived principally from historical operations at the Hobart zinc smelter site and the Boyer paper mill. Metal concentrations in Derwent estuary seafood have been assessed periodically since the early 1970s when high concentrations of zinc, cadmium, lead and mercury were detected in oysters from Ralphs Bay (Thrower and Eustace, 1973; Ratkowsky *et al*., 1975; Dineen and Noller, 1995; DEP, 2015). The most comprehensive and continuous seafood monitoring program in the Derwent is that conducted by the current and previous owners of the Lutana zinc smelter. This program has monitored metals in flathead fish (*Platycephalus bassensis*) since 1984, various metals in wild oysters and mussels since 1992 and caged oyster deployments since 2004 to evaluate metal accumulation rates (DEP, 2015). The DEP has intermittently partnered with other organisations to sample and analyse the concentration of metals in other fish species aiming to compare results to relevant health guidelines or generally expected levels (FSANZ, 2016).

2.3.1.3.1 Health advice

The Food Standards Australia New Zealand (FSANZ) guidelines (FSANZ, 2016) sets guidelines for seafood using a combination of maximum permitted levels, for arsenic, cadmium, mercury and lead, and generally expected levels for copper and zinc (**Table 2.1**). Maximum permitted levels have been set only for those foods that provide significant contributions to total dietary exposure for a given contaminant and are based on human health risk calculations. Maximum permitted levels are legally enforceable for food offered for sale. In contrast, generally expected levels are not legally enforceable and were developed for those contaminant/commodity combinations with a low level of risk to the consumer and only where adequate data were available.

Table 2.1 National food guidelines for metal levels in seafood (FSANZ, 2016)

	Maximum levels (mg/kg)				Generally Expected Levels median/90th percentile (mg/kg)	
	As (inorganic)	Cd	Hg	Pb	Cu	Zn
Fish	2	No set limit	0.5 for most fish, or 1 for large/ predatory fish	0.5	0.5 / 2	5 / 15
Molluscs	1	2	0.5*	2	3 / 30	130 / 290
Crustaceans	2	No set limit	0.5*	No set limit	10 / 20	25 / 40

Note: GELs are from the FSANZ Standard 1.4.1 Amendment dated March 2016. Where * represents a mean value from the minimum number of fish required to be sampled, see Schedule 19 of Standard 1.4.1.

Based on available information including the most recent metal analysis of seafood (DEP, 2020a) the public are advised by the Director of Public Health as follows:

- Do not consume any shellfish or bream from the Derwent, including Ralphs Bay.
- Other fish from the Derwent should not be eaten more than twice a week and the following people should further limit their consumption to once a week:
  - Pregnant and breastfeeding women
  - Women who are planning to become pregnant
  - Children aged six years and younger
- When eating fish from the Derwent, it is best to avoid eating fish from other sources in the same week.

There is always a risk to human health from eating wild shellfish, thus the Department of Health recommends that all shellfish is bought from retail outlets, because shellfish for sale is subject to a quality assurance program that tests for, and manages, human health risks.

All recreationally targeted fish species sampled from the Derwent in the general wild fish survey of 2019 exceeded the relevant health guideline or generally expected level determined by health authorities (FSANZ, 2016) for at least one metal/metalloid. Different species accumulated these toxicants differently:

- Mercury: bream, trout, eel (**Figure 2.27**)
- Copper: abalone, crayfish, Australian salmon (**Figure 2.28**)
- Arsenic: abalone, cod, crayfish, whiting (**Figure 2.29**)
- Zinc: abalone, Australian salmon, crayfish, eel, urchins, whitebait, whiting (**Figure 2.30**)
- Lead: not detected above the guideline limit for any finfish species (**Figure 2.31**)

Australian salmon were amongst the species with the highest concentrations of selenium, lead, cadmium and chromium, while mercury was highest in trout, bream and eel (DEP, 2020a). Lead was high in whiting and urchins, crayfish had the highest concentrations of arsenic and copper and abalone accumulated more copper, zinc and chromium. arsenic and zinc were the two metals detected in particularly high concentrations in most fish species (DEP, 2020a).

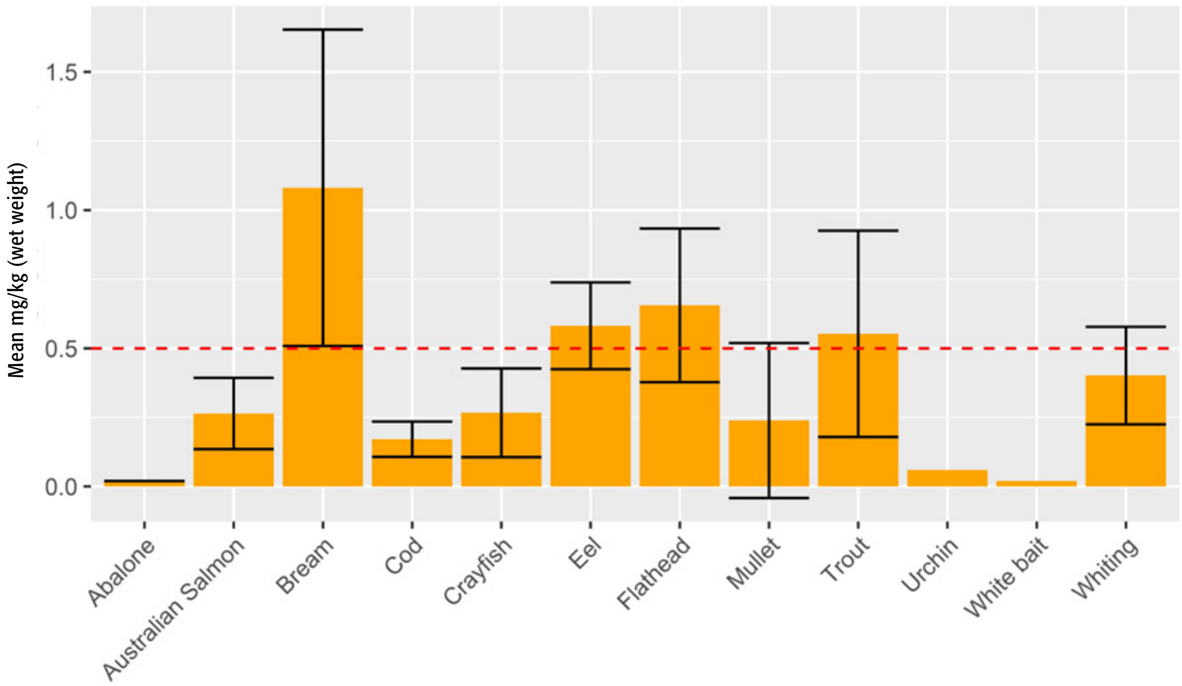


Figure 2.27 Comparison of mean mercury concentration in various species of wild fish collected from the Derwent estuary, where black lines indicate the standard deviation from the mean and the dashed red line indicates the national food guideline

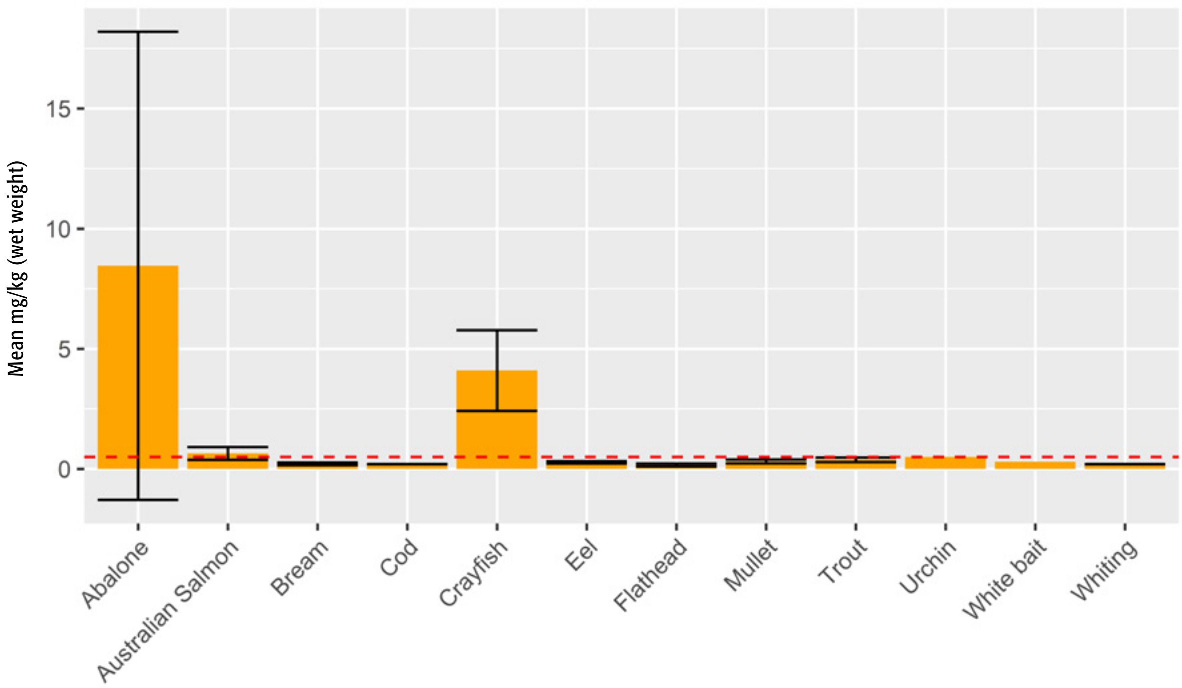


Figure 2.28 Comparison of mean copper concentration in various species of wild fish collected from the Derwent estuary, where black lines indicate the standard deviation from the mean and the dashed red line indicates the national food guideline

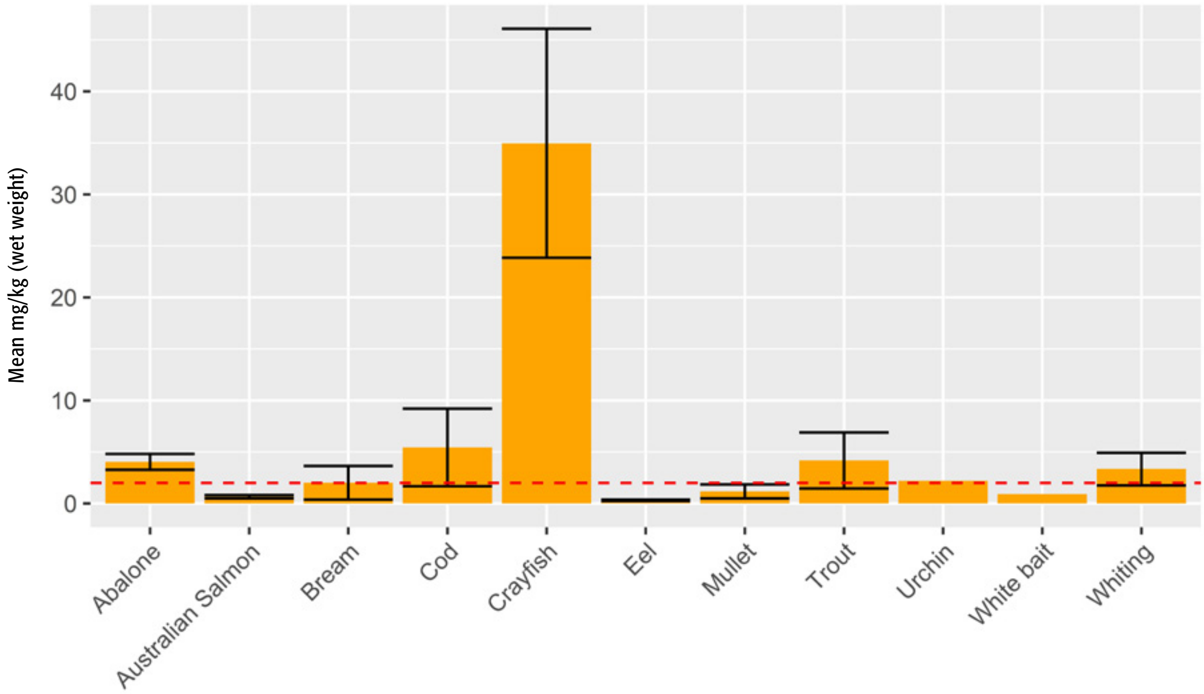


Figure 2.29 Comparison of mean arsenic concentration in various species of wild fish collected from the Derwent estuary, where black lines indicate the standard deviation from the mean and the dashed red line indicates the national food guideline

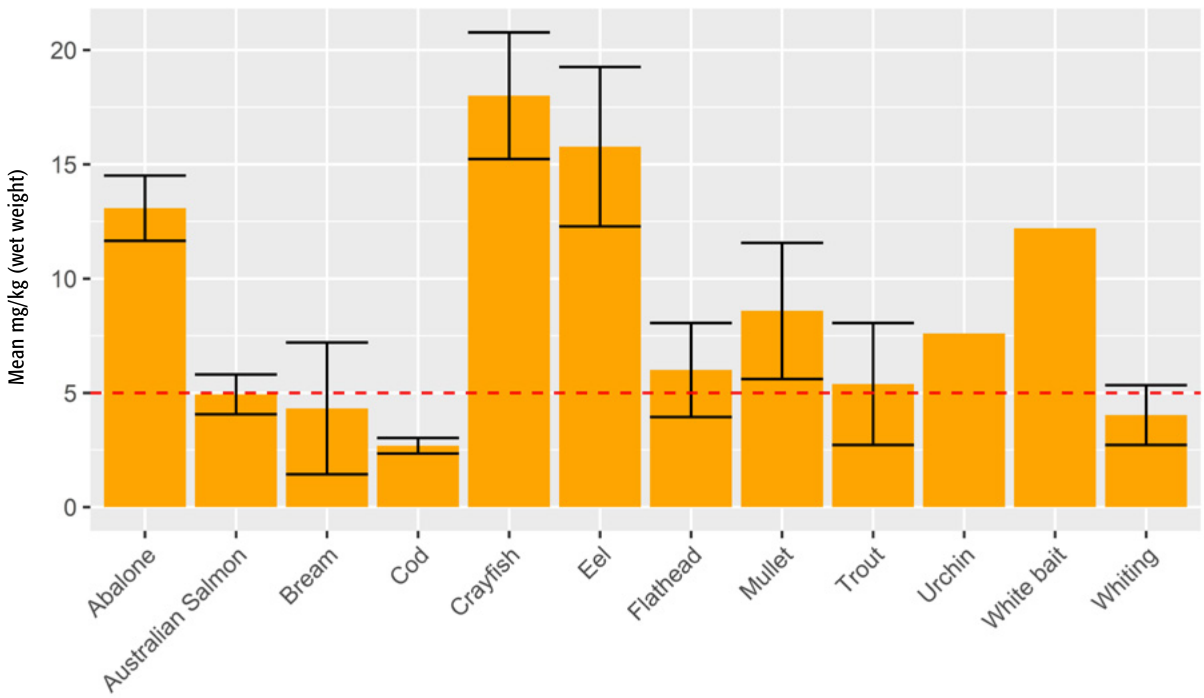


Figure 2.30 Comparison of mean zinc concentration in various species of wild fish collected from the Derwent estuary, where black lines indicate the standard deviation from the mean and the dashed red line indicates the national food guideline

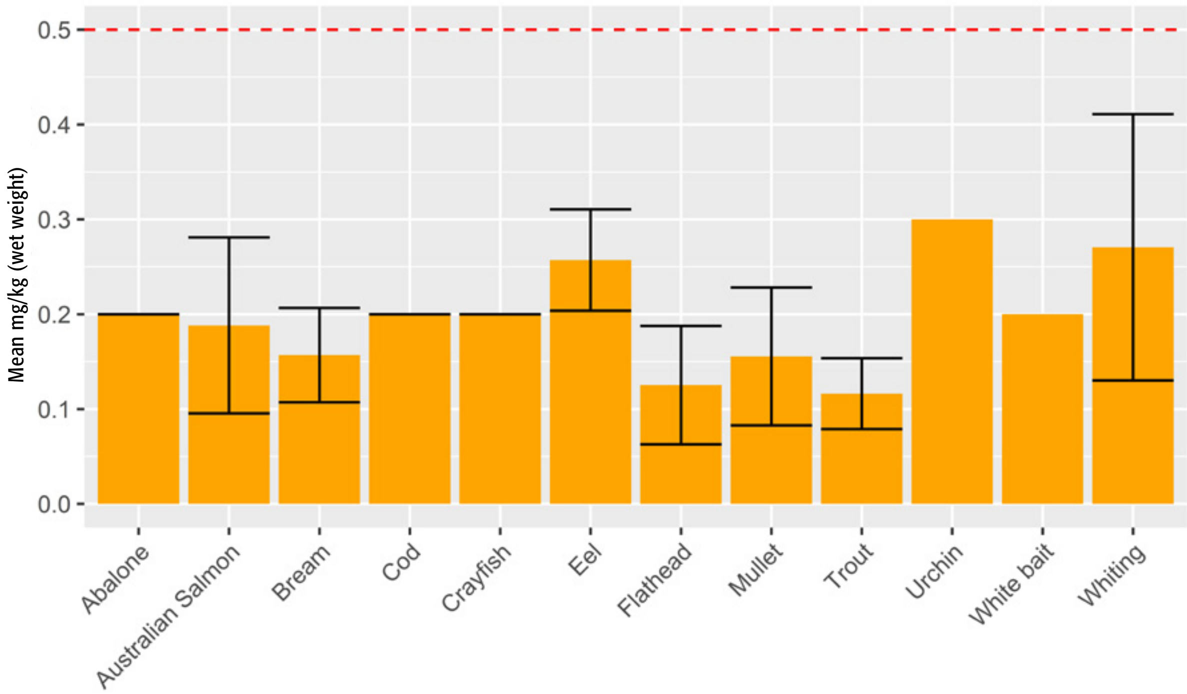


Figure 2.31 Comparison of mean lead concentration in various species of wild fish collected from the Derwent estuary, where black lines indicate the standard deviation from the mean and the dashed red line indicates the national food guideline

2.3.1.3.2 Spatial comparison

2.3.1.3.2.1 Finfish

Mercury concentration in flathead collected from all sites in the Derwent was higher than concentrations in fish collected from the reference site at Mickey's Bay, with the highest mercury concentrations recorded in fish from Ralphs Bay Spit and Opossum Bay (**Figure 2.32**). Comparisons between sites within the Derwent are likely misrepresenting the accuracy of the data given recent information showing that flathead are seasonally mobile (Tracey *et al*., 2020). Thus, fishers considering eating their catch should not expect that fish from the lower Derwent will have lower metal concentrations than fish from elsewhere, particularly given species migrate toward lower estuarine zones in spring and summer. Although fish length and weight are not robust explanatory variables for metal concentration in fish flesh, although higher mercury concentrations in fish from Ralphs Bay spit may be partly explained by generally longer and heavier fish from that site compared to other Derwent sites (Jones *et al*., 2013; DEP, 2020a). To improve understanding of the influence of fish biometrics on fish metal concentrations, Nyrstar Hobart commenced age and sex determination of fish samples in 2016. There is currently insufficient age and sex data for robust interpretation, but due to the complexities of mercury methylation and bioaccumulation, even with robust biometric data, it may not be possible to adequately explain variability in mercury concentrations in fish flesh, without robust monitoring program design, funding and implementation. Mercury methylation is subject to site specific drivers and fish diet and food chain variability affects accumulation both within and between species (Jones *et al*., 2013; DEP, 2020a).

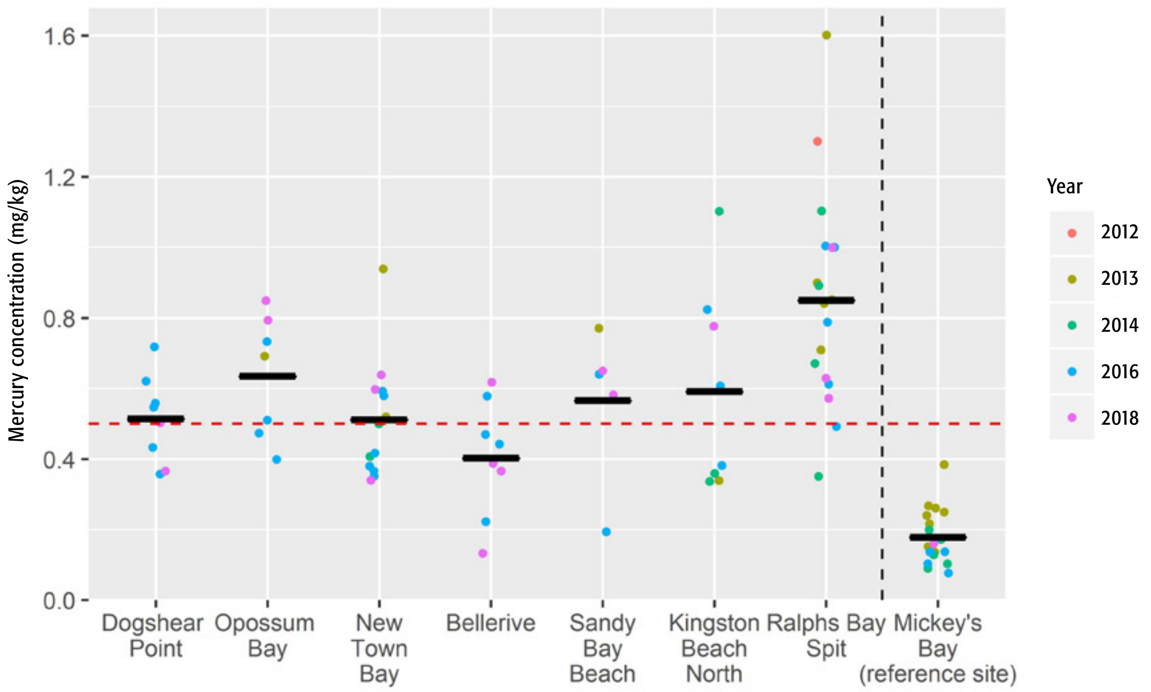


Figure 2.32 Between-site comparison of mercury concentration in legal-sized flathead where the red line indicates the maximum level or generally expected level, the black dotted line delineates sites within the Derwent compared to sites outside the Derwent and the solid black lines for each site indicate the median concentration

2.3.1.3.2.2 Shellfish

Unlike finfish, shellfish are not mobile and, therefore, are a useful biomonitoring tool for comparison of metal availability at small spatial scales, as required to compare metal accumulation between sites within the Derwent. Deployed oyster experiments (DEP, 2020a, **Figure 2.33**) detected that oysters deployed into the Derwent accumulated markedly higher concentrations of all metals than those deployed to the reference site outside the Derwent (Mickey's Bay) and a positive relationship with proximity to the zinc smelter (**Figure 2.34**). Results are aligned with zinc concentration in ambient waters (**Section 2.3.1.1**).

Figure 2.33 Deployment sites for transplanted oysters in the middle Derwent estuary, 2019

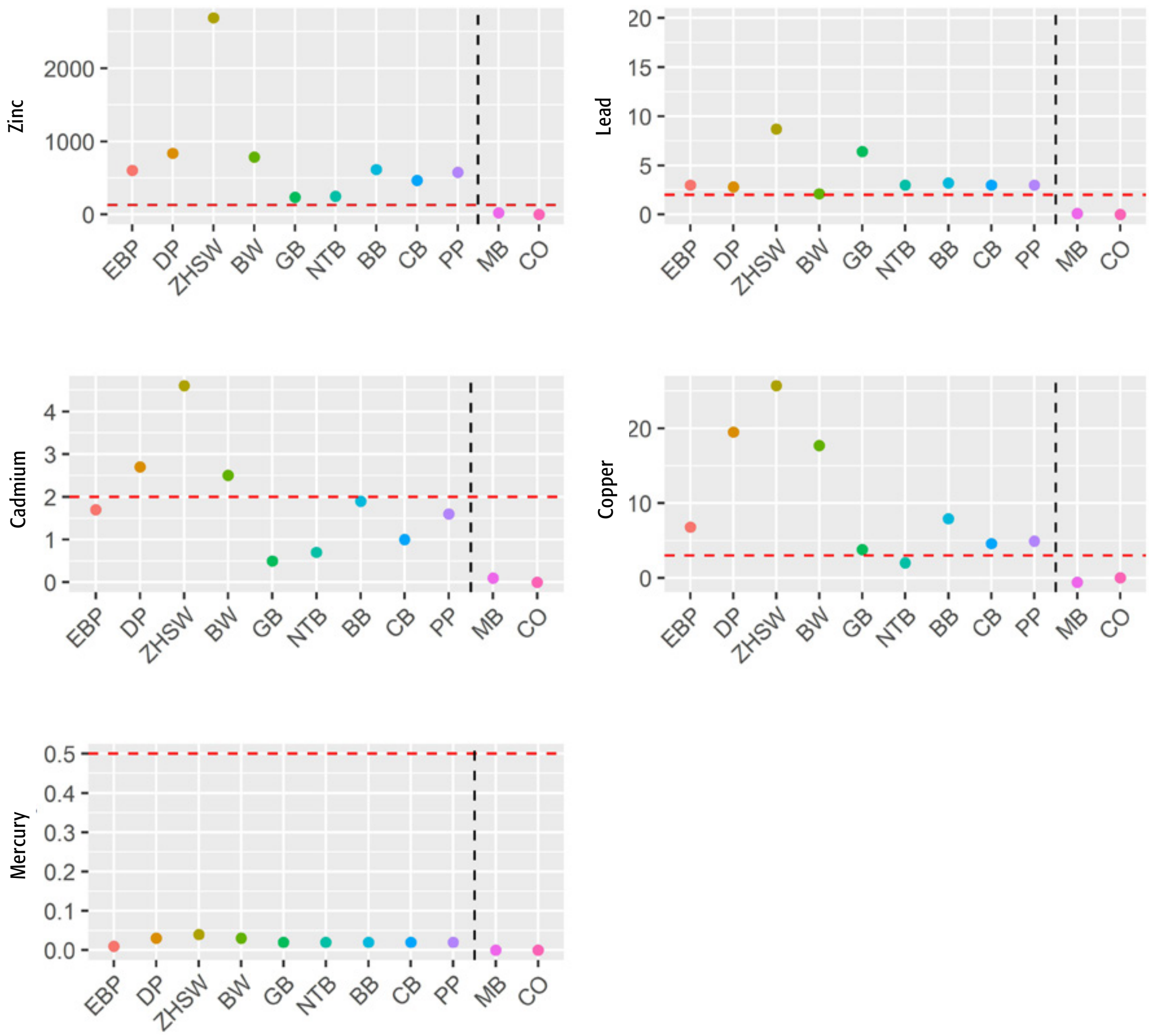


Figure 2.34 Comparison of metal accumulation in surface-deployed oysters between sites in 2019, where the red line indicates the generally expected level or guideline value

Higher metal concentrations with proximity to the zinc smelter are likely due to:

- The ongoing source of metal contaminated groundwater entering the estuary from the zinc smelter site.
- Ongoing metal contamination from current zinc smelter operations.
- The legacy of contaminated sediments and their remobilisation, with sites closer to the zinc smelter being most heavily metal-contaminated (DEP, 2015).

There have been major improvements in the operation of the zinc smelter and major efforts to remediate contaminated groundwater on site in recent years (DEP, 2015). Improved environmental management continues and includes expansion of interception and treatment of groundwater, stormwater harvesting and treatment and reduction in ongoing groundwater contaminant sources (DEP, 2015).

2.3.1.3.3 Trends

2.3.1.3.3.1 Finfish

Mercury concentration in wild flathead flesh declined in the last two rolling five-year periods (**Figure 2.35**). Whilst the declining mercury concentration indicates a gradual improvement in condition, 72% of legal-sized flathead collected from the Derwent in 2018 exceeded the maximum level for mercury and there is a lot of variability in the data, so at this point we consider the results with cautious optimism. Zinc concentration increased in 2016 and 2018 (**Figure 2.35**) due to combined analysis of fish samples with skin on, compared to former analysis of samples with skin off. A sub sample has been collected and will be used to determine an adjustment factor to be retrospectively applied to adjust the 2016 and 2018 data making it comparable to the longer-term record.

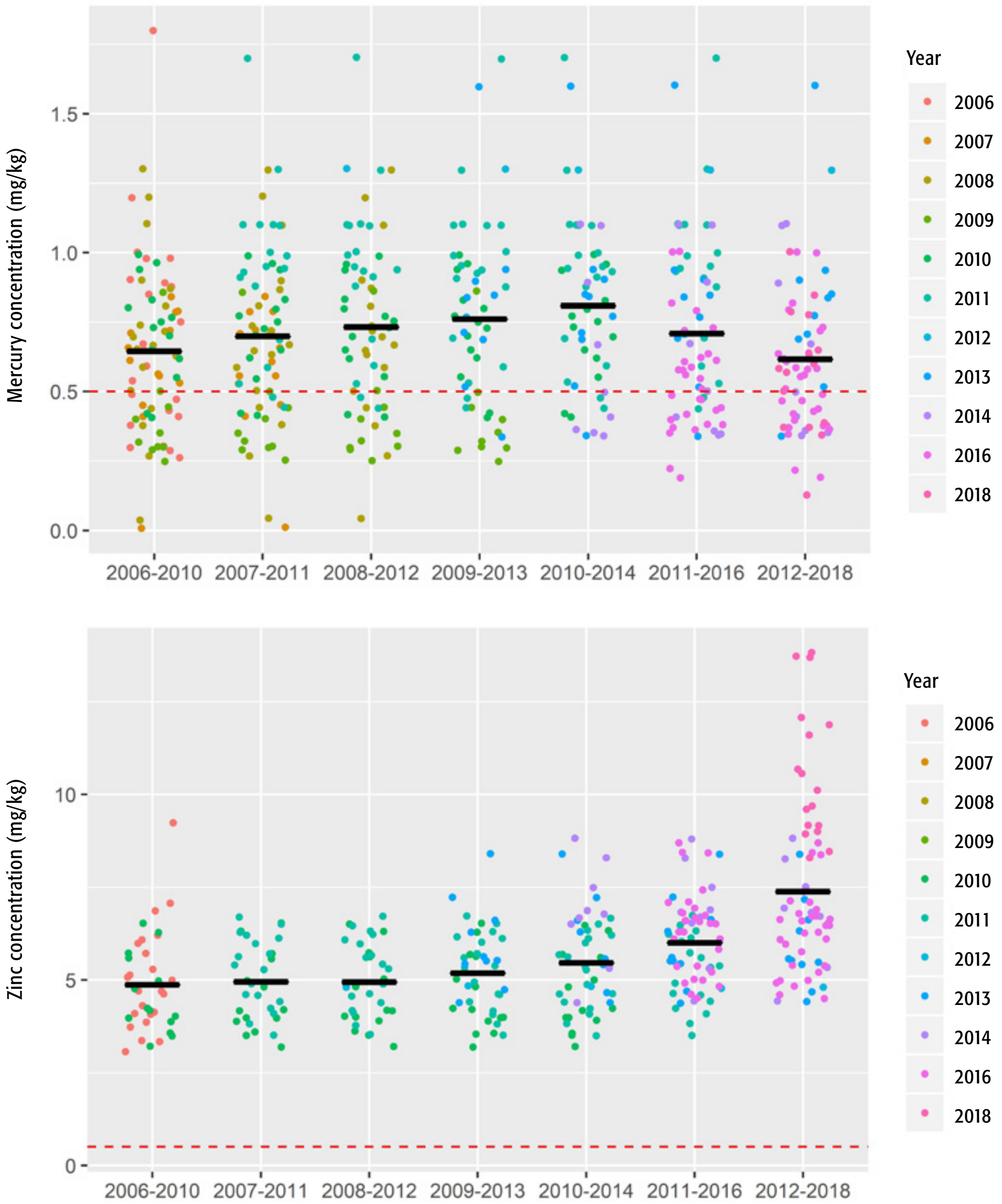


Figure 2.35 Five-yearly rolling average mercury (top) and zinc concentration (bottom) from legal-sized flathead sampled from the Derwent estuary, where the red line indicates the maximum level or generally expected level

2.3.1.3.3.2 Shellfish

Results since 2005 have been variable, but declines seem to have occurred for zinc, mercury and lead in oysters deployed to Elwick Bay, while zinc seems to have declined in oysters deployed to Cornelian Bay and Bedlam Walls (**Figure 2.36**, **Figure 2.37**), particularly since 2008. Zinc results at all sites in 2019 were higher than in either 2017 or 2018 (**Figure 2.36**), and this increase remains unexplained.

Data is highly variable which is attributed to multiple factors. While there appears to be some relationship between seasonal (December–March) ambient zinc concentration in surface waters from nearby sites (U4, U3, U2 and NTB05) and oyster results, the relationship is weak at best (**Figure 2.38**, **Figure 2.39**). Accumulation rates are likely influenced by the complex interactions of various components of water chemistry within the inherently dynamic nature of the estuary, coupled with biological variability such as spawning status and growth rates during deployment (Wright and Mason, 2000). Changes in the source population of oysters over the course of this program has contributed to variability in the control oyster data (DEP, 2018c) exemplified by elevated concentrations of zinc, mercury and copper in control oysters in 2017 and 2018 following the changed source population.

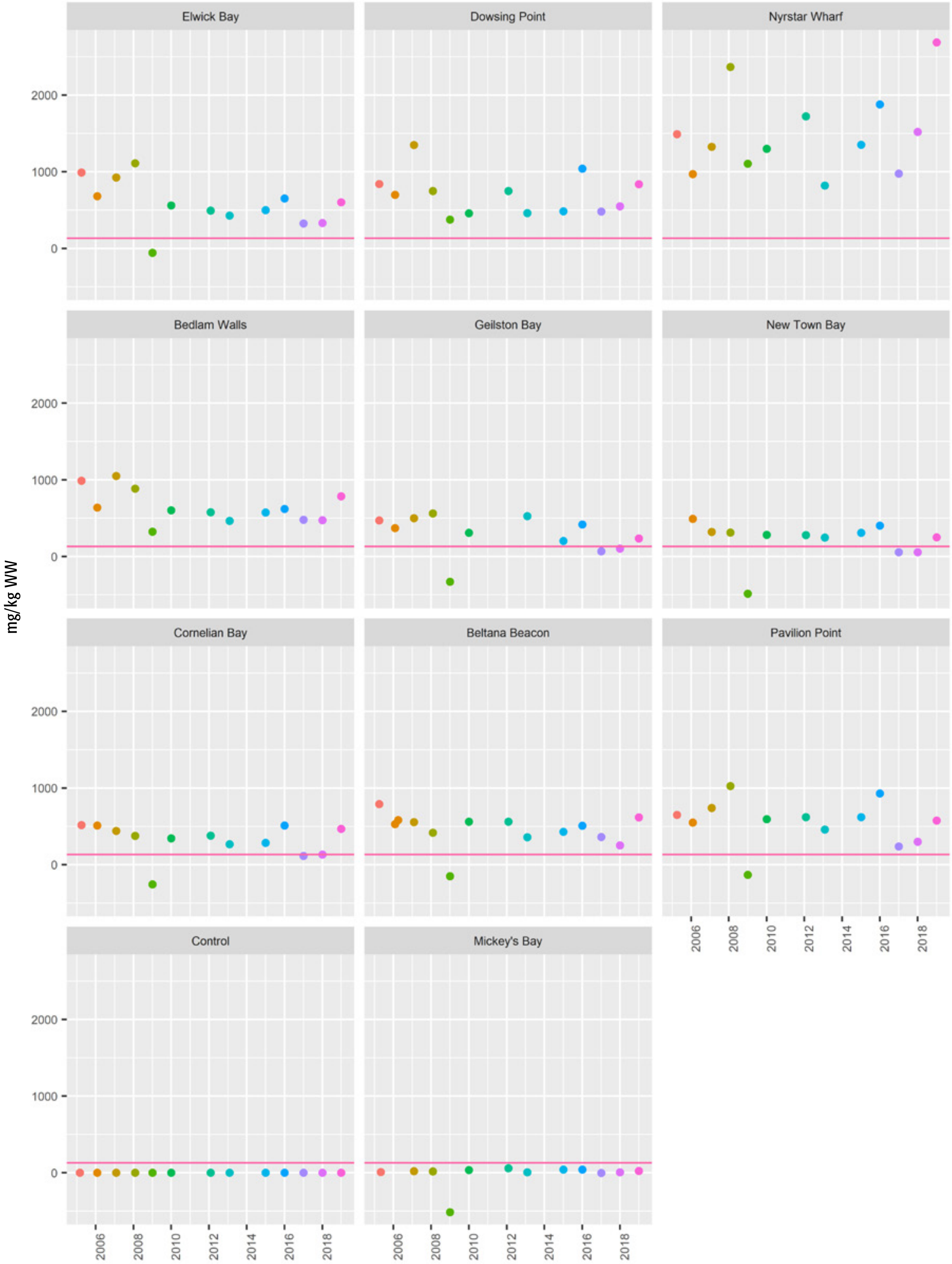


Figure 2.36 Zinc concentrations (mg/kg wet weight) accumulated by surface-deployed oysters at various sites in the Derwent estuary from 2005–2019 inclusive

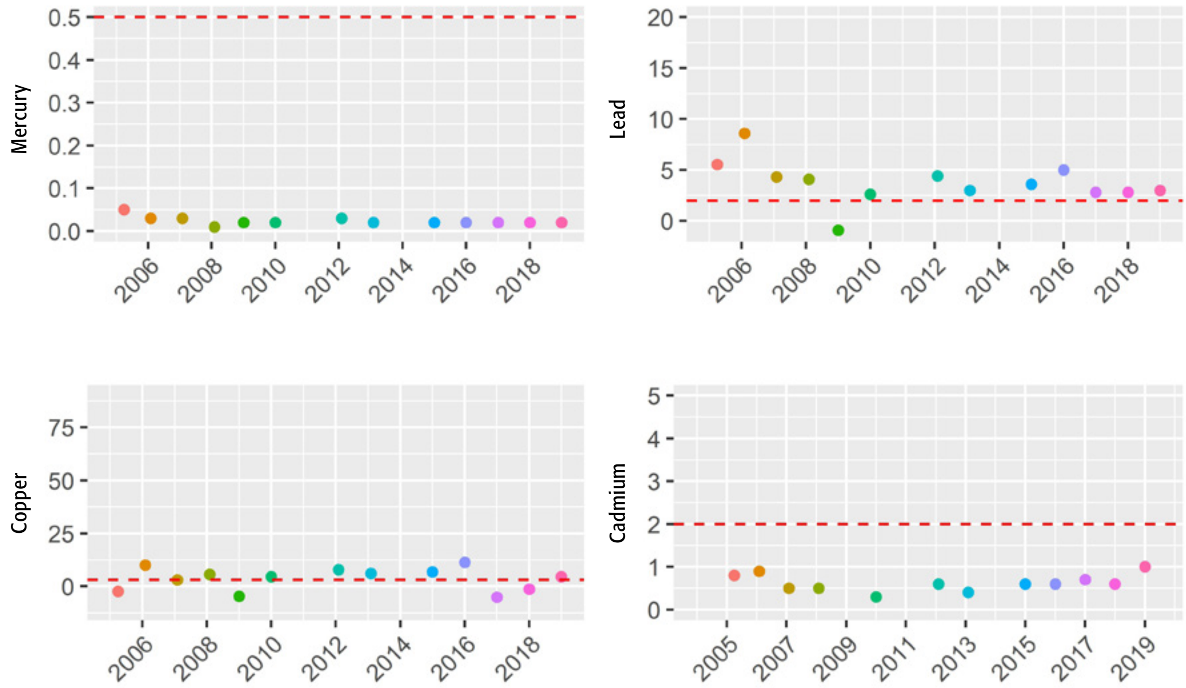


Figure 2.37 Metal concentrations (mg/kg WW) accumulated by surface-deployed oysters at Cornelian Bay from 2005 to 2019, where the red line indicates the relevant maximum level or generally expected level (FSANZ, 2016)

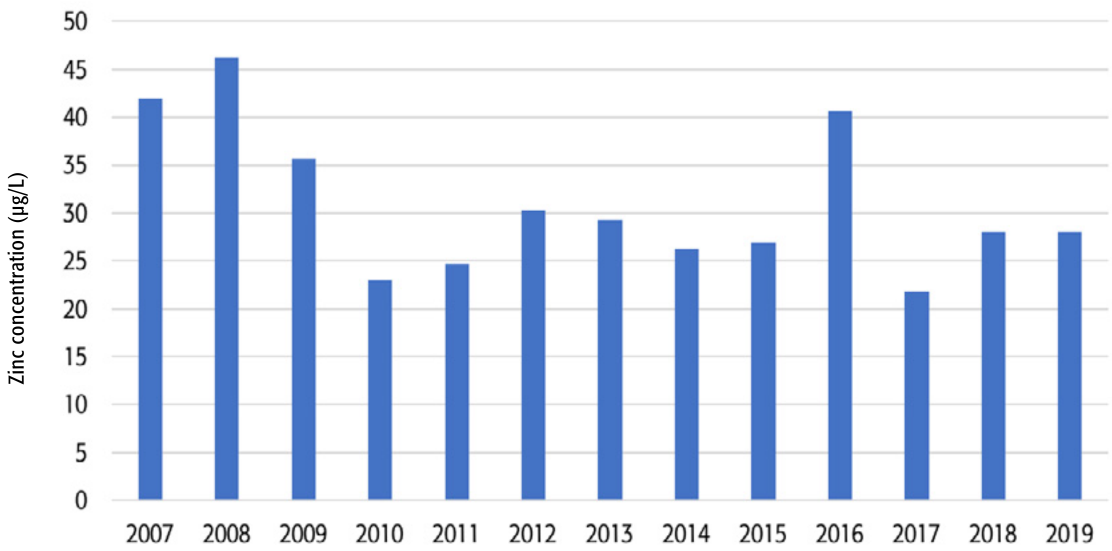


Figure 2.38 Zinc concentration (µg/L) from ambient surface water quality sampling conducted in December to March each year. The year label includes data from the preceding December. Data was collected from sites in the vicinity of deployed oyster sites: U4, U3, U2 and NTB05 and the mean zinc concentration from all sites was used

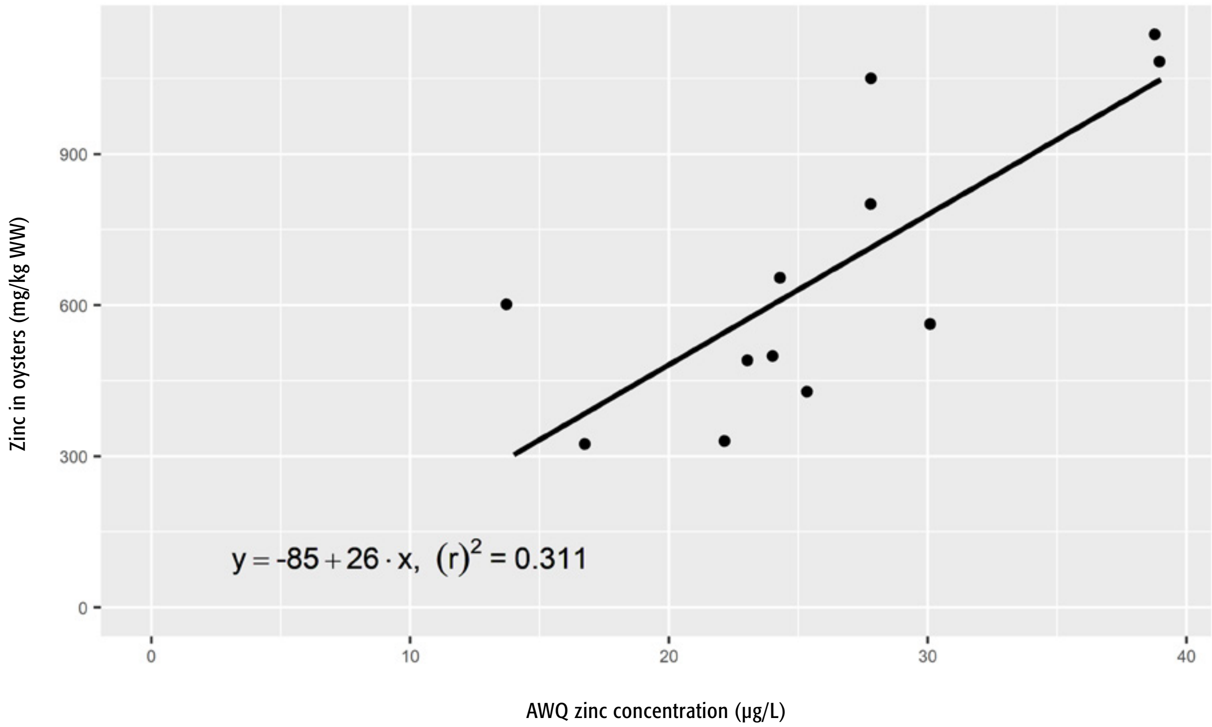


Figure 2.39 Regression between concentration of zinc in oysters deployed to surface waters near the Elwick Bay Pavilion and zinc in ambient waters from the nearest ambient monitoring site, U5

2.3.2 Future projects

2.3.2.1 Source management: zinc smelter

Nyrstar Hobart implemented a range of environmental performance improvements at the Lutana zinc smelter throughout the last decade and continuation of remediation work will ultimately lead to a cleaner estuary. Nyrstar Hobart aims to hydraulically isolate the areas of most significant groundwater contamination from the Derwent estuary by focusing on implementing a robust pathway-interruption based system. It has established:

- a site-wide stormwater interception program, catching and treating contaminated stormwater.
- a series of horizontal and vertical groundwater extraction systems enabling groundwater extraction and metals removal.
- A 700 m long pressure injected grout curtain reaching depths of approximately 20 – 25 metres below ground surface was installed in early 2020 through the centre of the site. The purpose of the curtain is to interrupt the groundwater pathways, enabling a higher volume of groundwater to be extracted and treated through their on-site effluent treatment plant.

Upon completion of an additional upgradient horizontal drain, the new grout curtain and associated groundwater extraction system will increase the volume of treated groundwater from the current 10 m^3/day to an estimated total of 94 m^3/day.

2.3.2.2 Source management: Metals in sediment

Other minor potential impacts on metal bioavailability are hypoxia severity (**Section 2.5**) and increased vessel traffic. Increased hypoxia severity and duration could theoretically trigger additional metal release from sediment (Banks *et al*., 2012). However, this mechanism of metal release may not be significant because, although there are accretion zones within the hypoxic zone, most of the benthos of the hypoxic zone seems to be flushed by high winter discharge each year. Annual winter flushing means that there may not a significant repository of metal contaminated sediment from which metals would be mobilised during summer hypoxia, although accurate mapping of accretion zones and calculation of total metal volume within these zones is required to test this assumption.

Infrastructure Tasmania's Hobart transport vision includes a small ferry network (Infrastructure Tasmania, 2018). Generally, vessel movement generates wake that can cause erosion and in the Derwent, such erosion could mobilise metals from sediment, although this is unlikely to be significant (Bilkovic *et al*., 2017). If an expanded ferry network progresses, an assessment of shoreline morphology and erosive potential, along with sediment sampling of those areas likely to experience additional sediment mobilisation is suggested.

2.3.2.3 Restoration: Shellfish reefs

Whilst reducing ongoing sources of contamination is essential, the legacy of metal contamination is likely to affect biotic composition for 15 to 25 years beyond cessation of metal input, and original species diversity is likely to take far longer to recover than this, if it is attained at all (Válega *et al*., 2008; Borja *et al*., 2010). A method of optimising this recovery process could be through restoration of the millions of native filter-feeding shellfish that formerly existed throughout the Derwent (Edgar and Samson, 2004; Fitzsimons *et al*., 2019; Shellfish Reef Restoration Network, 2020a).

Shellfish reefs slow water movement, leading to additional settlement of suspended particles as well as active particle filtration from the water column (Petersen *et al*., 2019), and successful projects have been deployed throughout Australia (Shellfish Reef Restoration Network, 2020b). A key management recommendation for the heavily metal-contaminated Derwent sediment is to leave sediment untouched and allow natural processes to continue to bury the worst of the metal contamination deeper and deeper beneath cleaner, more recently deposited sediment (DEP, 2010a). It is recommended that a pilot shellfish restoration project be established to monitor their ability to facilitate the burial of contaminated sediment due to additional sediment accumulation around the oyster shells.

2.3.2.4 Monitoring: online in-situ analysers

The DEP has previously partnered with UTAS, Eco Detection and TasWater in the submission of a CRC-P proposal for online in-situ analysers for the detection of metals in the Derwent estuary. The systems are based on capillary electrophoresis and would provide metal data collected every 15 minutes. Results would help to better understand metal cycling and dispersion in the estuary. We are working on resubmitting this proposal for CRC-P funding.

2.4 Nutrients

Human population growth and industrialisation such as the disposal of wastewater treatment plant effluent, agriculture, aquaculture, paper and fertiliser production, and urban runoff have increased nutrient inputs to many times their natural levels. Globally, excessive nutrient supply is known to cause eutrophication and is regarded as one of the greatest threats to coastal ecosystem condition (Howarth *et al*., 2000; Bricker *et al*., 2008). Initial symptoms of excessive nutrient supply include high chlorophyll a concentration and macroalgal blooms. This can progress to more serious impacts, often broadscale loss of submerged aquatic vegetation and the ecosystems they support, including fish (**Figure 2.40**) (Bricker *et al*., 1999, 2008; Bowen and Valiela, 2001; Han and Liu, 2014). Critically low dissolved oxygen, as observed each summer in the Derwent estuary, can also be a symptom of excessive supply of nutrients and the organic matter that can be derived from this nutrient supply triggering algal growth (Pedersen *et al*., 2004; Bricker *et al*., 2008; Rabalais *et al*., 2010). Eutrophication threatens both the abundance and diversity of fish and other biota (Bowen and Valiela, 2001; Breitburg, 2002), and may affect aesthetic and recreational values including fishing success, tourism, and real estate value (Hoagland *et al*., 2002; OzCoasts, 2020).

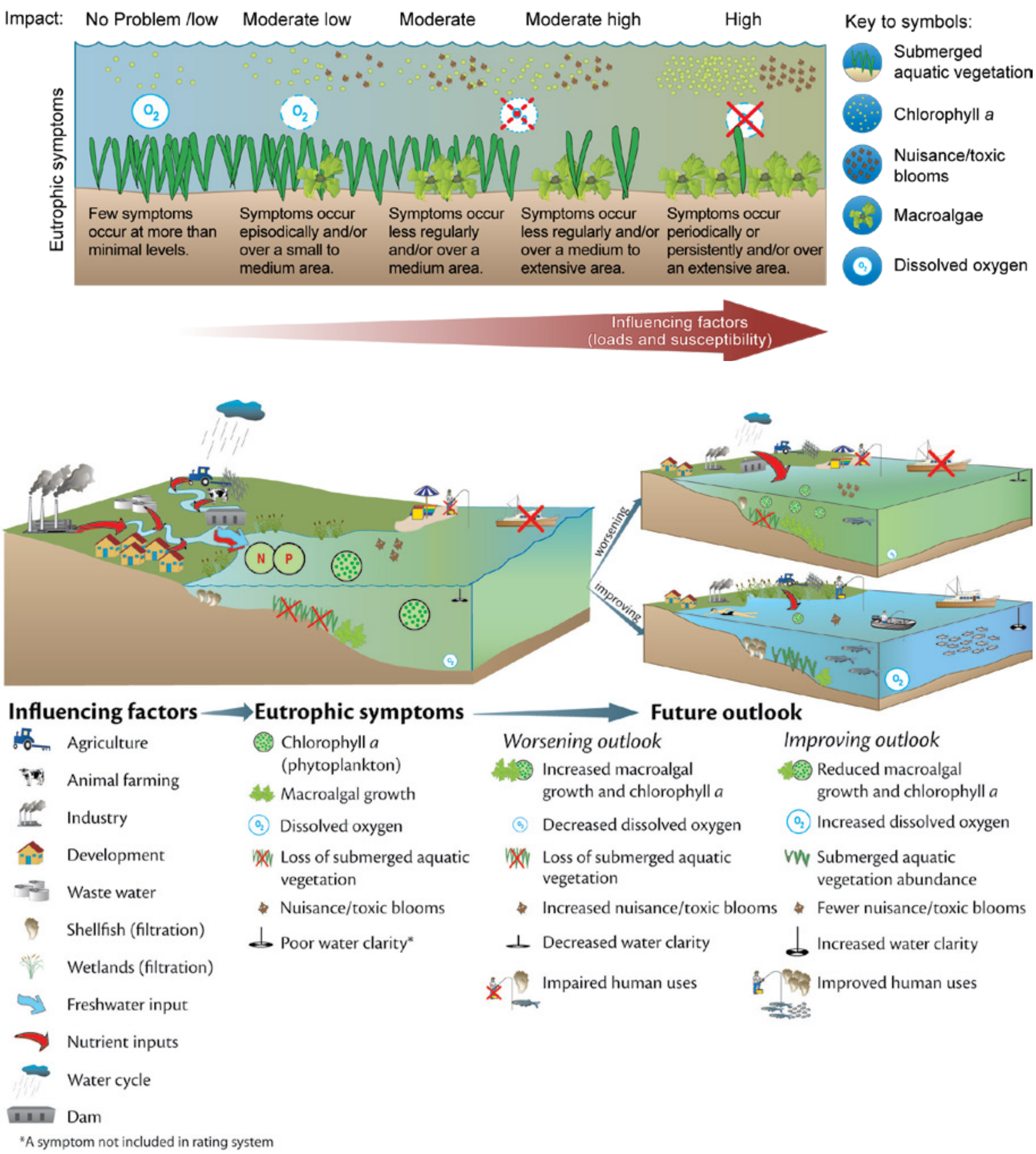


Figure 2.40 Conceptual relationship between a) eutrophic condition, associated symptoms and influencing factors, and (b) management framework of factors, eutrophic symptoms and assessment of future outlook (Source: Bricker *et al*., 2008)

Nutrients are rapidly cycled through various chemical forms, from species that are typically short-lived in the environment, such as ammonia and nitrate, to a bound state attached to sediment or in the bodies of organisms such as phytoplankton. Generally nutrient concentrations in the Derwent estuary are highest in the mid-estuary and in proximity to municipal wastewater treatment plants (**Figure 2.41**, **Figure 2.42**), however, there are some important differences from this estuary-wide scenario, particularly the high ammonium concentration that occurs with hypoxia in the upper estuary each summer and autumn (**Section 2.5**).

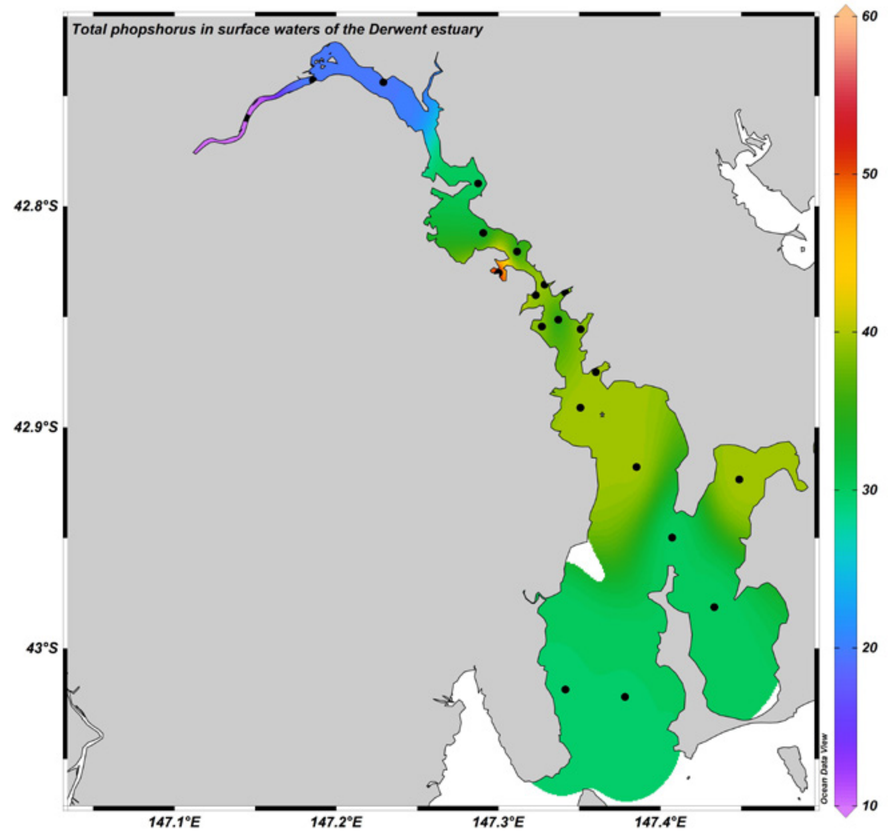


Figure 2.41 Median total phosphorus (µg/L) in Derwent estuary surface waters for the period 2007–2020

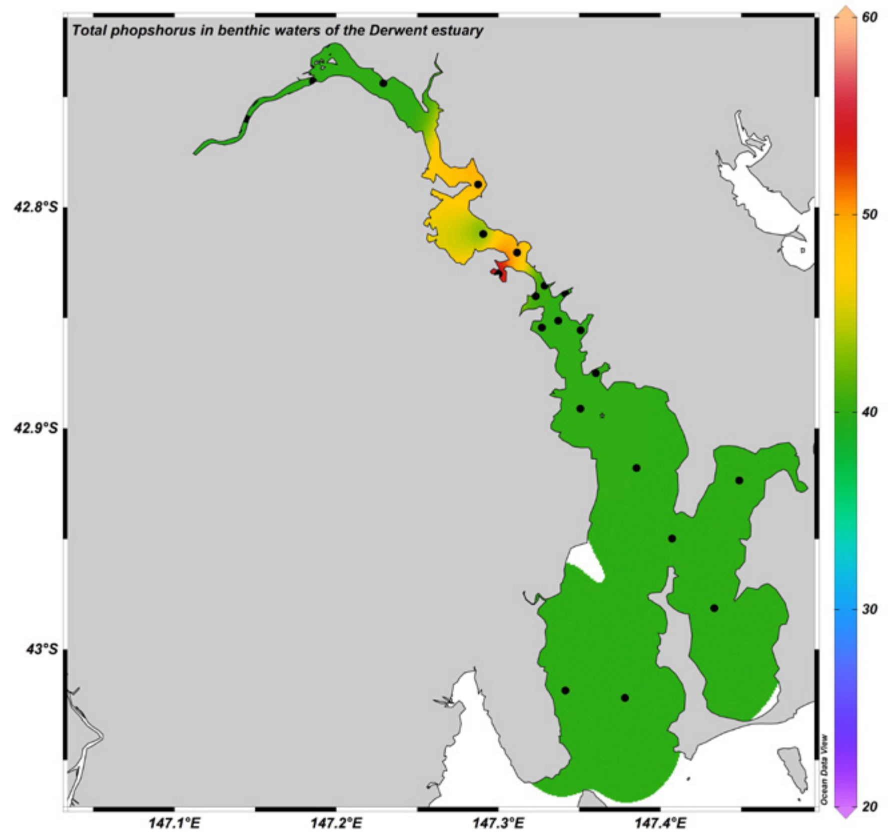


Figure 2.42 Median total phosphorus (µg /L) in the Derwent estuary benthic zone for the period 2007–2020

2.4.1 Status and trends

Municipal WWTPs were collectively the main source of labile nutrients to the Derwent estuary, exceeding contributions from all other sources, including diffuse sources within the River Derwent (**Figure 2.43**, **Figure 2.44**). TasWater operates 77 WWTPs state-wide, 11 of these are located within in the Derwent estuary catchment (**Figure 2.45**). Of these, ten discharge directly to the Derwent estuary with four also discharging effluent to recycled water schemes. Most of the effluent from Rokeby and Brighton is sent for agricultural reuse. Whilst the Macquarie Point, Prince of Wales Bay and Selfs Point WWTPs discharge approximately 70% of all WWTP effluent received by the Derwent, smaller plants that discharge into poorly mixed waters or nearshore environments may be of comparably greater ecological significance due to the sensitivity of the receiving environment (**Section 2.5**). TasWater recognises the challenge of managing its environmental impacts and in 2015 launched a targeted campaign to assess the environmental performance of each plant, appraising options for plant improvement and prioritising expenditure for improvements that are required throughout the state. An example of such improvements is the Blackman's Bay WWTP. This plant was upgraded in 2019 to accept waste from Snug, Electrona and Margate whilst improving plant performance such that reduced loads were discharged to the Derwent (**Figure 2.46**). This campaign also detectably improved effluent quality from Cameron Bay and Prince of Wales Bay WWTPs (**Figure 2.46**).

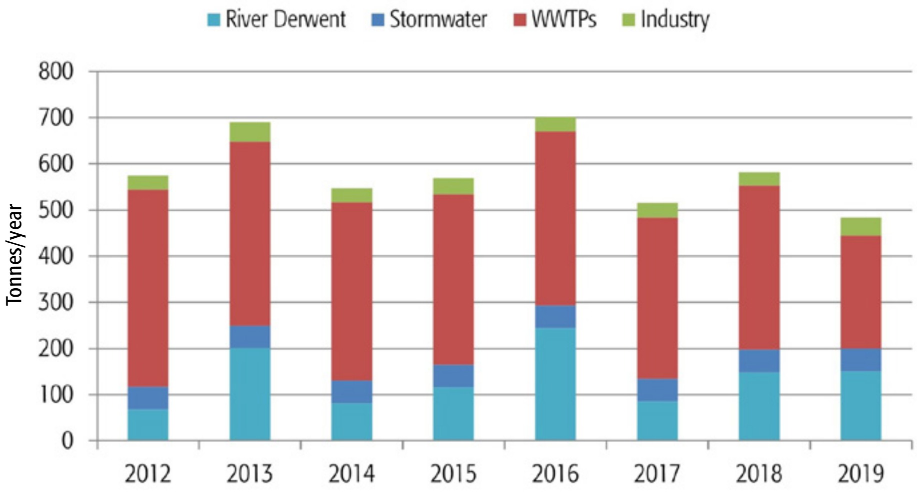


Figure 2.43 Comparison of dissolved inorganic nitrogen sources to the Derwent estuary

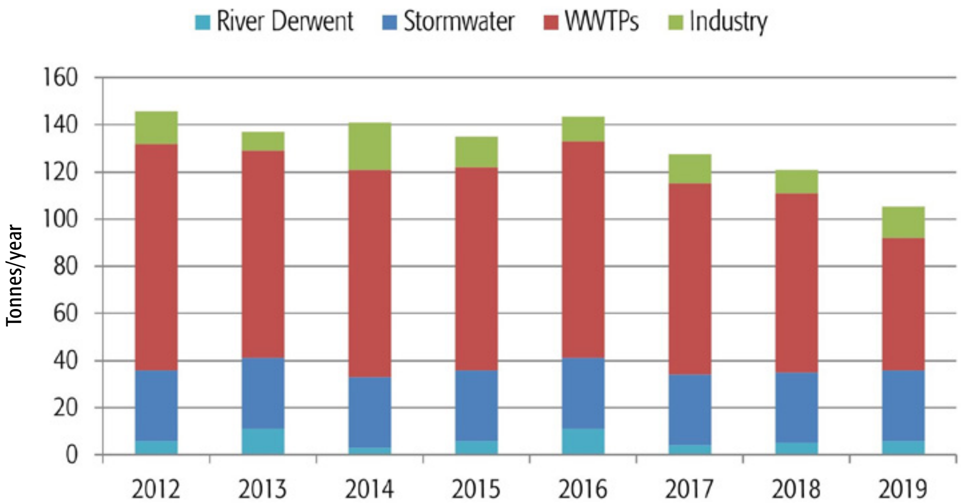


Figure 2.44 Comparison of phosphate sources to the Derwent estuary

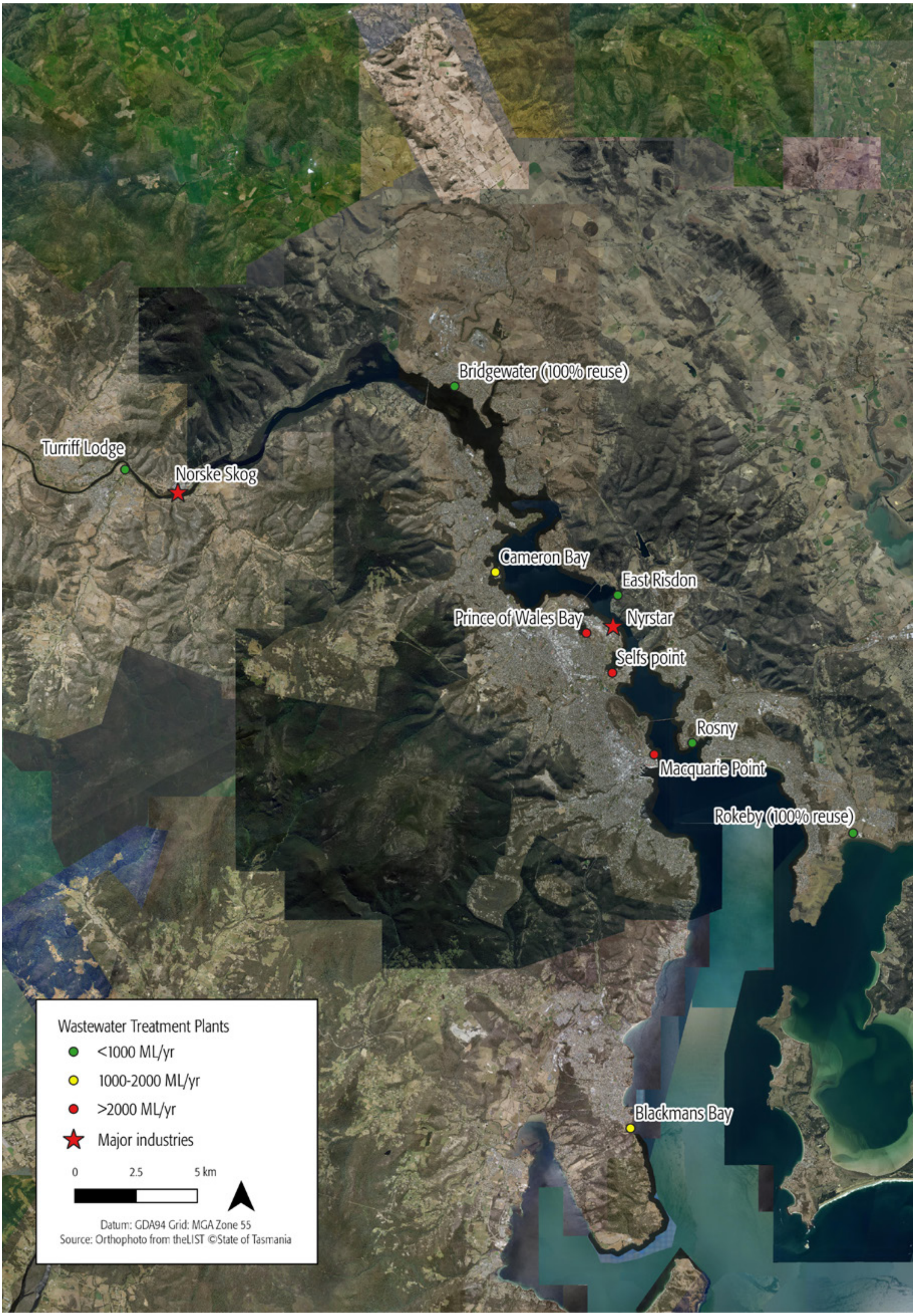


Figure 2.45 Major industrial discharge points to the Derwent estuary

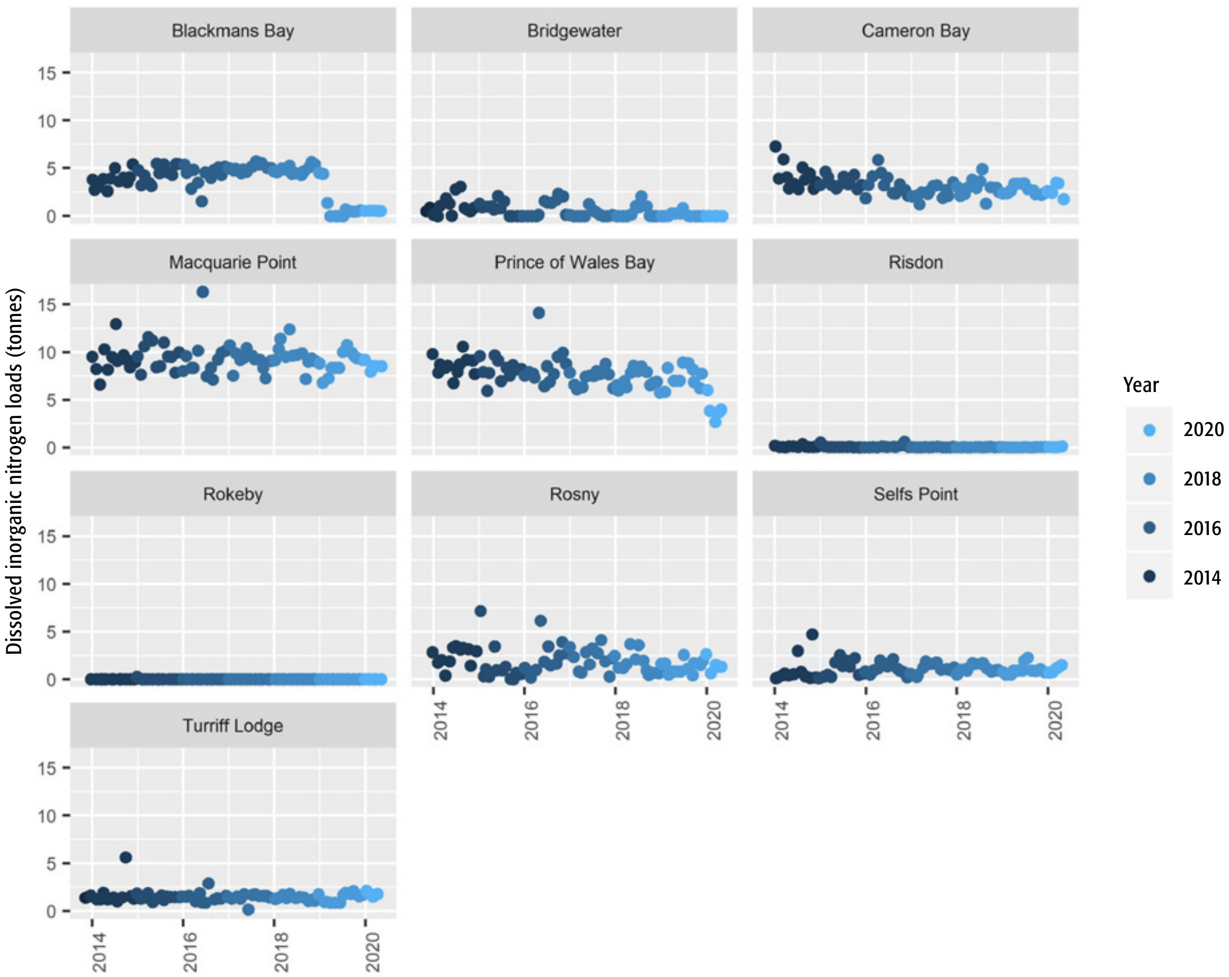


Figure 2.46 Monthly dissolved inorganic nitrogen loads (tonnes) from Derwent WWTPs

2.4.1.1 Sediment

A recent nutrient study using stable-isotope techniques and sediment cores collected from the estuary investigated the different sources of organic matter (OM) across the estuary (Stevens *et al*., 2020). Upper estuary cores were dominated by terrestrial OM inputs, including paper-mill effluent, while mid and lower-estuary cores were influenced by WWTP, marine OM and aquaculture waste. Overall, total nitrogen (TN) and total phosphorus (TP) contents in sediment were comparable with other Australian estuaries, however, mid-estuary cores showed considerably higher TN and TP concentrations when compared to other estuaries, with an increase in nutrients over the past 65 years with TN and TP mass accumulation rates (MAR) peaking over the past 35 years. This is likely a result of the increasing population around the Derwent estuary and associated WWTP effluent over the last two to three decades. Overall, TN MAR was highest in the upper middle estuary, and decreased towards the open ocean. More recently, TN MAR has started to drop, in line with decreasing WWTP TN effluent loads (**Figure 2.47**).

Upper estuary cores (DO20 and U12, **Figure 2.22**) showed evidence of anoxia at the sediment surface (See Hypoxia **Section 2.5**). This is in agreement with findings that upper estuary sediment is characterised by anoxic, organic-rich silt, likely derived from a combination of organic matter loads from the River Derwent coupled with formerly high loads from the Norske Skog paper mill at Boyer (NSR Environmental Consultants Pty Ltd, 2001).

Isotope analysis (see Appendix D for details) of sediment from core E, furthest towards the open ocean, suggests that aquaculture waste contributes to organic matter at this site (**Figure 2.48**). This study highlights the need for continuous improvement of nutrient management in the estuary, specifically relating to paper-mill effluent, wastewater treatment plant effluent and aquaculture waste.

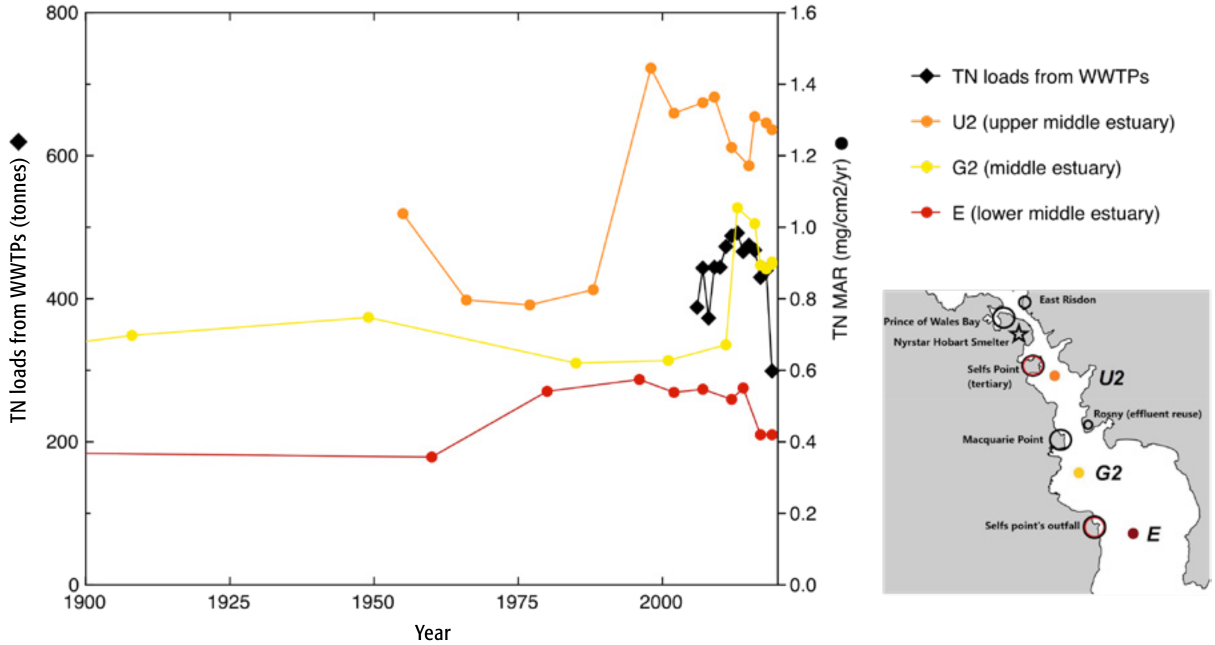


Figure 2.47 Total nitrogen mass accumulation rates (TN MAR) in sediment over time, alongside total nitrogen (TN) loads from WWTPs into the estuary (black diamonds). Sediment cores were collected at U2, G2, and E (see map insert for locations)

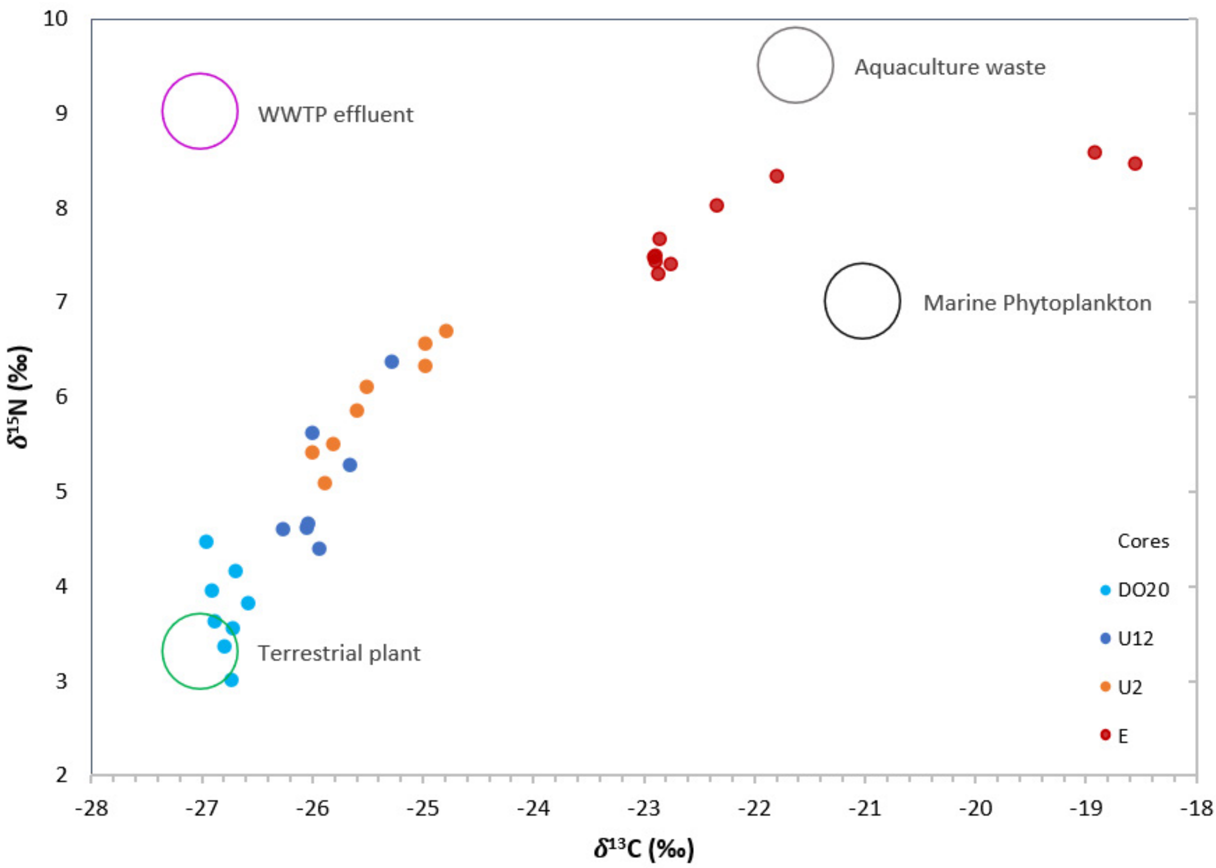


Figure 2.48 Nitrogen isotope values ($\delta^{15}N$) versus carbon isotope values ($\delta^{13}C$, see Appendix D for details) for Derwent estuary sediment cores, showing the different sources (shown as large circles) contributing to nitrogen and carbon in the estuary. Upper estuary sediment cores (DO20, U12) are predominantly influenced by terrestrial plant material (riverine input, pulp mill effluent). Sediment samples from the mid estuary (core U2) are a mixture of terrestrial plant material, WWTP effluent and marine phytoplankton, whereas lower estuary sediment (core E) is pointing towards marine phytoplankton and aquaculture waste as sources (Stevens *et al*., 2020)

2.4.1.2 Upper estuary

2.4.1.2.1 Ecological condition

Classic ecological stress responses to excessive nutrient loads frequently occur in the upper Derwent estuary, including dense algal smothering of the upper Derwent submerged aquatic macrophyte meadows (**Figure 2.49**, **Section 3.1.3**) and seasonally recurrent hypoxia (**Section 2.5**) with occasional extensive fish kills (**Figure 2.50**) (Naidoo, 2015). Whilst nutrient loads are likely a factor in both effects on ecological condition, they are interrelated with other factors. River discharge (Franklin *et al*., 2008; Rabalais *et al*., 2010) seems to be a key factor for both macrophyte condition and hypoxia, while hypoxia is likely also influenced by direct organic matter load discharge to the upper Derwent. Another factor for the existing nutrient and sediment conditions of the upper estuary is the absence of the highly productive shellfish reefs that once occurred throughout the estuary and provided a suite of ecosystem services, including sediment stabilisation and filtration of vast volumes of estuarine water daily (Edgar and Samson, 2004; Shellfish Reef Restoration Network, 2020a). Shellfish reefs extended throughout the Derwent from west of the Bridgewater Bridge to Tinderbox, the Iron Pot and beyond (Edgar and Samson, 2004) but aggressive harvest by European settlers drove the habitat to functional extinction Australia-wide (Shellfish Reef Restoration Network, 2020c), contributing to the current situation where by far the largest aquatic habitat type in the Derwent is unvegetated sandy silt that is dominated by invasive species. Re-establishment of shellfish reefs throughout the Derwent would improve water clarity, remove particulates, organic matter and reduce the impact of nutrient loads by filtering pelagic plankton out of the water column. They would provide three-dimensional structures for invertebrates and juvenile fish to shelter within, would provide substrate for plant and macroalgal growth and would bind cadmium for centuries through shell deposits (Huanxin *et al*., 2000; Edgar and Samson, 2004).

2.4.1.2.2 Ambient waters

Ambient waters are sampled at five sites throughout the upper Derwent estuary from Site NN at New Norfolk to U12 at the Bridgewater causeway (**Figure 1.3**) and results show that some of the lowest nutrient concentrations (see Appendices A-C for sampling and analysis details) occur in the upper Derwent compared to elsewhere (**Figure 2.51**, **Figure 2.52**). However, nitrite and nitrate and TN increased significantly at all three sites downstream of the Norske Skog Boyer paper mill between 2007 and 2019, due to a sustained increase in minimum concentrations, following the secondary treatment plant upgrade at the site in 2009 (**Figure 2.53**). Additional labile nutrient load and the risk that this increase posed to macrophyte meadows (**Section 3.1.3**) was forecast in the environmental risk assessment for the plant upgrade (NSR Environmental Consultants Pty Ltd, 2001). A concurrent increase in species of phosphorus was not detected, despite additional phosphorus load discharge occurring following commissioning of the secondary treatment plant, possibly due to rapid environmental assimilation of phosphorus as the main limiting nutrient in the upper Derwent. Dense macroalgal blooms occurred in summer 2015-2016 and 2016-2017, resulting in smothering rafts of decaying algae in the intertidal zone (**Figure 2.49**) coinciding with the death of thousands of juvenile barracouta within the hypoxic zone (**Figure 2.50**).

Figure 2.49 Dense algal mats lining the upper Derwent foreshore following a period of dense smothering of submerged aquatic macrophytes

Figure 2.50 Thousands of juvenile barracuda (*Thyrsites atun*) died most likely by suffocation in the upper Derwent hypoxic zone in February and March 2015 (pers. comm. Wronski, E. DPIPWE 16 March 2015)

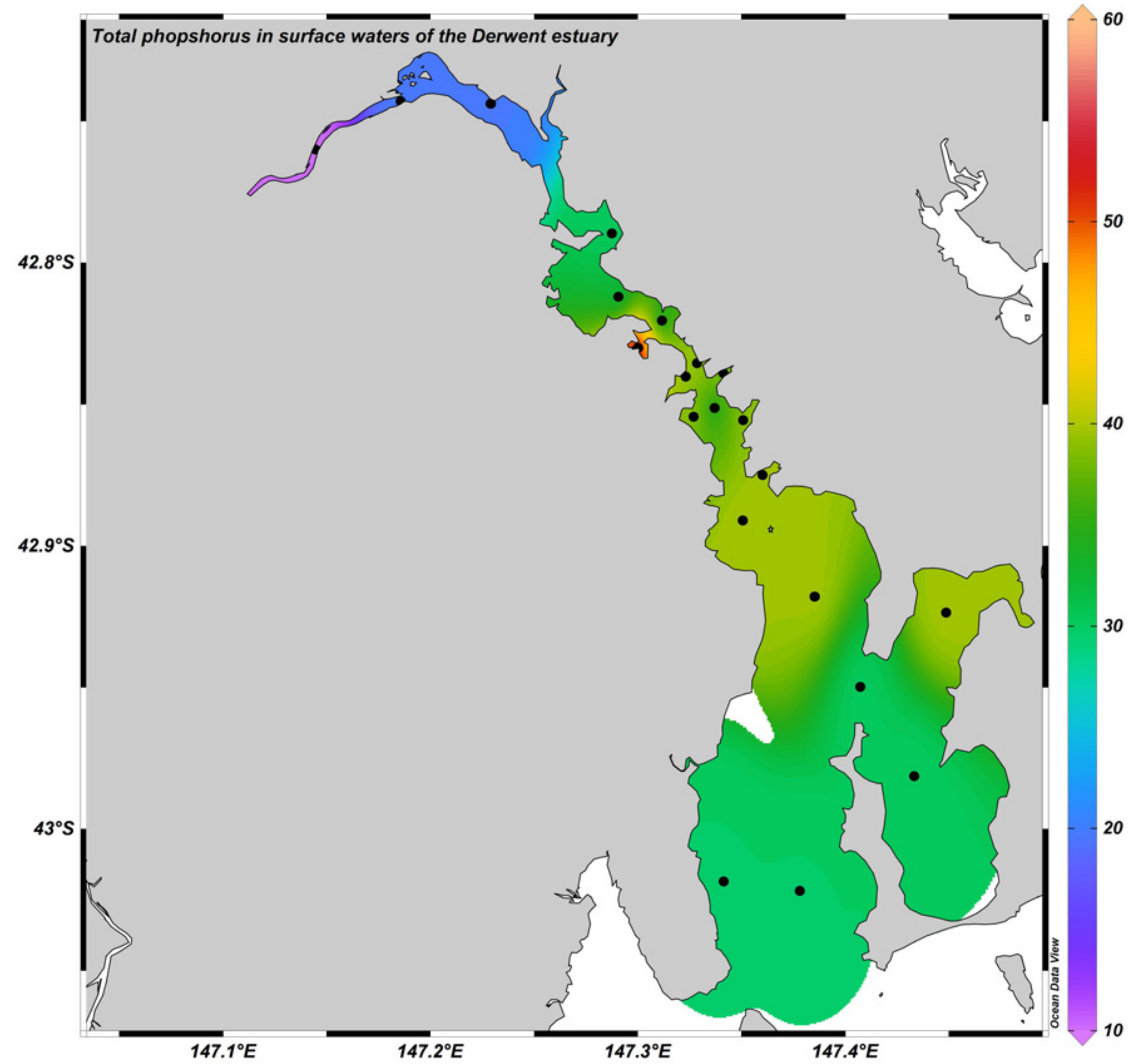


Figure 2.51 Median total phosphorus (µg /L) in surface waters of the Derwent estuary for the period 2007–2020

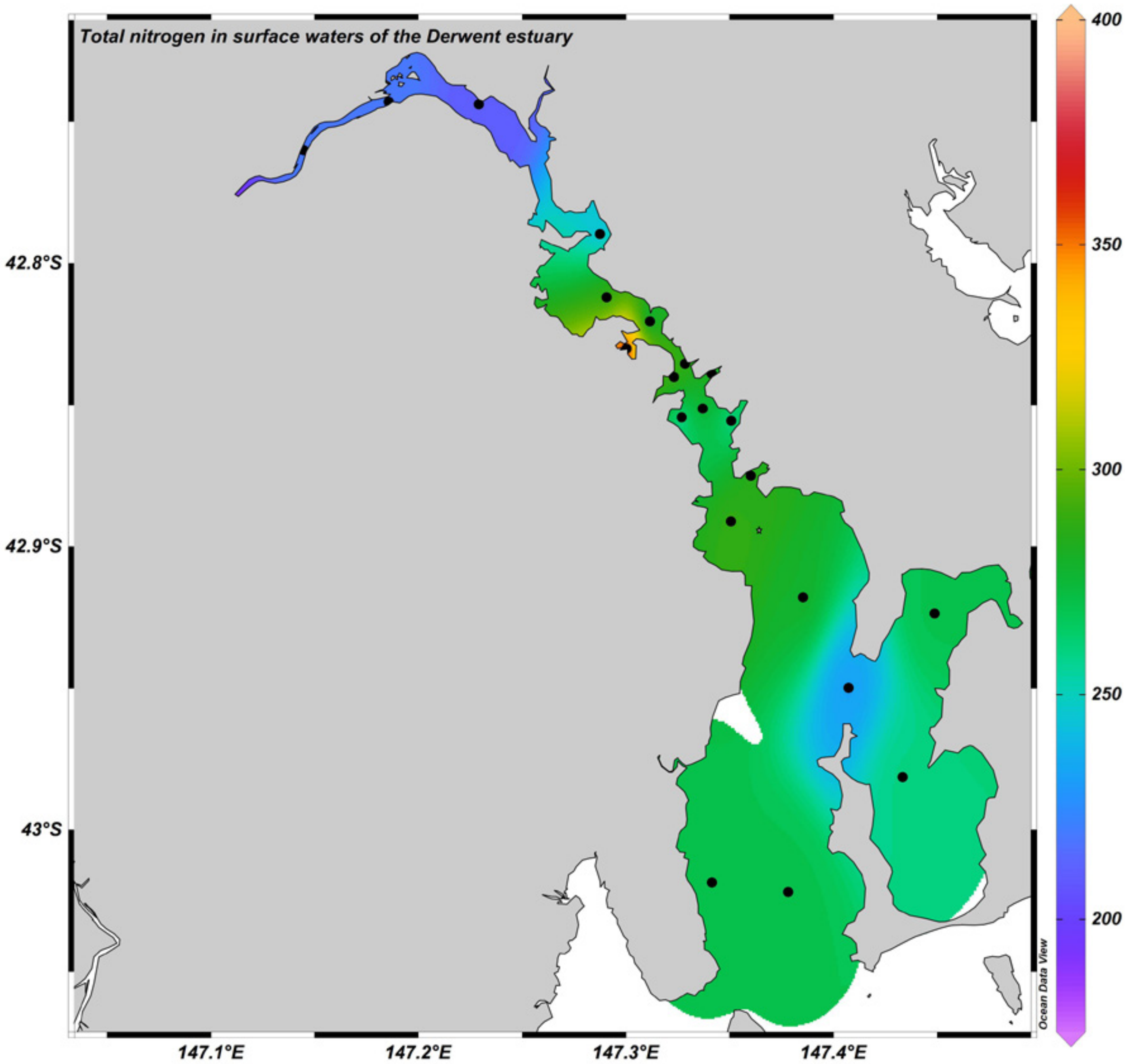


Figure 2.52 Median total nitrogen (μg /L) in surface waters of the Derwent estuary for the period 2007–2020

Hypoxia can be a symptom of nutrient enrichment, and in 2015 the DEP commenced a detailed assessment of hypoxia dynamics. Given low pelagic autotrophic production indicated by chlorophyll-a concentration in the upper Derwent (**Figure 2.54**), we hypothesise that the Derwent hypoxic zone is mainly a result of poor mixing during summer coupled with local organic matter supply, rather than nutrient enrichment leading to excessive pelagic plankton production (**Section 2.5**) (Edgar and Cresswell, 1991).

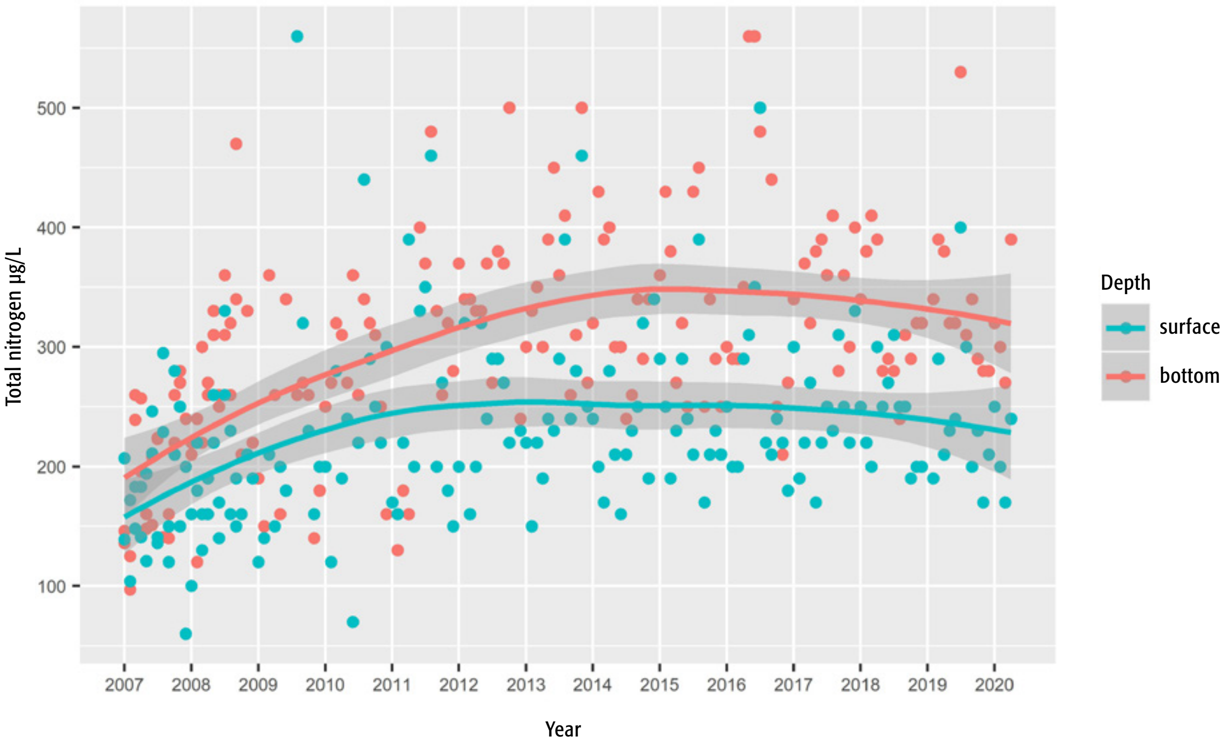


Figure 2.53 Total nitrogen (µg/L) sampled monthly at upper estuary site U16/17 between 2007 and 2019

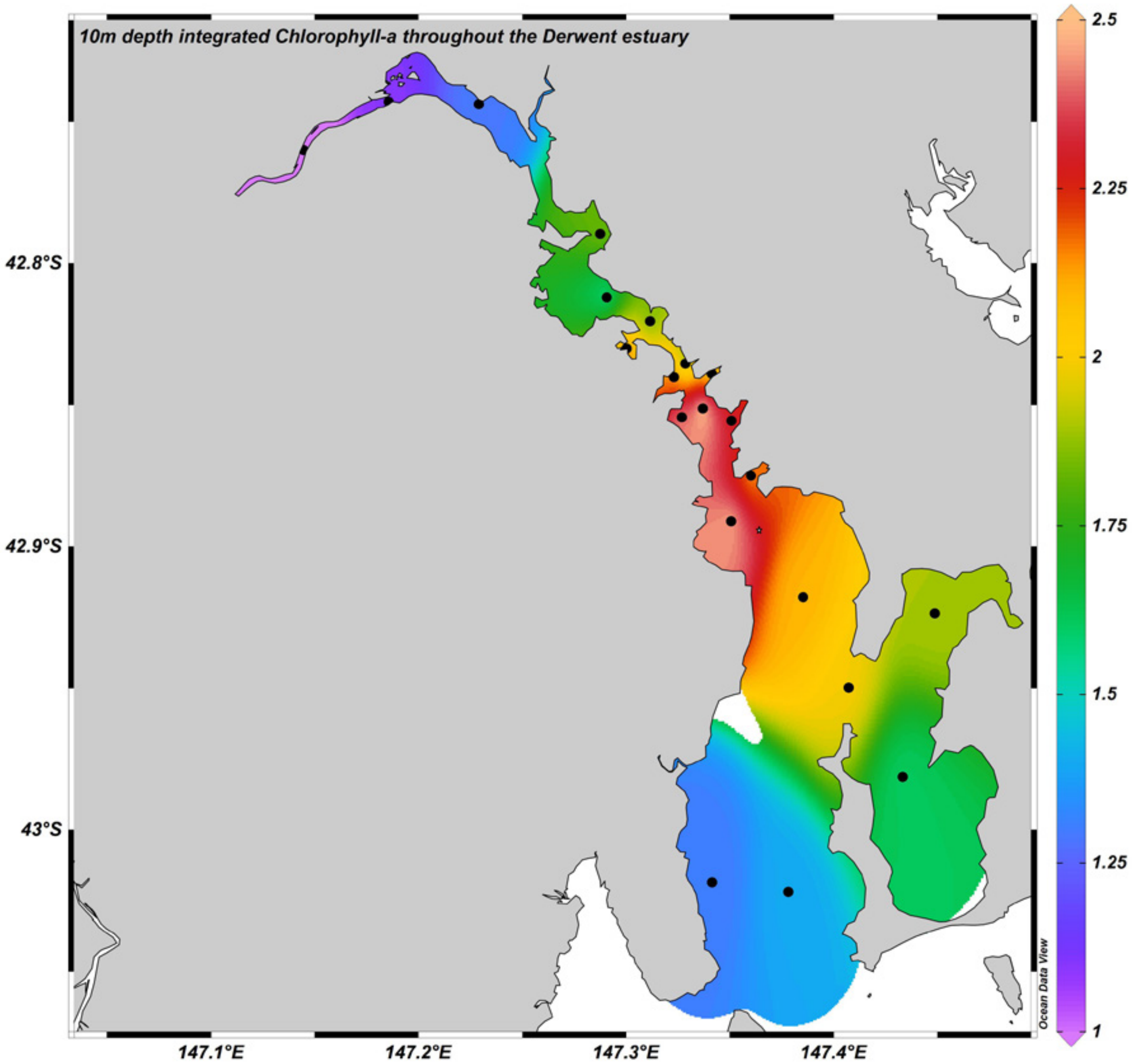


Figure 2.54 Median chlorophyll-a concentration (mg/L) from the entire DEP dataset for depth-integrated samples, using 10-m Lund tube from surface downward

2.4.1.3 Mid and lower estuary

2.4.1.3.1 Ecological condition

As well as affecting submerged macrophyte condition discussed above, nutrient availability can drive rocky reef algal community structure, with sustained nutrient enrichment tending to support the dominance of turfing algal species over canopy forming macroalgae. Functional changes in relative algal distribution may occur in response to changes in nutrient supply. The mid-estuary from below the mouth of the Jordan River to Macquarie Point is generally dominated by seagrasses in sheltered embayments while fringing rocky reefs are species depauperate, dominated by turfing algae, tufts of opportunistic algae such as *Ulva* spp. or encrusting worms. As the estuary opens out below Macquarie Point and Bellerive, rocky reefs are increasingly dominated by macroalgae, including isolated patches of giant kelp (*Macrocystis pyrifera*).

The more established macroalgal habitats such as that around Tinderbox marine reserve and Opossum Bay are diverse, functional ecosystems that support an abundance of invertebrates and vertebrates (Barrett *et al*., 2010; Stuart-Smith *et al*., 2015).

2.4.1.3.1.1 Rapid Visual Assessment

The DEP commissioned specialists from the University of Tasmania to conduct targeted assessments of nutrient enrichment status at six lower estuary sites (**Figure 2.55**). Biannual surveys conducted over long timeframes will indicate ecosystem condition with respect to nutrient loading and may be sensitive to changes in anthropogenically derived nutrient sources. The warm-season assessment conducted in March 2020 and a subsequent cooler-season assessment was conducted in September 2020. Preliminary results detected a possible nutrient enrichment signal at Bellerive Bluff and Tranmere point.

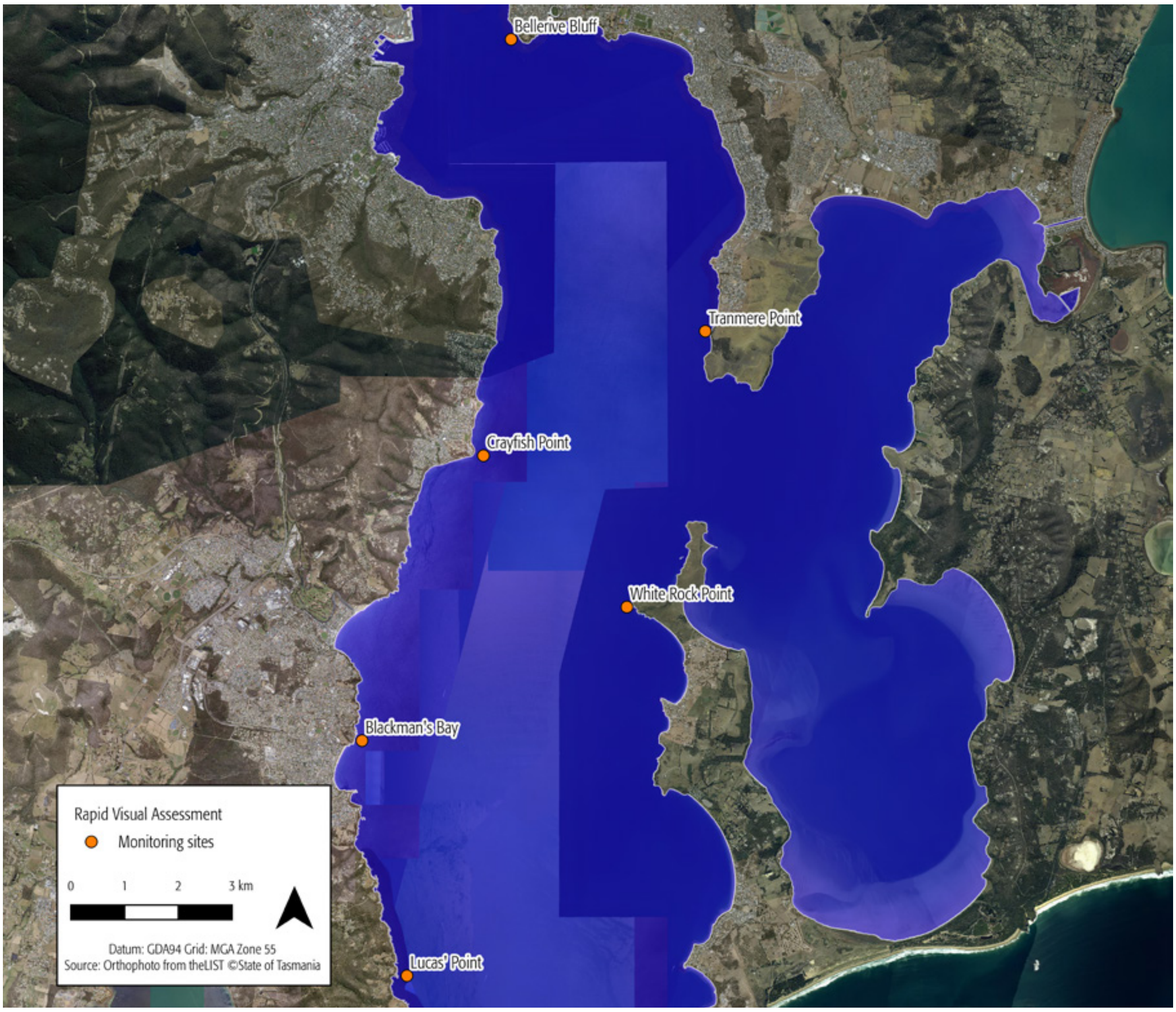


Figure 2.55 Rocky reefs where rapid visual assessment for nutrient enrichment indicators was conducted

2.4.1.3.1.2 Nutrient-source tracking

Previous research has shown that tracing the nitrogen isotopic fingerprint in macroalgae can be a useful tool for monitoring and identifying nitrogen sources. A pilot study conducted by the DEP in early 2019 identified *Ulva* spp. as a suitable bio-indicator, followed by an in-depth MSc study collecting Ulva spp. from 39 sites around the mid and lower estuary in February 2020 (van Os, 2020). This study found that the nitrogen isotopic composition ($\delta^{15}N$) of Ulva ranged from 7.15 ‰ to 14.01‰, revealing two main sources of nitrogen: marine nitrogen and sewage nitrogen. A two end-member mixing analysis was conducted showing that sewage nitrogen contributes on average 30–50% of the TN used by *Ulva* spp. in the estuary, with particularly high contributions of sewage at Cameron Bay (near WWTP outfall) and Prince of Wales Bay. Continuing improvement of WWTP effluent and reduction of other sewage inputs into the estuary is, therefore, desirable for nutrient management.

A sediment-core study of nutrient loads and sources using stable isotopes has found similar results, with terrestrial inputs (including paper pulp mill effluent) dominating organic matter in the upper estuary. Whereas, nutrients in mid and lower-estuary cores were dominated by inputs by WWTP effluent, marine organic matter and aquaculture waste (Stevens *et al*., 2020)(**Section 2.4.1.1**). The DEP will continue stable isotope analysis as one of multiple lines of evidence to understand links between anthropogenic nutrient-source loads and the condition of the Derwent's key habitats.

2.4.1.3.2 Ambient waters

Nutrients were highest in the mid-estuary, in proximity to the highest density of municipal WWTPs, particularly in Prince of Wales Bay (**Figure 2.56**, **Figure 2.57**). In the benthic zone, dissolved nutrients were also particularly high in the upper estuary, likely due to a combination of reduced flushing during summer and chemical processes related to summer hypoxia (**Figure 2.57**).

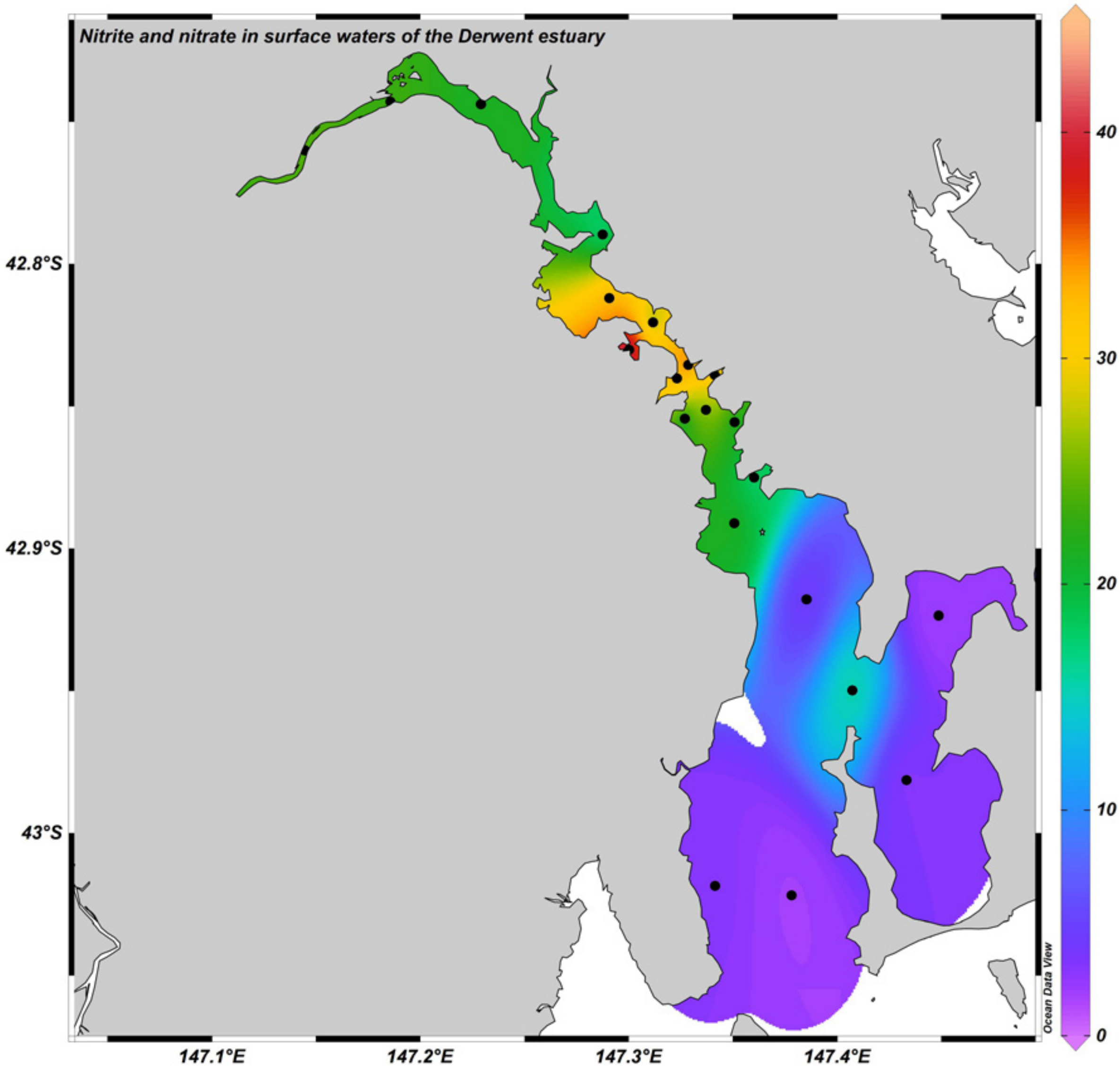


Figure 2.56 Median nitrite and nitrate (µg /L) in surface waters calculated from the entire DEP dataset

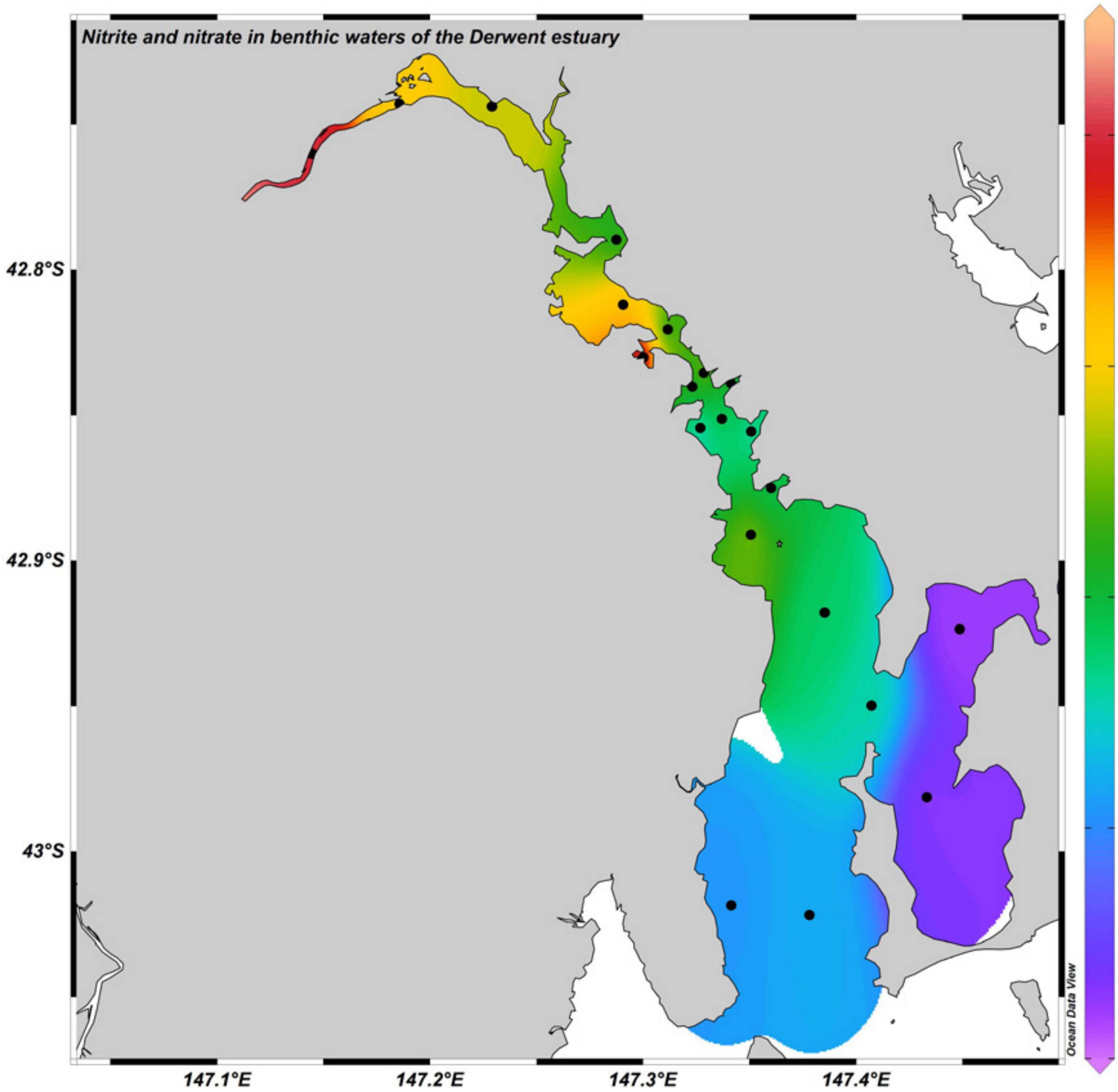


Figure 2.57 Median nitrite and nitrate (µg /L) in the benthic zone calculated from the entire DEP dataset

Despite highly variable ambient nutrient concentrations as expected in an estuary, ambient total ammonia nitrogen concentration decreased significantly at all mid-estuary channel sites (U7, U5, U4, U3 and U2) as well as in New Town Bay, without concurrent increases in other forms of nitrogen (**Figure 2.58**). No significant trend was detected for phosphate, possibly due to its rapid ecological assimilation, but total phosphorus did decline, at mid-estuary sites u7, U5, U3, Prince of Wales Bay, Geilston Bay and Kangaroo Bay (**Figure 2.59**). Total phosphorus concentrations are consistently low, with relatively coarse reporting limits (**Figure 2.59**) and extended periods of missing data, so this trend may not be ecologically meaningful.

Sampling was not conducted at most mid-estuary sites for the period from September 2008 until November 2010 and missing values were replaced by carrying forward the last observation. This will have interfered with statistical analysis results so professional judgement has been a significant part of our consideration of results from such sites. There was no significant trend in nutrient concentrations at lower estuary sites or in Ralphs Bay, where all dissolved nutrient concentrations are lower than elsewhere in the estuary.

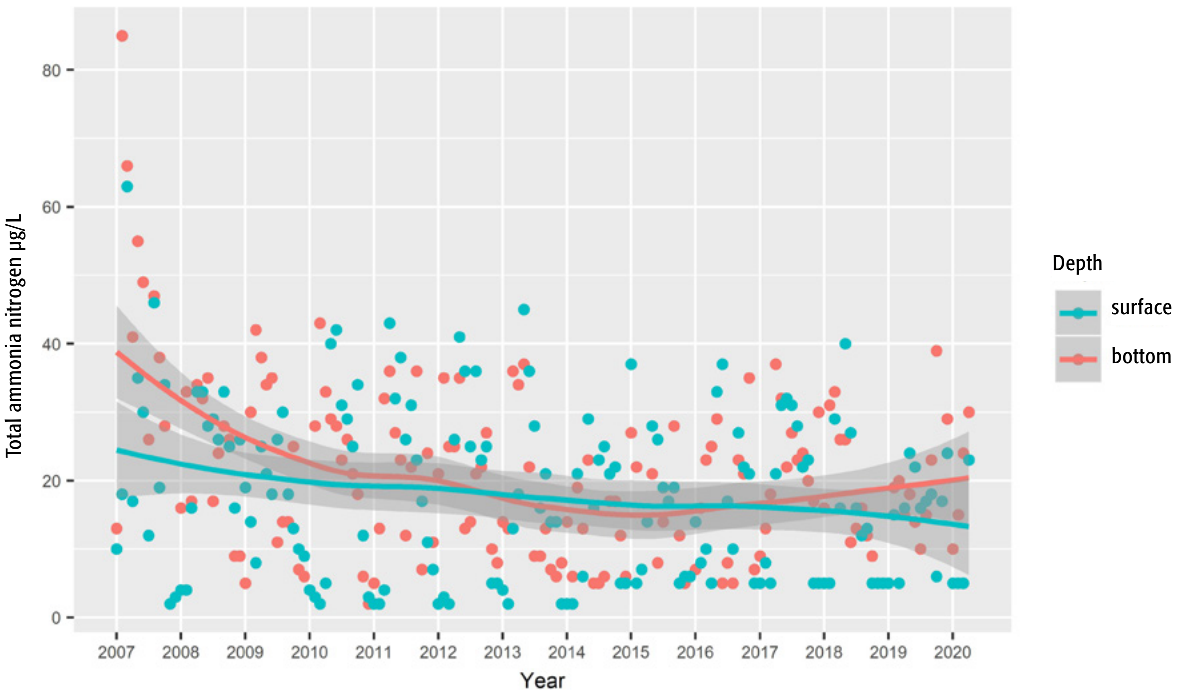


Figure 2.58 Total ammonia nitrogen concentration from mid-estuary site U4, representing declines observed throughout the mid-estuary

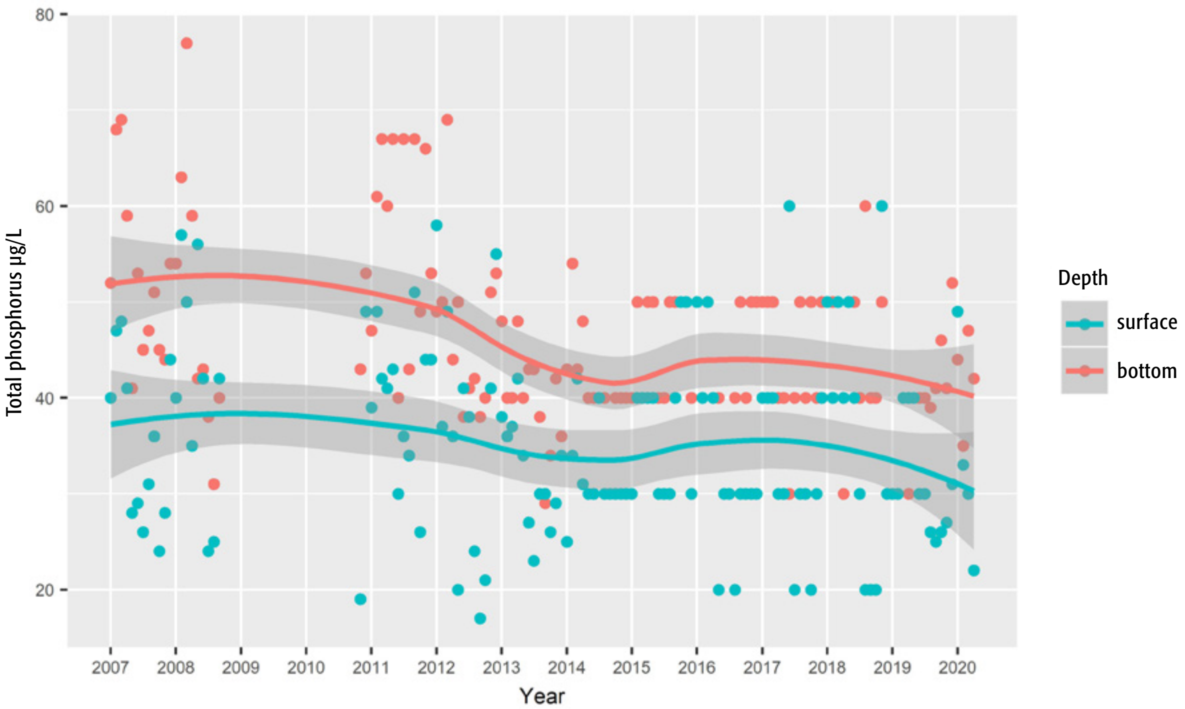


Figure 2.59 Total phosphorus concentration from mid-estuary site U3, representing a decline at a number of mid-estuary sites. The extended periods of missing data and the low detection limit coupled with low concentrations reduces confidence in the total phosphorus results at many mid-estuary sites

2.4.2 Future projects

Nutrient impact management will require source management and continued improved understanding of the ecological impact of nutrient loads.

2.4.2.1 Municipal wastewater (sewage)

TasWater will continue to work through its scheduled priorities for plant upgrades, improvements and process optimisation, but will likely retain its position as the principal source of labile nutrients to the Derwent estuary. TasWater inherited a vast network of sewage infrastructure problems when it was created in July 2013 and existing assets were transferred to it from councils. Problems included leaking and under-capacity wastewater pipes and pump stations, and poorly sited WWTPs, all of which continue to be problems for nutrient enrichment of the Derwent estuary.

However, opportunities to significantly reduce nutrient loads to the estuary may arise with significant co-investment from third parties:

- Movement of key infrastructure, such as the Cameron Bay and Macquarie Point WWTPs, could occur to satisfy other planning or development goals and may result in marked changes to effluent disposal to the Derwent.
- Effluent reuse: Effluent quality from Selfs Point and Blackman's Bay WWTPs is sufficient for reuse but is currently discharged to the estuary, due to the lack of existing pipes and pumps and a high-value end user who will commit to accepting reuse water. Effluent quality from other plants, such as Macquarie Point and Cameron Bay, does not currently meet reuse quality guidelines and would require significant capital expenditure to bring effluent quality up to reuse standard.
- Investigate the use of reuse in new irrigation schemes: Tasmania Irrigation is currently assessing a vast area of Tasmania for potential expansion of its irrigation network (Tasmania Irrigation, 2020). Partnerships between Tasmania Irrigation and TasWater to deliver high-quality effluent for reuse could provide significant volumes for irrigation whilst removing a waste stream.

2.4.2.2 Norske Skog Boyer

Additional nutrient load from Norske Skog Boyer since secondary treatment plant upgrade occurred because secondary treatment requires labile nutrient dosing of the effluent treatment pond, where formerly discharged wood fibre is decomposed into biologically available nutrients (NSR Environmental Consultants Pty Ltd, 2001). Management of the effluent treatment system requires excess labile nutrient dosing to maintain the required microbial community for effective secondary treatment. Nutrient loads from Norske Skog Boyer vary depending on product demand and there may be opportunities with co-funding and appropriate engagement with Norske Skog Boyer to investigate options for dissolved nutrient reduction from this system.

2.4.2.3 Finfish aquaculture

Nutrients derived from aquaculture enter the River Derwent from hatcheries in the catchment and from expanding marine aquaculture in Storm Bay. To refine our understanding of nutrient sources to the estuary, the DEP has worked with numerous stakeholders in both the catchment and the estuary to develop monitoring methods to detect nutrients from a variety of sources, including finfish aquaculture. For details of the catchment monitoring, see **Section 2.2.3**, and for details of the research being conducted in Storm Bay by IMAS and the CSIRO with support from FRDC see **Section 1.5.2**.

The DEP commissioned IMAS to collect baseline information on rocky reef condition in the estuary to contribute to the body of knowledge about rocky reefs in Storm Bay (**Section 2.4.1.3.1.1**). The reef assessments are comparable with the monitoring IMAS is doing in Storm Bay as part of their FRDC research. We have also commenced routine stable isotope analysis of rocky reef algae to identify nutrient sources used for their growth, partnered with CSIRO on an e-DNA assessment (**Section 2.3.1.2.1**) and will conduct routine sediment and end-member stable isotope sampling (**Section 2.3.1.2**).

2.4.2.4 Boat sewage

Boating is very popular in the Derwent estuary with six marinas and around 750 moorings (**Figure 2.60**). The DEP and EPA recommend treating and containing wastewater onboard until it can be disposed of properly on land. If disposal at sea is the only option, it can legally be done by following the rules laid out in the *Sewage Management Directive, The Discharge of Sewage from Certain Vessels into State Water*, which provides directions on sewage discharge into local waters (EPA Tasmania, 2013).

Figure 2.60 Sailboats in the Derwent estuary

The rules vary between small and large boats, in different bodies of water, with treated or untreated sewage. Details are available from EPA: https://epa.tas.gov.au/epa/water/boat-sewage-management/information-for-boat-owners. **Figure 2.61** shows the very limited section of the Derwent estuary where non-disinfected sewage can be disposed by all sized boats, which is 1 nautical mile off any land.

As of September 2020, the only public sewer pump-out facility in the Derwent estuary is located on the lower landing at Constitution Dock. This Sanivax pump-out facility, which is operated by TasPorts, is available to service yachts, recreational and commercial vessels, free of charge, seven days a week. Two additional pump-out facilities are currently planned for the Kangaroo Bay Marina and at the Derwent Sailing Squadron (**Figure 2.61**).

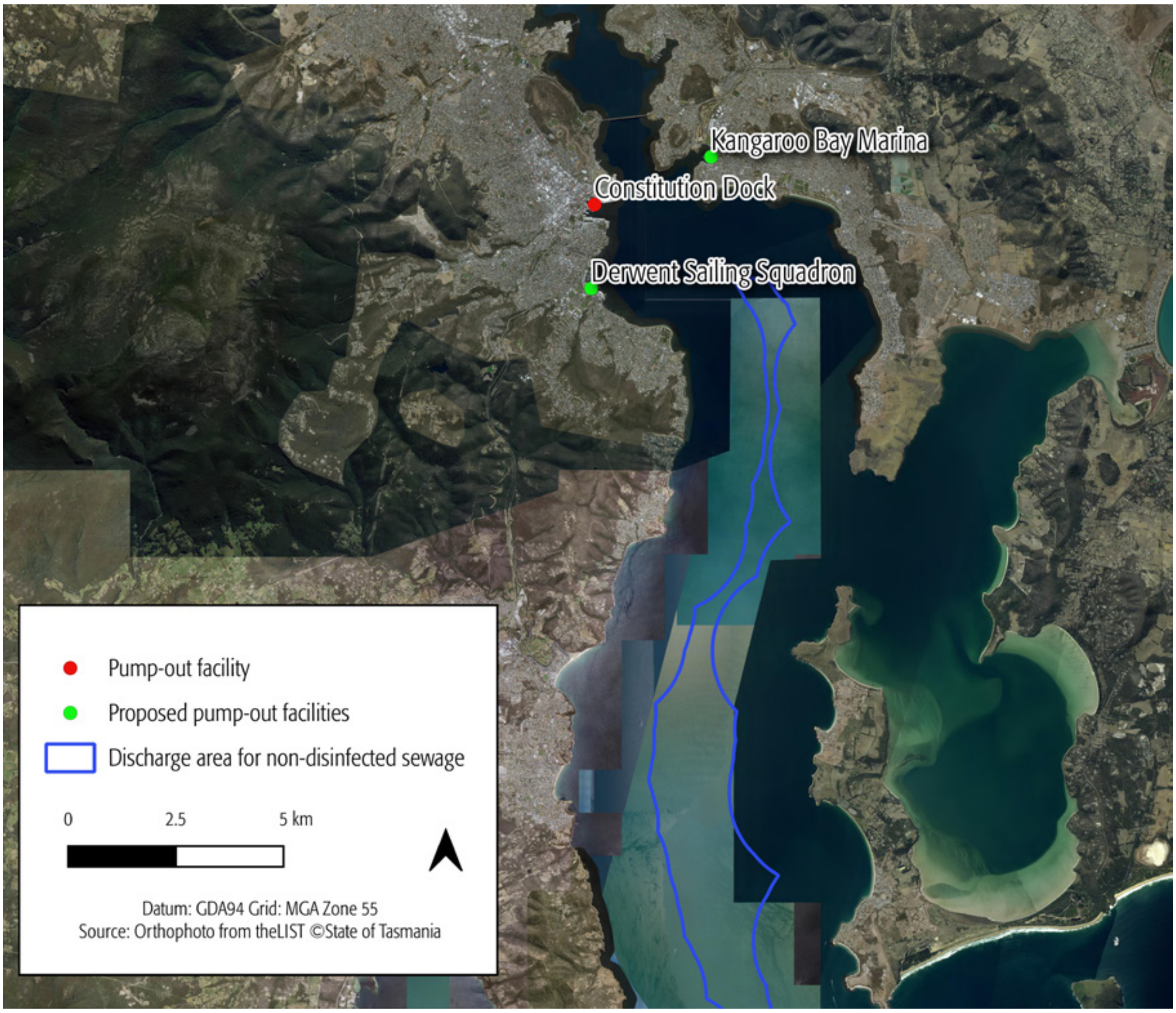


Figure 2.61 Boat sewage infrastructure and regulation in the Derwent estuary. Red dot: only current sewage pump-out facility in the Derwent estuary. Green dots: proposed sewage pump-out facilities. Blue line indicates the limited area where non-disinfected sewage can be disposed of within the Derwent estuary. Preferably all boat sewage is disposed of at authorised pump-out facilities

Environmental tips for your vessel's sewage system

- Maintain your marine toilet.
- Keep the disinfectant tank full.
- Use biodegradable treatment chemicals.
- Follow the manufacturer's suggested maintenance program.
- Have your marine toilet inspected regularly to ensure that it is functioning properly.
- Do not dispose of fats, solvents, oils, emulsifiers, disinfectants, paints, poisons, phosphates, nappies or other similar products.
- Greywater includes soaps and detergents from boat showers, dishwashing and laundry facilities.
- Soaps, even those labelled as 'biodegradable' contain substances that might be harmful to marine life.
- Use shore-side showers, dishwashing stations and laundry facilities whenever they are available.
- Check product labels and use low nitrogen and phosphorus detergents for on-board laundry, dishwashing and general cleaning.
- Use all soaps and cleaners sparingly.

Courtesy of Tasports (https://www.tasports.com.au/wp-content/uploads/2018/05/KPMVessel-Sewage-Pump-Out-Facility.pdf)

2.4.2.5 Ecological condition

2.4.2.5.1 Macrophytes

Initial results (**Section 2.5** and **Section 3.1.3**) and literature (Davies *et al*., 2002; Davies, 2005; Franklin *et al*., 2008) suggest that the existing summer river-discharge level and nutrient loads cause a stress response that may be alleviated with some combination between increased summer river discharge and decreased nutrient loads. Further assessment will improve our understanding of the factors influencing algal growth in macrophyte meadows.

2.4.2.5.2 Rocky reefs

The mid-estuary rocky reefs are home to species tolerant of highly variable environmental conditions, are subject to multiple stressors and are dominated by invasive species (Barrett *et al*., 2010; DEP, 2015). Unless the high nutrient loads delivered to the mid-estuary are markedly reduced, which currently seems unlikely, this will continue to be a factor for the currently poor ecosystem condition. However, the other key anthropogenic stressor is metal loads, which are decreasing from the Nyrstar Hobart zinc smelter. Further process improvements, groundwater isolation and groundwater remediation will ultimately alleviate the pressure exerted by metal contamination; however, we are unsure how this might be expressed ecologically.

2.4.2.5.3 Restoration – Shellfish reefs

Shellfish reef restoration is globally recognised as an opportunity to reduce nutrient stress in coastal waters (Petersen *et al.*, 2019) and successful projects have been deployed throughout Australia (Shellfish Reef Restoration Network, 2020b). See **Section 2.3.2.3** for suggestions on the re-establishment of native shellfish reefs in the Derwent estuary.

2.5 Hypoxia

Dissolved oxygen is essential for the survival of higher-order organisms including benthic invertebrates and fish. Approximately 100 hectares of the Derwent estuary experiences severe oxygen depletion (hypoxia) each summer and autumn (**Figure 2.62**). Hypoxia can occur naturally but is predominantly created by human impacts, particularly high nutrient load and modified flow (Rabalais *et al*., 2010). International policy and regulatory instruments recommend that investigations to understand hypoxia and the relationship with river dynamics is necessary to guide management (Water Framework Directive of the European Union, 2000). Guidelines (ANZECC, 2018) suggest waters should not have oxygen concentrations less than ~8-9 mg/L and hypoxic waters are generally defined as having a dissolved oxygen concentration of 2-4 mg/L. Hypoxia kills all organisms when their tolerance threshold is exceeded, and is a key factor in mass fish kills and local decimation of benthic invertebrates (Gammal *et al*., 2017). Hypoxia causes a shift from ecosystems dominated by fish, to those dominated by bacteria and algae, and it mobilises nutrients and metals from a sediment-bound state, releasing them into the water column (Diaz and Rosenberg, 2008; Banks and Ross, 2009; Banks *et al*., 2012; Ross *et al*., 2012; US EPA, 2017; NSW Department of Primary Industries, 2020).

Global studies identify that loading of nutrients and organic matter coupled with flow modification as factors influencing the severity and duration of hypoxia (Diaz and Rosenberg, 2008). To understand the local context, the DEP in 2015 started a detailed assessment of the drivers of the seasonally recurrent hypoxia in the upper Derwent (**Figure 2.63**). In 2019, Hydro Tasmania commissioned Austral Research and Consulting to further investigate the linkages between flow and hypoxia during summer low flow periods.

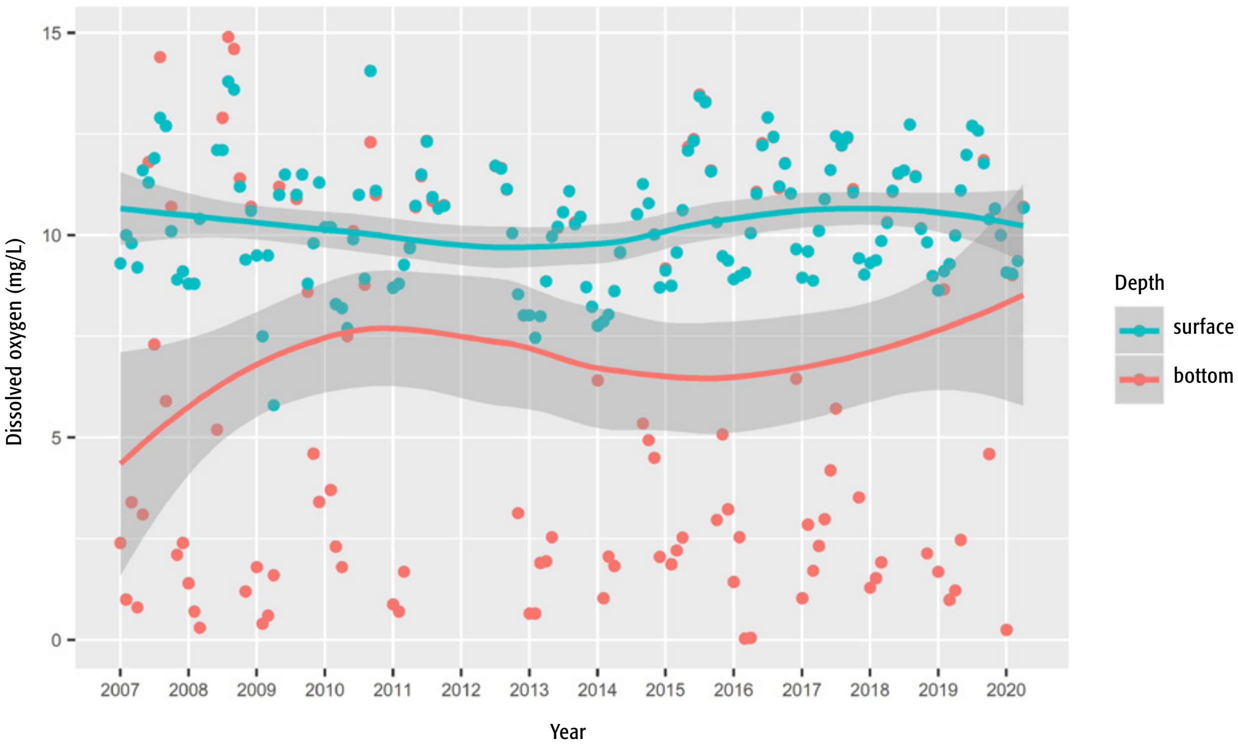


Figure 2.62 Dissolved oxygen concentrations from ambient water quality sampling at site NN (New Norfolk), representing severe and recurrent seasonal hypoxia

2.5.1 Status and trends

The DEP targeted hypoxia assessment included:

- Conducting profile analysis with a hand-held physicochemical multiprobe at 500-m intervals downriver from New Norfolk to Bridgewater Bridge, identifying that hypoxia occurred throughout a 10-km stretch of river from beyond the New Norfolk bridge to approximately 3.7 km east-north-east of Boyer/ Sorell Creek, equating to over 100 hectares of the estuary (**Figure 2.63**).
- Mapping bathymetry of the hypoxic zone, which identified a series of troughs and sills, and most importantly, a shallow sill located at the easternmost boundary of the hypoxic zone near the upper Derwent Motorboat Sailing Club, which is the ultimate barrier isolating hypoxic saline water from tidally oxygenated waters located east of the sill.
- Deployment of dissolved oxygen and salinity loggers at sites throughout the hypoxic zone, identifying that hypoxia persisted every year in late summer and early autumn. It also identified a strong relationship with river discharge. The relationship between hypoxia and river discharge was not linear; Hypoxia (<4 mg/L) generally persisted between November to May each year at Boyer, corresponding with mean river discharge < ~70 m^3/s. Hypoxia at New Norfolk generally persisted between January and April, corresponding with mean river discharge < ~50 m^3/s. When discharge occurs at these levels, a halocline is established, with freshwater running over an underlying saltwater wedge that itself moves westerly toward New Norfolk.

Slower water transit times during lower flow allows increased settlement of organic matter through the overlying freshwater leading to accumulation on the benthos below the halocline, where bacteria decompose it. In the process of bacterial decomposition of organic matter below the halocline, bacteria consume oxygen from surrounding waters, which, in the absence of flushing or mixing with oxygenated water, can lead to hypoxia. River discharge of ~40 m^3/s (**Figure 2.64**) disconnects the saltwater west and east of the motorboat club sill, meaning the salty water within the hypoxic zone is no longer mixed by freshwater discharge, and is isolated from the minor mixing effects of tidal exchange. Bacterial consumption of organic matter generally depleted oxygen at ~4 mg/L every 5 days. Maintenance of oxygen levels at around 2 mg/L throughout the hypoxic zone occurs as long as tidal connectivity is maintained east and west of the motorboat club sill. Marked reoxygenation occurs under the following two recharge events:

- Entire displacement of the salt wedge by sustained high river discharge (>~100 m^3/s), such as occurs from late autumn until mid-summer (**Figure 2.65**).
- Partial recharge due to salt wedge incursion over the motorboat club sill, driven by very low flow and tidal influence (**Figure 2.66**). Less than ~25 m^3/s permits connectivity of the salt wedge across the motorboat club sill and the alleviation of pressure resulting from rapidly reduced freshwater discharge draws oxygenated saltwater westerly over the motorboat club sill, which mixes with any remaining deoxygenated saltwater. These recharge events are temporary, and oxygen is typically quickly depleted until river discharge substantially increases.

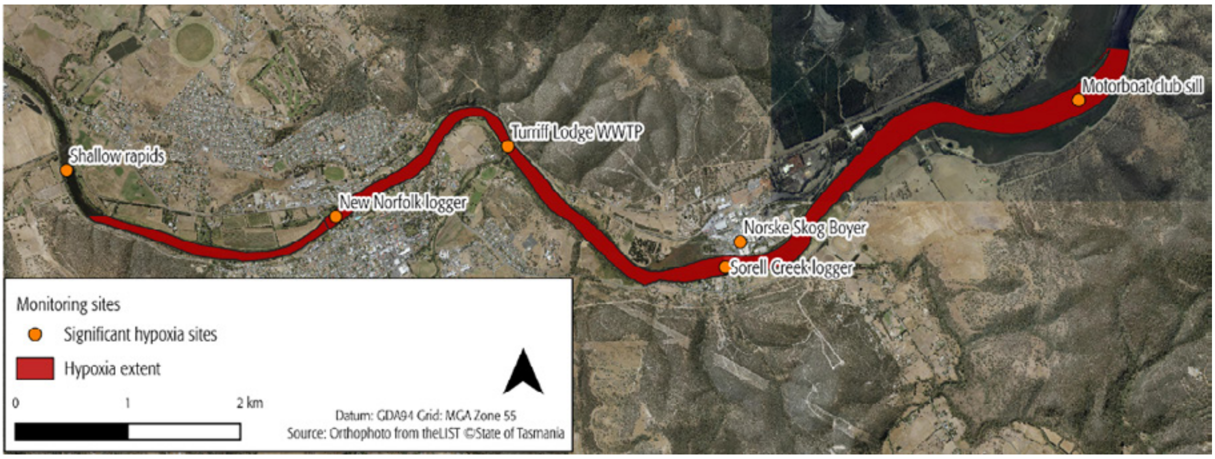


Figure 2.63 Hypoxic zone and significant locations

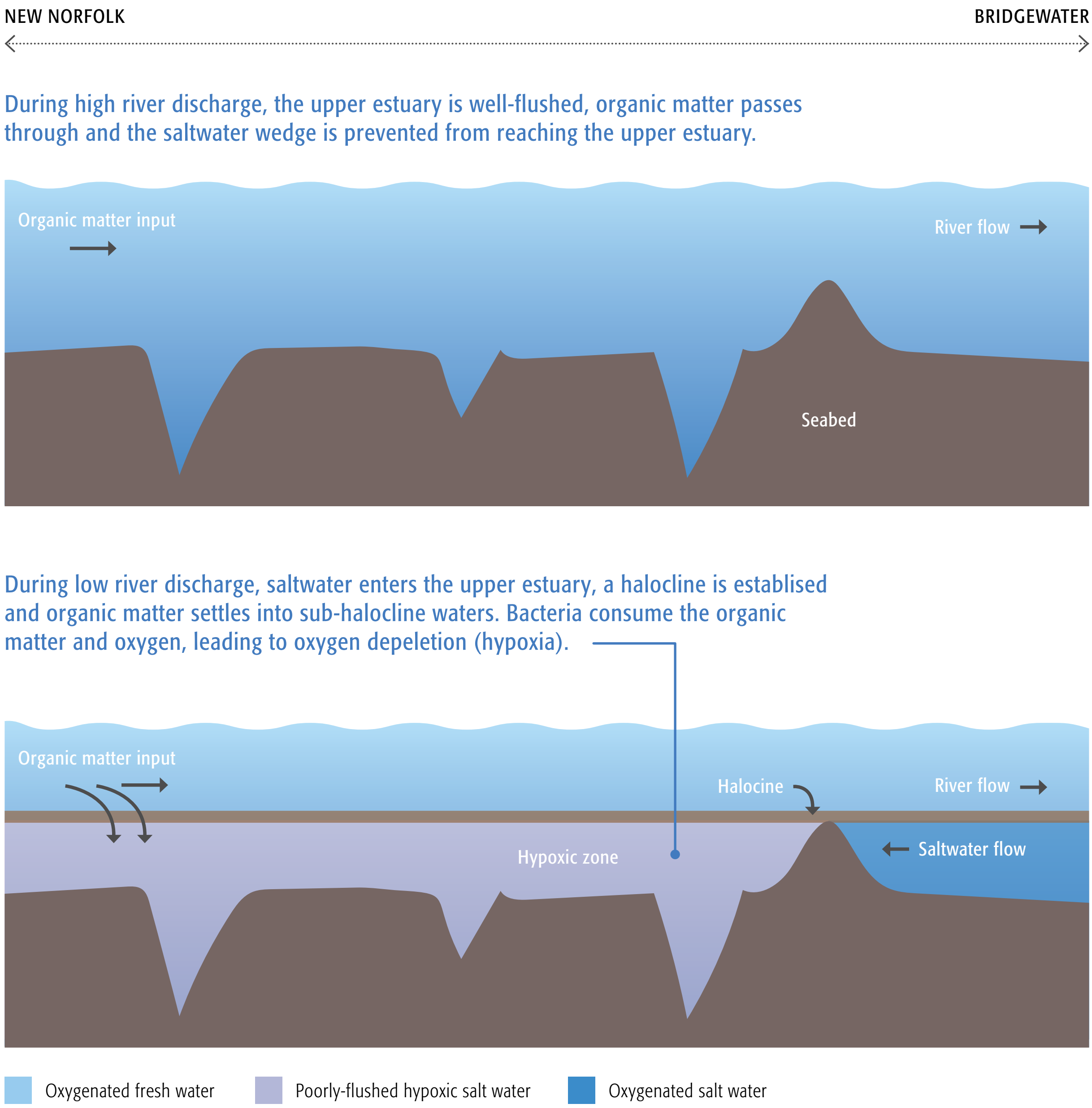


Figure 2.64 Conceptual diagram of upper Derwent estuary hypoxia dynamics

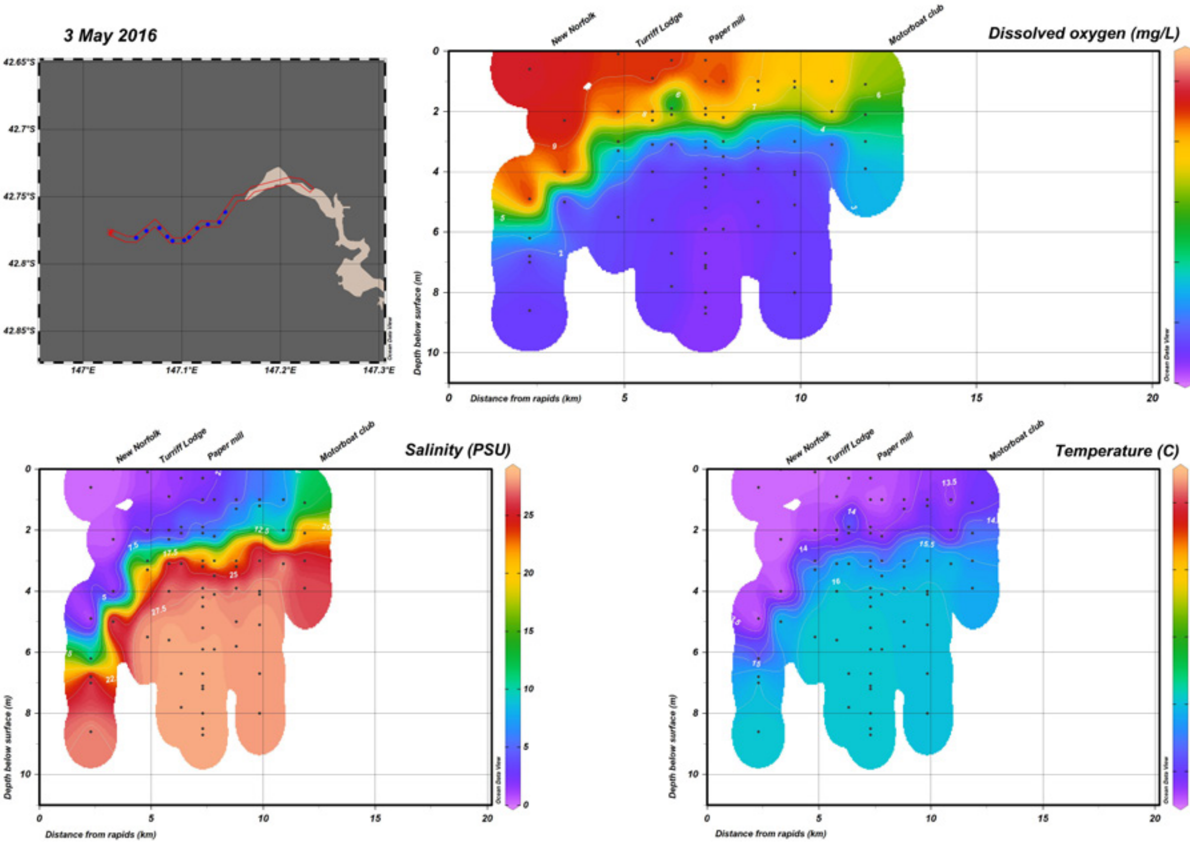


Figure 2.65 Hypoxic water displacement at the commencement of a high river-discharge event

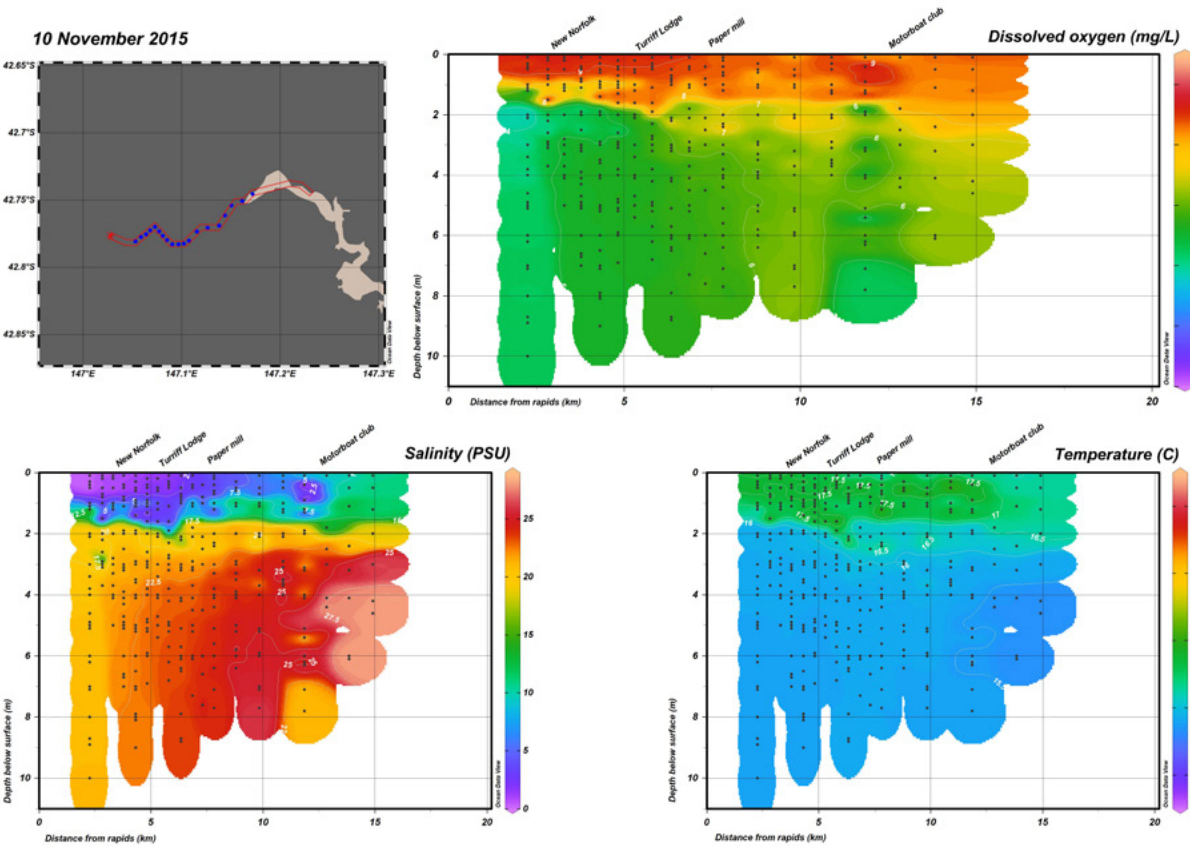


Figure 2.66 Hypoxic water recharge during low river discharge

2.5.2 Future projects

The following two anthropogenically influenced factors contribute to hypoxia in the Derwent estuary:

- River discharge
- Organic matter loads

Whilst low river discharge is a key driver for the onset of hypoxia, a detailed analysis and modelling of existing river discharge level compared to a natural scenario is suggested to better understand the levels of river flow required to maintain the health of the hypoxic zone.

Assessment and management of the source of biological oxygen demand is recommended. Key potential BOD sources for assessment would be:

- Norske Skog Boyer – Since commissioning the secondary treatment plant in 2007, Norske Skog Boyer discharges less than 1 t BOD/day. There is currently no information about how much discharged organic matter enters hypoxic sub-halocline waters during periods of low river discharge and we recommend further study.
- TasWater's Turriff Lodge WWTP – as part of a project to remove public health risk from surface waters, TasWater received in-principle approval from EPA Tasmania in 2019 to divert 51 kilograms of biological oxygen demand each day directly into sub-halocline hypoxic waters. This oxygen demand would all be exerted on the hypoxic zone except during flushing events caused by high river discharge. The EPA expects this discharge to be reduced over the medium-to-long term.
- The River Derwent is also a potential, but unconfirmed BOD source. BOD was analysed in samples collected each month from surface waters at New Norfolk from January to August 2020 and was not detected above the limit of reporting. Although there was no detectable biological oxygen demand, it is possible that organic matter is actually discharged by the River Derwent but in concentrations so dilute that it is not detectable. Given the huge volume of water discharged from the River Derwent to the estuary, even minute concentrations of BOD could exert considerable oxygen demand on the system, if riverine BOD settles in the hypoxic zone.

Management of hypoxia and its symptoms could be achieved through any combination of reduced BOD loads to the hypoxic zone or an altered river discharge regime during low flow periods. Organic-load-impact assessment may include settlement analysis on BOD in effluent from Norske Skog Boyer and source tracking in receiving waters and sediment. Methods of BOD source tracking may include:

- Fluorescence excitation emission scans of dissolved organic matter in water (Cawley *et al*., 2012; Holland *et al*., 2019; Rodríguez-Vidal *et al*., 2020).
- Amino acid composition analysis of waters (Harris *et al*., 2018)
- Environmental DNA analysis of sediment (CSIRO Environomics Future Science Platform, 2020).

2.6 Pathogens

2.6.1 Overview

Water contaminated with human and animal faeces may contain pathogenic micro-organisms (bacteria, viruses, protozoa) which can cause illnesses such as gastrointestinal disorders, respiratory illnesses, eye, nose and throat infections and skin disorders. Infection may occur if contaminated water is swallowed, inhaled or if the water comes into contact with ears, nasal passages, mucous membranes or cuts in the skin (N.Z. Ministry for the Environment, 2002). Full immersion or 'primary contact' activities such as swimming, diving and water-skiing in contaminated waters places people at greater risk of infection than do 'secondary contact' forms of recreation, such as fishing, boating or wading.

Key sources of faecal contamination to coastal water include:

- Discharge of sewage from WWTPs and associated infrastructure (pump stations and pipes) via large-scale spills, leaks caused by cracked or blocked pipes or rainfall-induced infiltration.
- Direct or indirect discharge of animal faeces, including ducks, gulls and other water birds, dogs on beaches and other native animals.
- Stormwater runoff during heavy rains, which transports accumulated faecal contamination from the wider catchment to receiving waters;
- Resuspension of contaminated sediments.

2.6.1.1 Recreational water program

Recreational water quality (RWQ) monitoring of beaches and bays in the Derwent estuary throughout each summer (December–March) is coordinated by the DEP in collaboration with DoH (Department of Health), EPA (Environment Protection Authority) and the six councils that border the estuary (Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough).

The primary objectives of the RWQ program are to coordinate monitoring, investigations and assist councils and the DoH in managing human health risks associated with poor water quality. The DEP's role in the program is to:

- Coordinate recreational water quality monitoring in the Derwent estuary.
- Compile and analyse data, including classification of beaches and bays, annual reporting and analysis of long-term trends.
- Report monitoring results to the public (via the DEP website and Facebook page) on a weekly basis.
- Support site-specific investigations into poor or deteriorating water quality at targeted sites.

This section is adapted from annual RWQ reporting. For more information regarding methods and historic data, see annual RWQ reports listed on the DEP publications web page https://www.derwentestuary.org.au/publications/. The chapter focuses on RWQ data collected over the past five summer seasons (1 December 2015 to 31 March 2020).

2.6.1.2 Site location

During the reporting period, up to 43 sites were sampled between New Norfolk and Iron Pot each summer. Sites are categorised as either *swimming sites* or *environmental sites*, as described below, and site locations are shown in **Figure 2.67**.

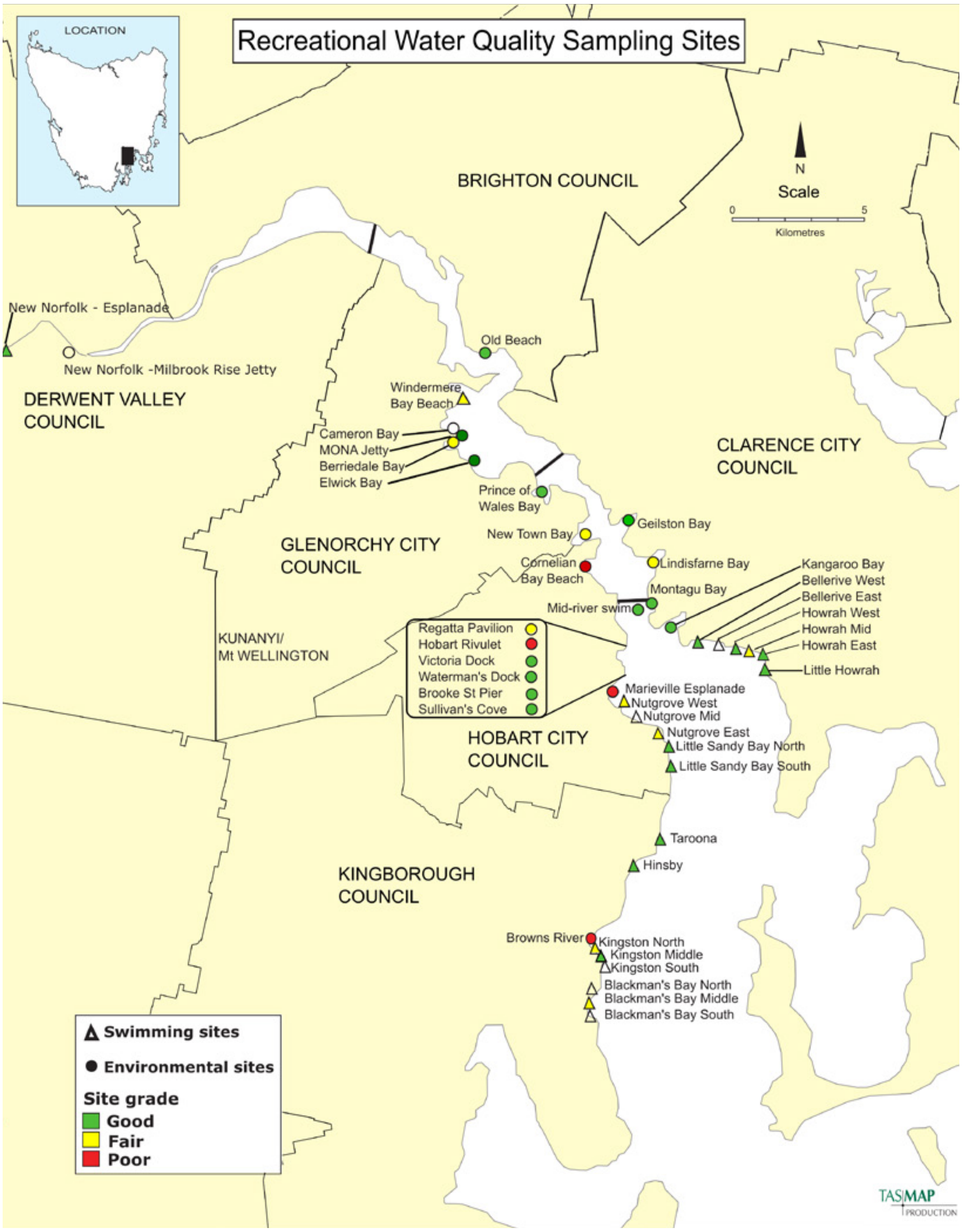


Figure 2.67 Location of Recreational Water Quality sampling sites (swimming and environmental sites) with current water quality classification based on data collected in the summer months over the reporting period (December 2015 and March 2020). Sites without five years of data (N/A) are shown without a rating.

- *Swimming sites* were monitored in locations where a significant number of people swim or conduct other primary contact recreation. These sites were sampled by the local councils to provide a basis for public health information. Up to 21 *swimming sites* were monitored each summer season during the reporting period.
- *Environmental sites* provide a broader context for interpretation of swimming site results and for other purposes. Up to 22 *environmental sites* were monitored seasonally during the reporting period. These sites were sampled by either the councils or EPA/DEP, and were selected based on the following rationale:
  - » Bays and coves that are frequently used for secondary contact recreation and/or have foreshore parks.
  - » Areas with identified potential sources of faecal contamination.
  - » Sites with relatively low risk of contamination, sampled to contextualise *swimming site* results.
  - » Sites associated with major swimming events, such as the Trans Derwent Swim.

The number of sites sampled each summer over the reporting period varied. Some years new sites are added and others removed, and sometimes sites are moved to a more appropriate location, based on public usage and health advice. Importantly, all sites require five years of data in one location to calculate a long-term rating.

For the 2019-2020 season, four new *swimming sites* were added to the program. Bellerive Beach (east) and Blackmans Bay Beach (north) were both added to provide additional and consistent sampling along the length of these two popular beaches. Kingston Beach (south) and Blackmans Bay Beach (south) were moved from their previous locations by stormwater outfalls, which is consistent with DoH advice of not swimming near outfalls (DEP, 2020b).

2.6.1.3 Pathogens, sampling and analysis

In the Derwent estuary, enterococci are sampled as the key faecal indicator bacteria, as required by the Tasmanian Recreational Water Quality Guidelines 2007 (Department of Health, 2007). Aseptic grab samples, taken from approximately 10 cm below the surface were collected every Tuesday by councils and the EPA/DEP throughout the Derwent estuary during summer and early autumn each year (from 1 December to 31 March). All samples were analysed at the Public Health Laboratory using the 'Enterolert' method, which provides confirmed results within 24 hours of analysis (DEP, 2020b).

2.6.1.4 Recreational water quality guidelines and 5-year site ratings

Swimming and *environmental sites* in the Derwent estuary are graded as 'Good', 'Fair' and 'Poor'. This is in accordance with the Recreational Water Quality Guidelines for Tasmania which are largely based on the National Guidelines for Managing Risks in Recreational Water (NHMRC, 2008) and adopt a three-tiered approach to classifying the long-term (five years of data) quality of a site based on available data:

- Good: rolling 5-year 95th Hazen percentile value of < 200 enterococci MPN (Most Probably Number)/100 mL.
- Fair: rolling 5-year 95th Hazen percentile value of 200 – 500 enterococci MPN/100 mL.
- Poor: rolling 5-year 95th Hazen percentile value of > 500 enterococci MPN/100 mL. In this case, water at these sites is considered to be a threat to public health in the event of primary contact recreation and the particular local council is required to advise the general public and to erect warning signs to this effect

In addition to long-term site classification, trigger levels have been set to manage public exposure to episodic or emerging water quality issues. If a sample exceeds 140 enterococci MPN 100 mL^{-1}, the council is required to resample, and if two consecutive samples return a result above 280 MPN 100 mL^{-1}, the public must be notified via signage on the beach in question. This signage can only be removed by Council's Authorised Officer in consultation with DoH.

2.6.1.5 Rainfall data

Rainfall data collected and reported by the Bureau of Meteorology (BoM) at four representative weather stations throughout the Derwent estuary catchment is used to compare total rainfall for each RWQ season (December to March) against the long-term average (BoM, 2020a). Observations of daily rainfall are nominally made at 9 am and record the total for the previous 24 hours. Hobart (Ellerslie Rd.), Kingston (Greenhill Dr.), Hobart Airport and New Norfolk (west) have been selected as representative of sampling sites in the Derwent estuary.

2.6.2 Status and trends

2.6.2.1 Seasonal rainfall

Given the significant impact rainfall has on recreational water, it is important to consider these results in the context of summer rainfall (NHMRC, 2008; DEP, 2020b). Summer rainfall records for the past five years, at four representative weather stations across the estuary are presented in **Figure 2.68**.

Rainfall varies across the estuary, with long-term averages for the summer months ranging between 163 mm at Hobart Airport to 202.1 mm at Kingston (Greenhill Dr.). Whilst there is variation in the amount of rain recorded at each of the BoM weather stations, the general trend is consistent across sites over the reporting period. The above-average rainfall recorded in 2017-2018 predominantly fell in a heavy three-day rainfall event in early December; otherwise that season was largely dry. Overall, summers are wetter in the Kingston catchment than anywhere else in the estuary (**Figure 2.68**).

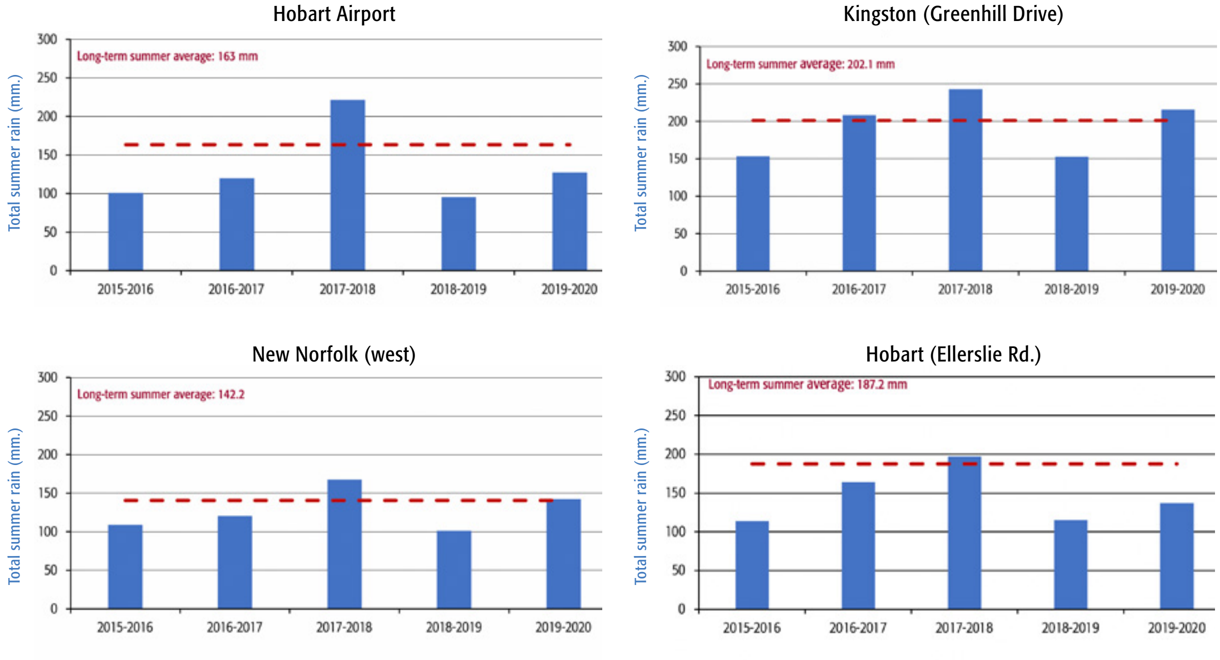


Figure 2.68 Total rainfall (mm) at four weather stations in the Derwent estuary catchment during the last five RWQ program seasons (between December and March), as recorded by the Bureau of Meteorology (2020). The long-term average rainfall for the period is indicated in red text and by dotted line.

2.6.2.2 Swimming Sites

As shown in **Figure 2.69**, recreational water quality at *swimming sites* has varied slightly over the reporting period. Recreational water quality was best during the 2016-2017 and 2017-2018 seasons, with the largest number of sites with 'Good' long-term ratings. The number of sites rated as 'Good' have increased since the beginning of the reporting period, and for the first time in five years, no sites were rated as 'Poor' at the conclusion of the 2019-2020 season (**Figure 2.69**).

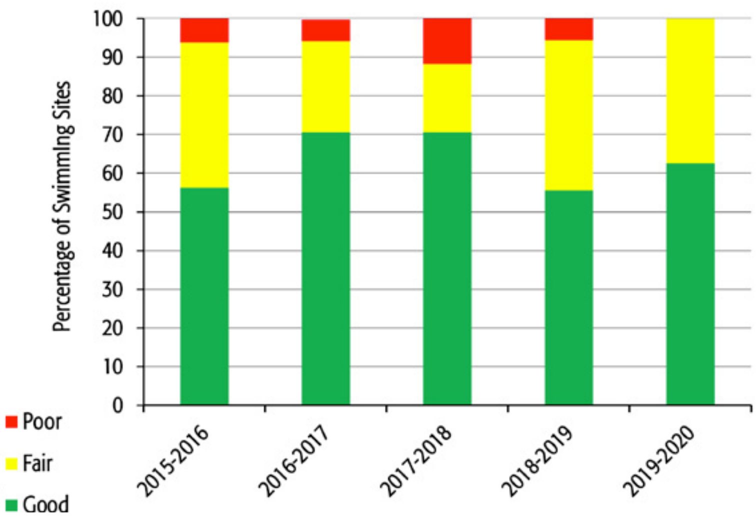


Figure 2.69 Proportion of *swimming sites* graded as 'Good', 'Fair', and 'Poor' in the last five RWQ seasons. Proportions are based only on those sites with five years of data.

At the end of the 2019-2020 season, 10 *swimming sites* were classified as 'Good', six sites were classified as 'Fair', no sites were classified as 'Poor', and five sites are yet to be classified due to incomplete five year data-sets (**Figure 2.70**, **data-set Figure 2.70**). The two *swimming sites* with the best recreational water quality are Hinsby Beach and Little Sandy Bay Beach (south). The sites with the poorest results are Howrah Beach (mid) and Blackmans Bay Beach (mid) (**Figure 2.70**). While no sites are currently rated as 'Poor', the high number of Fair sites is a warning signal for councils to take corrective action to prevent sites deteriorating.

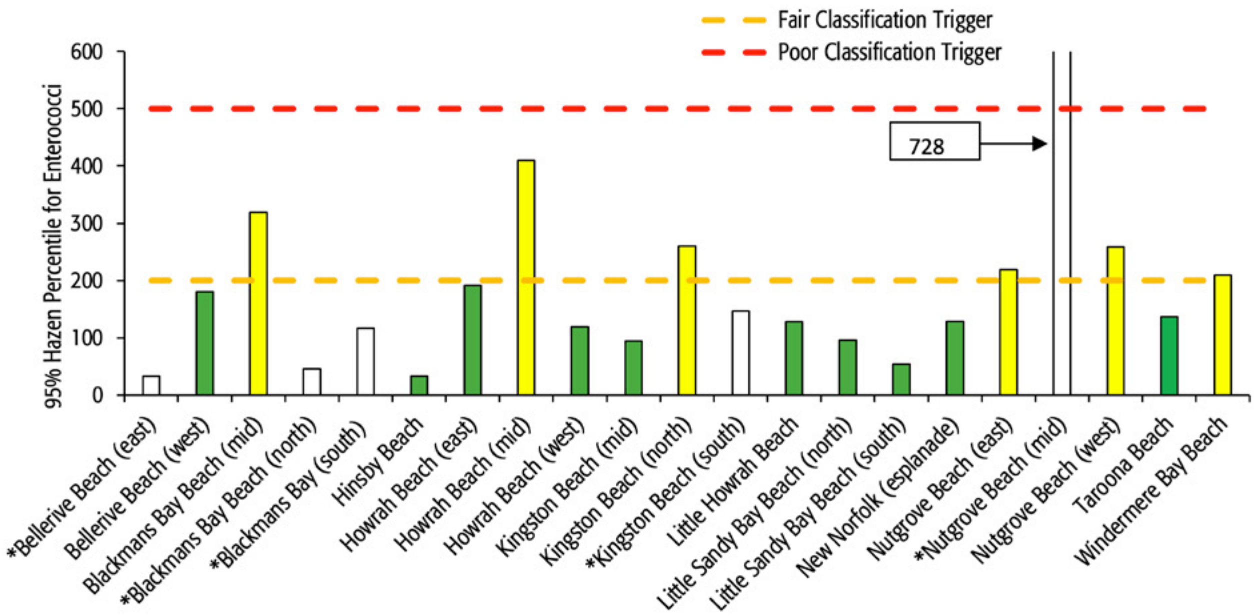


Figure 2.70 Rolling 5-year Hazen percentile enterococci results for *swimming sites* in the Derwent estuary at the end of the 2019-2020 season. Green denotes Good (< 200 MPN/100 mL), yellow denotes Fair (200 – 500 MPN/100 mL), red denotes Poor (> 500 MPN/100 mL), and the classification trigger lines are indicated with dotted lines. * indicates that less than five years of data is available, thus, those results are less robust.

Over the reporting period significant changes include:

- No sites were rated as 'Poor' at the conclusion of the 2019-2020 season for the first time in over a decade.
- Nutgrove Beach (east) improved to a 'Fair' rating at the conclusion of the 2018-2019 season, after a decade of being rated 'Poor'.

2.6.2.2.1 Rainfall at swimming sites

Although the relationship between enterococci results and rainfall events can be complex, there appears to be relationship between rainfall prior to sampling (24 hours) and high enterococci results. Using 2019-2020 season as an example, there were four days throughout the 2019-2020 summer where rainfall was > 10 mm in the estuary. None of these events preceded (24 hours) a sampling event. On only four days, did any rain precede sampling, and none of these events exceeded 5 mm (DEP, 2020b).

Of the 373 enterococci samples collected in 2019-2020, 99% (368 samples) were < 140MPN/100 mL. Low rainfall (0.1–5 mm) did not negatively influence enterococci results, with 69 of 70 low rainfall samples < 140 MPN/100 mL (**Figure 2.71**). The lack of heavy rainfall preceding sampling (24 hours) is likely to have had a positive impact on results during the 2019-2020 season, and the results suggests that the little rain that did precede sampling had a negligible influence.

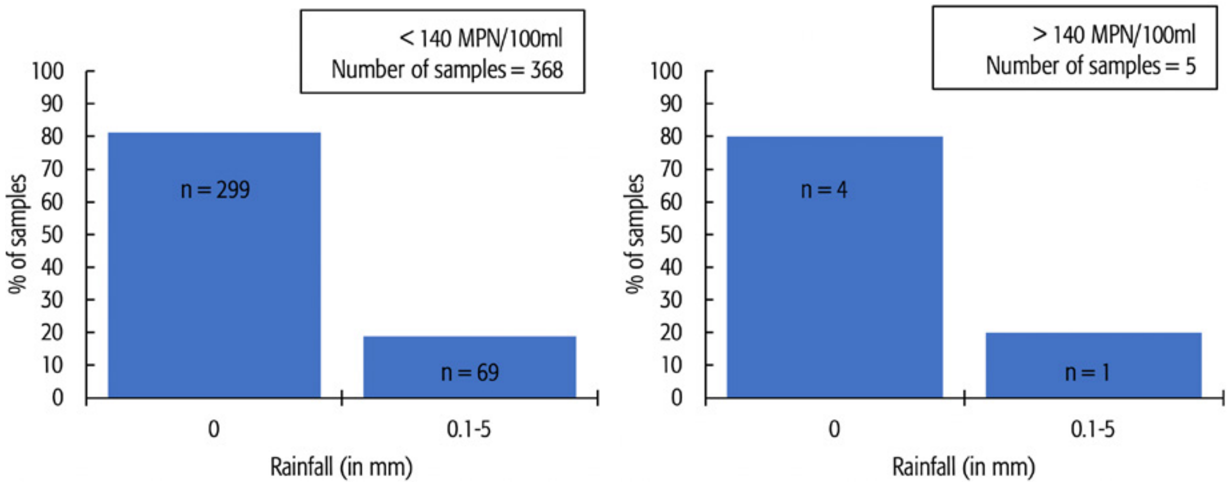


Figure 2.71 Proportion of samples < 140 MPN/100 mL (a), and > 140 MPN/100 mL (b), that respond to rainfall. Graphs include all enterococci samples collected at swimming sites during the 2019-2020 RWQ season (DEP, 2020b).

2.6.2.3 Environmental Sites

Figure 2.72 shows that the recreational water quality at *environmental sites* has generally improved over the reporting period. Though 2017-2018 has the most sites rated as 'Good' and the fewest rated as 'Poor', the 2019-2020 season had the second-best quality over the reporting period and has improved significantly since the 2015-2016 season.

At the end of the 2019-2020 season, 12 sites were graded as 'Good', four as 'Fair', four as 'Poor' and two yet to be classified due to incomplete five year data-sets (**Figure 2.73**). The two *environmental sites* with the best recreational water quality are Montagu Bay and Mid-river Derwent. The sites with poorest ratings are Browns River and Marieville Esplanade (**Figure 2.73**).

Over the reporting period, there have been several noteworthy changes:

- Hobart Rivulet improved significantly over the reporting period from 6334 MPN/100 mL (2015-2016) to 1080 MPN/100 mL-1 (2019-2020).
- Waterman's Dock improved from 'Poor' to 'Good' at the conclusion of 2018-2019 season and has remained 'Good'.
- At the conclusion of the 2019-2020 season, three sites improved their rating from 'Fair' to 'Good', having been rated 'Fair' for three seasons (Elwick Bay, Geilston Bay and MONA jetty).

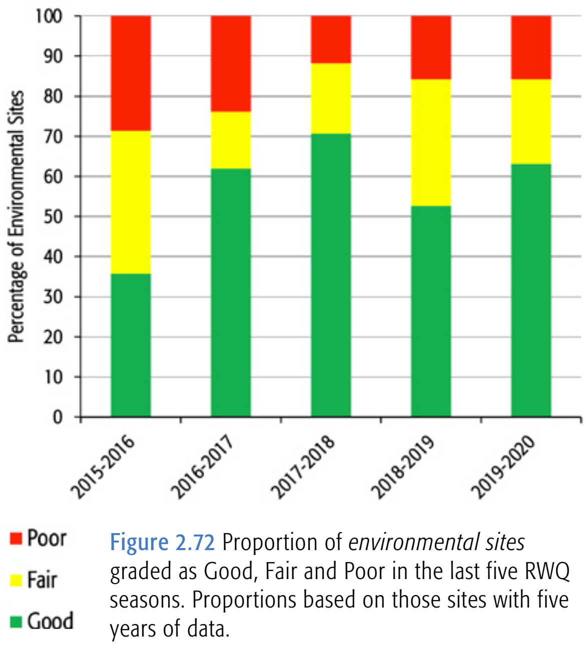


Figure 2.72 Proportion of *environmental sites* graded as Good, Fair and Poor in the last five RWQ seasons. Proportions based on those sites with five years of data.

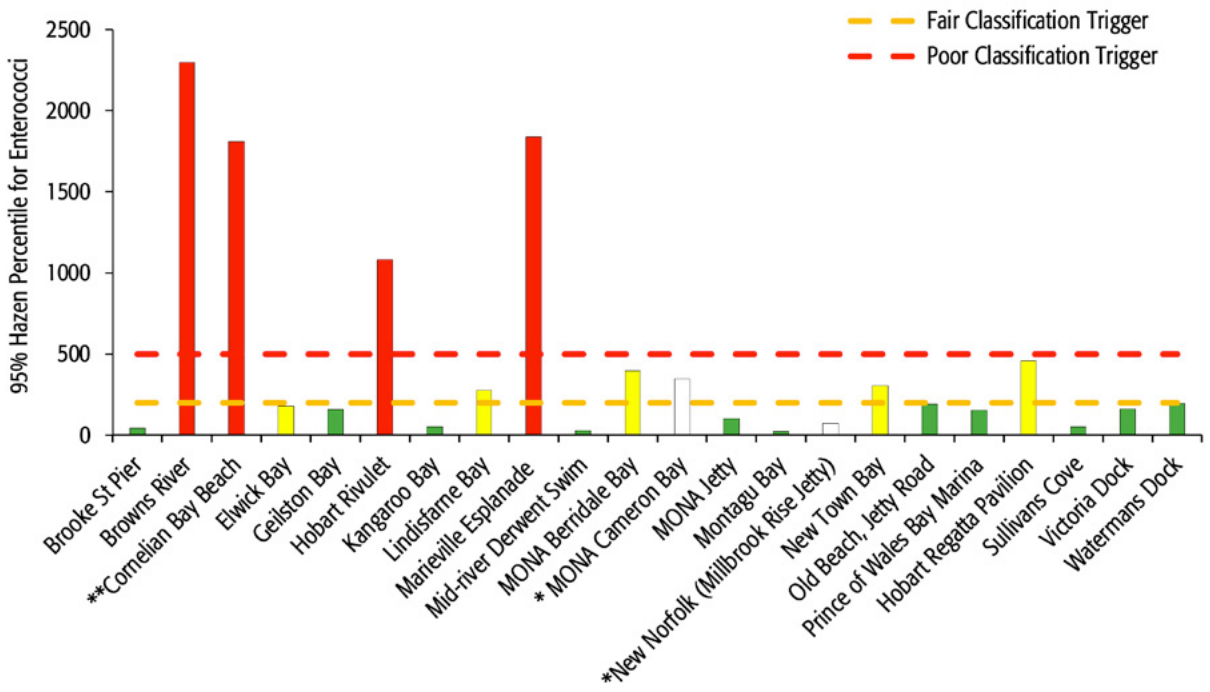


Figure 2.73 Rolling 5-year Hazen percentile enterococci result for environmental sites in the Derwent estuary at the end of the 2019-2020 season. Green denotes Good (< 200 MPN/100 mL), yellow denotes Fair (200 – 500 MPN/100 mL), red denotes Poor (> 500 MPN/100 mL), and the classification trigger lines are indicated with dotted lines. * indicates that less than five years of data is available, thus those results are less robust. **Cornelian Bay have been monitored intermittently, when conditions allow, thus those results are less robust.

2.6.3 Future projects

The DEP will continue to look for ways to improve the RWQ program and the recreational water quality across the Derwent. It is the vision for all *swimming sites* will have 'Good' long-term ratings by 2024, and for all RWQ sites to be managed proactively to prevent water quality decline.

2.6.4 Management response

Over the reporting period a variety of management responses were employed to improve recreational water quality. These include the development of tools, resources, as well as site-specific investigations and remedial action. A couple of significant management responses and outcomes are described below.

2.6.4.1 Response protocol

The DEP developed a Response Protocol to assist councils in responding to high enterococci results. The protocol is a tool that can be employed to improve communication between RWQ stakeholders. This protocol was developed in response to confusion over the correct process to follow in response to high enterococci results. It was produced by DEP with the help from DoH and input from council partners and TasWater. It is a flowchart outlining what to do when the results fall within particular ranges, e.g. exceeds guideline trigger levels (**Figure 2.74**).

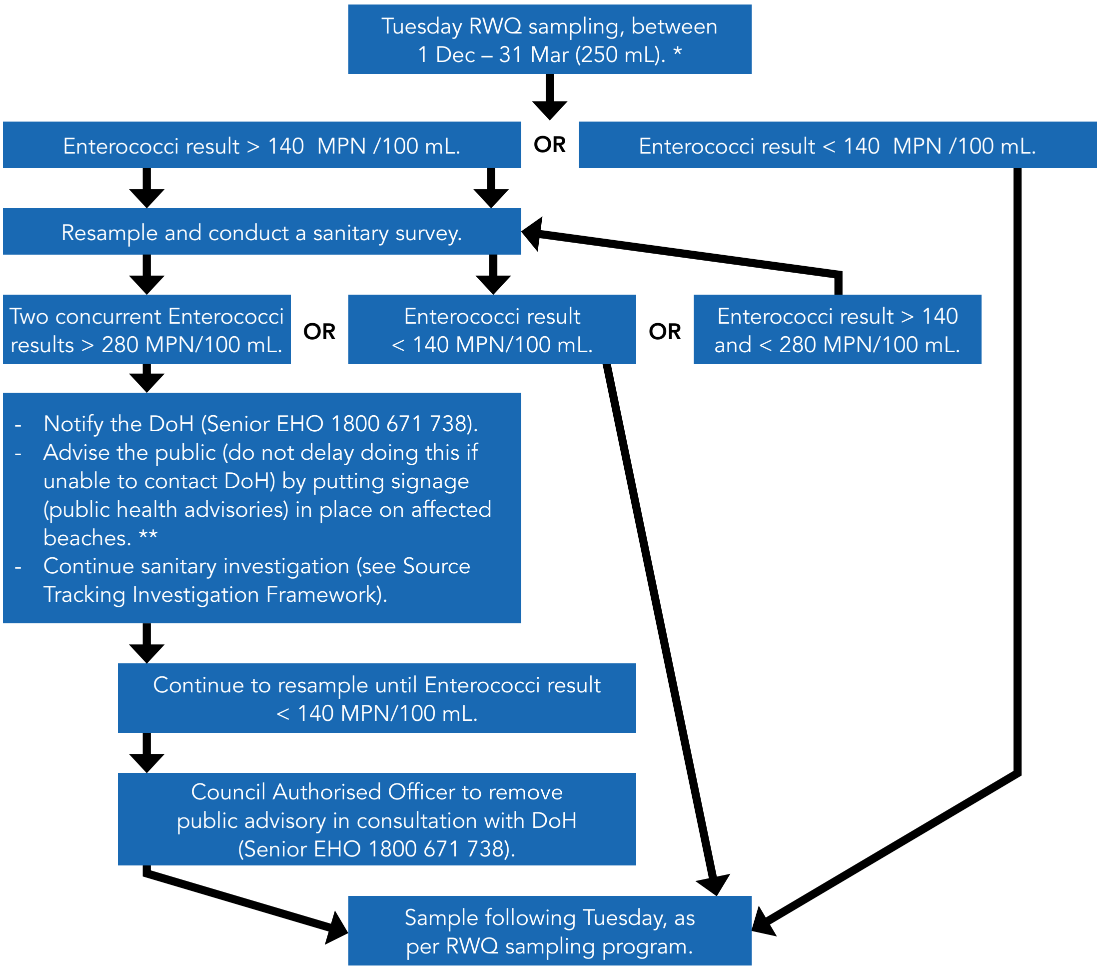
Beach Watch Response Protocol For the Derwent Recreational Water Quality Program (RWQ)

Derwent Estuary Program

Background

This Beach Watch Response Protocol is based on the requirements of the *Recreational Water Quality Guidelines (RWQG) 2007*. It has been developed to assist councils in how to proceed when prescribed water quality trigger levels are exceeded throughout the RWQ season. The protocol specifies a proactive approach to water quality management. It is only relevant for designated swimming sites, and not environmental sites.

The *Public Health Act 1997* and the RWQG provide the legislative head of power for councils to manage recreational water quality in their municipality. In addition to the Tasmanian RWQG, the national *Guidelines for Managing Risks in Recreational Water* (National Health and Medical Research Council) also provide information on the suitability of water bodies for recreational use and should be consulted for information on recreational water issues and advice followed, unless that advice conflicts with RWQG.



* If possible, conduct a sanitary survey at time of sampling, at least for Fair and Poor sites. Use the Sanitary inspection checklist for natural recreational water bodies from the Draft Recreational Water Quality Guidelines 2018.

** Council may choose to issue a media release and inform public via social media.

Figure 2.74 Response Protocol. Flowchart of how to respond to RWQ sample results.

2.6.4.2 Source Tracking Framework and Toolkit

The *Source Tracking Framework and Toolkit* (the manual) was published in 2020 to provide support tools for councils to conduct source-tracking investigations (DEP, 2020c). The manual was developed as a response to requests from council for support regarding:

- Conducting strategic stormwater investigations.
- Differentiating between human and animal sources of faecal contamination.
- Providing knowledge and accessibility to new and emerging source tracking methods and techniques.

Figure 2.75 *Source Tracking Framework and Tool Kit*. Left: front page of manual. Right: framework and flowchart of how to conduct a source tracking investigation (DEP, 2020c).

The manual is broken into two sections:

- Framework/decision support tool help investigators find the pollution source by taking them through easy-to-follow screening, tracing and remediation phases (**Figure 2.75**).
- Toolkit which reviews source-tracking tools (sub-surface tools, water quality indicators and microbial source-tracking methods) and indicates if the methods are available for implementation in Tasmania, and in what situations they are most relevant.

The manual identifies ammonia test-kits as an exciting source-tracking method for quick detection of pathogens. Given the price ($30 for 130 tests, from an aquarium shop!), speed to get result (5 min.) and the amount of sample water required (5 mL), the DEP recommends that councils incorporate the ammonia testing into their investigations, particularly for rapid assessments of stormwater sub-catchments to pinpoint contamination hotspots. Since the publication of the manual, three councils have incorporated ammonia testing into source-tracking investigations and have had very positive results.

Several projects are underway to test the efficacy of different source-tracking techniques in Tasmania:

- Analytical Services Tasmania are conducting a pilot study to trial the use of 'sterol biomarkers' as a tool to distinguish between human and on-human sources of contamination in recreational waters. Sterols are a family of lipid compounds that are converted to stanols by bacteria in the gut of warm-blooded animals. The ratio of sterols to stanols in water samples has frequently been used around the world to trace human faecal pollution in waterways.
- Due to the lack of microbial source tracking techniques available to discriminate between contamination sources in Tasmania, the Public Health Laboratory have initiated a project to test a 'phenotyping' technique called the PhenePlate system (PhPlate). The PhPlate is a biochemical fingerprinting method that characterises bacterial isolates based on the measurement of the reaction products formed by the metabolisation of different substrates. This system has been used successfully In source-tracking investigations (Ahmed *et al*., 2005), and is being trialed due to low establishment and sample costs. The manual will be updated as new methods and learning become available.

2.6.4.3 Local investigations

The DEP is strongly recommending that councils proactively conduct investigations of the beaches and catchments at sites with 'Poor' and ''Fair' long-term ratings. A 'Fair' rating should be viewed as a warning that the water quality may be deteriorating, and action should be taken as soon as possible.

2.6.4.3.1 Nutgrove Beach (west)

Nutgrove Beach (west) is a great success story for a beach with a legacy of poor water quality and a good example of how collaborative investigations and persistence can result in good water quality outcomes. The western end of Nutgrove Beach had a poor recreational water quality rating for over a decade due to faecal contamination transported to the beach via the Lipscombe Rivulet and stormwater outfall. Over the summers of 2016-2017 and 2017-2018 a collaborative investigation between TasWater, City of Hobart (CoH) and the DEP took place to identify the source of contamination and rectify problems found.

The investigation included additional end-of-pipe and targeted street sampling; tracking for anthropogenic tracers; hydraulic sewer modelling / pipe pressurisation; dye testing; as well as Closed Circuit Television (CCTV) investigations.

Results from those investigations confirmed a sewage signal in the stormwater from the Lipscombe Rivulet; a crack was discovered in a sewerage pipe causing sewage to enter gravel surrounding the stormwater pipe at a crossover point; several possible sagging/compromised sewer pipe joints were detected; as were two cross connections at private properties. During the spring summer of 2017-2018 TasWater undertook significant repairs and pipe re-alignment and the council removed the two sewage/stormwater cross connections.

Post-work sampling results showed a marked improvement in water quality, with the rolling 5-year 95th Hazen percentile value for enterococci improving leading to the long-term rating moving from 'Poor' to 'Fair' at the end of the 2018-2019 RWQ season.

2.6.4.4 Communications

Information to the public about the recreational water quality at Derwent swimming and environmental sites was provided in several formats:

- Weekly reporting via the DEP website https://www.derwentestuary.org.au/beach-watch/. The website was updated in 2017 and has continued to see a significant increase in web traffic. Between 2015 and 2020, views per season increased from 2000 (in 2015-2016) to 3500 (2019-2020). Seasons characterised by poor water quality resulted in significant increases in viewership, with 19500 website views during the 2018-2019 season.
- Posts on the DEP Facebook page https://www.facebook.com/derwentestuary. The DEP began sharing RWQ results on Facebook in 2016, and since then views per post have increased six-fold from approximately 50 to 300. As with the website, views were maximised during periods of poor water quality, and when posts were shared. During the 2018-2019 season, that post that was shared the most (30 shares) also had the most views (6900).
- Signs installed at swimming sites. The DEP recommends that local councils conduct an annual review of signage in their municipality to ensure that all signs are located in the most appropriate locations (i.e. visible to most visitors), are in good condition (e.g. free of graffiti), and that they are replaced with new signs as required (e.g. when the water quality category changes).
- Media releases, usually released at the beginning and conclusion of the season, as well as in response to any significant changes or events during the season. During the 2018-2019 season, due to above average trigger-level exceedances, and the Poor water quality advisory at Blackmans Bay beach (south), there was a significant increase in media attention. There were 10 media reports throughout the season, most of which focused on the poor water quality results at Blackmans Bay (south) and Nutgrove Beach (west).

2.7 Stormwater

2.7.1 Overview

Increased urbanisation in catchments draining to the Derwent estuary has resulted in many impervious surfaces. When rain falls onto impervious surfaces it is converted directly to runoff rather than being infiltrated into the ground. This can have significant impacts on localised flow rates and volumes. Stormwater runoff erodes banks of urban rivulets, can cause urban flooding, potentially damage infrastructure, and transports pollutants that have built up in catchments during dry periods directly to receiving waters, i.e. the Derwent estuary.

The impacts of stormwater pollution pose a significant threat to ecosystem and human health in the Derwent estuary. Urban stormwater is contaminated with many pollutants, including suspended solids, metals, nutrients, litter, hydrocarbons, oxygen-demanding waste (decomposing organic matter), and microorganisms. Suspended solids impact receiving waters by increasing turbidity and sedimentation, which can lead to a reduction in photosynthesis and dissolved oxygen availability (due to microbial decomposition of organic material). Solids also play a significant role in transporting other pollutants such as metals and hydrocarbons, which are bound to particle surfaces and can be toxic to aquatic flora and fauna. Similar to organic matter, nutrient enrichment, such as nitrogen and phosphorus from fertilisers and sewage etc., can also lead to reduced dissolved oxygen levels caused by the occurrence of bloom-forming algae (Goonetilleke and Lampard, 2019). Pathogens found in human and animal waste can also have significant adverse impacts on human health (NHMRC, 2008). More details of pollutant types, sources and impacts are outlined in **Table 2.2**.

Stormwater monitoring programs in urban waterways in the Derwent estuary region have previously demonstrated the impact of urbanisation on the water quality of urban rivulets. Between 2002–2005 and 2010-2011, the DEP coordinated monthly stormwater and urban rivulet monitoring in collaboration with six councils (Brighton, Clarence, Derwent Valley, Glenorchy, Hobart, Kingborough), with 11 rivulets sampled at an upper and lower location. Stormwater monitoring in 2010-2011, which sampled a suite of parameters, notably total suspended solids, total nitrogen, total phosphorus and enterococci, clearly demonstrated a deterioration of water quality between most upper and lower sites, as well as significant differences in water quality between rivulets (DEP, 2011). Monitoring between 2002-2005 also demonstrated a clear relationship between poor water quality and urban catchment size (Milne, 2005; DEP, 2011). Comparison of the 2002-2005 and 2010-2011 results suggests a general decline in water quality between the two monitoring periods, particularly at the upper sites, consistent with impacts of increased urbanisation. However, this could also be attributable to the fact that the 2002-2005 monitoring program experienced a higher proportion of dry weather than the 2010-2011 monitoring. Details of the two programs and results are published in *Stormwater and Rivulet Monitoring Report* (2002-2005) and *Stormwater and Rivulet Monitoring Report* (2010-11).

The following section provides an overview of stormwater issues related to the Derwent estuary, including a review of stormwater legislation and policy, and stormwater management actions undertaken by the DEP and partners during the period 2015–2020.

Table 2.2 Some stormwater pollutants, their possible sources and potential impacts

Pollutant	Source	Impact
Suspended solids	• Soil erosion • Construction sites • Road/footpath wear	• Smother ecosystems • Block sunlight • Cause respiratory problems in fish • Increase water temperature
Metals	• Vehicle wear and emissions • Atmospheric deposition • Illegal/accidental discharges	• Toxicity to aquatic organisms • Bioaccumulation
Nutrients	• Detergents • Animal wastes • Fertilisers • Sewerage leaks	• Promote aquatic plant, algal and weed growth, which may lead to eutrophication
Pathogens	• Sewerage overflow/leak/illegal connection • Animal faeces	• Disease in humans and animals • Reduce recreational amenity
Hydrocarbons	• Vehicle wear and emissions • Spills and leaks • Illegal discharges	• Toxic to aquatic organisms • Loss of aesthetic amenity
Litter (gross pollution)	• Community rubbish	• Reduce aesthetic amenity • Human health hazard • Aquatic animal and bird health hazard • Reduction in stormwater system effectiveness/ efficiency

2.7.2 Status of stormwater management

Stormwater management is a shared statutory responsibility between state and local government. State government is responsible for the development of legislation, strategies, and guidelines. Local government is responsible for implementing and maintaining public stormwater systems. In Tasmania, stormwater management is administered by several pieces of legislation, policy, regulations, and guidelines. Relevant instruments are reviewed below in **Section 2.7.2.1** and **Section 2.7.2.2** to provide an overview of the framework for stormwater management in Tasmania. The review provides context for a current project, facilitated by the DEP, to draft a policy for the implementation of stormwater management under the Tasmanian Planning Scheme (**Section 2.7.2.2**). These legislative and policy instruments are used to implement stormwater management measures that address both stormwater quantity and quality, such as Water Sensitive Urban Design (WSUD), Erosion and Sediment Control (ESC), Gross Pollutant Traps (GPTs), and urban rivulet management.

2.7.2.1 Stormwater legislation, policy, strategy and guidelines

The purpose of the *State Policy for Water Quality Management 1997* (SPWQM) is to protect and enhance water quality while allowing for sustainable development. The SPWQM provides a framework for the management and regulation of water quality, including stormwater. The SPWQM emphasises the need to manage stormwater at the source and requires stormwater to be managed using best-practice environmental management for diffuse sources, and according to stormwater-management strategies, at the construction and development phase of construction. The primary means for planning authorities to implement the provisions outlined in the SPWQM is through local-government planning schemes (**Section 2.7.3**). The SPWQM is also the driver for the implementation of Water Sensitive Urban Design (WSUD) in Tasmania.

The State Stormwater Strategy 2010 supports the need to manage stormwater as set out in SPWQM, and sets out a range of best management WSUD practices, as well as stormwater quality and quantity targets for private developments based on Integrated Water Management and WSUD principles. In alignment with the SPWQM, the strategy emphasises the need to manage stormwater at its source, and identifies performance criteria for stormwater discharges from new developments of:

- 80% reduction in the average annual load of total suspended solids
- 45% reduction in the average annual load of total phosphorus
- 45% reduction in the average annual load of total nitrogen.

To further the objectives of the SPWQM and the State Stormwater Strategy, the manual *WSUD: engineering procedures for stormwater management in Tasmania* (Wet Environment *et al*., 2012) was produced for Tasmania conditions. The manual provides technical construction, engineering and development assessment advice for stormwater management systems in urban landscapes, and details best practice WSUD management.

The *Urban Drainage Act 2013* (The Act) provides for the management of urban drainage and stormwater systems and infrastructure in Tasmania. The objectives of The Act are to:

- *'Protect people and property by ensuring that stormwater services, infrastructure and planning are provided so as to minimise the risk of urban flooding due to stormwater flows'; and*
- *'Provide for the safe, environmentally responsible, efficient and sustainable provision of stormwater services in accordance with the objectives of the resource management and planning system of Tasmania'.*

The Act requires councils to develop a Stormwater System Management Plan (SSMP) for the management of stormwater system assets, and to reduce flood risk. An update of councils' progress with SSMPs is provided in 2.7.3.6

Other legislative and policy instruments relevant to stormwater management include the following: *Local Government Act 1993, Local Government (Building and Miscellaneous Provisions) Act 1993, Environmental Management and Pollution Control Act 1994, Building Act 2016, Plumbing Regulations 2014, and Building Regulations 2014*.

2.7.2.2 Stormwater regulation and the Tasmanian Planning Scheme

The Tasmanian Planning Scheme (TPS) sets out the requirements for use or development of land in accordance with the *Land Use Planning and Approvals Act 1993*. The TPS consists of two parts: State Planning Provisions (SPPs) (state-wide consistent set of planning rules); and Local Provisions Schedule (LPSs), which will apply the SPPs to each municipal area (Tasmanian Planning Commission, 2020). Though the TPS was enacted in 2017, the TPS will only come into effect in each council area once the LPSs for that council area is finalised. The TPS is yet to come into effect for councils in the Derwent estuary region.

The purpose of the TPS is to further the objectives set out by the *Land Use Planning and Approvals Act 1993* by providing consistent state-wide planning controls, whilst staying consistent with state policies. In the case of stormwater, the TPS should be consistent with SPWQM. Though the TPS is the key instrument for managing stormwater in private developments (as specified by the SPWQM), a stormwater code that embeds stormwater quantity and quality performance outcomes into the local government planning system, currently in councils' interim planning schemes (IPSs), was omitted from the TPS, and thus, will be removed when LPS come into effect.

In March 2016, the draft TPS was published and did not include a stormwater code. In December 2016, the Tasmanian Planning Commission released a draft report outlining the Commission's considerations and recommendations of the draft SPPs (Tasmanian Planning Commission, 2016). The Commission showed support for a stormwater code and stated that: '*While the State Policy on Water Quality Management 1997 (SPWQM) can be met with modifications to the SPPs without the addition of a code, the Commission encourages the inclusion of a code that more comprehensively addresses stormwater*'. However, it also stated that '*while there was widespread agreement that a code was needed, representers (planning authorities, practitioners, and community groups) were not in agreement about the drafting of the code*', and further that '*the assessment process of the draft SPPs is not the appropriate process for introducing new codes*'. In the absence of a stormwater code the Commission broadened Clause 6.11.2 of the TPS to provide a head of power for conditions addressing stormwater to be included on planning permits, and recommended that: '*the Minister gives consideration to whether the SPPs require a code or further provisions to better manage stormwater quality, and if so that this be included by amendment to the SPPs*.'

The omission of a stormwater code in the TPS means provisions for regulating stormwater management in development applications will be limited to applying conditions. For councils, the lack of a code means there is no ability to inform Development Applications (DA), and proposal design prior to a DA being lodged. For developers, this is also a problem, as it means the first time they learn about stormwater obligations is through conditions on a planning permit.

Out of the DEP's Stormwater Taskforce, the Stormwater in New Developments Working Group (SNDWG) was formed to develop a stormwater management policy document that will fill the gap by assisting councils to establish a robust and consistent regime for applying stormwater conditions on planning permits, as well as informing development proponents of design requirements prior to lodging a DA. The policy will be voluntary, and councils will have the choice to adopt it as a local policy or not. In addition, the working group aim to produce a set of WSUD developer resources that support development proponents to meet design requirements. The collaboration is an initiative of (and led by) the DEP, and includes personnel from Brighton Council, Clarence City Council, City of Hobart, City of Launceston, NRM North, Local Government Association Tasmania (LGAT) and Institute of Public Works Engineering Australasia (IPWEA) Tasmania members. The working group has begun state-wide engagement with a widely attended introductory webinar; is in the process of recruiting a technical representative from the northwest councils; is working on a first draft of the policy; and has engaged with interstate capacity building organisations to identify suitable WSUD developer resources, guidelines and tools.

2.7.3 Stormwater management actions

Councils in the Derwent estuary manage stormwater to reduce pollutant load and mitigate flood risk within their municipalities. There are a number of ways to manage stormwater. These include 'at source' controls to minimise and capture pollutants before they enter the system, 'end-of-pipe controls' such as large GPTs and floating litter booms, WSUD systems that integrate stormwater treatment within urban landscapes, detention tanks to minimise flood peaks, education and training programs, and litter clean-ups. A summary of key areas and actions supported by the DEP and partners during the reporting period is provided below.

2.7.3.1 Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) represents best practice for stormwater management, managing urban stormwater as a resource, and protecting receiving waterways and aquatic ecosystems. Examples of WSUD include collecting and reusing roof runoff (e.g. in rainwater tanks), promoting infiltration by retaining native vegetation and installing porous pavements, construction of stormwater treatment swales, wetlands and other biofiltration systems, and larger-scale stormwater-harvesting projects. For more details on the benefits of WSUD see the *State Stormwater Strategy* (DPIPWE, 2010).

A number of WSUD projects were constructed in the Derwent estuary region over the reporting period. In this period, WSUD features were funded either by council or acquired as assets from new developments (as required under IPSs), as opposed to many previous WSUD features that were implemented with Federal Government funding. A summary of WSUD features/assets installed during the reporting period is provided in **Table 2.3**, with the locations as shown in **Figure 2.76**.

2.7.3.2 Erosion and Sediment Control (ESC)

Poorly managed construction sites are a major source of sediment run-off to urban stormwater systems and associated waterways, particularly on sites with steep slopes. The DEP has previously coordinated significant projects to improve building site practices in Tasmania with the development of Sediment and Erosion Control Fact Sheets, training courses for builders and council work crews and provision and demonstration of materials.

A current focus is on compliance and enforcement of Soil and Water Management Plans and ESC control measures. The DEP engaged Topo. (https://www.topo.com.au/) to deliver ESC training to council planning and engineering staff, as well as works crews to better support councils to implement and enforce ESC measures in the Derwent estuary region. This training is scheduled for early 2021.

2.7.3.3 Litter research and management

The accumulation of litter along the foreshore of the Derwent estuary is one of the biggest concerns to the local community (Myriad Research, 2019). Litter and marine debris is not only aesthetically unpleasant, but can threaten the survival of marine life (Wilcox *et al*., 2015), as well as posing a potential threat to human health (Wright and Kelly, 2017). Litter, particularly plastics, enter the estuary through the stormwater system, urban rivulets and via beach and coastal users.

Litter is regulated via the *Litter Management Act 2013* and can be managed a number of different ways. A combination of improved infrastructure (GPTs, WSUD and litter traps), public education, clean-up events, strategic placement of water refill stations and more rubbish bins at popular beaches are likely to decrease marine debris in the Derwent estuary (Willis, Hardesty, *et al*., 2017). GPTs have been strategically installed in the Derwent estuary catchment to reduce pollutant loads discharged to the estuary. GPT assets installed during the reporting period are summarised in **Table 2.3**, with the locations as show in **Figure 2.77**. The following section documents research, and clean-up actions conducted in the Derwent estuary during the reporting period.

2.7.3.3.1 Marine debris research

The Commonwealth Scientific and Industrial Research Organisation's (CSIROs) marine debris research team conduct world-wide research into the sources, distribution and fate of marine debris. Several of these studies have a strong focus on the Derwent, and those published during the reporting period are summarised below.

- Marine debris sources: A survey was conducted to identify the anthropogenic factors that affect the distribution of estuary (Derwent and Tamar) and coastal debris (East Coast) (Willis, Hardesty, *et al.*, 2017). In the Derwent, plastic accounted for 40% of the debris observed, followed by glass. Shorelines with close proximity to stormwater drains and highly visited beaches had more debris.
- Microplastic distribution in sediment cores: Two sediment cores from the Derwent were analysed to assess the accumulation of microplastics through time (Willis, Eriksen, *et al*., 2017). Sediment cores were collected and made available for analysis by the DEP. Results were consistent with the hypothesis and demonstrated that frequencies of plastic in the sediment corresponded with the increases in plastic production and coastal populations. Plastic micro fibers were the most abundant microplastic in the samples. The study also identified that sediments deposited prior to the presence of plastic in the environment were contaminated with fibers, indicating possible contamination of sediment cores during sampling or laboratory analysis. The authors noted that results in this study and others (particularly where sediment samples are used opportunistically to look for microplastics) should therefore be interpreted with contamination in mind.

Table 2.3 Stormwater management actions conducted by five local councils in the Derwent estuary region between 2015 and 2020. Numbers (GPTs) and letters (WSUD) correspond with **Figure 2.76**, which shows the asset locations.

	Gross Pollutant Traps (GPTs)	WSUD	Urban Rivulets
Brighton	Demountable Litter Traps (Syrinx) installed by council at: 1. School Farm outlet 2. Cheswick outlet 3. Cove creek outlet	WSUD assets installed by council at Old Beach to capture stormwater irrigation reuse, including: a) Infiltration basin b) Pond	Future works: • Cheswick Creek – Creek restoration to be funded by Interim Contributions Scheme • Tivoli Green – Council has partnered with developer to engage consultant (Syrinx) to incorporate WSUD into open-space planning
Glenorchy	Various GPTs and litter traps installed by council: 4. Humphreys Rivulet litter trap relocated to Derwent estuary outlet 5. Demountable Litter Trap installed at Gepp Parade capturing pollutants prior to discharge at Prince of Wales Bay	WSUD assets installed by council: c) Various bioretention basins/ rain gardens installed by council as part of the Glenorchy CBD upgrade	

	Gross Pollutant Traps (GPTs)	WSUD	Urban Rivulets
Hobart	GPT installed by council: 6. GPT (SPEL) installed to treat piped Maypole Rivulet (near Pizza Hut) Various GPTs installed by developers including the following developments: 7. Athleen Rd subdivision – GPT/detention basin 8. Athleen Rd subdivision – GPT/detention basin 9. McDevitt subdivision – GPT (Humeceptor) 10. Montrivale Rise subdivision – GPT (Humeceptor)	WSUD assets installed and maintained by council: d) Ongoing maintenance of Bell St bioretention basin (council) WSUD assets installed by developer: e) Various bioretention basins and small WSUD features at the Brickworks subdivision Council installed various rain gardens as part of 'pedestrian improvement projects' which are not marked on the map, including; Main Rd, Newtown; Augusta Rd, Lenah Valley; and, Macquarie St, South Hobart.	Removal of willows and other weeds, revegetation and bank stabilisation works undertaken at various rivulets including: • New Town Rivulet • Salvator Rosa Glen Creek • Hobart Rivulet • Lipscombe Rivulet
Clarence	Various GPTs installed by developers including the following developments: 11. Brookston Dr, Mornington (2x Stormwater 360) 12. Acme Dr, Clarendon Vale (Rocla CDS) 13. Hawthorn Place, Rokeby (SPEL Ecoceptor 6000) 14. Carella St, Tranmere (Humeceptor STC-2)	WSUD assets installed by council, including: f) Raingarden as part of Kangaroo Bay redevelopment project g) Stormwater harvesting project to irrigate Cambridge oval	Kangaroo Bay rivulet riparian works including weed removal
Kingborough		WSUD assets installed by developers including the following developments: h) Spring Farm development: Two bioretention basins and streetscape rain gardens that treat stormwater discharged to Whitewater Creek i) Whitewater Park development: Two large bioretention units installed that treat stormwater discharged to Whitewater Creek (upstream of Spring Farm)	Riparian restoration of several rivulets including: • Drysdale Creek – Creek restoration works including removal of weeds, planting of natives, rock rip rap protection for stormwater outfalls and along creek bed • Whitewater Creek – Restoration works to restore the creek banks and reduce sediment transportation downstream following major impacts of 2018 floods Future works: • Developer to install a bioretention unit in conjunction with the Kingston Wetlands as part of the Kingston Park development • Maintenance and upgrades of the Kingborough Wetlands will also be undertaken including installations of a new GPT, potential new trash racks, removal of silt and sediment from the ponds and appropriate revegetation work

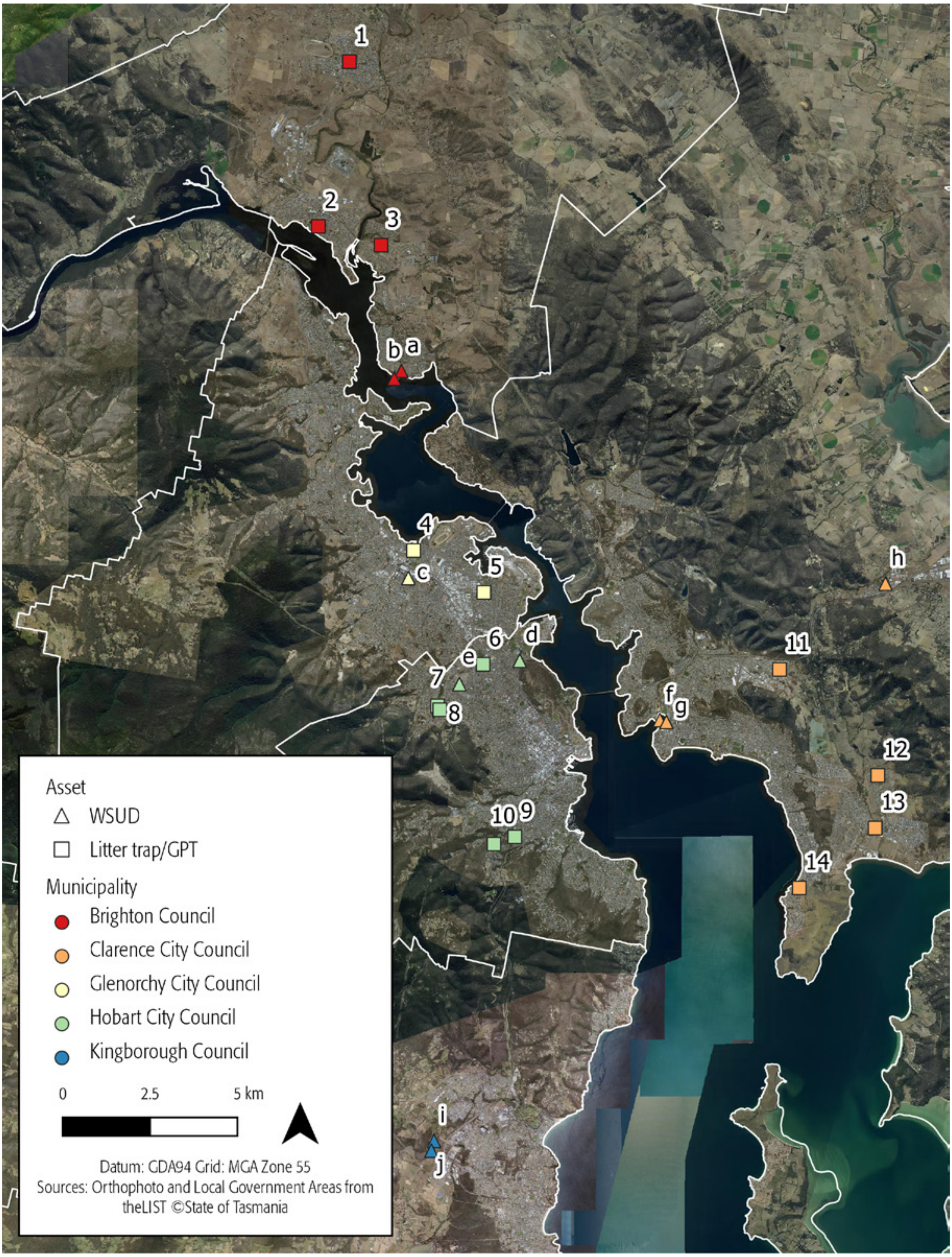


Figure 2.76 Location of WSUD (triangle) and GPT (square) assets, installed in the Derwent estuary region between 2015 and 2020. Colours represent the different municipalities and are identified in the legend. Further asset detail is provided in **Table 2.3**.

2.7.3.3.2 Community Clean-ups

Public education and clean-up events play a key role in prioritising and influencing the reduction of litter entering the Derwent estuary (**Figure 2.77**). Several community groups and motivated individuals regularly volunteer to clean up the estuary. These projects are summarised below.

- The Bridgewater/Gagebrook clean-up group was founded in 2016, and work to promote appreciation for their local area and to inspire change. A focal area for the group is the Jordan River, which feeds into the Derwent estuary. Over the last five years the group has removed 20 truckloads of house-hold rubbish, approximately 500 tyres and 300 shopping trolleys from the Jordan River, plus various white goods and burnt-out cars.
- Our Coast Our Mission is a not-for-profit organisation focused on beach and foreshore clean-ups, as well as delivering educational talks about marine debris and plastic pollution to the wider community. In 2019, Our Coast our Mission began hosting regular clean-up events in the Derwent estuary, targeting areas including Prince of Wales Bay, Elwick Bay, Montrose Bay and Newtown Bay. Over two clean-up events, 63 volunteers removed 463 kg from foreshore wetlands in Elwick Bay.
- The Hobart chapter of the Sea Shepherd organises regular clean-up events in the Derwent estuary region as part of the nation-wide 'Sea Shepherd Marine Debris Campaign'. The campaign is dedicated to driving community change and to cleaning up Australian waterways and beaches through education and beach clean-ups. Over the five-year reporting period, Sea Shepherd Tasmania hosted 29 events across 13 different sites in the Derwent estuary. The events usually include one hour of collecting rubbish, followed by sorting and counting items and entering them into a national database, Tangaroa Blue (see https://www.tangaroablue.org/). More than 1000 volunteers attended the events, and collected in excess of 1668 kg of rubbish, and approximately 81280 items. On average, three quarters of all debris collected by Sea Shepherd (nation-wide) is made from plastic.
- The DEP coordinates annual Clean Up Australia Day events throughout the Derwent estuary. Notably, the DEP focused cleanup efforts at Prince of Wales Bay (POWB) from 2018–2020, a bay that has historically accumulated high loads of litter. Clean-up efforts at POWB have been a collaborative effort with DEP partners (TasWater, Nyrstar, Glenorchy City Council (GCC), Hydro Tasmania), many POWB businesses (notably Plastic Fabrications Group, Impact Fertilisers

Figure 2.77 Various Derwent estuary clean-up events clockwise from left; Before and after at Prince of Wales Bay Clean Up Australia Day event 2018; Shoreline clean-up Prince of Wales Bay 2018; Sea Shepherd clean-up, Kingston Beach. (photograph provided by Michael Bruhn).

and Incat), Aquatic informatics, Our Coast Our Mission and local community members. These events are a great example of collaboration between local business, industry and the community, and have helped contribute to litter load reduction in POWB, however, there is still much work to be done. In 2019, GCC installed a GPT at Gepp Parade, which captures pollutants prior to discharge at POWB. See **Table 2.3** and **Figure 2.76** for more details and location.

2.7.3.4 Faecal source tracking

Stormwater contaminated with human and animal faces contains pathogens which pose a significant risk to beach goers, as described in detail in **Section 2.6**. A key source of contamination is sewage discharge from sewerage infrastructure via spills, leaks caused from cracked or blocked pipes, or direct cross-connections to the stormwater system. Local councils conduct a range of monitoring and source-tracking activities to locate and rectify sewer intrusions to stormwater. In 2020 the DEP published a Faecal Source Tracking Framework and Toolkit to assist council to conduct effective investigations, which is discussed in more detail in **Section 2.6.4.2**. Several investigations are discussed below.

- Following poor water quality at high-profile swimming beaches, Kingborough Council commenced an extensive sampling regime and investigation of the Blackmans Bay and Kingston beaches and stormwater catchments. Council has conducted weekly recreational water and stormwater outfall samples from since November 2018. The results are discussed in detail in Blackmans Bay Recreational Water Quality Review (Coughanowr, 2019) . Council appointed a Stormwater Investigation Officer in November 2019 whose key responsibility is to investigate, identify and rectify sewer/stormwater cross-connections, degrading infrastructure, sewer leaks and sewer spills within the municipality. The officer has successfully used a combination of methods including visual inspection as well as ammonia, bacterial and dye-testing to track sources of contamination back up the catchment to their source. This has been very successful in locating ageing sewer infrastructure impacting stormwater as well as domestic cross-connection issues, which have been promptly rectified by TasWater, Kingborough Council and property owners. Council's commitment to improve recreational water quality continues.
- The Howrah catchment in the Clarence municipality is highly susceptible to stormwater contamination (DEP, 2020b). Council remains committed to stormwater investigations to identify and rectify sewer intrusions. Over the summer of 2019-2020, Council used a combination of ammonia, bacterial and dye-testing as well as CCTV footage to successfully identify several contamination sources including cross-connections and leaking/broken pipes. Council has worked closely with TasWater to rectify identified issues and remain committed to investigating the Howrah sub-catchments.

2.7.3.5 Urban rivulets

Urban rivulets provide many benefits to the natural environment and to people, habitat and food resources for birds, frogs, fish, invertebrates and aquatic mammals, such as platypus and native water rats. Rivulets also provide important breeding areas for fish. Natural vegetation cover, particularly along riparian zones, promotes stormwater infiltration, and slows overland flows. Naturally flowing and vegetated waterways can filter contaminants before they are discharged into downstream waterways. As well as providing natural values, rivulets provide a source of aesthetic beauty and recreational uses, such as bushwalking, jogging, riding and contemplation.

Over a dozen major waterways and rivulets drain to the Derwent estuary. Local governments are primarily responsible for the management of urban rivulets; however, there are several community groups and schools that undertake restoration and educational activities, e.g. Friends of Sandy Bay Rivulet and Newtown Rivulet Catchment Care Group. Rivulet management issues are discussed in further detail in previous State of the Derwent Reports (DEP, 2010b, 2015). Urban rivulet actions conducted during the reporting period are summarised in **Table 2.3**.

2.7.3.6 Flood management

2.7.3.6.1 Stormwater System Management Plans

A summary of the approach local councils have taken to preparing Stormwater System Management Plans (SSMPs) and the stage they are at in their development is provided below.

- **Brighton Council (BC)**: The urban area of Brighton municipality was divided into four areas; Brighton, Gagebrook, Herdsmans Cove and Bridgewater. All modelling and management plans are being developed in-house. Each management plan identifies overland flow paths, risks and opportunities from overland flow management, as well as stormwater quality treatment opportunities. The SSMP is currently being drafted and is focused on prioritising capital works for key high-risk areas from each catchment area.
- **Clarence City Council (CCC)**: The urban area of the Clarence municipality was divided into eight areas. Consultants were engaged to prepare detailed catchment level SSMPs for seven areas. The remaining catchment modelling was undertaken in-house. Because of the CCC interpretation of the word 'urban', modelling of the majority of the municipality has been undertaken.

Each study includes detailed hydrological and hydraulic modelling (using either Two Dimensional Unsteady Flow (TUFLOW) or InfoWorks Integrated Catchment Modelling) to categorise flood risk under a number of different storm events, climate change and development scenarios. Flood mitigation options were then investigated for each catchment. Each plan also includes a summary of the key water quality issues in the catchment, and concept design of quality improvement options recommended. Most studies included catchment-level Model for Urban Stormwater Improvement Conceptualisation modelling.

An overarching report was prepared by council officers to collate the findings of these studies. CCC adopted the Stormwater System Management Plan 2019 in December 2019. Several key recommendations to come out of the CCC SSMP are as follows:

- » Review/update Stormwater Asset Management Plan.
- » Develop a flood-risk communication strategy and release flood information to community–currently underway.
- » Implement structural flood mitigation options in accordance with prioritised projects in SSMP, Asset Management Plan and Long Term Financial Plan.
- » Develop stormwater strategy for use when TPS comes into play – underway with working group.
- » Develop a Water Quality Improvement Plan in next update of SSMP document.

- **City of Hobart (CoH)**: The urban area of the Hobart municipality was broken into 11 catchments (from 35 sub-catchments). CoH has completed broad-scale flood modelling of all its urban catchments, using 1-m LiDAR data and a 2D 'rain on grid' methodology. This methodology identified high risk areas, which formed the basis for more detailed analysis. The focus of the SSMP at CoH has been to identify flood risk and prioritise areas for potential mitigation measures. Draft SSMPs are complete and are being used to inform capital works planning and development application assessments. The SSMPs will likely go to Council for endorsement at the end of 2020. Future iterations of the SSMPs will include water quality improvement plans.
- **Kingborough Council (KC)**: KC prepared a municipal wide SSMP including the urban areas of Taroona, Bonnet Hill, Kingston, Kingston Beach, Blackmans Bay, Huntingfield, Margate, Electrona, Snug, Conningham and Kettering. The study has been finalised and endorsed by Council. KC's SSMP consists of several investigations, these include:
  - » A high-level assessment of the current level of service provided by Council's stormwater network (quantity).
  - » A preliminary identification of areas exposed to elevated flood risk from overland flow.
  - » An identification of stormwater management opportunities available for Council to consider improving the current level of service provided to the community.
  - » Water quality was not considered as part of KC's SSMP.

Future iterations of the SSMP will improve the level of in-depth analysis of urban catchments and will consider aspects such as water quality.

- **Glenorchy City Council (GCC)**: The urban area of the Glenorchy municipality was divided into 20 catchments. All catchment modelling was completed in-house, apart from the CBD flood study which was completed by a consultant. Models were simulated using the XPSWMM model and are currently being transferred to TUFLOW for calibration and to determine flood risk and critical events. In 2019, the Central Business District flood-risk study was released to the community, including a mail-out to all high-risk properties with an FAQ letter. A similar process will be followed for other catchments.

2.7.3.6.2 Flood events and recovery response

Flood events have significant impact on the health of the Derwent estuary, as well as council and private infrastructure and possibly lives. In May 2018, flash flooding (> 100 mm in one day) resulted in significant impacts to waterways and councils. Several recovery efforts are summarised:

- **Clarence City Council**: The May 2018 flood event resulted in significant damage and flash flooding in the CCC municipality. The South Arm/Opossum Bay area was the most impacted. Since 2018, several projects have been funded as a result of this storm, with the aim of improving stormwater networks along two sections of Blessington Street, and a section of South Arm Road, South Arm. Under the 2020/21 budget Half Moon Bay and Spitfarm Road areas will receive stormwater upgrades. Other smaller projects have also been undertaken to reduce the flood risk during future large storm events.
- **Kingborough Council**: Following significant damage from the May 2018 floods, KC secured four grants from the Community Resilience and Recovery Grant from the State Government. These included a:
  - » Community Questionnaire
  - » Whitewater Creek Flood Study
  - » Kingston CBD Catchment Resilience Program
  - » Blackmans Bay Catchment Resilience Program

All studies, except the community questionnaire, have been finalised and more detail is available on KC's website (https://www.kingborough.tas.gov.au/services/beach-watch/). The result of all studies will be used to inform future capital works projects and investigations to further improve the level of service Council's stormwater system is providing the community and to reduce the urban flood risk in hotspot areas.

2.7.3.7 DEP role and coordination

The DEP has continued to play an important role in coordinating stormwater initiatives within the region, as well as providing capacity building opportunities. Key activities included:

- Continuation of the Stormwater Taskforce (SWTF). The SWTF is a collaborative working group consisting of specialists from local councils, State Government and TasWater, and meets quarterly to share management ideas and experiences and review management priorities. During the reporting period the focus has included the following: contributing to the development of a draft stormwater code (for submission to Tasmanian Planning Commission (TPC) hearing, see **Section 2.7.2.2**), addressing the gap in the Tasmanian Planning Scheme and subsequently forming a targeted working group to address this issue, SSMPs, and impact of climate change on management of stormwater assets.
- Formation of collaborative working group to address the gap in the TPS, left by the omission of a stormwater code. See **Section 2.7.2.2** for more information.
- Facilitation of specialist training courses that address key management issues. In February 2019, the DEP engaged Syrinx consulting to deliver a tailored training course to local councils that addressed the need (as expressed by local councils) to improve the efficiency and lifecycle of WSUD assets by improving communication between stakeholders at crucial stages of design, construction and maintenance. Future erosion and sediment training is planned and discussed in **Section 2.7.3.2**.
- Development and publication of guidance materials. In 2020, the DEP published the *Faecal Source Tracking (FST) Framework and Toolkit* (2020). At the conclusion of the 2018-2019 RWQ season, councils expressed the need for guidance in conducting source tracking investigations and selecting appropriate source tracking tools. In response, the DEP published the FST toolkit, which provides a framework for conducting investigations, and a review of relevant source tracking tools available to practitioners in Tasmania. Further detail is provided in **Section 2.6.4.2**.
- Provided and facilitated networking opportunities, as well as technical advice where required.

2.7.4 Future projects

- Review previous DEP stormwater monitoring programs and scope future monitoring to characterise pollutants entering the Derwent estuary via urban rivulets, and compare pollutant concentrations to previous monitoring results.
- Develop a set of WSUD resources to support development proponents meet design requirements.
- Proposed litter management projects include:
  - Conservation Volunteers Australia launched the #SeaToSource initiative (2020) to tackle ocean litter, by reducing the amount of plastic litter entering creeks, rivers and oceans. The three-year initiative will focus on eight waterways around Australia, and the Derwent estuary is included as a focus site. The initiative is in its early stages, and activities are yet to be determined.
  - The Marine Debris Research at CSIRO will work with Derwent estuary councils to monitor plastic waste in urban waterways. The project will involve the use of time-lapse cameras and machine learning to identify plastic items in the 'water stream'.
  - Several WSUD, GPT and rivulet projects have already been included in council budgets and several are referenced in **Table 2.3**.
  - Councils will include WSUD and GPT projects in their SSMPs, which should help leverage future funding of assets.

3

Habitats and associated biota

3 Habitats and associated biota

3.1 Aquatic habitats

3.1.1 Extinct shellfish reefs and silty sand

The vast majority of the Derwent estuary benthos is poorly productive silty sand habitat that supports a comparably depauperate ecosystem, but it was not always like this. Three-dimensional shellfish reefs used to dominate these habitats, filtering millions of litres of water every day, providing structure for fish to shelter in and food for them to graze upon, reducing erosion and contributing to the clear waters that the Derwent was renowned for when Europeans first arrived. These shellfish reefs occurred throughout temperate Australia, from Western Australia to Tasmania and southern New South Wales. Early colonists quickly dredged these shellfish reefs to functional extinction throughout their entire Australian range, using them for food and burning them to produce lime (Beck *et al*., 2011). The only known remaining functional shellfish reef habitat in Australia is in St Georges Bay, Tasmania. However, efforts are underway to rebuild these lost habitats, including projects in Western Australia, South Australia, Victoria and New South Wales. Project details are available from The Nature Conservancy. Re-establishment of millions of filter-feeding shellfish offers striking potential for improved water quality and productivity of the Derwent estuary. The DEP is part of a close network of collaborators who are working toward re-establishing oyster reefs in the Derwent.

3.1.2 Microbes: CSIRO Hobart Environmental Genomics

Hobart is fortunate to have a wealth of oceanic and estuarine specialists from both CSIRO and IMAS. Specialists are working on cutting-edge science to improve environmental monitoring and management. The following content was provided by the CSIRO Hobart Environmental Genomics team discussing some of its recent work.

"Environmental DNA (eDNA) is DNA purified from environmental samples, such as sediment and seawater. Marker genes from this DNA can be sequenced to identify organisms across the breadth of the tree of life–from microbes to fish. It is a non-invasive, standardisable sampling approach, which is revolutionising biodiversity science. Researchers, industry and governments are increasingly incorporating eDNA surveys into their toolkits for biomonitoring because it is highly accurate, captures all organisms, and is easy to deploy. Biomonitoring with eDNA can provide information about; whole biome biodiversity, rare and cryptic species, native/threatened and endangered species and conservation, invasive species and incursions, biosecurity, and the assessment of ecosystem state as a whole.

"Beginning mid-2018, the Environmental Genomics team at CSIRO in Hobart, in collaboration with the DEP, has been collecting sediment and water samples from sites in the lower, middle and upper estuary to demonstrate the utility of eDNA in monitoring. Research has been largely from the following avenues:

- The CSIRO Environomics FSP has undertaken temporal sampling of Derwent estuary sediments under its National Baseline Microbial Sampling Programme (https://research.csiro.au/environomics/our-research-projects/team-projects/microbes-healthy-waterways/).
- The Australian Microbiome (AM; https://www.australianmicrobiome.com/) is a continental-scale, collaborative project aspiring to develop a comprehensive, publicly accessible database of microbial diversity across Australian terrestrial and aquatic ecosystems. With the AM, CSIRO and DEP have generated microbial-diversity data from eDNA at the DEP's Ambient Water Quality (AWQ) Monitoring Program sites. Here, we describe some preliminary examples utilising eDNA data collections from the Derwent estuary.

"Sample processing and data-analysis workflows can be found at: https://www.australianmicrobiome.com/protocols/

"Although less conspicuous than marine animals and plants, marine microbes comprise the majority of global biomass, are responsible for ~50% of global primary production, drive earth's major biogeochemical cycles (e.g., C, N, P, S, Fe) that ultimately control climate, and can play direct and indirect roles in the health of all organisms. Less than 1% of microbes can be grown from the environment. As eDNA does not require growing the organisms under investigation, it has been utilised for microbial biodiversity studies for ~30 years to overcome this problem. To contribute to a greater understanding of the Derwent ecosystem we have been building a baseline dataset of microbial diversity throughout the estuary. Estuarine environments are dynamic and demonstrate a high level of spatial and temporal variation, which is reflected in the spatial and temporal variation detected in the distributions of microbial "species". However, if we zoom out to a lower level of taxonomic resolution (e.g., Phylum) we can discern broad-scale trends. Microbial communities in the water column are different to those in the sediments, and the sediments harbour more diverse communities than the water column (**Figure 3.1**). At higher taxonomic resolution, the composition of microbial communities has been shown to be a sensitive indicator of ecosystem stress discernible from natural environmental variation inherent to complex estuarine systems across Australia (Sun *et al*., 2012; Jeffries *et al*., 2016; Kaestli *et al*., 2017). Our baseline dataset

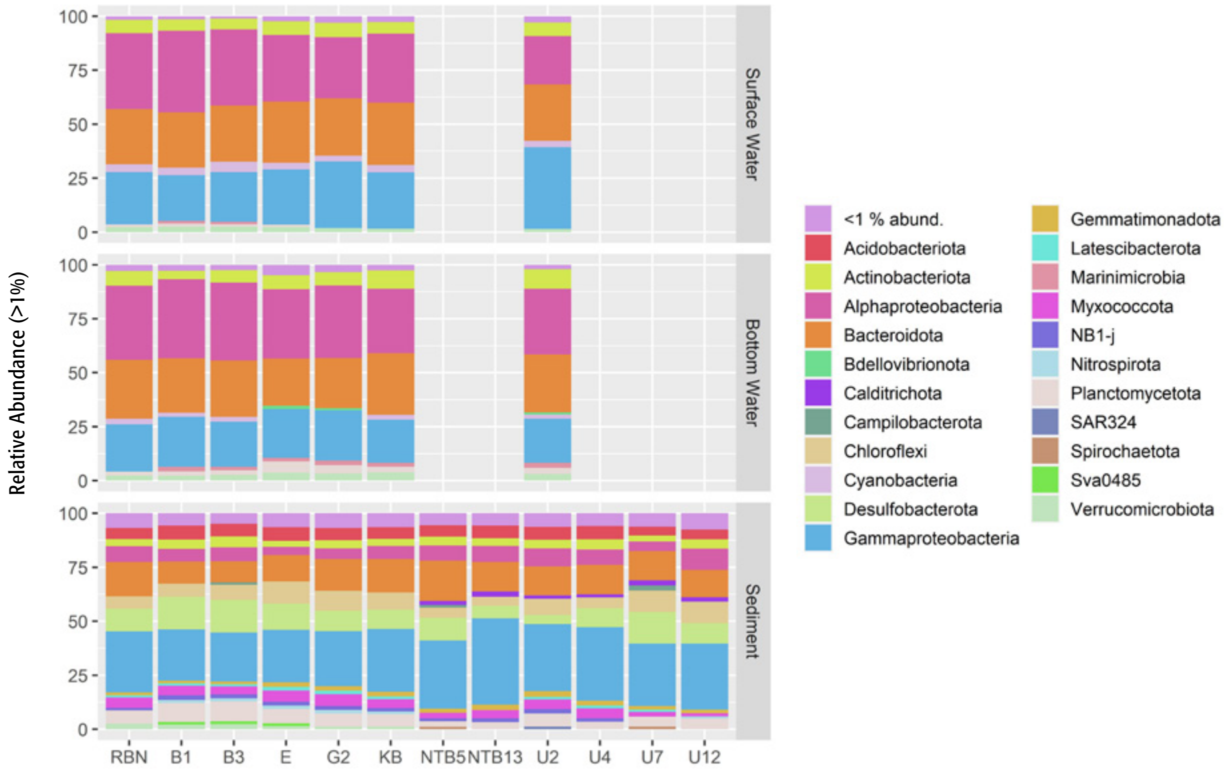


Figure 3.1 Derwent estuary microbes – Relative abundance of Bacterial Phyla in the water column and surface sediments along the salinity gradient in the lower, mid and upper Derwent estuary. At the Phylum level, the Bacteria we see in the water column and sediments are typical of temperate estuarine sites. The water column is dominated by Alpha- and Gammaproteobacteria, Bacteroidota and, in lower abundances, Actinobacteriota. Whereas the sediments are dominated by Gammaproteobacteria and, to a lesser extent, Bacteroidota, Chloroflexi, Desulfobacterota. There are smaller-scale trends visible along the estuary, for example, Calditrichota are present in the upper estuary, but not the lower reaches of the Derwent. DNA was isolated from sediment and water samples collected about monthly from May 2018 to February 2020. Data displayed was derived from 'metabarcoding' of the bacterial 16S (v1-3) marker gene. Note that there is no eDNA data for the water column in the upper estuary beyond Site U2

of microbial diversity data will be utilised to discern microbial community patterns in an impacted system subject to heavy-metal loads, high nutrient concentrations and a variety of pollutants."

3.1.2.1 Dinoflagellates: CSIRO Hobart Environmental Genomics

The economic impact of harmful algal blooms (HABs) on Australia's aquaculture and tourism industries can be extensive. The toxic dinoflagellate *Gymnodinium catenatum* was discovered in the Derwent estuary in the mid-1980s (Hallegraeff and Sumner, 1986; Hallegraeff *et al*., 1987). It can be distributed throughout the water column during blooms or in the sediments as resting-stage cysts. Toxic dinoflagellates are one of several marine pests considered to have the greatest ecological impact on the Derwent estuary, though there are no routine algal monitoring or species identifications being undertaken (DEP, 2008). We used metabarcoding of a marker gene for small eukaryotes to investigate the distribution and relative abundance of dinoflagellates in water samples collected as part of the DEP Ambient Water Quality Monitoring Program in 2019.

Our data demonstrated increased relative abundance of *G. catenatum* at mid-estuary sites in autumn and early winter; particularly during May and June where its relative abundance is 40–60% of the total community at Sites G2 and KB (**Figure 3.2**). In October, we detected an increase in relative abundance of another dinoflagellate genus, *Noctiluca* (commonly known as sea sparkle), in the lower estuary. Eradication of *G. catenatum* is not possible, and options for control are limited to preventing the further spread of the species and minimising activities that might promote bloom formation (DEP, 2008). By increasing the temporal and spatial resolution of these observations through the continued collection of this data, we have the potential to enhance our understanding of algal bloom dynamics, through coupling eDNA observations of dinoflagellates with physical observations of blooms and the physicochemical observations collected through the DEP AWQ Monitoring Program.

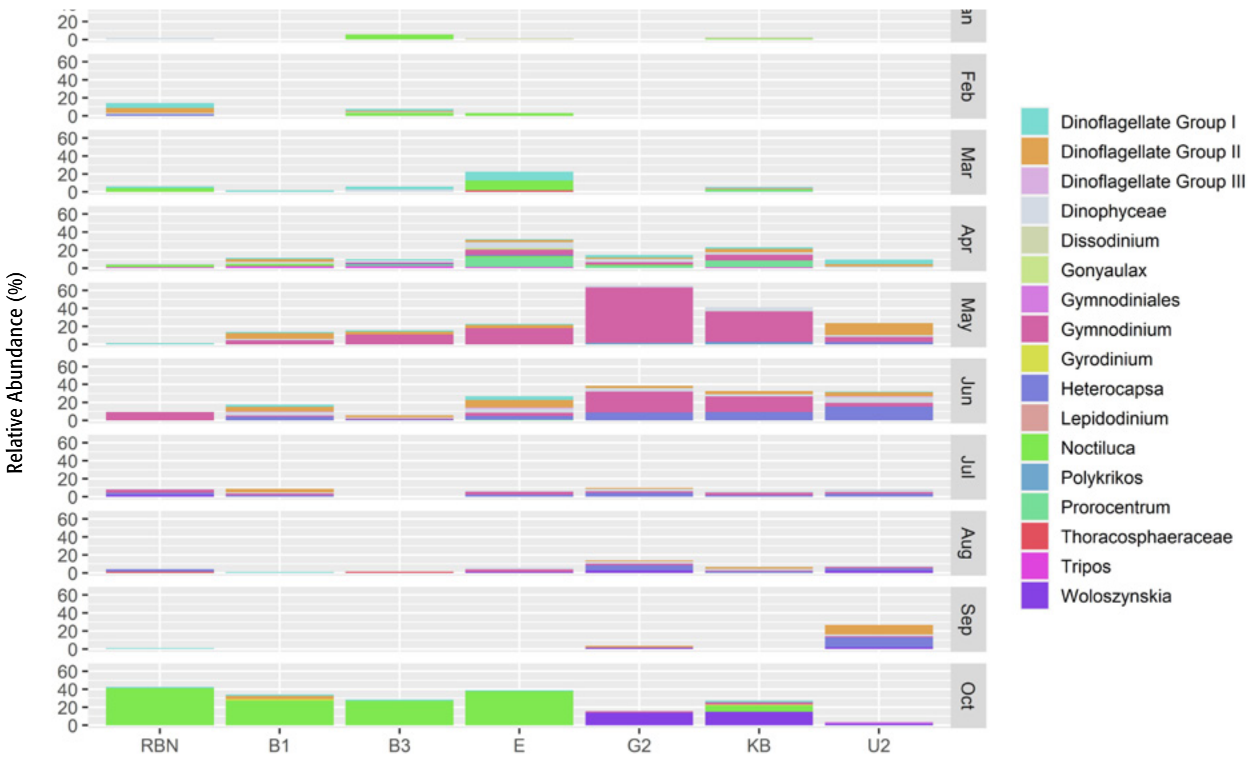


Figure 3.2 Derwent estuary dinoflagellates – Relative abundance of Dinoflagellates in surface waters at DEP Ambient Water Quality Monitoring sites. eDNA was isolated from water samples collected monthly between January and October 2019. Data displayed was derived from metabarcoding of the eukaryotic 18S (v4) marker gene.

3.1.3 Macrophytes

The brackish-water macrophytes of the upper Derwent estuary cover an area of over 600 hectares (**Figure 3.3**). They are the major benthic primary producers in the area, and they sustain an ecosystem with a considerably higher diversity and abundance of animals than in non-vegetated habitats. They support recreationally targeted fish and large numbers of black swans and, thus, underpin the values that resulted in declaration of the Upper Derwent Conservation Area. They partially oxygenate the water column and sediment (Cambridge *et al*., 2012; Blandon and zu Ermgassen, 2014), filter nutrients and suspend sediment from the water and help bury the worst of the metal contamination beneath cleaner sediment (Wild-Allen, Skerratt, Parslow, *et al*., 2009; Wild-Allen, Skerratt, Rizwi, *et al*., 2009; Wild-Allen *et al*., 2011).

Macrophyte-meadow condition in lowland riverine environments, such as the upper Derwent wetlands, can exhibit marked interannual variability, principally influenced by river discharge and nutrient loads (Franklin *et al*., 2008). River discharge influences water residence time, dilution of contaminants from local point sources and delivers nutrients and organic matter and can alter ecological condition. Long water-residence times due to low river discharge, coupled with supply of highly biologically available (labile) nutrients, can cause algal blooms. Algal blooms reduce the light available for underlying macrophyte growth, reproduction and energy storage and are a key factor in the global decline of submerged aquatic macrophyte meadows (Boynton *et al*., 1982; Kemp *et al*., 2005; Orth *et al*., 2006). A shift toward algal-dominated habitats reduces energy transfer up to higher-order organisms, such as fish, and instead supports systems dominated by algae and bacteria. Local sources of labile nutrients are agricultural fertiliser, aquaculture hatcheries, the Norske Skog paper mill at Boyer and WWTPs at New Norfolk and Bridgewater.

Lawler (2009) and Mount (2011) found the upper Derwent macrophytes were in good condition with less than 10% of macrophytes were covered by algae, but in summers 2014-2015, dense algal smothering was observed. In summer 2015-2016, the DEP commenced targeted sampling of the upper Derwent meadows using a drop camera and 'point count technology' to determine the percentage of the meadows that were classed as algae, bare substrate or macrophyte (**Figure 3.4**). This program has observed high variability in macrophyte habitat condition (**Figure 3.5**). In summer 2015-2016 and 2016-2017, ~61% of sampling points were recorded as densely smothering macroalgae, such as *Cladophora vagabunda, Chaetomorpha billardierii and Ulva intestinalis*. All these species are known opportunistic, bloom-forming, nutrient responders (Teichberg *et al*., 2010; Martínez *et al*., 2012; Han and Liu, 2014). Following algal smothering, former macrophyte habitat had partially transitioned to unvegetated silt before a successional recovery was recorded.

The changes in macrophyte condition provide an opportunity to identify the drivers of condition, and to develop hypotheses for subsequent experimental and statistical analysis. The limited temporal range and highly variable data limits our capacity for robust statistical analysis at this point. However, it seems macroalgal smothering is correlated with river discharge and nutrient load, and this is supported by the relevant literature from other sites (Franklin *et al*., 2008). The seasonal mean of the daily average discharge for the River Derwent, measured below Meadowbank Dam, was ~22% higher in the summer seasons 2017-2018 and 2018-2019 compared to when algal blooms and bare substrate dominated the macrophyte regions in 2015-2016 and 2016-2017 (**Figure 2.21**). Nutrient loads from Norske Skog Boyer and the TasWater WWTPs were not markedly lower over the same intervals (**Figure 3.6**, **Figure 3.7**). Algal cover increased slightly in summer 2019-2020, corresponding with increased nutrient loads, but also markedly higher river discharge. These findings align with a hypothesis that nutrient loads and river discharge are integrated drivers of macrophyte habitat condition. The DEP will continue working toward sufficient data for robust statistical analysis of the drivers of habitat condition, focusing on river discharge, nutrient loads and ambient water quality indicators (turbidity, true colour and ambient nutrient concentrations) relating to observed algal-cover change.

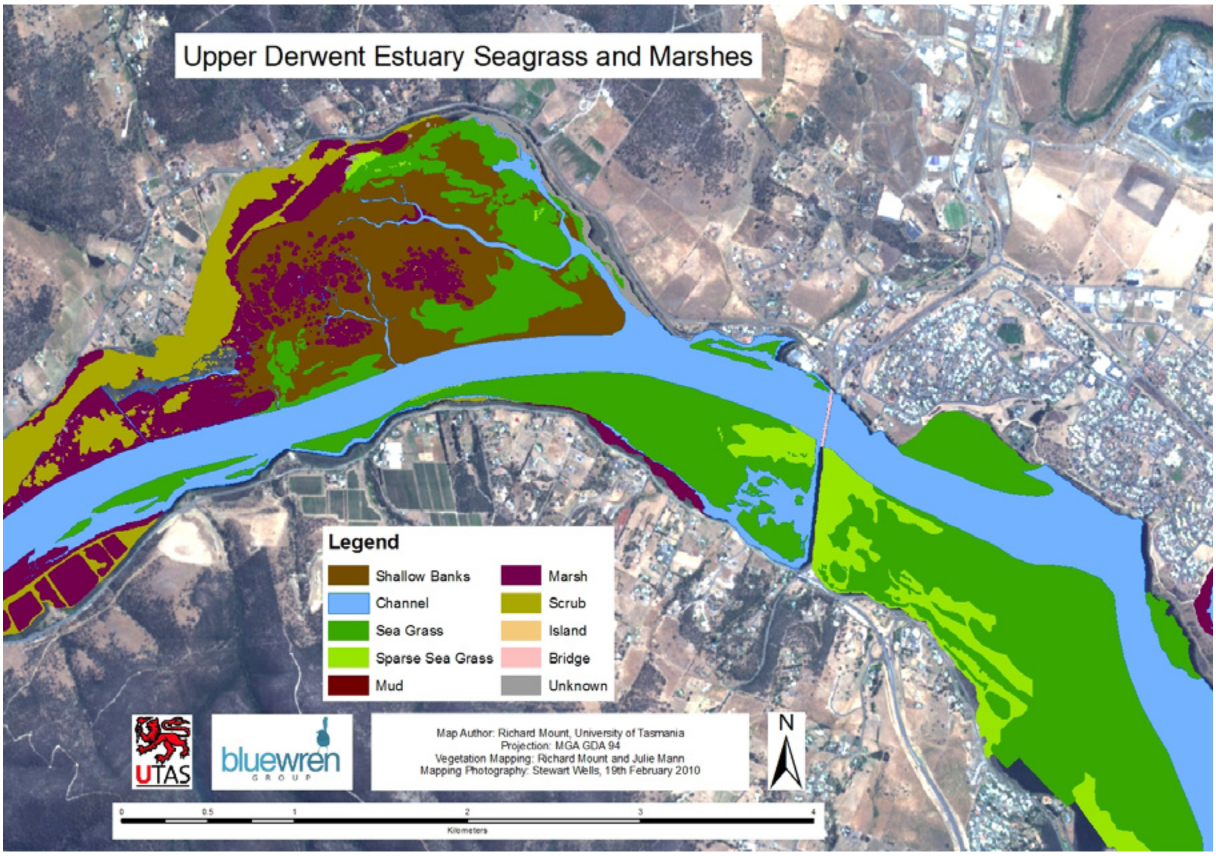
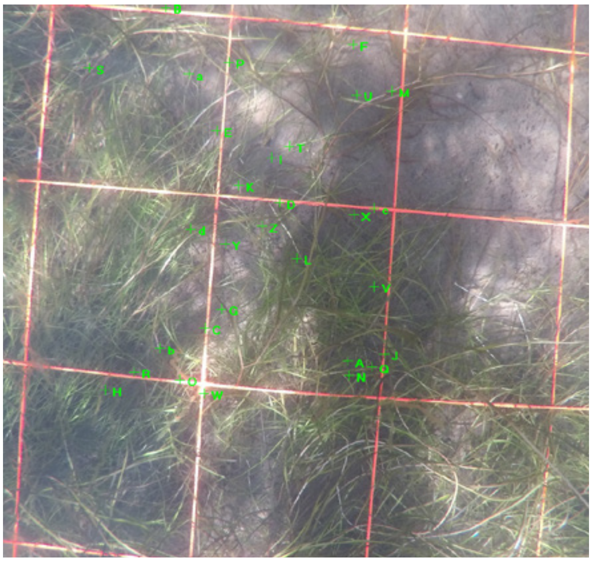
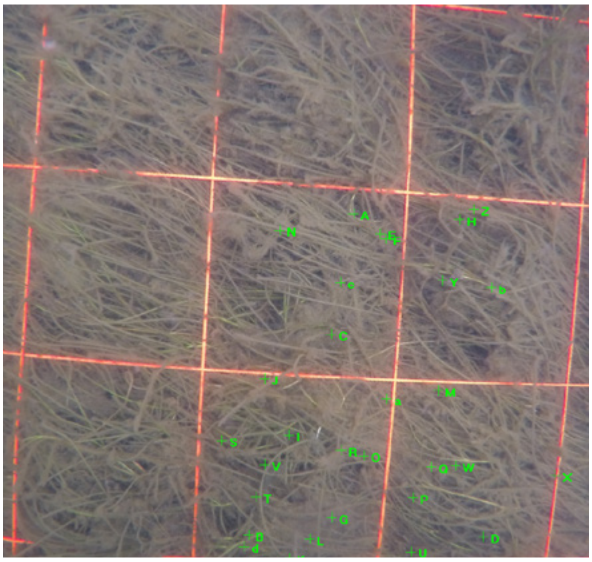


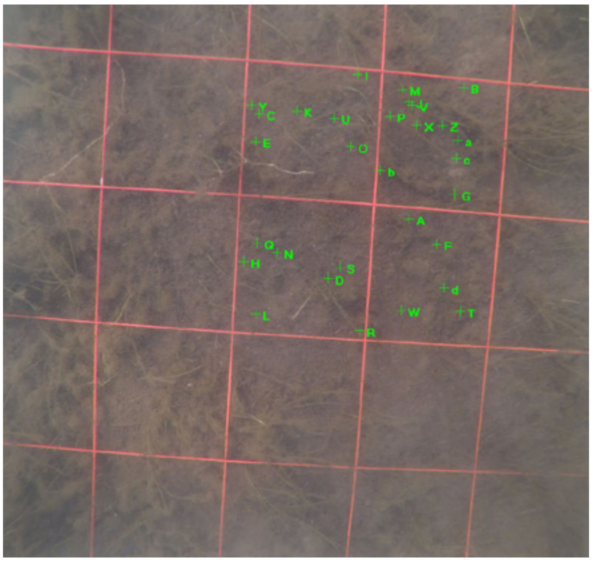
Figure 3.3 Aquatic plant and wetland communities in the upper Derwent estuary. Source: BlueWren group pty. ltd.



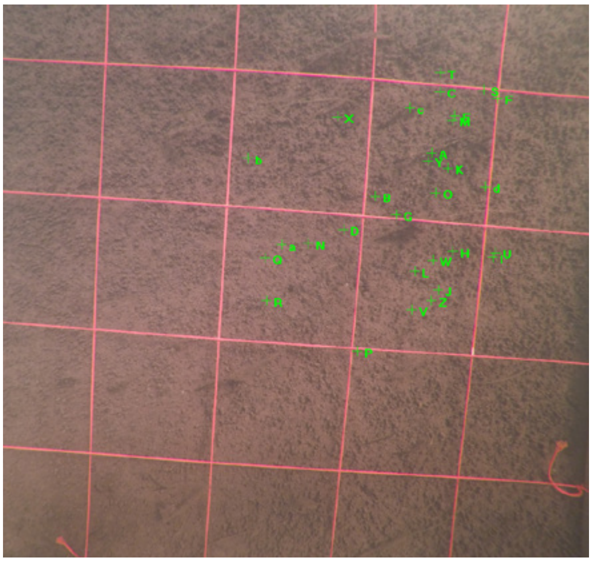
A) MF 10 event 1, recorded as 67% plant, 33% bare substrate



B) MF 10 event 2, recorded as 100% algae given the ubiquitous epiphytes



C) MF 10 event 3, recorded as 46.7% algae and 53.3% bare substrate



D) MF 10 event 4, recorded as 100% bare substrate

Figure 3.4 Examples of captured images with random point overlay (Beijbom, 2020) and the recorded result for one site (MF10) through four sampling events

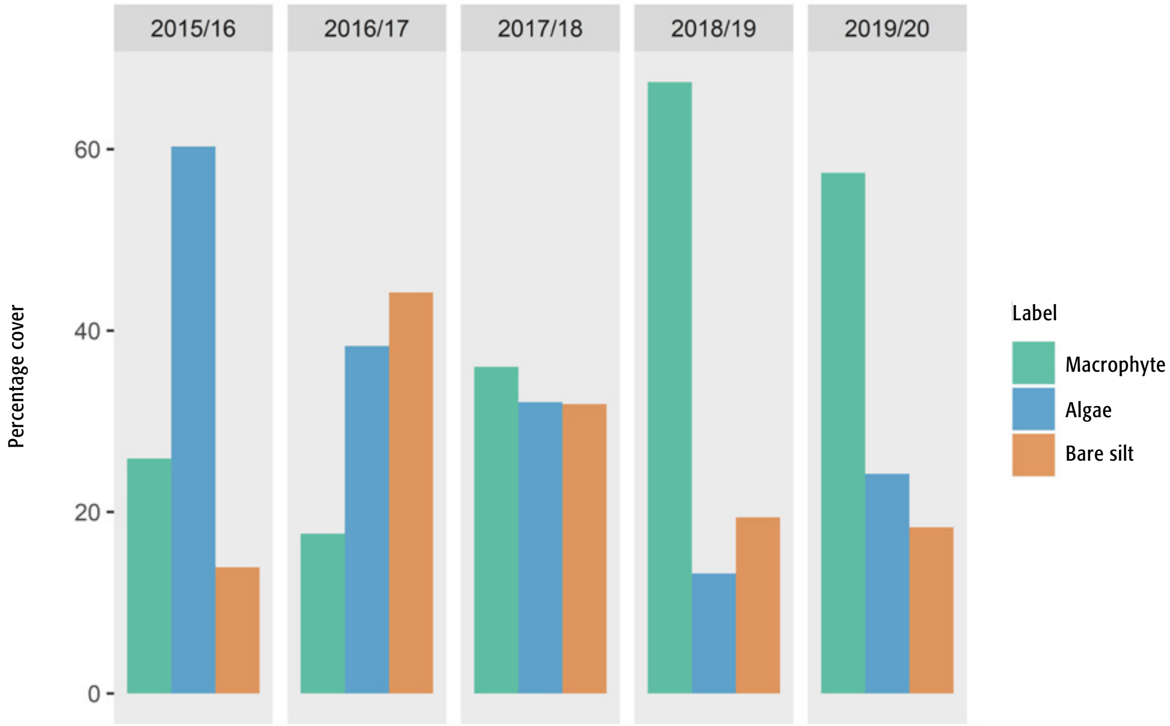


Figure 3.5 Relative proportion of macrophyte, algae and bare silt within the known upper Derwent macrophyte meadow range

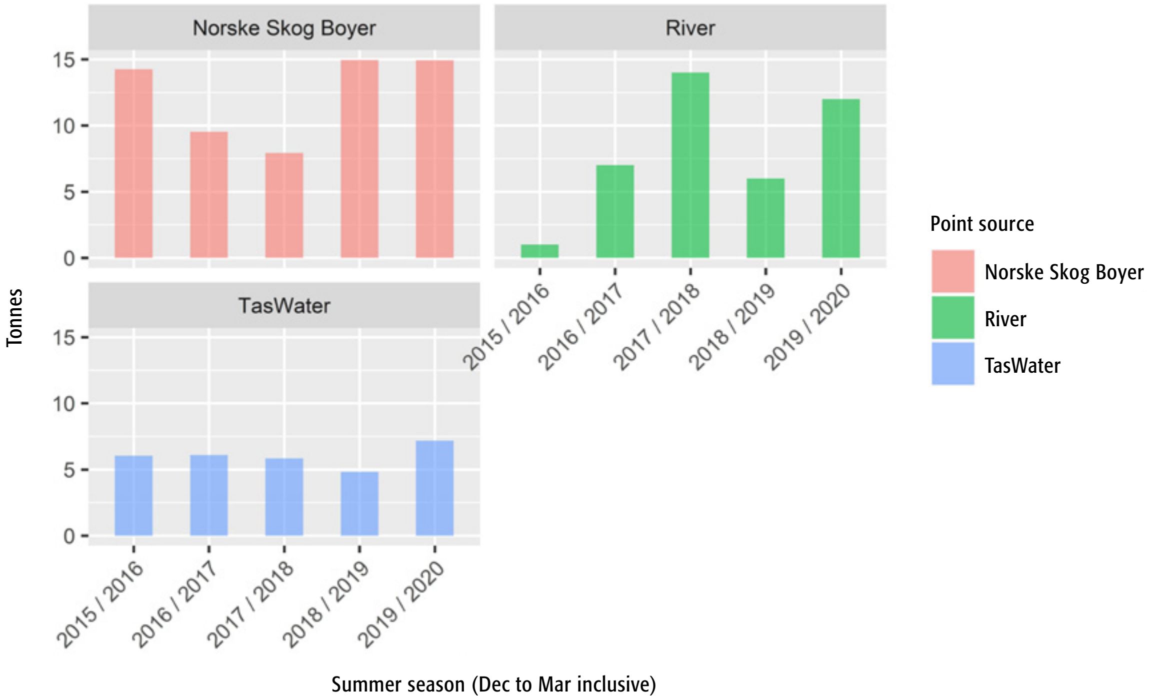


Figure 3.6 Dissolved inorganic nitrogen load from upper-estuary point sources (with riverine contribution represented by surface water samples from site NN, upstream of New Norfolk township)

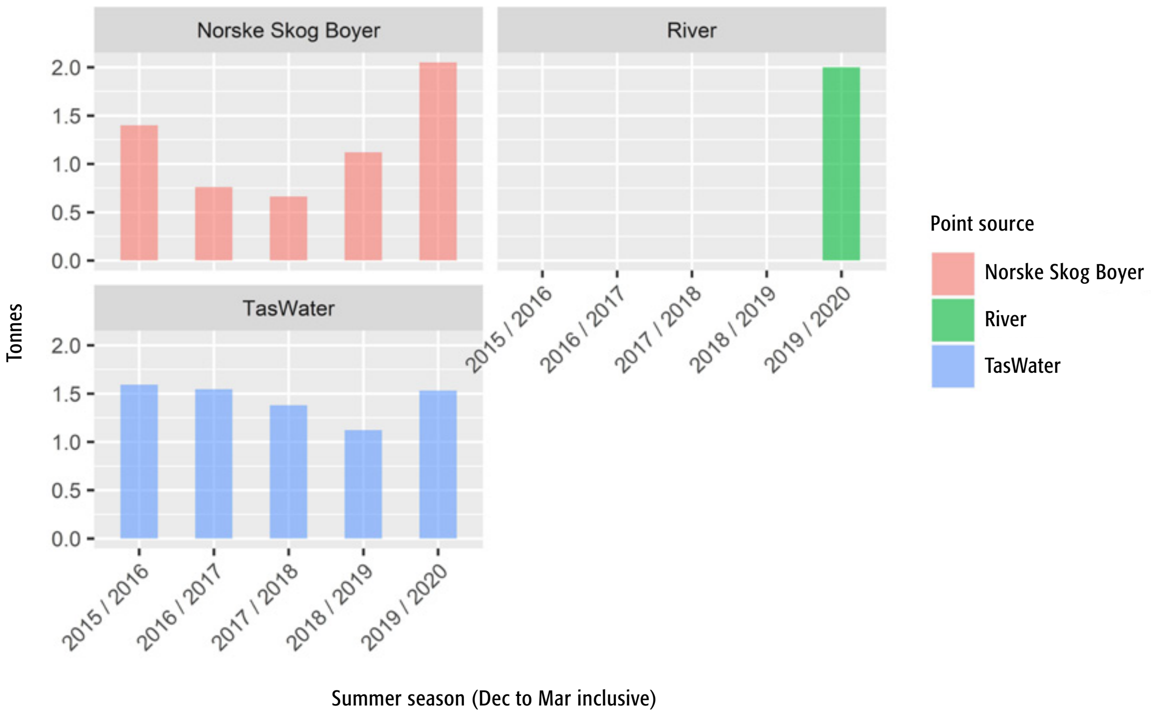


Figure 3.7 Phosphate load from upper-estuary point sources, with riverine contribution determined from surface water samples from site NN, upstream of New Norfolk township, multiplied by river discharge

3.1.4 Rocky reefs

The mid-estuary from below the mouth of the Jordan River to Macquarie Point is generally dominated by seagrasses in sheltered embayments while fringing rocky reefs are species depauperate, dominated by turfing algae, tufts of opportunistic algae such as *Ulva* spp. or encrusting worms. As the estuary opens out below Macquarie Point and Bellerive, rocky reefs are increasingly dominated by macroalgae, including isolated patches of string kelp. The more established macroalgal habitats, such as that around Tinderbox marine reserve and Opossum Bay, are diverse functional ecosystems that support an abundance of invertebrates and vertebrates (Barrett *et al*., 2010; Stuart-Smith *et al*., 2015). The DEP commissioned specialists from the University of Tasmania to conduct targeted assessments of six sites throughout the lower estuary to assess their nutrient enrichment status (White *et al*., 2020). Reefs of the lower Derwent were found to have between 45 and 60% macroalgal canopy cover, typically predominantly *Ecklonia radiata*, although *Macrocystis pyrifera* was also present at Lucas Point and Blackmans Bay. Epiphytic algae occurred at every site except Lucas Point, averaging nearly 20% cover at Bellerive Bluff and Tranmere Point. This was the only enrichment indicator regularly recorded across the survey area.

In 2017, Fiona Scott identified a new species of algae at Blackman's Bay that was not formerly known to science, *Entwisleia bella* Scott, Saunders and Kraft. This species has restricted geographical and depth distribution.

Figure 3.8 The Derwent River seastar (*Patiriella littoralis*) specimen that was scanned to confirm its species status (Hipsley, 2018)

3.1.5 The sad Derwent River seastar riddle

"It was prickly, slimy, and had no backbone or eyes. It used its five spiny arms to cling to the sides of a muddy river bank, where it hunted by pushing its stomach out of its mouth, engulfing its prey, and dragging the liquefied remains back inside" (Hipsley, 2018).

This is a slightly gruesome description of the Derwent River seastar, which after extensive surveying over several decades, in 2009 was federally declared Critically Endangered, and in Tasmania noted as possibly extinct. This did not stop a long-running debate of whether the Derwent River seastar was in fact its own species. To settle the question once and for all, Tasmanian scientists in 2018 joined a team at Museums Victoria that used non-invasive X-ray computed tomography (similar to CAT-scan) to study the holotype specimen (the very one that designated the species) and confirmed that yes, it is indeed a unique species (**Figure 3.8**). The species confirmation was based on the discovery of internal ossicles (ear bones) that strengthened the disc margin. This detail could not be seen without dissecting the specimen, which was too precious, but the scan picked it up. The findings moved the species into another genus than originally thought. The correct name is now *Patiriella littoralis*, and not as previously named *Marginaster littoralis* (O'Hara *et al*., 2019).

This echinoderm was first collected on the shore near the Tasman Bridge in Hobart in 1969–and only found four more times in the Derwent–all in the mid-estuary. There does continue to be some conjecture as to whether this species is indeed an endemic or an introduced species (pers. comm. N. Barrett, IMAS Aug. 2020). While we can be pleased that this animal found in the Derwent has been confirmed as a unique species, it is still sadly assumed to be extinct, with the dubious distinction of possibly being Australia's first recorded extinct marine animal. But while the Derwent River seastar is not officially declared extinct (a species is not officially declared extinct until 50 years after the last confirmed sighting)–we still need to be on the look-out for it–and just imagine if we found it again!

3.1.6 Introduced marine species

Introduced marine and intertidal species are a particularly insidious form of ecological pollution in that, once established, they can be extremely difficult or impossible to eradicate. The establishment of marine pests can have severe consequences on the marine environment, commercial and recreational fishing, aquaculture and public health. These species most often arrive in Tasmanian waters via ballast water, biofouling, deliberate introductions or aquaculture.

The maintenance visit of the Ocean Monarch drill rig in 2018-2019 and its associated support vessels had the potential to introduce an invasive marine pest into the Derwent. Between November 2018 and February 2019, the rig was anchored in the mouth of Ralph's Bay, and there was concern that the highly invasive fouling species, the white sea squirt (*Didemnum perlucidum*) was a passenger. This species was first recorded in Western Australia in 2010, and is now fully established in that state and in the Northern Territory (MPSC, 2019). This pest species has a strong association with harbours, marinas and ports in Australia and worldwide, suggesting that it has been carried from location to location via shipping (Dias *et al*., 2016). Prior to its visit to the Derwent estuary, the Ocean Monarch had been to Western Australia and Bass Strait. The rig was eventually surveyed for marine pests and there was no evidence of the white sea squirt. The new *Tasmanian Biodiversity Act 2019* will support the State Government's efforts to prevent marine pest introduction.

The previous State of the Derwent 2015 listed 79 introduced and cryptogenic (possibly introduced) marine species in the Derwent estuary (DEP, 2015), and a previous DEP paper discusses introduced species distribution, issues, actions and management options (DEP, 2008). Additional species and updates that have been recorded since 2014 include:

- The clubbed tunicate (*Styela clava*) was detected in Hobart Port (2017) and Sandy Bay (2018). It is a subtidal, epibenthic ascidian that attaches to solid structures and is thought to have an impact on aquaculture. It is deemed impossible to control on a large scale, but if caught early, controls could be put in place for aquaculture infrastructure and commercial vessels to minimise movement. Recorded in Victoria, New South Wales and Western Australia, and there is no known control methods to prevent it spreading to Tasmania or South Australia (MPSC, 2019).
- The bay barnacle (*Amphibalanus improvises*) was observed on two ship hulls in Prince of Wales Bay (2014) and in Hobart Port (2017) with no confirmed specimens detected on fixed substrates/structures. This species can tolerate a wide range of salinities and is globally a common ship-fouling organism that has been reported in Western Australia and thought to be in Australian waters more widely. There is no strong evidence of its impact (MPSC, 2019).
- The sea squirt (*Ciona savignyi*) was detected in Hobart Port (2017). It is a solitary, benthic, suspension-feeding ascidian that has wide temperature and salinity tolerance and grows on submerged substrates, where it can quickly form dense aggregations which can smother and eventually exclude other fouling species. It grows well in polluted waters (CABI, 2020). It was first seen in the Southern Hemisphere in New Zealand in 2010 (Smith *et al*., 2010).
- The American spider crab (*Pyromaia tuberculate*) was picked up in benthic sampling in Storm Bay, below the Derwent estuary. This is a sub-tidal species that lives in reef habitat types that has been found in New South Wales, Western Australia and South Australia, and could become established in Tasmania and Queensland given its environmental tolerances. The impacts are as yet unknown (MPSC, 2019).

Through recent genotyping, the toxic dinoflagellate complex *Alexandrium tamarense* has been split into different genetic groups, with group. 4 (*A. pacificum*), group. 5 (*A. australiense*) and group. 1 (*A. catenella*) expected to be present in the Derwent estuary.

New species data were provided by A. Coutts, Biofouling Solutions; J. Valentine, Aquenal; K. Ellard, DPIPWE; and G. Hallegraeff, UTAS, August 2020.

A new national Marine Pest Plan 2018–2023 has been developed to provide direction for effective management of marine pest biosecurity threats, through improved marine pest prevention, strengthened surveillance, enhanced emergency response capability, support for research and development, and greater stakeholder engagement (MPSC, 2018).

The algae didymo–also known as 'rock snot' (*Didymosphenia geminata*)–is another example of a highly invasive species that is not yet in Tasmanian waters, but has the potential to devastate our water habitats by smothering rocks and plants and growing large blooms that would impact the wider food web. It has been present in New Zealand since 2004 (DPIPWE, 2020d). All commercial and recreational boat owners and land-based fishers need to partake in the effort to prevent establishment and movement of Didymo and other invasive marine pests by:

- Checking, cleaning and drying all boating, trailer, fishing and diving gear before coming into the estuary and after each trip to the estuary, is the key. Biosecurity field hygiene kits are available from NRM South https://www.nrmsouth.org.au/biosecurity/fishclean/.

- Getting to know marine pests, and knowing if they are outside their known distribution area https://dpipwe.tas.gov.au/conservation/the-marine-environment/marine-pests-and-diseases/pest-identification.
- Report any new sightings of marine pests (or suspect species) to DPIPWE on 1300 368 550.

3.1.6.1 Pacific oysters and POMS

The Pacific oyster, *Magallana gigas* (also known as *Crassostrea gigas*) was introduced into Tasmania from Japan in the 1940s to establish an oyster aquaculture industry. As a result, the Pacific oyster spread widely and is now abundant in the Derwent estuary, inhabiting a wide range of substrates in the intertidal and shallow subtidal zone. Despite their economic value, the Pacific oyster is an introduced pest species in the Derwent estuary and there are concerns related to the loss of coastal aesthetic and amenity (cuts etc.), damage to property, competition for habitat, and carrying a parasitic copepod that can be transferred to other bivalves.

Pacific Oyster Mortality Syndrome (POMS) was first detected in south-eastern Tasmania in January 2016. The outbreak of this disease, caused by the virus OsHV-1, resulted in mass mortalities of cultured Pacific oysters on farms in major oyster growing areas, including Pittwater, Blackman's Bay, Little Swanport and Pipeclay Lagoon. Biosecurity Tasmania assessed potential pathways and timing of introduction of POMS and identified that the OsHV-1 virus was present in the Derwent estuary and Hobart ports prior to the outbreak in local farms. This was achieved by testing environmental DNA, extracted from Hobart plankton samples prior to the outbreak, for traces of the virus. A Control Area has been declared for the whole of Tasmania under the *Animal Health Act 1995*. This enables a risk-based movement permit system to limit the movement of oysters.

- Much has happened since the initial Tasmanian POMS outbreak and there is now a positive outlook for the future of the local industry after a significant recovery (pers. comm. M. Conningham ASI Sept 2020). Local projects have contributed to the status and knowledge of the virus:
- In 2016, an IMAS Honours student studied how spatial data may be used to improve coastal management, focussing on the risk posed by POMS to Pacific oysters in the Derwent estuary (Trung, 2016). He found that a POMS risk model could be useful in assessing POMS risk; that it would help to make use of Landsat 8 satellite imagery (sea-surface temperature) if a relationship was found between water temperature and POMS mortality, and if Derwent sampling coincided with the date of satellite image capture.
- In 2017, thanks to an NRM South Culturally Inspired Grant, pakana services participants received training from the D'Entrecasteaux and Huon Collaboration and the DEP in surveying wild Pacific oysters. pakana services is a not-for-profit social enterprise committed to providing Indigenous Tasmanians with the opportunity to develop working skills through natural resource management, agriculture and other industry sectors. The participants monitored sites in the Channel and in the Huon and one site in the Derwent estuary (Kangaroo Point) to look at oyster density, abundance and general health. This training and work extended the skills of participants in land management and provided an opportunity to share knowledge.

Australian Government Cooperative Research Centre Project (CRC-P) Future Oysters program funded projects:

- The Australian Seafood Industry focused its research project "Enhancing Pacific oyster breeding to optimise national benefits" on breeding POMS-resistant broodstock (Cunningham, 2019). Results included a selective breeding program that improved genetic resistance to POMS with results available to all Pacific-oyster-growing regions, and for the oyster industry to recover to full stocking and employment levels within three years of the outbreak; and the development of a bio-secure breeding facility at the IMAS aquaculture facility to ensure the resistance breeding continues in Tasmania.
- Findings from the IMAS research project "Advanced understanding of POMS to guide farm management decisions in Tasmania" (Crawford and Ugalde, 2019) included supporting previous studies, that warm water temperature is a major driver of POMS, with risk period for outbreaks ranging from mid-November to late March; that density of oysters in culture containers has limited effect on mortality rates; smaller oysters are more susceptible to infection; and that mortalities from POMS have rapidly declined from an average of 67% of stock in 2016 to 9% in 2018-2019. Changes to farming practices, developed through this project, include more careful handling of oysters during summer, selling a higher percentage of stock before the risk period, and purchasing spat when temperatures are declining.

3.1.7 Future projects

- Continue summer (and winter) sampling of seagrass and macroalgae to increase our understanding of species diversity and growth dynamics.
- Continue algal functional community assessment and stable isotope analysis to detect response to changing nutrient concentrations.
- More rigorous assessment of invasive species distribution and standardised monitoring to detect new invasive marine pest incursions.

- Integrate eDNA biomonitoring into current regular monitoring programs to build a comprehensive time-series dataset which will increase our ability to track change and make connections between stressors and responses. Including:
  - Microbial time-series data towards understanding responses to, and indications of, nutrient loading and other perturbations.
  - eDNA to complement Chl-*a* data to predict and track blooms, and responses to nutrients.
  - eDNA methods to increase spatial and temporal assessments/monitoring of important habitats (rocky reefs/algal beds).
  - eDNA to increase the temporal and spatial resolution of endangered and introduced species monitoring.
  - Incorporation of eDNA methods into biodiversity assessment.
  - eDNA methods to improve understanding and response to public health threats in the Derwent estuary, including water quality assessments and AMR modelling.

3.2 Foreshore

3.2.1 Our evolving foreshore

Shorelines have always been subject to change as environmental forces, such as river discharge and storm events sculpt the coastline, and recent human activities have become a new force for shoreline modification. Often natural habitats and species have been displaced by infrastructure, such as housing, jetties and seawalls, changing coastal morphology and affecting the habitats and species that occur there (Office of Environment and Heritage NSW, 2009; Strain *et al*., 2018). In addition, climate change is contributing to rising sea levels and increasing the frequency and magnitude of storm surges and resultant flooding and erosion, impacting landforms, ecological systems and habitats, and the integrity of coastal infrastructure (Department of Climate Change, 2009; Ware, 2016).

Introduced flora and fauna also play a significant role within our changing foreshore habitats. Weeds are prevalent almost everywhere (**Section 3.2.2**), and introduced fauna such as European rabbits (*Oryctolagus cuniculus*) not only compete with native species for food and shelter, but can degrade landscapes by changing the composition of native plant communities (DPIPWE, 2019a).

Vegetation and priority habitats along the entire Derwent estuary foreshore have been mapped in detail (North Barker Ecosystem Services, 2010; DEP, 2015). This includes our semi-urban saltmarshes, which occupy the critical intertidal zone between land and river, as discussed in **Section 3.3.2**.

The DEP contributes scientific information to council planners to assist them manage environmental impacts from proposed local developments in proximity to the estuary. Developments have included marinas, housing subdivisions, infrastructure and industrial upgrades.

3.2.1.1 Aboriginal heritage on the foreshore

The majority of the Derwent estuary foreshore contains objects of Aboriginal heritage that are of significant cultural value to Aboriginal Tasmanians. Shell middens are the most common of these artifacts. Shell middens are distinct concentrations of shell containing evidence of past Aboriginal hunting, gathering and food processing activities (Aboriginal Heritage Tasmania, 2017). Middens are Tasmanian Aboriginal cultural material and defined as 'relics', protected under the *Aboriginal Heritage Act 1975*.

An Honours student surveyed the Derwent estuary foreshore in 1980 for Aboriginal middens and quarry sites. He recorded and mapped 754 shell mounds (154 on western shore, 591 on eastern shore) within 416 middens (118 on western shore, 298 on eastern shore) (Officer, 1980). As this survey was conducted so long ago, these numbers are likely to be an underestimate of the cultural material present further highlighting the need for vigilance when planning any foreshore works. A permit is required for any works that disturb the ground near any Aboriginal heritage. Weed surveying and above-ground vegetation work are not considered work that disturbs the ground. There are several ways to find out whether there are registered relics in a particular area, and whether a permit is required:

- Contact the Aboriginal Heritage Office for information about the area in question and its significance to Aboriginal Tasmanians.
- Conduct an aboriginal heritage property search on all freehold land that has a PID (Property Identification number) via https://www.aboriginalheritage.tas.gov.au/propertysearch/.
- Lodge enquiry via Dial Before You Dig https://onecall.1100.com.au/au-b4-en/tempcoverpage.html, which includes gas, electricity, tele communication infrastructure, as well as aboriginal heritage.
- Fill in a Aboriginal Heritage Desktop Survey form https://www.aboriginalheritage.tas.gov.au/Documents/Aboriginal%20Heritage%20Desktop%20Review.pdf and the Aboriginal Heritage Office conducts an assessment for you (within 10 working days).

3.2.1.2 Living seawalls

Seawalls of varying kinds have become a dominant feature on the Derwent estuary foreshore and are likely to extend in range as sea level continues to rise and density of human urbanisation increases along the coast. Seawalls are mainly installed to protect low-lying foreshore infrastructure, both public and private. This has significant implications for the environmental health of estuaries, due to the resulting loss of natural intertidal habitats that are vital in providing a range of ecosystem functions, and by modifying wave effects on the adjacent aquatic habitats, leading to marked changes in aquatic habitat condition (Office of Environment and Heritage NSW, 2009; World Habour Project, 2020). Traditional vertical seawalls have limited potential to provide habitat and other environmental services and are, therefore, poor habitat substitutes. **Figure 3.9** shows the difference between a natural low-sloping intertidal zone and an artificial vertical seawall.

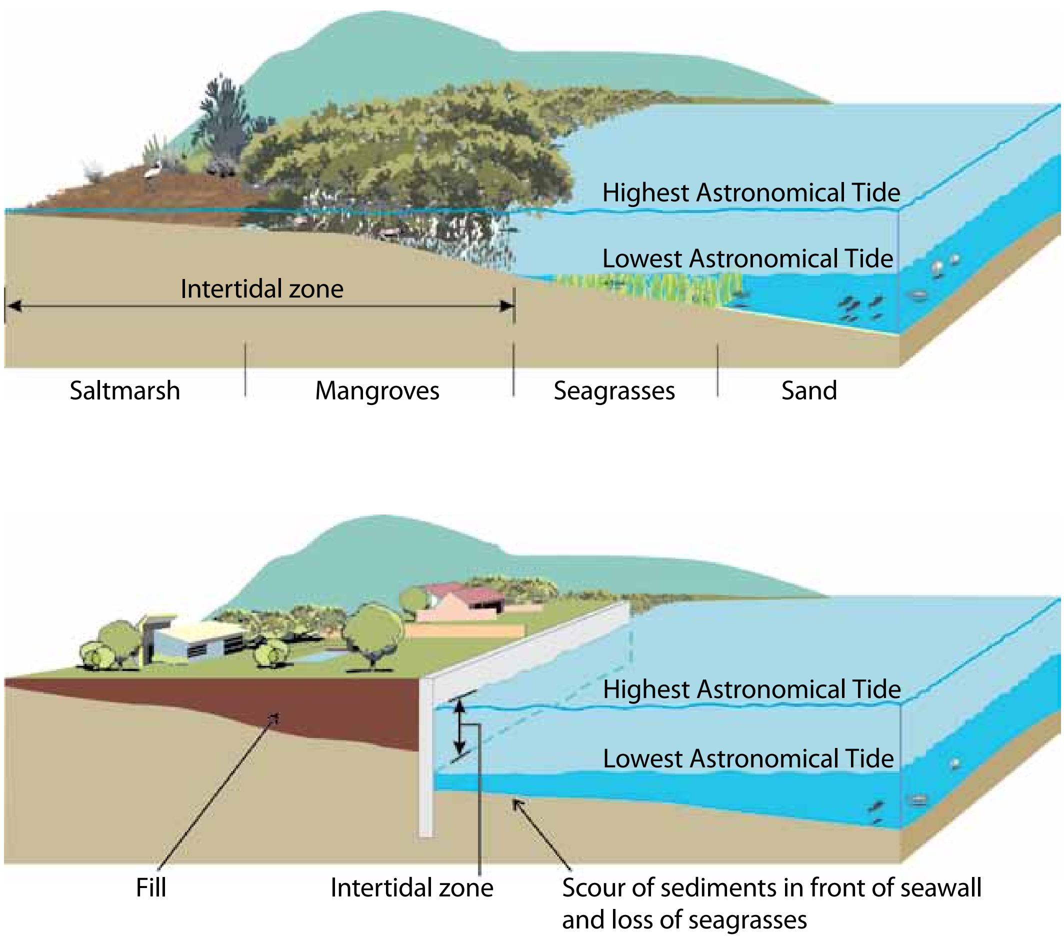


Figure 3.9 Comparison of a common low-sloping, estuarine shoreline (top) with a traditional vertical seawall, showing the substantial loss of intertidal area and important habitats, such as saltmarsh and seagrasses (bottom) (Office of Environment and Heritage NSW, 2009)

Worldwide, researchers are exploring and implementing new techniques to enhance the biodiversity of natural communities on artificial marine structures, such as seawalls. These interventions are trying to ensure artificial structures support, rather than degrade, their surrounding ecosystems by mimicking the micro-habitats of natural rocky foreshores (Office of Environment and Heritage NSW, 2009; World Habour Project, 2020). Hobart scientists are part of the World Harbours Project (https://www.worldharbourproject.org/) that aims to develop resilient urban ports and harbours through a global collaborative network bringing together international research institutions and agencies concerned with the health of heavily urbanised waterways and the increasing challenges they face.

One of the Hobart (World Harbour) projects involved installing 70 micro-habitat tiles onto seawall-type structures in Sandy Bay and Battery Point, with different design complexities (**Figure 3.10**).

One of the hypotheses tested was that the installation of complex tiles on pre-existing artificial habitats increases the number of micro-habitats available to support native biodiversity, with greater effects on biodiversity observed on habitat enhancements with greater complexity.

The findings suggested that installation of complex habitat enhancements has the potential to increase overall native species populations. But the findings also highlighted the complexity of the issue caused by the very high levels of introduced species in the estuary, because complex tiles also increase the abundance of introduced species (Ho, 2018). This issue may be managed by seeding tiles with competitive native species to preclude the establishment of invasive species. For example, seeding with blue mussel spat to preclude the establishment of invasive Pacific oysters.

Figure 3.10 One of 70 micro-habitat tiles used in the Hobart-based World Harbour Project, with a 2.5-cm elevation, unseeded design (Ho, 2018)

With rising sea levels and increase in storm surges, it is likely more seawall-type structures will be proposed for more sites throughout the Derwent estuary. If a seawall is required, there are many innovative options available, for both improving the environmental value of existing seawalls and by creating new seawalls that have greater habitat potential than traditional designs (Office of Environment and Heritage NSW, 2009; Strain *et al*., 2018; SIMS, 2020). **Figure 3.11** shows some of the many techniques, as well as site constraints and considerations that will determine which techniques are possible. Thanks to the intensive research conducted in this field over the last decade, we have the opportunity to improve environmental outcomes for the estuary by modifying our existing seawalls.

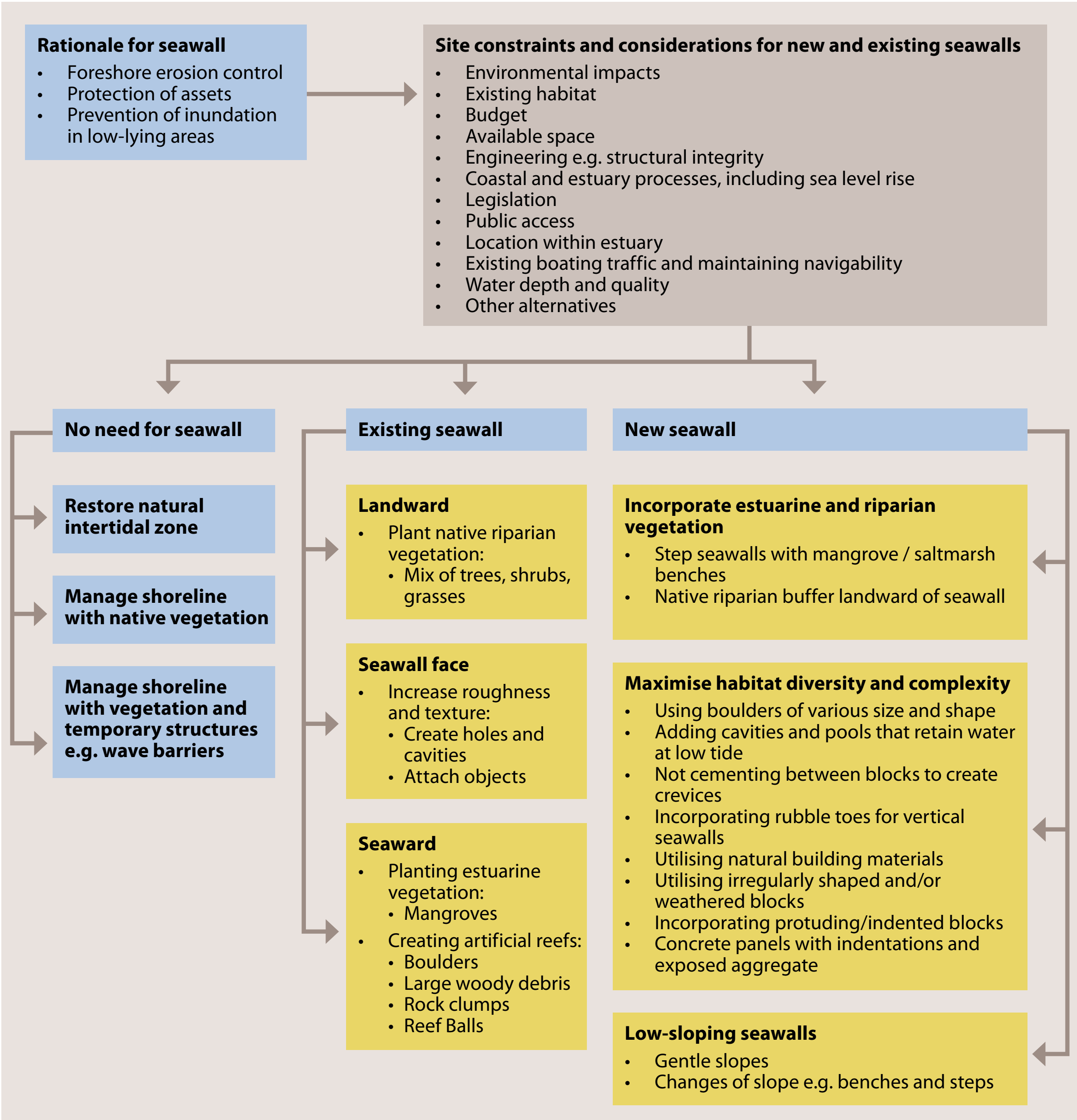


Figure 3.11 Summary guide of considerations for building new seawalls or modifying existing seawalls (Office of Environment and Heritage NSW, 2009)

3.2.2 Weeds

Introduced plants play a significant role in the Derwent estuary ecology. Whilst many weed species provide a threat to native vegetation and are a considerable impost on both private and public finances, they also, in many locations along the river, provide important habitat for native species.

A previous Weed Assessment and Vegetation Prioritisation Project (North Barker Ecosystem Services, 2010) identified significant weeds and priority vegetation areas across the estuary, and DEP initiated two on-ground works projects: Karamu control in the upper estuary, which is ongoing (**Section 3.2.2.3**), and a Bushcare project at Bedlam Walls near Geilston Bay together with Clarence City Council and the Southern Coastcare Association of Tasmania (DEP, 2015). Weed control work was conducted and in 2017 the Conservation Volunteers Australia (CVA) received a community grant from Nyrstar for a 4-day follow-up to assess the effectiveness of the initial control work. Working alongside staff from the Parks and Wildlife Service, CVA found that initial control had been largely successful and follow-up work weeded 750 m^2 and removed 100 kg of rubbish.

3.2.2.1 Emerging problem weeds and new methods

New weed species of concern continue to emerge. Spiny rush (*Juncus acutus*) is an invasive plant that has been identified by DPIPWE's Invasive Species Branch as an emerging environmental weed threat in Tasmania. It has invaded a number of wetland and coastal areas across the East Coast and parts of the Derwent and Tamar estuaries, where it has the potential to expand and become a monoculture, replacing native species (Fenner *et al*., 2014). Spiny rush was first recorded in the Derwent estuary in1998, at Windermere Bay, and this remains the only location in the estuary where it is has been observed. In 2016, DEP and the Tasmanian Herbarium conducted a survey of spiny rush at Windermere Bay, detecting significantly more plants than in 2011. Subsequently, a Windermere Bay Spiny Rush Works Plan 2017–2020 was developed by Glenorchy City Council, outlining a staged approach of control works, followed by native planting and work is progressing well.

Drone survey

Weed surveying on-foot is time consuming and at times not practical due to steep or dense terrain. In April 2019, Fulcrum Robotics trialled the use of a drone as a weed survey tool in the Murphys Flat Conservation Area in the upper estuary (**Figure 3.12**). Murphys Flat was chosen for this trial due to its importance as a valuable conservation asset in the Derwent estuary, and it being largely inaccessible by foot. There was considerable interest in this survey from Parks and Wildlife Services and some council staff. The survey captured approximately 1100 images over ~70 ha in ~45 min of flying time, highlighting the efficiency of this technology in gathering information.

Figure 3.12 Drone survey conducted by Fulcrum Robotics staff over Murphys Flat Conservation Area on 16 April 2019

Images were processed and provided as a single 'orthomosaic' (2D), elevation and 3D model. A second survey will be conducted with a multispectral camera as soon as COVID-19 restrictions and bird breeding allows to help with the identification of individual plants.

3.2.2.2 Derwent Estuary Weed Collaboration

In 2018, after discussions with several weed officers from local councils, the DEP took the initiative to invite public land managers from across the estuary to explore whether there was the interest and capacity to work collaboratively on foreshore weeds. The answer was resoundingly affirmative, and the Derwent Estuary Weed Collaboration (DEWC) was established.

DEWC comprises of representatives from Glenorchy City Council; Kingborough Council; City of Hobart; Clarence City Council; Brighton Council; Derwent Catchment Project; DEP; Parks and Wildlife Service – Property Services; Parks and Wildlife Services – Southern Region; Tasmanian Herbarium TMAG – State Growth;, NRM South; State Roads – State Growth; and Biosecurity Tasmania.

The scope for the group is the riparian zone of the Derwent estuary, which will vary in width according to tenure, resources, and community interest, as defined by individual members. Group aims include "To enjoy the benefits of our combined local knowledge, expertise and resources to explore weed management within a whole-of-estuary framework". Work has begun on a Derwent Estuary Strategic Weed Assessment and Prioritisation Plan.

3.2.2.3 Karamu

Karamu (*Coprosma robusta*) is an evergreen shrub originating from New Zealand (**Figure 3.13**). It is a declared weed under the *Tasmanian Weed Management Act 1999*, requiring landholders to remove it from their property. The area around New Norfolk is the largest infestation in Tasmania (DPIPWE, 2006), and control here is a high priority, as it threatens to spread into the high conservation value wetlands between Boyer and Granton.

Control and monitoring activities started in 2010 (DEP, 2015). In 2017, a new seven-year Karamu Management Plan was developed by the Derwent Catchment Project, with input from the DEP, Dept. of State Growth, Dept. of Parks and Wildlife Services including Property Services, to manageme Karamu in the Derwent, across all tenures (Kelman, 2017). Active stakeholders in the management and control effort are the Derwent Catchment Project, Dept of State Growth, Parks and Wildlife Services, DEP, Norske Skog, and Derwent Valley Council.

Karamu is an extremely difficult weed to control. Access to the plants remains one of the key limitations to successful control, with blackberry infestations requiring brush-cutting in places, significantly impacting on the time dedicated for karamu control. Also, high water levels have hampered control efforts. Several control method trials were undertaken in 2015–2017. The 'cut and paint' control method had been found to be very resource intensive so more efficient methods were explored (Strutt, 2015). Results suggested that 'frilling' and treating with chemicals was successful for larger plants.

However, it was later encountered that where drilling and filling was previously undertaken on larger plants, the remaining dead material made access difficult for control of seedlings and any re-sprouting. For this reason, all plant material is now removed rather than being left in-situ. In the 2018-2019 control season over 20 ten-tonne-truck loads were removed and buried at the tip by the Derwent Valley Council. Since 2019, the Parks and Wildlife Service has supported the control works around the cliffs at New Norfolk with use of a boat and staff (DCP, 2020c).

All tributaries in the New Norfolk area have been surveyed, and plants are limited to the area between Bryn Estyn in the west and just past Boyer in the east. The Lachlan River is predominantly free of karamu from the headwaters to Humphries Road. From here to the River Derwent, primary control has been conducted. Sorell Creek had some small individuals near where the creek flows into the Derwent, which has also been controlled. Much of the remaining areas with karamu are on private land, which has challenges with access and participation. **Figure 3.14** shows updated maps of the karamu control works in the upper estuary, which is progressing in accordance with the 2017 Karamu Management Plan (Kelman, 2017).

Figure 3.13 Karamu (*Coprosma robusta*) with fruit. Karamu reproduces by seed, with male and female flowers occurring on separate plants. Seed is dispersed mainly by birds or other animals or when garden waste is dumped (DPIPWE, 2019b). Image by Sandy Leighton

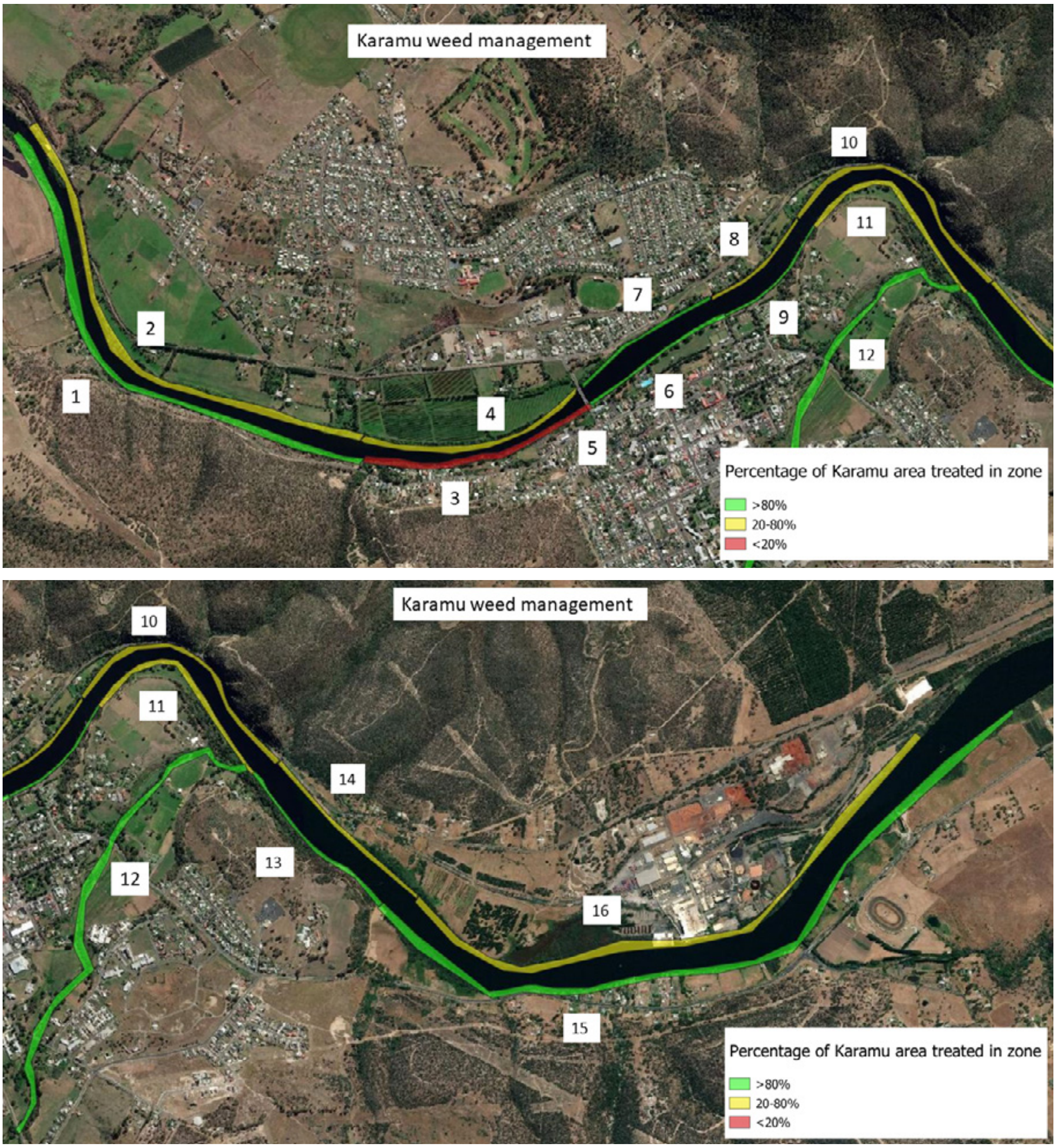


Figure 3.14 Karamu control work conducted. Top image is western side of New Norfolk, and bottom image is eastern side of New Norfolk. Colours refer to the percentage of karamu that has been treated in individual areas since 2017. Maps provided by M. McPherson, Derwent Catchment Project, August 2020

Additional map notes:

- Zones 1 and 2: low karamu density left, except the infamous 'karamu island', and can be treated by boat.
- Zones 3 and 5: The highest density left and the most difficult access, with only one treatment to date.

3.2.2.4 Rice grass

Rice grass (*Spartina anglica*) is an invasive intertidal weed classified as a Weed of National Significance, which was deliberately introduced from England to Tasmania, initially in the late 1920s and later into the Derwent estuary in the 1930s. The earliest known population in the Derwent estuary was at Austins Ferry in 1930. DPIPWE and the DEP have had a long history of surveying and successfully controlling this weed in the Derwent, such that none or only very few plants remain. Nonetheless, monitoring of this highly aggressive species will be imperative for a while longer.

In 2017, a DEP report recommended a change in the DEP survey methodology (DEP, 2017). It moved the focus to annual surveys of areas where rice grass has been found previously (termed 'hot spots'), supported by surveys of the entire foreshore area between the Bowen and Bridgewater bridges on a four-yearly rotational basis. Changes were adopted principally due to finding that rice grass seeds are not as persistent as previously thought, and that most, if not all, reproduction is vegetative (as opposed to sexual).

DEP has been generously assisted in rice grass surveying over the years by council partners, Parks and Wildlife Services, NRM South, Tasmanian Herbarium, EPA, UTAS, Threatened Plants Tasmania and many others.

Principal results

In the 1990s, some areas around the estuary were described as having "meadows" of rice grass (DPIPWE, 2002). Over the last decade, only eleven small patches of rice grass have been observed across the Derwent at seven locations (**Figure 3.15**). Rice grass was last observed in the Derwent estuary in spring 2016, when a 1-m^2 patch was found on the northern side of Dogshear Point, and a couple of smaller patches in front of Montrose Bay High School (**Figure 3.16**). These patches were controlled by Glenorchy City Council. Rice grass surveying also provides an opportunity to look out for other significant weeds, rubbish and other issues in areas that are not regularly visited, information which is shared with all landowners.

Rice grass survey methods will be reviewed again following the spring 2020 surveys.

Figure 3.15 Locations where rice grass (*Anglica spartina*) has been observed in the Derwent estuary since 2011, with distinct colours for the different years it was found.

Figure 3.16 Rice grass patch located at Montrose Bay High School, November 2016

3.2.3 Foreshore legacy contamination

The Derwent estuary foreshore has been contaminated by:

- Metals from zinc smelting and other industrial practices (**Section 2.3**)
- Diffuse urban contaminants, such as litter and oils (**Section 2.6.4**)
- Use of urban bays as tip sites (DEP, 2010b)
- Biocidal waste from boat slipways where maintenance occurs (Fowles *et al.*, 2018)

Many of the activities undertaken at boat repair and maintenance facilities in the estuary have the potential to cause environmental harm, as they often involve the release of hazardous chemicals to receiving waters, resulting in sediment contamination to the detriment of marine biota (Fowles *et al.*, 2018).

The Environmental Guidelines for Boat Repair and Maintenance (Department of Environment Parks, Heritage, and the Arts, 2009) provide practical advice to help facility operators meet their general environmental duty under the *Environmental Management and Pollution Control Act 1994* (EMPCA) and related legislation. While the Guidelines are not directly enforceable, they can be used by regulatory authorities to assess the standard of environmental management at sites. Specific contamination events can be investigated by local government. There are >10 slipways across the Derwent.

The Macquarie and Franklin wharfs are examples of sites that have legacy contamination impacts on the Derwent estuary foreshore. To remedy this, TasPorts has in the last five years undertaken extensive site contamination investigations and management to improve the environment at and around these sites.

This has been informed by the *TasPorts Environmental Guideline – Managing Contaminated Material During Excavation and Ground Penetration*, which requires any soil excavation works in the Port of Hobart to be proactively managed to prevent contamination of the Derwent estuary.

Macquarie Wharf has been contaminated by historical bulk fuel storage and past activities. Groundwater, soil and vapour monitoring programs undertaken between 2014 and 2018 confirmed that there is no identified unacceptable risk to human health or the Derwent estuary foreshore and aquatic environment from residual contamination on this site. At Franklin Wharf, TasPorts in 2017 removed potential sources of the legacy contamination by removing, decommissioning and backfilling underground fuel tanks.

Future TasPorts foreshore projects include upgrading the fire protection system at Selfs Point to use more contemporary fire-fighting foam with lower environmental impact; and improving the controls around re-fuelling with the aim of preventing leaks and spills into the harbour environment.

3.2.4 Threatened fauna and flora species

32 threatened native fauna species observed in the Derwent estuary regions (terrestrial and aquatic) are listed in the last State of the Derwent report (DEP, 2015). They include the White-bellied Sea-eagle (*Haliaeetus leucogaster*) and the Chevron looper moth (*Amelora acontistica*), both listed as Vulnerable under the Tasmanian Threatened Species Protection Act 1995. **Table 3.1** lists the threatened fauna species that have been listed since then, and a couple not previously mentioned.

Table 3.1 Threatened fauna species observed around the Derwent estuary region, not listed in the State of the Derwent 2015 (NVA search, 26 Aug. 2020)

		Listing status (year listed)		
Common name	Species name	*Threatened Species Protection Act 1995* (state)	*Environment Protection and Biodiversity Conservation Act 1999* (federal)	Comments
Hooded Plover (eastern)	*Thinornis cucullatus cucullatus*		Vulnerable (2014)	
Curlew Sandpiper	*Calidris ferruginea*		Critically endangered (2015)	Migratory
Eastern quoll	*Dasyurus viverrinus*		Endangered (2015)	
Gunn's screw shell	*Gazameda gunnii*	Vulnerable (2004)		Only beached shells have been observed in the Derwent estuary.
Lesser Sand Plover	*Charadrius mongolus*		Endangered (2016)	Migratory
Tasmanian Azure Kingfisher	*Ceyx azureus subsp. diemenensis*	Endangered (2014)	Endangered (2010)	The last confirmed Derwent estuary sighting was in 1961
White-throated Needletail	*Hirundapus caudacutus*		Vulnerable (2019)	Migratory

A 2010 DEP desktop study listed 147 state and/or federally-listed threatened plant species in the Derwent estuary catchment region (DEP, 2010c). This was reported on in the State of the Derwent 2015, which also listed the threatened vegetation communities found along the estuary foreshore. Since the 2010 report only two additional foreshore-region plant species have been listed under the *Threatened Species Protection Act 1995*:

- Tasmanian endemic smooth New Holland daisy (*Vittadinia burbidgeae*); species was split from the narrowleaf New Holland daisy (*Vittadinia muelleri*) after its 2016 listing.
- Stinking pennywort (*Hydrocotyle laxiflora*), uplisted in 2011 from Vulnerable to Endangered. This plant has only been observed on the Queens Domain in Hobart.

3.2.5 Future projects

- Collate information and examples of living seawalls and other types of green foreshore engineering, as alternatives to traditional hard-substrate rock or concrete walls, to be shared with Derwent estuary planners, developers, and public and private landowners, to encourage improvement and preservation of natural intertidal habitats.
- Finalise the Derwent Estuary Strategic Weed Assessment and Prioritisation Plan and seek funding for estuary-wide/cross-tenure, on-ground weed projects.
- Continue rice grass monitoring and method evaluation in the middle estuary, and support karamu control in the upper estuary.
- Explore the capacity for improving environmental outcomes from small and large slipways across the estuary.

3.3 Wetlands

Wetlands are ecological communities characterised by the presence of water, either permanently or periodically, and cover 3.5 km^2 of the Derwent estuary (Prahalad *et al*., 2009). They provide valuable wildlife habitat, fish spawning grounds and nurseries, flood and erosion control, pollution abatement, as well as visual and recreational amenities. Many plants actively regulate the wetland hydrology and through the combination of reduced current velocities and biochemical interactions with soils and plants, these vegetation communities act as a natural filter, removing silt, nutrients, pathogens, metals, hydrocarbons and other pollutants (DEP, 2015).

The wetlands in the Derwent estuary vary between tidal freshwater and brackish to saline sedgeland/rushland communities mostly above the Jordan River mouth, and saltmarshes below, on saline flats and estuarine areas fringing low energy foreshores. Many of the original wetlands of the Derwent estuary have been destroyed, particularly those at the heads of small bays in the middle estuary, with some sites used as municipal tips. Goulds Lagoon and Otago Lagoon represent some of the last remnants of this type of wetland. The wetlands between Bridgewater Bridge and Dromedary, and Goulds Lagoon are listed as Nationally Important Wetlands and are a key reason for the declaration of the area as a conservation area (Department of Agriculture, Water and the Environment, 2019).

Wetlands are among the most threatened ecosystems in the world, with threats globally and in Tasmania particularly from drainage and other alterations to natural water patterns, pollution from upstream and local activities, damage from recreational activities, and the introduction and spread of pest species (DPIPWE, 2000; Xu *et al*., 2019). Freshwater and some saline wetland communities in Tasmania are listed as Threatened Native Vegetation Communities under the *Nature Conservation Act 2002*, while coastal saltmarshes are federally-listed under the *Environment Protection and Biodiversity Conservation Act 1999*. The Derwent Estuary Conservation Action Plan (CAP) identified all estuary wetland communities as key conservation assets (DEP, 2012).

The 2nd February each year is World Wetlands Day (WWD), which raises global awareness about the vital role of wetlands for people and our planet. This day marks the date of the signing of the Convention on Wetlands of International Importance (the Ramsar Convention) on 2 February 1971 in Ramsar, Iran on the shores of the Caspian Sea. In 2021, it will be the 50-year anniversary of the signing. Since 2013, a collaboration of local and state government and others, have come together to organise a local WWD celebration in southern Tasmania. In the last few years, these large free community events have been held at Lauderdale and Dodges Ferry primary schools, the largest bringing together over 500 people.

3.3.1 Upper estuary wetlands – freshwater, saline

The River Derwent Marine Conservation Area (gazetted in 1941) includes most of the upper Derwent estuary tidal wetlands and incorporates the Murphys Flat Conservation Area and the extensive marshes at Dromedary. These wetlands consist of a mosaic of freshwater and saline sedgeland/rushland communities, ranging from a few metres to several hundred metres in width. Stands of tea tree and acacia scrub are also present on better drained areas, together with small patches of the federally-listed 'critically endangered' *Eucalyptus ovata forest and woodland community* (North Barker Ecosystem Services, 2008; Department of Agriculture Water and the Environment, 2020). Between the Jordan River and Dromedary, a complex network of marshy islands, mud flats and submerged aquatic macrophytes are present. The geology of the Lower River Derwent Estuarine Delta and Flood Plains (between Norske Skog and Austins Ferry) is listed for its geoconservation significance: "*One of the best developed estuarine sedimentary sequences and landform complexes in Tasmania*" (Natural Values Atlas DPIPWE, 2020). These wetlands, their main vegetation communities and significance have been mapped and described in previous State of the Derwent reports (DEP, 2010b, 2015).

3.3.1.1 Waterbirds

The upper estuary has long been a haven for waterbirds. Four species are annually surveyed by the Wildlife Management Branch (DPIPWE) as part of their now three decade-long state-wide waterbird monitoring program. Each February, the Derwent count is completed from south of Dromedary to the Bridgewater causeway and downstream to Green Point, which is the major zone for waterbirds in the estuary. **Figure 3.17** shows the annual counts of Pacific Black Duck (*Anas superciliosa*), Chestnut Teal (*Anas castanea*), Blue-winged Shoveler (*Anas rhynchotis*), and Black Swan (*Cygnus stratus*) between 1990 and 2020 (Source: Wildlife Management Branch, DPIPWE, 2020). The most common waterbirds surveyed are the Black Swans, which have increased in numbers in the last few years. This contrasts to the trend for swans state-wide, which were lower in numbers in 2020. Waterbirds can be extremely mobile, and the high Derwent result may be an outcome of the dry spring/summer that we had, indicating that birds have shifted en masse to the Derwent from other Tasmanian locations. For example, Black Swan numbers at Moulting Lagoon on the east coast were extremely low, which suggests low water flows causing food resources to be limited (pers. comm. R. Gaffney Wildlife Management Branch, DPIPWE, Aug 2020). The Pacific Duck, Chestnut Teal and Blue-winged Shoveler numbers are consistently much lower and fluctuate under 500 per count.

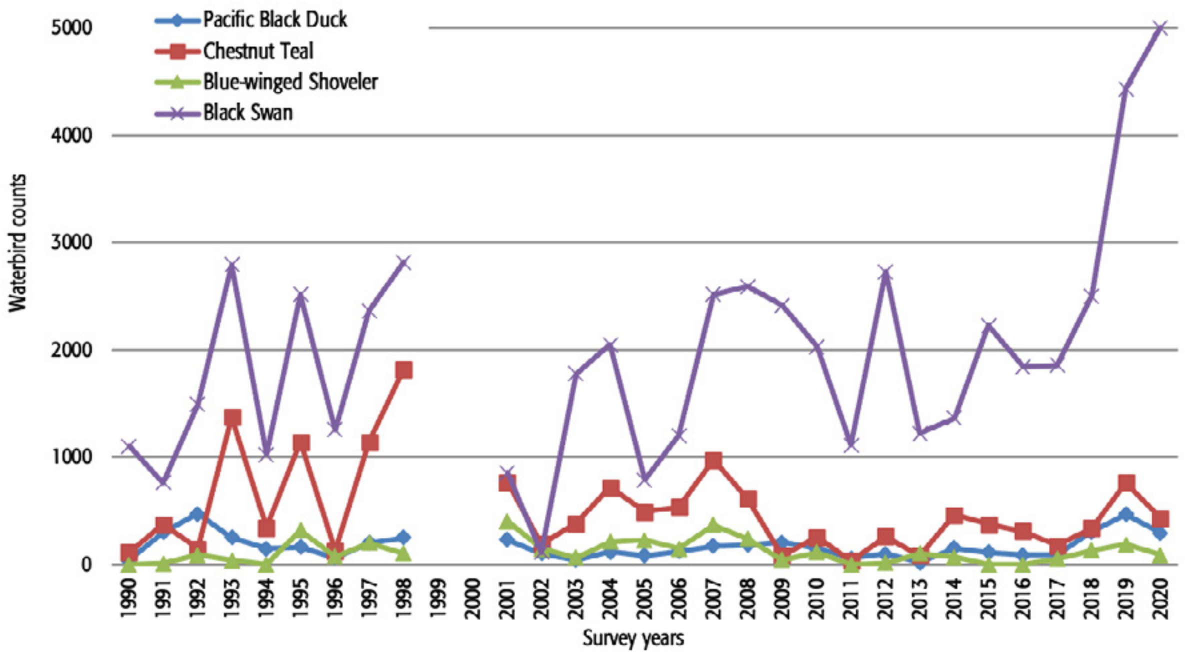


Figure 3.17 Numbers of four waterfowl species observed in the upper Derwent estuary wetlands on annual February counts between 1990 and 2020 (Source: Wildlife Management Branch, DPIPWE, 2020)

3.3.1.2 Black swans

The Black Swan (*Cygnus stratus*) is the most iconic water bird species in the upper estuary, which tourists come from afar to admire (**Figure 3.18**). Prior to being named the River Derwent Marine Conservation Area, this area was proclaimed a "sanctuary with respect to black swans" in 1920 under the *Animals and Birds Protection Act 1919* and later a "sanctuary for birds generally" to protect all birds in the reserve, particularly native ducks which were being hunted within the reserve (Tasmania Parks and Wildlife Services, 2020). Having permanently inundated wetlands in this area, the swans remain here all year round.

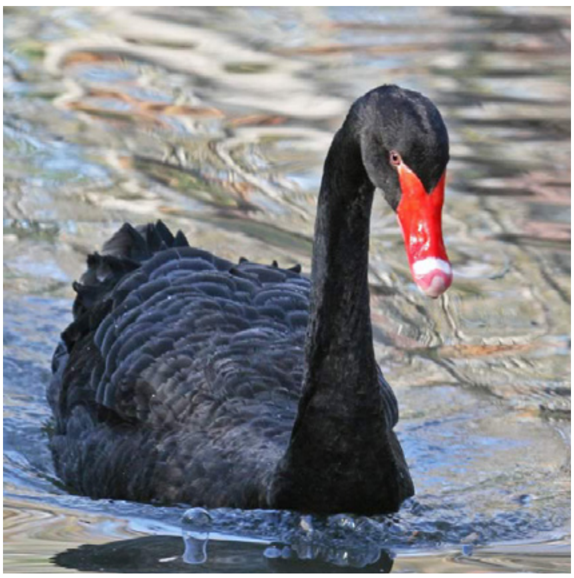


Figure 3.18 Black Swan (*Cygnus stratus*). Image by Dick Daniels

The Black Swan was one of eight aquatic bird species that was studied in the first inventory of metal contamination conducted within the Derwent estuary's resident bird community (Einoder *et al*., 2018). Feathers were analysed, as metals bind to the proteins in feathers. Stable carbon and nitrogen isotopes were used to identify dietary sources of contaminants, trophic level, and potential biomagnification through food chains. High metal loads were observed in the marsh-feeding Black Swans, suggesting contaminated marsh plants. The study showed that the metal contamination in the physical estuary environment does result in bioaccumulation in birds to levels that may be harmful, and that there is evidence of biomagnification through estuary food webs (Einoder *et al*., 2018). Benthic waters in the Bridgewater area have some of the highest concentrations of metals due to estuarine circulation patterns delivering metals from the principal source: contaminated groundwater at the zinc smelter site (**Section 2.3**). Also, it is likely that geochemistry is a key factor, as the high concentration of silt in the area preferentially binds contaminants compared to coarser sediment further downstream, and may be released under particular circumstances (Laanbroek and Veldkamp, 1982; Dent and Pons, 1995; Sammut *et al*., 1995; Mangimbulude *et al*., 2009).

See https://birdlife.org.au/bird-profile/black-swan for specific species details.

3.3.1.3 Australasian Bittern

"*SUCCESS!!! In a jaw dropping display, the Bittern emerged from the reeds and calmly fed in the open, catching a large frog and generally showing off, allowing much in the way of photos, films and awed observation!*" (Vaughan, 2018, Murphys Flat).

The Australasian Bitterns (*Botaurus poiciloptilus*) are one of the most cryptic birds that have their home in the upper estuary wetlands (**Figure 3.19**), and bird watchers revel in any observation of this rare bird. It is listed as Endangered under the federal *Environment Protection and Biodiversity Conservation Act 1999*, and globally on the International Union for Conservation of Nature (IUCN) Red List.

With its camouflage-coloured plumage that blends in perfectly with background reedy vegetation, this bird is heard more often than it is seen. It has a very distinctive booming call that can be heard over large distances. Birds will freeze if approached, and on windy days may even sway to match the movement of the reeds, which adds to their elusive nature (Threatened Species Section, 2020). They require large, relatively undisturbed wetlands, such as in the upper Derwent estuary, where they breed in densely vegetated areas, building nests in deep cover over shallow water. See BirdLife Australia's special Bittern Project http://birdlife.org.au/projects/bittern-project for more species details.

Figure 3.19 Australasian Bittern, image by R. Hall

While formerly widespread in Tasmania, particularly in the east of the state, the number of bitterns and their range has contracted over the last twenty years, following a particularly extended dry period. The main threat to the species is clearing and draining wetlands (Threatened Species Section, 2020). Actual numbers of Australasian Bitterns in the upper estuary are unknown but opportunistic observations in the last five years have included five sightings from the Lyell Hwy, west of Murphys Flat, looking in the marsh on the other side of the river, in 2016, 2018, and 2019 (Sources: E. Wakefield 2016, G Vaughan 2019).

3.3.1.4 Weeds, cows and garden waste

Despite their partial protection within a conservation area, the wetlands of the upper Derwent are vulnerable to degradation and incremental loss. DEP, assisted by the Tasmanian Herbarium, surveyed the foreshore on both sides of the river by boat between the Bridgewater Bridge and Norske Skog, a 12.5-km stretch of river, in March 2018 and Feb 2019. The main purpose was to update previous weed mapping (North Barker Ecosystem Services, 2008).

Fewer weeds were detected than expected with relatively few weeds around the important wetlands, which were dominated by long healthy bands of southern reed (*Phragmites australis*) in front of a mixture of prickly moses (*Acacia verticillata* subsp. *verticillata*), woolly tea tree (*Leptospermum lanigerum*), sea rush (*Juncus kraussi*i subsp. *australiensis*), and various eucalyptus species, mainly white gum (*E. viminalis* subsp. *viminalis*), white peppermint (*E. pulchella*) and black gum (*E. ovata*) (**Figure 3.20**). Willows (Salix spp.) were common throughout the wetlands and forty-three other species of weeds were recorded, particularly towards Sorell Creek/Boyer and in the suburban/peri-urban areas at Bridgewater and Granton. One area of concern is the Derwent Valley Rail Line corridor, which contains significant weed infestations. The DEP plans to work with TasRail and other stakeholders on curtailing the threat to the wetlands from this weed source (DEP, 2019).

Figure 3.20 Northern shore of the River Derwent with healthy riparian freshwater wetland habitat, west of Boyer. 7 Feb 2018

No weeds were detected along the river frontage of the Murphys Flat Conservation Area. Dept. of State Growth weed contractors found the highest density of weeds within this reserve occurred along the road verges adjacent to the Lyell Highway (Enviro-dynamics, 2018). Under the Dept of State Growth Priority Weed Program, weed contractors treat high-priority weeds on an annual basis. The Dept. of State Growth is committed to control of declared and significant environmental weeds on the roadsides along the Lyell Highway and Boyer Road where they adjoin Murphys Flat Conversation Area and where funding permits. In addition, Dept of State Growth controls weeds in roadside areas adjoining Murphys Flat to further buffer reserve values from weed invasion (pers. comm. S Leighton, Dept. of State Growth Aug 2020).

Willows (*Salix spp*.) are one of the more visually prominent introduced species in the upper estuary, on both the Derwent and in most tributaries. They are a declared weed in Tasmania and a Weed of National Significance. Willows can choke watercourses, increase erosion and silting, reduce water availability and damage aquatic habitats for fauna and flora, (DPIPWE, 2019c). **Figure 3.21** shows locations of observed willows from land surveys in 2010 (North Barker Ecosystem Services, 2008) and boat surveys in 2018-2019 (DEP, 2019), which in many localities are dominating the foreshore. The DEP surveys observed 350+ plants. Because of their highly invasive habit and ability to spread by small fragments taking hold on a bank downstream, willows need to be controlled from the top of the catchment in a downstream direction. In the Derwent catchment, the 'Willow Warriors' are successfully working on the Tyenna River (DCP, 2020b). It is hoped that control work downstream in the estuary will eventuate.

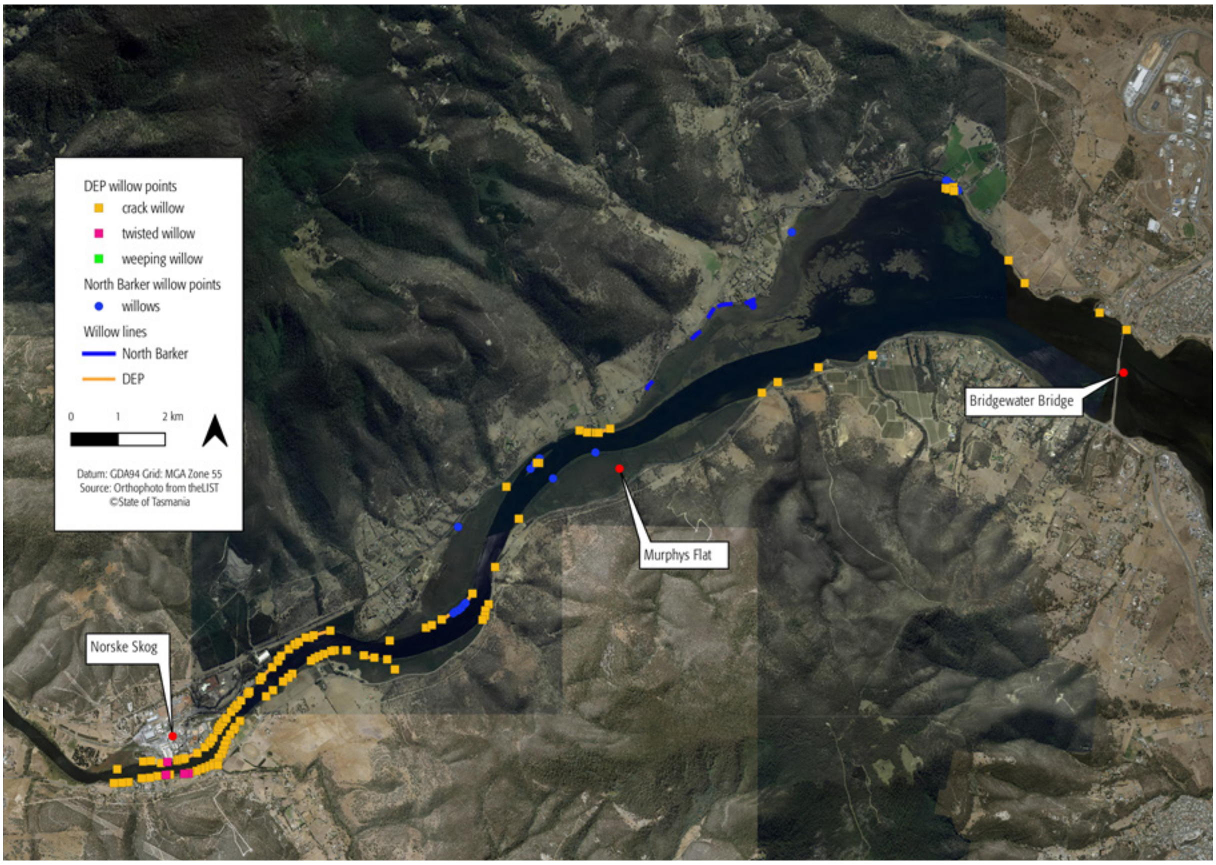


Figure 3.21 Combined willow (*Salix spp.*) observations by North Barker Ecosystem Services in 2008 (by foot or car) and by DEP in 2018/19

Three cows with direct access to the river were observed during the survey, polluting the water and eroding the bank (**Figure 3.22**). This kind of environmental destruction is generally less common, and The Derwent Catchment Project works closely with farmers encouraging them to install fences and water troughs to prevent stock accessing the river.

In another site, a very large garden waste pile was observed right on the bank of the river. The spread of garden plants into the river foreshore areas around New Norfolk and Sorell Creek is considerable, including blue periwinkle (*Vinca major*) and cotoneaster (*Cotoneaster* sp.). The wetlands downstream are directly threatened by the spread of garden weed seeds and fragments flowing down the river. Landowners are encouraged to ensure that all garden waste is located well back from the river, where there is no chance of it blowing or falling into the river, or being swept out at times of high tide or flooding.

Further weed details, including maps, and other observations from the 2018-2019 upper estuary surveys are available from DEP (DEP, 2019).

Figure 3.22 Stock observed with direct access to the River Derwent, Jan 2019

3.3.1.5 A rare find

A small patch (1 m^2) of the threatened perennial herb Lythrum salicaria (purple loosestrife) was discovered by DEP and the Tasmanian Herbarium on the northern side of Green Island in the upper estuary in Feb 2018 (**Figure 3.23**). It is listed as Vulnerable under the Tasmanian Threatened Species Protection Act 1995 and is predominantly found in northern Tasmania. The closest record of this species was from a location near Mt Dromedary in 1894.

Figure 3.23 Sample of the threatened purple loosestrife (*Lythrum salicaria*) from Green Island, Feb 2018

3.3.2 Middle to lower estuary wetlands – saltmarshes

Most of the wetlands from the Jordan River and downstream are saltmarshes, which are wetland communities generally defined by the presence of halophytic communities (salt tolerant plants e.g. **Figure 3.24**) that can tolerate high salinity levels and are subject to waterlogging (Adams, 1990). They occur in low-energy coastal environments where the shoreline is protected, and in Tasmania they occupy the upper intertidal areas starting below the mean high-tide mark and extending inland to the extent of storm-tide flooding and salt spray (Prahalad *et al*., 2009; Mount *et al*., 2010). They rely on tidal connectivity to the sea as their primary driver of development, extent and function (Prahalad *et al*., 2009). This connectivity can be regular (with semidiurnal tidal flows) or intermittent (with episodic spring tides and storm surges), and can also include groundwater connectivity (Prahalad *et al*., 2018).

Saltmarshes are critically important habitats that provide a range of ecosystem services. Prahalad and Jones (2013) summarise these services as: supporting biodiversity, including crucial feeding, roosting and breeding habitats for resident and migratory shorebirds, water birds and many terrestrial bird species and aquatic organisms; sequestering carbon (popularly titled 'blue carbon', with tidal marshes having been included in the National Greenhouse Gas Inventory since 2015) and attenuating global warming; increasing coastal food production through the production of organic materials that are exported to coastal waters with the tides; providing feeding, resting and nursery habitat for fish; improving the coastal water quality by intercepting land-derived nutrients and stabilising nutrient flows and reducing the likelihood of nutrient spikes in the system that can cause algal blooms; intercepting and trapping suspended sediments in the water column, which is critical for maintaining and enhancing coastal water quality; and for providing opportunities for recreation and education.

Sea level rise is likely to be a dominant climate change impact on saltmarshes, with range reduction expected if accretion/sediment input cannot keep pace with rising water levels (Department of Climate Change, 2009). In the Derwent estuary Conservation Action Plan, saltmarshes were given an overall Poor viability rating based on: (i) historic saltmarsh loss meaning a smaller extent left across the estuary; (ii) the individual patches left are small; and (iii) limited retreat areas to move/migrate to with rising sea levels (DEP, 2012).

Figure 3.24 Examples of salt-tolerant plants: roundleaf pigface in flower (*Disphyma crassifolium* subsp. *clavellatum*) in between beaded glasswort (*Sarcocornia quinqueflora* subsp. *quinqueflora*). Dorans Road saltmarsh, Dec 2018

3.3.2.1 Baseline monitoring and management

Despite saltmarshes being recognised as key environmental assets in the Derwent estuary, there has been a lack of knowledge about the plants, birds and ongoing human impacts in these wetlands. In response to this information gap, an estuary-wide, cross-tenure, saltmarsh survey commenced in 2018. Plant, bird, and human impact baseline data was collected in field surveys of small and large representative saltmarshes across the estuary. Some limited photographic monitoring was also conducted in select locations. Past and future range of each saltmarsh was examined using historical aerial photos and modelling of future (potential) saltmarsh extent. This project, a DEP and UTAS collaboration, providing the first detailed estuary-wide assessment (including the smaller and lesser-studied saltmarshes) of: (i) the current states of saltmarshes; (ii) their future conditions; and importantly, (iii) actions that can be taken by public and private land managers now and in the future, with key areas identified for improved management (Visby and Prahalad, 2020).

An example of an observed problem are dogs chasing birds within saltmarshes. This is likely to be a common occurrence in our urban to semi-urban marshes (**Figure 3.25**). It is a serious problem due to the potentially significant disturbance to the many bird species using the marshes for roosting, feeding and breeding (Spencer *et al*., 2009). DEP plans to work with individual councils and other landholders to interpret saltmarsh and bird values to local communities constructively (Visby and Prahalad, 2020).

Related to our changing climate, the project examined the Future Coastal Refugia Area overlay (Prahalad, Whitehead, *et al*., 2019) across the sites to assess the potential for saltmarshes to migrate upland as sea levels rise and storm surge height increases. The estuary marshes with adequate refugia area are located across multiple private and public tenures, and despite the modelled 'compatibility' significant goodwill and effort will be required to achieve the desired outcomes. The rest of the sites have limited options for any future retreat due to either topography (high to steep land) or their urban settings, so they will most likely be subject to complete loss or at least shrink, over time. While there is limited potential for retreat for these latter sites, it is still important that their current location and surrounding habitat remains able to support a functioning saltmarsh. DEP will work with public and private landholders to encourage long-term protection of potential saltmarsh habitat, as well as current marsh locations.

Overall, the most common concerns identified from the surveys pertained to weeds, rubbish, soil compaction, limited bird diversity, lack of vegetation buffer zones, and impacts from major developments within and adjacent to the saltmarshes. Despite these issues, the overriding finding was that the surveyed sites were mostly functioning saltmarshes that, with attention to the issues identified, will continue to perform critical environmental services for years to come (Visby and Prahalad, 2020).

All saltmarsh survey results, and individual site recommendations, are available on the DEP publication webpage.

Figure 3.25 Windermere Bay saltmarsh, a good example of a healthy saltmarsh in the Derwent estuary, May 2020

3.3.2.2 Lauderdale

The Lauderdale saltmarshes are the largest in the estuary and span > 1 km^2 including Racecourse Flats saltmarsh on the landward side of the South Arm Highway and the Dorans Road saltmarsh, on the seaward side of the highway (adjacent to Ralphs Bay). While the saltmarsh vegetation at Lauderdale is dominated by succulent saline herbland, a complex mosaic of vegetation communities reflects variations in salinity, water levels and disturbance regimes. The condition of Racecourse Flat is declining due to lack of tidal connectivity with Ralphs Bay, caused by the design and location of this section of South Arm Road. A long-term goal for this site is to increase the tidal flushing and associated nutrient exchange between the saltmarsh and the bay.

Recent activities around the Lauderdale saltmarshes include:

- In 2016 a UTAS student with DEP assistance repeated a 2012 Vegetation Condition Assessment (Prahalad, 2012), confirming that Racecourse Flats saltmarsh is indeed becoming drier and more saline, likely signifying a changed ecological character due to the impeded tidal connectivity of the site (Ng, 2016).
- The forest community in the northeast corner of Racecourse Flats was registered as "*Eucalyptus viminalis – Eucalyptus globulus coastal forest and woodland*" (i.e. TasVeg code: DVC) on the Land Information Service Tasmania (LIST). This is a threatened community under the *Nature Conservation Act 2002*.
- Since 2016, DEP has conducted a comprehensive photo-monitoring project across Racecourse Flats Saltmarsh and nearby Doran Road Saltmarsh, to record visual changes at these two sites to assist site management (**Figure 3.26**).
- A UTAS Honours student conducted "A Demonstration Case Study of Monitoring Bird Use of Saltmarsh Wetlands in South Arm Peninsula, South East Tasmania", which included Racecourse Flats and Doran Road saltmarshes, and provides strong baseline data for use in assessing changes in saltmarsh condition (Reid, 2016).
- Since Dec 2017, the Racecourse Flats and Dorans Road saltmarshes have been included as sample locations in a global litter decomposition initiative–see details in **Section 3.3.3**.
- In 2019, the Dept of State Growth, in collaboration with Clarence City Council, cleared blockages from two drains between Racecourse Flats and Ralphs Bay to improve much-needed tidal connectivity. The drains now require regular maintenance to stay open.
- Fish sampling at the Dorans Road saltmarsh began in July 2020, as part of a UTAS project into fish use of coastal saltmarshes. The sampling expanded on a previous study from northwest Tasmania that suggests that restoring basic saltmarsh structure through tidal re-connection will expand habitat range and increase fish productivity (Prahalad, Harrison-Day, *et al*., 2019).

Figure 3.26 Example of photo monitoring at Racecourse Flat saltmarsh at Lauderdale. Comparing images of the creek system between the Lauderdale sports oval and old tip site, which annually are inundated with algal blooms, raising questions as to the source of the nutrient leading to regular blooms. Top left: 7 Dec 2016. Top right: 18 Nov 2017. Bottom left: 18 Jan 2018. Bottom right: 11 Oct 2018. Images by DEP

The present study will sample fish throughout the year (one sample, with four replicates, per season) to both develop baseline information on fish species diversity and abundance, and to see if there is any seasonal variability in fish use of our saltmarshes.

- Clarence City Council has drafted a comprehensive Lauderdale Saltmarsh Reserve Activity Plan 2020–2030 to ensure the reserve is sustainably managed to preserve and enhance its natural, cultural and social values. The Plan also includes a recommendation to progressively reinstate the marine tidal flushing to Racecourse Flats. Information: https://www.yoursay.ccc.tas.gov.au/lauderdalesaltmarshrap.

3.3.2.2.1 Birds at Lauderdale

Saltmarshes provide roosting and foraging services to native birds; thus, any degradation or loss of saltmarshes may impact dependent bird species (Saintilan and Rogers, 2013). In Tasmania, recent indications are that 113 bird species use saltmarshes, 33 of these species are saltmarsh specialists (Prahalad *et al*., 2015) (**Figure 3.27**). A full list of birds of the Derwent estuary region can be found in the State of the Derwent 2015 report (DEP, 2015).

“Lauderdale supports one of the largest congregations of Australian pied oystercatchers nationally. Their numbers build up in winter as birds seek shelter from the more exposed locations where they breed during the summer months following seasonal patterns that are unchanged for more than fifty years. Numbers have increased over time, suggesting that Lauderdale plays a critical role in the life cycle of the species, particularly for inexperienced immature birds at risk of starvation during inclement weather. While the bay provides abundant food, it increasingly lacks secure roosts when there are storm-driven high tides, which have eroded features like the spit adjacent to the canal. The lack of viable roosts also affects the migratory shorebirds, which continue to frequent the area, although in much smaller numbers than in former years. Migratory shorebirds have decreased throughout their flyway, which is a matter of international concern” (pers. comm. M. Newman Aug 2020).

3.3.3 TeaComposition H_2O project

In December 2017, the DEP joined the ‘TeaComposition H_2O Project’, a three-year Global Wetland Litter Decomposition Initiative coordinated by the Blue Carbon Lab at Deakin University (http://www.bluecarbonlab.org/teacomposition-h2o/), referred to as the “tea bag project”. This project aims to establish which wetland environments are most effective at carbon sequestration and to place a value on their sequestration potential. Atmospheric and oceanic carbon is captured and stored (i.e. sequestered) by marine environments, especially mangroves (of which Tasmania has none), saltmarshes and seagrasses, where, if not disrupted, carbon can be stored for millennia. Plant litter decomposition is the key process in the early sequestration and emission stages of the carbon cycle, with microbial soil communities dictating whether carbon is sequestered or emitted as a greenhouse gas.

Figure 3.27 Examples of Tasmanian saltmarsh bird species. Illustration and design by Rachel Tribout, 2015

The novel idea in this research is the standardised method used for investigating carbon retention, by use of the humble teabag. In a nutshell, tea is buried and later recovered (**Figure 3.28**). Rapid degradation of the tea indicates that the site does not effectively sequester carbon and that carbon is being released into the atmosphere. However, if the tea stays relatively intact and decays slowly, the wetland is a stable environment that is suitable for carbon sequestration. Two types of tea were used: *Rooibos* tea, characterised by a slow decomposition rate (recalcitrant) and green tea, characterised by a faster decomposition rate (labile). The two types of tea represent the variability in litter types in different wetland habitats (Blue Carbon Lab, 2017)

How it works

In the top few centimetres of the saltmarsh there is aerobic decomposition occurring, meaning oxygen is assisting the decomposition of organic matter. Below that top level, in a healthy saltmarsh, there is very little oxygen, i.e. it is an anaerobic environment, which slows the organic matter decomposition, ensuring the carbon stays put. In a healthy saltmarsh, there is a hypoxic environment, where oxygen is quickly depleted, followed by a sequence of anaerobic processes starting with denitrification and finishing with methanogenesis (the production of methane). These conditions are absent in a degraded, e.g. a drained saltmarsh, where there will be increased oxidation penetration (down to 10 cm or more) leading to loss of organic matter and reduced sediment carbon concentration (Anisfeld, 2012).

The DEP was keen to participate in this research for two reasons: To contribute data to important global research questions, and secondly, to take the opportunity to compare a healthy saltmarsh (Dorans Road) and a degraded saltmarsh (Racecourse Flat), as part of assessing the case for rehabilitating Racecourse Flat saltmarsh. So far, we have dug up tea bags that have been buried for 3 months, 6 months, 1 year and 2 years, and will dig up the last tea bags after 3 years in December 2020. Our hypothesis is that the tea will decompose quicker at Racecourse Flat due to its degraded state. Data analysis since the project start has been generously provided by Associate Professor L. Barmuta (UTAS).

Preliminary results

Figure 3.29 shows the decay rate for each tea type in each saltmarsh, with more Rooibos left than green tea in both marshes. The proportion of green tea remaining at Racecourse Flats by Year 1 and Year 2 is likely overestimated as tiny roots contaminated the teabags adding to their weight (though considerable time was spent picking them out by hand!). Overall project data from the Blue Carbon Lab team now suggests that the Rooibos tea more closely represents saltmarsh vegetation litter (pers. comm. S. Trevathan-Tackett, Deakin University Aug. 2020). By comparison, the green tea more closely resembles the decay dynamics of seagrass leaves (Trevathan-Tackett *et al*., IN REVIEW). We hypothesised that a degraded site with no tidal connectivity, such as Racecourse Flats, contains a more aerobic vegetation layer where litter breaks down more quickly. When saltmarsh litter breaks down in a site cut off from the marine environment, there is minimal sediment to regularly supplement what is being broken down (as occurs in healthy saltmarshes), resulting in subsidence of the marsh, as discussed in Anisfeld (2012) and in a previous scoping

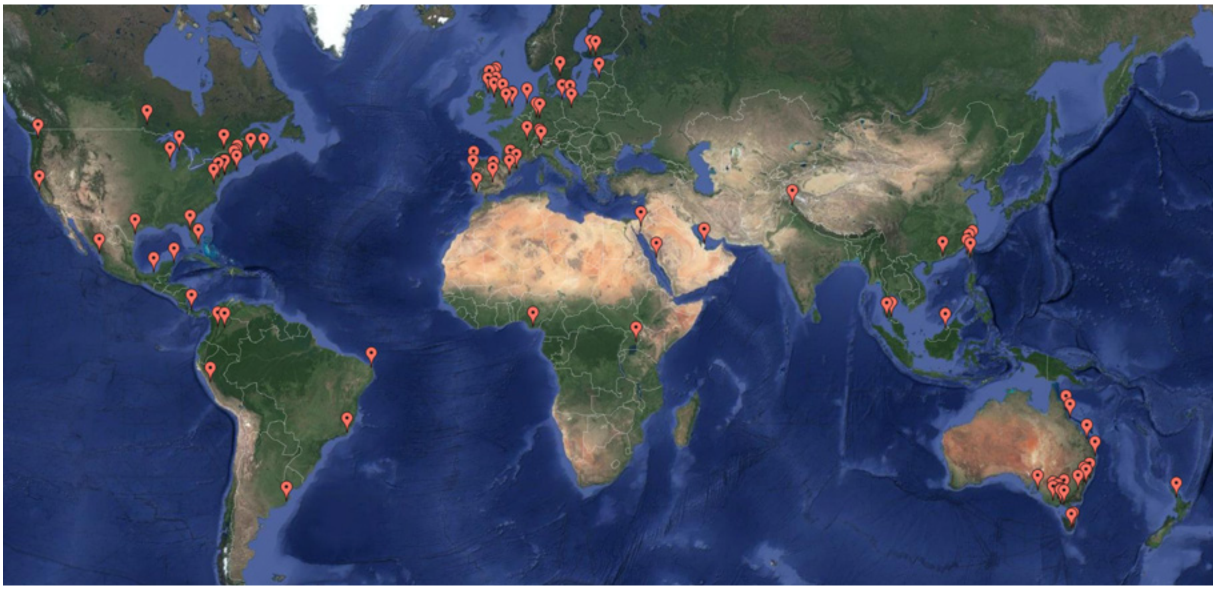


Figure 3.28 Locations where 19,000 teabag have been buried at 300 sites across 30 countries as part of the TeaComposition H2O Project (Blue Carbon Lab Deakin University, 2020b)

for a Racecourse Flat restoration project (Cook, 2012). Consistent with this hypothesis, Rooibos did decay slightly faster at Racecourse Flats (decay rate per day: -3.02×10^{-4} (95% CI: -4.47×10^{-4}, -1.57×10^{-4})), although not significantly faster than at Dorans Road (decay rate per day: -2.07×10^{-4} (95% CI: -3.51×10^{-4}, -6.41×10^{-5})). A degraded marsh over time will lose its ability to provide the ecosystem services outlined in **Section 3.3.2**. The final results for this project will be added in December 2020–if there is any tea left by then!

3.3.4 Goulds Lagoon

The Goulds Lagoon Wildlife Sanctuary is located on the western shore of the Derwent estuary, north of Austins Ferry. This shallow lagoon (~6 hectares) is an example of critical wetland habitat with its importance for migratory birds listed under the Japan – Australia Migratory Bird Agreement (JAMBA) and the China – Australia Migratory Bird Agreement (CAMBA) (Department of Agriculture Water and the Environment, 2019). The tidal connectivity between

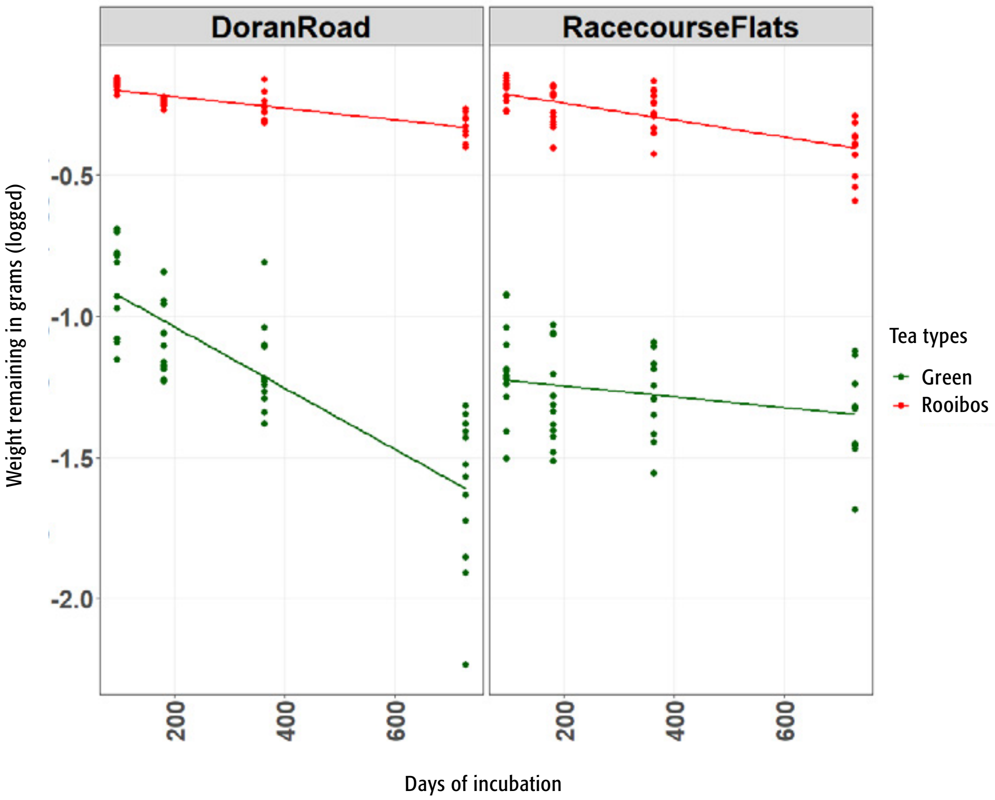


Figure 3.29 Decay rate for green and Rooibos tea at Dorans Road saltmarsh and Racecourse Flats saltmarsh over the four incubation periods (three months, six months, one year, two years). Each dot represents weight remaining in recovered tea bags, with lines indicating decay rate (rates stated in text). Local Derwent project partaking in the TeaComposition H_2O Project, Blue Carbon Lab, Deakin University

the river and the lagoon has been significantly reduced by the construction of the Hobart to Launceston road 200 years ago and the railway between the two cities in the 1870s. Over the last twenty years Glenorchy City Council (GCC) has worked extensively with the local community to undertake restoration works including weed removal, native plant revegetation and fencing critical habitat. On World Wetland Day 2020, GCC arranged a successful guided morning bird tour to this popular destination.

3.3.5 Future projects

- Develop an upper estuary wetland monitoring program to ensure weeds and inappropriate human activities do not impact the high-conservation-value habitats.
- Work with public and private landholders on implementing recommendations from the 2018–2020 Derwent estuary saltmarsh monitoring project, including encouraging long-term protection of areas with potential as future saltmarsh habitat, as well as current marsh locations.
- Work with TasRail and other stakeholders on weed management along the rail corridor in the upper estuary, to protect the high-conservation-value wetlands around Dromedary and Bridgewater.
- Support Clarence City Council's implementation of the Lauderdale Saltmarsh Reserve Activity Plan 2020–2030 to improve conditions for the largest saltmarsh community left in the Derwent estuary.

4

Iconic species

4 Iconic species

4.1 Little Penguins

In the Derwent estuary we see all year-round activities in the Little Penguin colonies, including winter breeding. This means that awareness of the impact of disturbance along our coastline, e.g. from dogs, cats, people, machinery, boats is important at all times. Targeted management does work. We have seen no major penguin attacks in the estuary since a predator fence was installed around our largest local colony, but we still need pet owners to be responsible for their animals. Because of a changing climate, we need to consider the impact of rising sea levels and increased storm surges on Little Penguin colonies and adjust our management of their habitats accordingly.

4.1.1 Background

Little Penguins (*Eudyptula minor*), previously known as Fairy Penguins (**Figure 4.1**), are the smallest of all penguins and breed across southern Australia, with the majority of colonies found in Tasmania. Here in the busy, metropolitan Derwent estuary, Little Penguins can be found foraging in coastal waters and nesting on the foreshore, sometimes in private gardens. Colonies range in size from just a few to over 50 breeding pairs, with penguin numbers and colonies having decreased over the years (Stevenson and Woehler, 2007).

Figure 4.1 Little Penguins in a burrow. Image by P. Marker

In Tasmania, Little Penguins are listed as Protected Wildlife in the *Wildlife (General) Regulations 2010* under the *Nature Conservation Act 2002*.

Since 2004, the DEP has facilitated the Derwent Penguin Advisory Group (PAG), a collaboration that has coordinated a multi-staged collaborative project called the Derwent Estuary Penguin Project, between local and state government, scientists and students, conservation groups, and community members. In 2013, formal funding for the project ceased, but the PAG continued its work, which still includes regular colony monitoring; support of on-ground works, including installing artificial nests; organising community education activities; providing expert scientific advice, and engaging in other information sharing as needed.

The PAG is currently supported by the University of Tasmania (IMAS), City of Hobart, Kingborough Council, Clarence City Council, the Tasmanian Parks and Wildlife Service, NRM South, Tasmanian Conservation Trust and the Marine Conservation Program (DPIPWE).

4.1.2 Local activities completed since 2014

- Little Penguin events updating private residents, who are neighbours to Little Penguin colonies, about the local penguin population, and how they can take part in the conservation effort.
- Revegetation projects by local councils; weed control followed by native planting and nest box installations, supported by volunteers from the Wildcare Friends of the Derwent and Channel Penguins group.
- Creation of handy reference cards for neighbours of Little Penguin colonies. It provides them with details of who to contact if they see injured or dead penguins, dogs and cats in prohibited areas, how to volunteer, or seek general penguin information.
- Regular Little Penguin neighbour newsletter update provided by councils about local colonies.
- A Little Penguin workshop at the 2018 Coast to Coast Conference, which brought together coast care and ‘friends of’ volunteers, neighbours to Little Penguins, and government and council employees from across Tasmania highlighted an urgent need for state-wide collaboration to support penguin conservation and ensure sustainable penguin tourism.

4.1.3 Tasmanian Penguin Advisory Group

In part inspired by the Little Penguin workshop, the Department of Primary Industries, Parks, Water and Environments (DPIPWE) Marine Conservation Program (MCP) established the Tasmanian Penguin Advisory Group (TPAG) in early 2019, with a structure based on the PAG model. TPAG includes representatives from MCP, the University of Tasmania, Commonwealth Scientific and Industrial Research Organisation (CSIRO), BirdLife Tasmania, the Local Government Association of Tasmania, DEP, and a community-based penguin expert. The primary role of TPAG is to provide expert advice on penguin conservation and management to the General Manager of DPIPWE's Natural and Cultural Heritage Division.

At the time of printing, a state-government-funded Little Penguin Conservation Project is being finalised, having been developed by Cradle Coast NRM. The project will deliver a training and survey 'toolkit' for community groups and land managers that will help facilitate a state-wide assessment of colony status and threats, and prioritise areas of key concern for targeted management and threat mitigation (DPIPWE, 2020e). TPAG will oversee the roll-out of this toolkit across Tasmania and provide expert advice to state and local government and other stakeholders regarding conservation and management of Little Penguins in Tasmania.

4.1.4 Threats

Threats to Little Penguins and their habitat are many and varied in both their terrestrial and marine habitats. They include vegetation removal as our urban areas expand; trampling or blocking burrow entrances; weed infestation around nesting and moulting sites; noise and light disturbance; tourists or locals interfering with Little Penguins; seasonal changes to natural food supplies; pollution; storm surges and coastal erosion causing damage to nest sites; and entanglement in marine debris and fishing gear (Pryor and Wells, 2009; Ong, 2015). Domestic and feral cats are an ongoing threat, with uncontrolled dogs being able to decimate colonies in a matter of hours, as continue to be seen in extreme events across Tasmania. Incidental drowning in gillnets also continues to be a threat for Little Penguins in Tasmania, as highlighted in the journal Endangered Species Research (Crawford *et al*., 2017), but these nets are thankfully no longer permitted in the River Derwent.

Metal pollution is also a threat to Little Penguins. A recent local study highlighted that the metal contamination in the physical environment does result in bioaccumulation in birds to levels that may be harmful, and that there is evidence of biomagnification through the food webs (Einoder *et al*., 2018).

4.1.4.1 Dog management

In 2019, in response to repeated dog attacks on Little Penguins across Tasmania, the Minister for Primary Industries and Water, declared Little Penguins as 'Sensitive Wildlife', and declared particular locations around the state to be 'Sensitive Areas'. This was followed by an amendment to the *Dog Control Act 2000* of an increase in fines to dog owners, if their dog should attack Little Penguins within a declared location. These areas are located at Bicheno and parts of the north coast. More details and maps of Sensitive Areas: https://dpipwe.tas.gov.au/wildlife-management/marine-conservation-program/little-penguins-in-tasmania/monitoring-and-protection/dog-control-act.

The PAG will continue to provide input into local councils' dog management strategies, when opportunities arise, and will seek to have the Derwent listed as a Sensitive Area. Thankfully, we have not had a known dog attack in the Derwent estuary since 2012, when two dogs killed 25 penguins in a single night. That particular colony has subsequently been surrounded by a dog proof fence by the Kingborough Council.

A recent Honours project examined dog owner attitudes towards the conservation of Little Penguins in the Derwent estuary. The study found that dog owners were mostly aware of dog management regulations in the area they walk their dogs, and mostly exhibited a high level of concern towards native wildlife on beaches, with some unease expressed about interactions between their dogs and native wildlife. Unfortunately, this did not always translate into a behaviour that protects native wildlife, with several comments suggesting that dogs should not be regarded as a threat to native wildlife, and some dismissing the concept of threatened or sensitive wildlife in urban areas. The study suggested that compliance with regulations may be improved with regular enforcement, community engagement and dissemination of information, with most dog owners prepared to modify their behaviour to protect native wildlife (Ong, 2015).

4.1.4.2 Cat management

Cats have posed a serious risk to Little Penguins in Tasmania for many years (Stevenson and Woehler, 2007). This was highlighted in the Derwent estuary when cat kills over multiple years were confirmed at a local colony, evident from penguin remains (e.g. detached heads) (Kalmari, 2014). This colony was formally declared a Cat Prohibited Area in 2013.

In 2015, and again in 2019, Kingborough Council used remote cameras to monitor for cats, dogs and black rats in one of its colonies. All three predators were detected on camera and the local community were informed about the presence and impacts of domestic animals. Local residents were also reminded of their pet owner responsibilities and Council's intention to trap cats within this area. Trapping was undertaken in 2015 and no cats were trapped. Follow-up remote-camera monitoring (for predators) was undertaken in 2016 by an IMAS Honours student (Wabiko, 2016) and no cats or dogs were detected. More trapping, with remote cameras aimed at the trap area, was undertaken again in 2020, with one cat seen on cameras approaching a trap. Kingborough Council and their Cat Management Officer will continue to work on cat education and compliance around this colony.

4.1.5 Where do they swim?

In 2016, Little Penguins from the Derwent estuary were the subject of a fascinating study that investigated where penguins from three colonies in South East Tasmania foraged, and how they adjusted their movements to subtle changes in environmental conditions to find food. IMAS and CSIRO researchers fitted 29 Little Penguins with GPS trackers to see how they interacted with their environment when locating patchily distributed prey. The study found that all the penguins stayed out for less than 24 hours, although the distances they travelled all varied depending on their colony. The Derwent penguins were observed to swim as far as Variety Bay, Bruny Island and around Betsey Island. The trackers also revealed the birds remained relatively close to the coast and exhibited a high level of variability between colonies. Foraging behaviour was correlated with different environmental factors at each colony, and there were substantial differences in at-sea activities among birds from the different colonies, suggesting a capacity to behaviourally adapt to variable and changing environmental conditions (Phillips *et al*., 2019).

4.1.6 New management plan

In April 2020, the PAG approved a new Derwent Estuary Little Penguin Management Plan to promote best-practice management of Little Penguins and their on-shore breeding and moulting habitats, and to improve the viability of the Derwent estuary populations. The plan outlines priorities for on-ground work, monitoring and research and education and awareness activities (Derwent Penguin Advisory Group, 2020).

4.1.7 Penguin colony monitoring

PAG oversees monthly and seasonal monitoring of eight Little Penguin colonies on the western shore of the estuary (**Figure 4.2**). Data informs land managers (including local councils) to act on threats and continuously improve conditions for Little Penguins to increase breeding success. The monitoring is currently undertaken by UTAS scientists and students, and DEP volunteers with support from MCP.

Figure 4.2 A section of rocky and inaccessible Derwent estuary foreshore where Little Penguins nest, which is monitored on a seasonal basis. Jan 2020

All monitoring takes place in daytime, when most penguins are foraging at sea. This minimises disturbance, however, it also makes it much more difficult to determine the exact population size of each colony. Population numbers are estimates from the number of observed occupied nests, i.e. nests with either eggs, chicks, or adult birds, multiplied by two, to signify a breeding pair of Little Penguins; while also avoiding counting the same chicks twice. Survey efforts have differed greatly between, and within, the years for various reasons, including volunteer availability and permits, which also adds to the uncertainty of an exact population number. **Figure 4.3** shows an estimate of the number of penguins in the Derwent estuary between 2011 and July 2020 (per financial year), which varied between100 and 150 birds. Furthermore, the population estimate does not include any data from the Eastern shore, and other sites around the estuary, where there is anecdotal evidence of a penguin presence; therefore it is highly likely that the figures are an underestimate of the actual estuary Little Penguin population. Although a very rough estimate, these numbers do assist our understanding of the Little Penguins population in the Derwent. The PAG is working on gathering more consistent data from extended areas going forward. Data analysis has been generously assisted by T. Travers (IMAS).

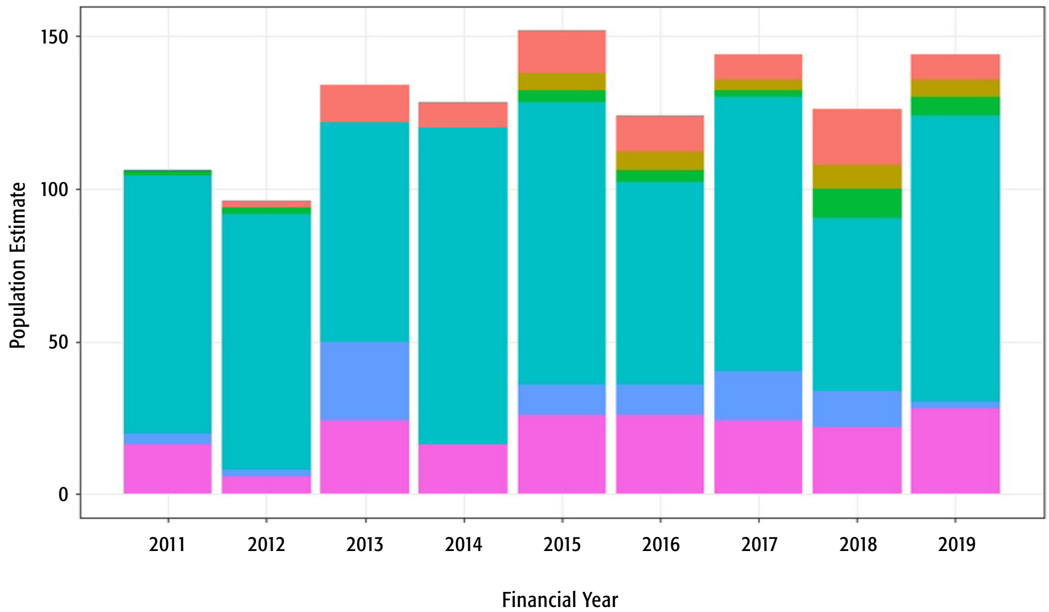


Figure 4.3 Estimate of Little Penguin population size in the Derwent estuary, based on data collected and shared by DPIPWE, BirdLife Tasmania, IMAS and DEP between July 2011 and June 2020 financial years (penguin breeding seasons). See above information about the uncertainties in this estimation. Colours refer to different Little Penguin colonies

The method of data collection has changed over time. In 2018–2019, the 'Little Penguin Monitoring App', a modified ARC-GIS Collector App (https://esriaustralia.com.au/collector-for-arcgis), was created for the DEP by Land Tasmania (DPIPWE), to ensure efficient and effective data collection and management. Now the Little Penguin surveyors enter the data into the app, either during a survey, or immediately after a survey (there are still some issues with the app for one colony). App survey fields include: Nest signs (i.e. feathers, splash), number of adults, number of adults moulting, number of chicks, the stage of the chick (e.g. small and downy or fully feathered), number of eggs, nest condition change (e.g. damaged from land slide or overground by weeds) and whether occupied. In addition, the surveyors fill in an overall Site Visit Summary for each colony, which includes extra details such as cat and dog observations, number of nests needing repositioning or repairing, neighbour mentioned something relevant, or access issues. This additional information helps land managers plan maintenance at colonies.

4.1.8 Colony management

Assisted by PAG and guided by the new Derwent Estuary Little Penguin Management Plan and penguin survey data, landowners (including local councils) oversee on-ground colony management. Regular monitoring allows land managers to quickly and strategically act on issues, such as rectifying landslides that collapse nest and moulting sites; controlling weeds and planting native vegetation; identifying productive nest sites and those that are never used; removing roaming cats and dogs and beach parties within the colony or installing artificial burrows. To streamline colony management and to compare the effect of interventions from year to year, the PAG is developing a system to track progress against the new Management Plan and associated site works plans. Presently, there are just under 300 individual nest sites that are part of the estuary monitoring program.

Knowing when Little Penguins breed assists land managers plan activities within and around colonies with the least amount of disturbance. Little Penguins are known to breed predominantly during spring and summer, which is also the case in the Derwent. Our surveys also indicate that winter breeding is becoming a regular occurrence, albeit in much lower numbers. The reason for the winter breeding in the Derwent is unknown, other than the environmental conditions must be suitable for it to occur. Our winter data backs up anecdotal evidence of breeding outside the spring/summer period, but further targeted research is required to understand the extent of this breeding activity. The **Figure 4.4** bar charts show the timing of some of the Little Penguin's key life cycle events within the Derwent estuary colonies, based on the monthly averages of number of times a life stage was observed per nest survey across all years (2011-2020). It highlights that adult nest occupancy (during daytime when surveying takes place) is high in spring and peaks over summer, which correlates with an increase of egg-laying beginning in October, and all chicks having fledged by the end of February. The figures also show that a second smaller breeding event has been occurring in winter, with most chicks fledging by the end of September. This reinforces that penguins can be present at colonies all year round, and that autumn may be the preferable time to conduct colony management activities, but that great care is needed even at this time of the year to avoid disturbance.

To ensure minimal disturbance to birds at colonies, it is imperative that tourists and keen locals are encouraged to watch Little Penguins in areas that are designed for specialised viewing with dedicated infrastructure (Agnew and Houston, 2020). The closest place to the Derwent is the Bruny Island Neck Reserve. Penguin watching guidelines can be found at: https://dpipwe.tas.gov.au/wildlife-management/caring-for-wildlife/penguin-watching-guidelines.

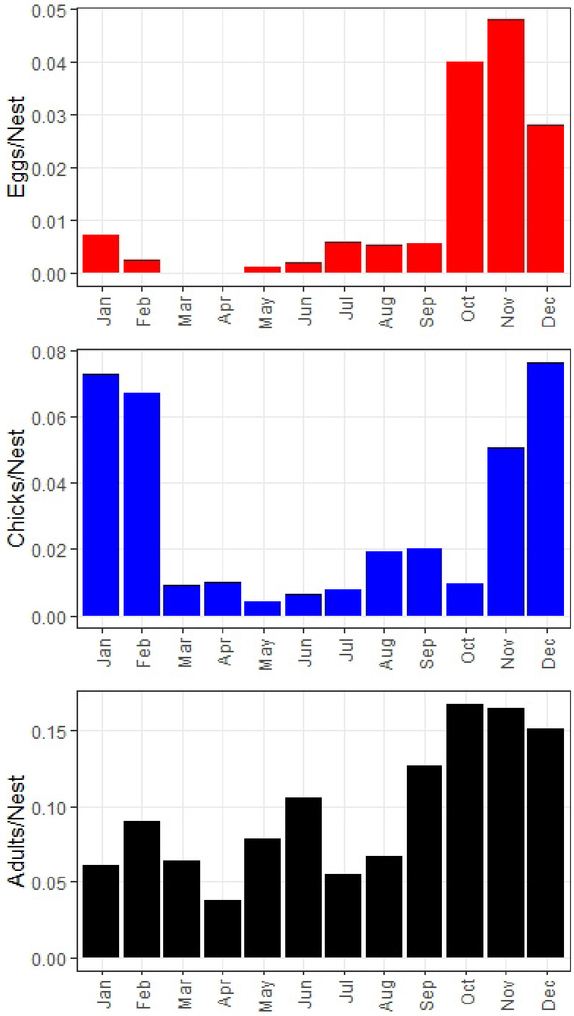


Figure 4.4 Bar charts showing Little Penguin phenology/lifecycle events in Derwent estuary colonies throughout the year. From the top down, it is the monthly averages of number of times a life stage (i.e. eggs, chicks or adults) was observed per nest survey, based on data collected and shared by DPIPWE, BirdLife Tasmania, IMAS and DEP between July 2011 and June 2020

4.1.9 Planning and Recommendations

- Survey foreshore areas of the Derwent where Little Penguins have been seen in the past to improve the knowledge of the extent of estuary populations and inform management options for sites.
- Implement the 2020 Derwent Estuary Little Penguin Management Plan in cooperation with the PAG, which includes actions such as:
  - Promote the inclusion of the Derwent estuary as a 'Sensitive Area' under the Dog Control (Sensitive Wildlife and Areas) Order 2019.
  - Assess the impact of predicted 100-year sea level rise and storm surge on Little Penguin colonies in the estuary, to identify the long-term viability of the colonies, and direct on-ground actions to sites for long-term protection.

4.1.10 Get involved

Learn more about Little Penguins with these resources:

- Comprehensive Little Penguin online learning package from Cradle Coast NRM https://www.cradlecoast.com/online-learning-packages/.
- Marine Conservation Program https://dpipwe.tas.gov.au/wildlife-management/marine-conservation-program/little-penguins-in-tasmania.
- Little Penguin poster for children https://www.derwentestuary.org.au/assets/Derwent_little_penguins_kids_poster.pdf.
- Join the Wildcare Friends of the Derwent and Channel Penguins to get involved with conservation and maintenance work in Little Penguins colonies https://wildcaretas.org.au/branches/wildcare-friends-of-the-derwent-and-channel-penguins/.

4.2 Spotted handfish

4.2.1 Background

The spotted handfish (*Brachionichthys hirsutus*) is a member of the fish family Brachionichthyidae, which comprises 13 species globally restricted to SE Australia, of which 11 occur in the seas around Tasmania (**Figure 4.5**). Listed as Endangered in Tasmania, Critically Endangered federally and on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, the spotted handfish is a small (up to 120 mm long) benthic fish that use their hand-like fins to "walk" along the seafloor, rather than swim.

Figure 4.5 Spotted handfish (*Brachionichthys hirsutus*) image by R. Stuart-Smith

Throughout the 1960s, 70s and early 80s, handfish were frequently seen by divers along the eastern and western shores of the Derwent, and adjoining bays. However, major declines occurred in the mid-1980s, and extensive surveys of the estuary floor in 1994 and 1996 found only a handful of specimens at several locations throughout their former range. Threats include predation and competition, degradation and loss of habitat, pollution, population size and fragmentation, and illegal collection. The total known extant locations for spotted handfish is 13, with recent observations from Storm Bay (Lynch *et al*., 2020). This includes nine known populations in the Derwent estuary, two of these on the eastern shore, and seven on the western shore.

Conservation actions have been carried out since 1999, and are currently guided by 'Recovery Plan for Three Handfish Species': spotted handfish *Brachionichthys hirsutus*, red handfish *Thymichthys politus*, and Ziebell's handfish *Brachiopsilus ziebelli*, after a federal review in 2015 (Department of the Environment, 2015). Most of the current conservation work is undertaken by CSIRO for the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Programme (NESP), as part of the A10 Handfish Conservation Project. The conservation work is overseen and supported by the National Handfish Recovery Team (NHRT), which currently includes CSIRO and Institute for Marine and Antarctic Studies (IMAS, University of Tasmania) scientists and students, and representatives from the Zoo and Aquarium Association of Australia, Sea Life Melbourne Aquarium, Reef Life Survey Foundation (RLS), Aquenal, Seahorse World, Department of Primary Industries, Parks, Water and Environment (DPIPWE), Marine Solutions, DEP, Sydney University, and the Australian Government.

4.2.2 Recent research and conservation activities

To implement the updated recovery plan, CSIRO, in 2015, commenced a new project under the National Environmental Science Programme (NESP) building on past research. In collaboration with all of its partners and the NHRT, CSIRO has over the last five years undertaken extensive research and related activities that include the following.

4.2.2.1 Surveying and population research

Annual performance assessment surveying is now conducted, after CSIRO and UTAS in 2015 trialled a new monitoring methodology across all nine known spotted handfish sub-population sites in the estuary and successfully implemented the first meta-population-scale survey. These surveys provided a pilot for establishing a baseline dataset for long-term monitoring (Wong and Lynch, 2017).

In 2019, a fifth annual round of annual performance assessment surveys was completed. Annual estimates were calculated from search effort by the dive team of 8–12 transects per site, which were of ~250 m x 3 m swath size. **Table 4.1** shows the number of spotted handfish counted in 2019 and the previous four years, together with number of transects (Lynch *et al*., 2020). The 2020 survey was cancelled due to Covid-19.

Table 4.1 Number of spotted handfish counted at nine locations in the Derwent estuary (Soo, L. CSIRO 2019)

	Total number of fish	Adults	Juveniles (< 70 mm)	Number of transects per site
2015	70	56	14	8
2016	101	88	13	12
2017	55	45	10	8
2018	56	52	4	8
2019	56	45	11	8

This work allowed for the calculation of a total of 45 annualised density estimates (five per site) with variance. **Figure 4.6** shows the 2019 densities across the nine estuary monitoring sites, with significant density variation between sites, with 35 fish per hectare observed at one site, and five sites with about 10 or less fish per hectare. At one site no fish were observed in the 2019 survey (Lynch *et al*., 2020).

Density estimate data from pre-2015 has also been analysed, and added to post-2015 data, bringing it to a total of 71 estimates of fish densities, keeping in mind that the older estimates are annually uneven in their occurrence across sites (**Figure 4.7**) (Lynch *et al*., 2020).

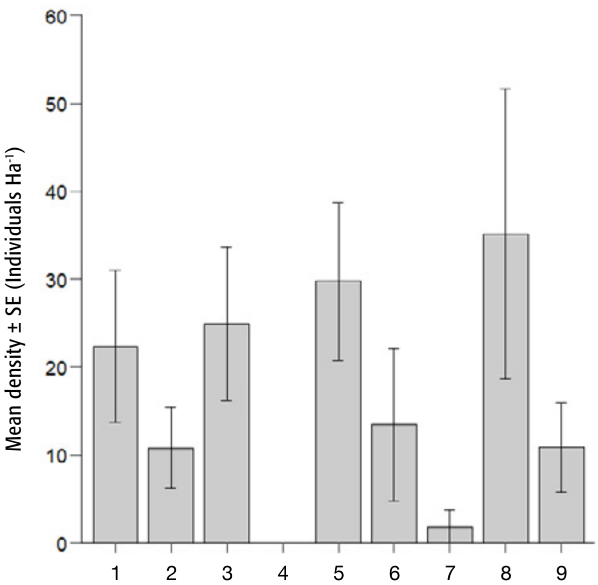


Figure 4.6 2019 mean densities per hectare of spotted handfish across nine unnamed Derwent estuary monitoring sites (Lynch *et al*., 2020). One site recorded no handfish. Exact location of the sites is not provided

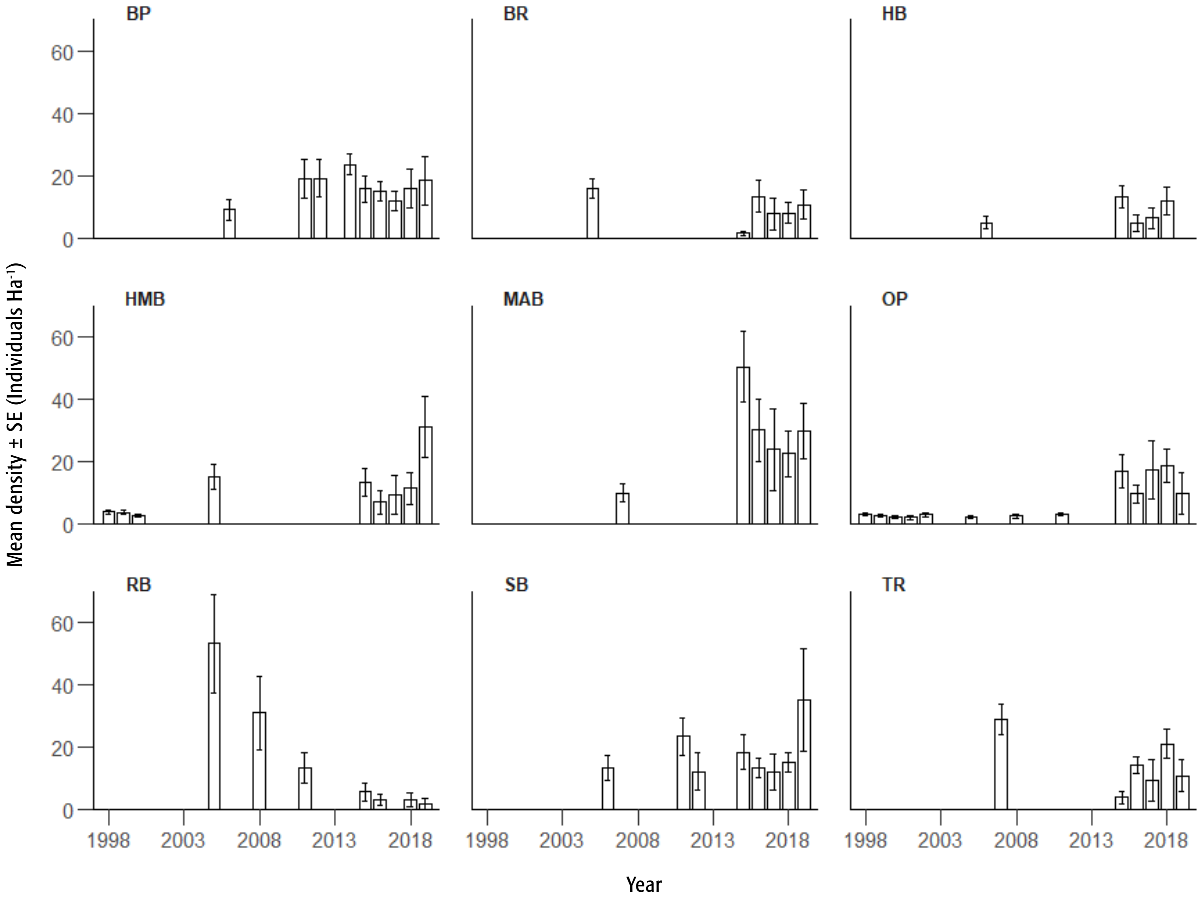


Figure 4.7 Time-series 1998–2019 of mean density of spotted handfish per ha at nine sites in the Derwent estuary (Lynch *et al*., 2020). Location of sites are not provided

Estimating the number of spotted handfish in the Derwent estuary is not possible with the current data. What we can say is that the time-series data suggests that although there has been much variation over the years, and much variation between colonies, that over the last few years there may be a level of stability in the spotted handfish population size at most sites, and that these fish may be able to survive in very low numbers (Lynch *et al*., 2020). At one site in Ralphs Bay, there has been a decline and recent discoveries about the species relatively short life spans, destruction of spawning habitat by uncontrolled introduced marine pests and lack of handfish movement and genetic connectivity, means that declines and local extinctions are distinct possibilities.

4.2.2.2 Survey techniques

The spotted handfish survey technique has been revised to a diver-towed GPS system, used to define the distance surveyed, rather than assessing handfish populations in set transects as had been conducted previously (Cooper *et al*., 2014). The new survey technique is much more efficient and provides equally robust results (Green *et al*., 2014; Lynch *et al*., 2015).

Another survey technique takes advantage of the spot pattern of individual handfish being unique. An extensive collection of photographs of spotted handfish have been collected since 2015 and have now been used for a non-invasive, capture-mark-recapture (CMR) study. The photo database was constructed using the software Interactive Individual Identification System (I3S), which creates a pattern fingerprint for each photo to allow comparison of individual pattern.

A protocol has been developed for processing all images based on preliminary testing and previous trials (Wong and Lynch, 2017). Few recaptures have been made, which we think is due to the relatively short life span of the fish and the limited sampling undertaken to track density estimates.

4.2.2.3 Spawning habitat research

The installation of artificial spawning habitat (ASH), to look like stalked ascidians, the natural breeding habitat of the handfish, has long been a critical part of spotted handfish conservation work. Different student projects have led to the design and manufacturing of improved ASH (**Figure 4.8**). Initially ASH was produced in plastic, but ceramic has been found to be preferred by the handfish at a rate of 2:1. Targeted planting of ASH has been based on an assessment of ascidian densities during surveys outside of the breeding season. Fish, however, prefer natural spawning habitat, such as stalked ascidians.

In 2018, a local artist fired and glazed over 3,000 ceramic poles to be used as ASH. A comparative study showed that ceramic ASH was successfully used by handfish, but they had higher failure in structure, so work to improve design continued. In 2019, an improved ceramic ASH was designed, which was thicker and more robust, compact, and importantly also easy to handle underwater as bundles could be transported easily in dive bags. Further research suggested that 9mm ASH were the optimum for survivorship and handfish preference (Lynch *et al*., 2020).

Figure 4.8 Adult spotted handfish guarding its eggs on an artificial spawning habitat. Image by A. Hormann

4.2.2.4 The Ambassador Fish/captive breeding project

During 2016, the planning for the capture of spotted handfish brood stock and establishment of an 'ambassador fish' project to build capacity to undertake a captive breeding project got underway. The project started in 2017 with in-kind commitments to breed spotted handfish in captivity at two aquaria, Seahorse World at Beauty Point, Tasmania and Sea Life Aquarium in Melbourne, with support from industry partners CSIRO and the Zoos and Aquaria Association (ZAA), and the State and Federal Governments. Spotted handfish were permitted to be displayed as 'ambassador fish' as part of both aquaria's exhibits, providing a tourist attraction, and allowing for public engagement, outreach and education (Wong and Lynch, 2017).

In 2017, brood stock of 20 adults were collected from eight of the nine estuary colonies, to ensure genetic diversity (Lynch *et al.*, 2018). A CSIRO CAPEX grant allowed for the construction of multiple holding tanks at the CSIRO Battery Point site, to be used for temporary holding of handfish and act as a buffer between the wild and captive populations. As a critically endangered species, surplus spotted handfish from any breeding program cannot be euthanised or sold to third parties; thus, captive-bred fish must either be held in additional tanks within this aquarium or released back into the wild (Wong and Lynch, 2017).

Since the program's beginning, many lessons about breeding handfish and the general biology of the spotted handfish have been learnt. A stud book is being kept for all wild-caught fish held in captivity, tracking date, time and location collected, size, sex, breeding, flight response, and where they are sent to. Also, protocols of how to receive, quarantine and release captive-bred animals, as well as handling of diseased fish, have been established (Lynch *et al*., 2018). There are still many outstanding questions concerning survival when translocating handfish, including around genetic diversity.

One egg-laying event and two mortality events have taken place in captivity, and 30 juveniles have been released so far. Overall the program is well underway with spotted handfish currently being held at both Seahorse World and Sea Life Melbourne Aquarium (Lynch *et al*., 2020).

4.2.2.5 Breeding behaviour

Video footage from both the field and the captive breeding program have been used to study different behaviour of the spotted handfish, including the interaction with potential predators on its eggs. Handfish have been observed guarding their egg mass from a variety of species, including northern Pacific seastars (*Asterias amurensis*). The footage showed that without the parent guarding, the eggs are quickly preyed upon, but by guarding them few predators seem able to disturb the eggs, including the northern Pacific seastar (Lynch *et al*., 2019). See video of spotted handfish protecting its eggs against a northern Pacific seastar: https://youtu.be/P9Y90nIRzHk (Hormann, 2018).

4.2.2.6 Habitat research and moorings

Wong *et al*. (2018) found spotted handfish prefer complex micro-habitats within their broader habitat which range from well-sorted coarse sand and shell grit, to areas of fine sand and silt. Complex microhabitats may enable the spotted handfish avoid predators, increase foraging opportunities or provide higher quality spawning sites. The scouring by traditional boat moorings remove this habitat complexity, in addition to directly destroying egg masses which may be laid within mooring scour zones (Lynch *et al*., 2015; Wong, 2015).

These findings led to further studies on moorings and their impact on handfish habitat through a PhD study, in close collaboration with CSIRO's engineering department. Objectives included examining the influence of moorings on different benthic ecology; management implications; and attitudes to environmentally friendly moorings (EFMs)–previously referred to as 'eco-moorings'. The gathering of a multi-disciplinary working group/task force, allowed for ongoing consultation between the researchers, local maritime authority, mooring contractors, the environmental arm of government, engineers, and ecologists, including DEP. Meetings provided insight into a deployment pathway, including engineering and permit issues.

Activities as part of this study have included:

- Replacement of five traditional swing moorings with EFM moorings to minimise spotted handfish habitat damage, and raise awareness of impacts of traditional moorings on spotted handfish habitat and breeding success. This activity was enabled by DEP, the Royal Hobart Yacht Club, and the Derwent Sailing Squadron with funding from NRM South through their Waterways and Coasts Grant.
- A further four study sites were established in Sandy Bay and North West Bay, where private mooring owners became part of a replacement trial, changing from traditional swing moorings to EFMs. There was a strong interest from members of the public to become involved, suggesting that if a suitable, simple, safe and cost-effective solution is available, many will want to change to a more environmentally-friendly mooring design. Surveys to examine the influence of EFM mooring on benthic ecology is being undertaken, with more diving required for 'after deployment' comparisons. It is too early for conclusions, but there have been the very exciting sightings of spotted handfish twice within areas where swing moorings were replaced with ES moorings treatments (pers. comm. L. Wong, UTAS 2019) and recovery of stalked ascidians.
- The CSIRO engineering department worked on developing an EFM-mooring design to minimise the impact on the benthic habitat, while satisfying boat owners and complying with the safety concerns of marine authorities. Multiple brands and designs were tested and modelled. Tasmania, including the Derwent estuary, has many very dense mooring fields. It is important to have an understanding about how different sized boats on an EFM-mooring will behave in all-weathers. After multiple iterations, the final design incorporates a nylon top section to the EFM mooring strops, which increase elasticity for effective force dissipation. Modelling suggests that while this type of ES mooring provides a superior solution in extreme conditions, in mild conditions chain moorings may still place lower loads on mooring components; and therefore, further refinement of the EFM mooring design is needed. More details are provided in Lynch *et al*. (2020).
- The CSIRO EFMs survived for 15 months and have been through their first servicing period. Numerous lessons were learnt and will be reported as part of the final NESP report (Lynch *et al* in prep).

4.2.2.7 Biological parameters

An Honours project completed in 2018 discovered handfish biological parameters (Lynch *et al*., 2019), including:

- It is unlikely that spotted handfish move between sites. Using the CMR method, handfish movement was observed to range between 32 m (over 13 days) and 567 m (over 585 days) with mean movement of 1.16 m/day.
- By using otoliths (calcium carbonate structure of the inner ear) the age of spotted handfish was determined by calculating growth rings. A 10-year life span was observed, and it was found that only 10% of fish were older than five years.
- It was learnt that at one-year old the spotted handfish are around 45–47 mm long. At about five years, they are generally about 100 mm long. One ten-year-old fish was 125 mm long.
- In a spot-plasticity study, spots on handfish in captivity were observed to change in colour, which might relate to substrate colour, and could be important to consider at the time captive fish are released.

4.2.2.8 Genetic population study

In 2018-2019, scientists studied the population diversity and structure of spotted handfish in the Derwent estuary with a genome-wide, single-nucleotide-polymorphism (SNP) approach, by extracting DNA from 262 fin clips collected at eleven sites between 1998 and 2008.

The results clustered the collection sites into three main genetic groups (with a fourth emerging), indicating a low level of gene flow among local Derwent estuary populations. The reasoning for these distinct groupings may be a combination of destruction of spawning habitat by introduced marine pests; species-specific biological attributes; and impacts of by-catch and collapse of bivalve communities from historical dredge fisheries.

These results provide critical information for future spotted handfish conservation work by highlighting the need for protection of all individual handfish at each location in the Derwent estuary, as recruitment and gene flow between all, but the closest, local fish populations are limited.

More details about this world-first study can be found in Lynch *et al*. (2020).

4.2.2.9 Outreach, fundraising

In order to raise much needed funds for handfish research, a fundraising campaign was launched in December 2018, and a website where the public can donate was created https://handfish.org.au/. All money raised is independently administered by the University of Tasmania Advancement Office. To oversee the distribution of monies raised, and ensure independence from researchers, a Handfish Conservation Project Finance Steering Committee has been formed. It consists of Tasmanian and federal government and independent representatives. The NHRT will develop the research priorities, and the Finance Steering Committee will approve projects in line with the National Recovery Plan. Terms of References have been created for the Handfish Conservation Project research and fundraising processes. The project has tax-deductible status. At the end of the 2019/20 financial year, $46,777 had been raised.

4.2.3 Future projects

The close and supportive collaboration between the two aquaria and CSIRO and IMAS around the captive-breeding program is providing unprecedented opportunities for handfish research. This conservation effort will help improve knowledge of:

- Breeding behaviour triggers, including egg and sperm development.
- Methods to differentiate sexes in live fish to increase mating success in captive-breeding trials.
- Handfish husbandry.
- Translocation methods, including genetic implications and survivorship.
- Methods to 'teach life skills' to handfish prior to release into the Derwent estuary (through environmental-enrichment methods).
- Advantages and disadvantages of remote operated vehicles (ROV), towed-camera and UVC surveys for spotted handfish.
- The use of eDNA to find additional remnant handfish populations in the estuary.

An updated Tasmanian Threatened Species Listing Statement is underway for the spotted handfish.

For further information about the spotted handfish and other critically endangered handfish in southern Tasmania, such as the Red handfish (*Thymichthys politus*) and the Ziebell's handfish (*Brachiopsilus ziebelli*) visit https://handfish.org.au/.

4.3 Marine mammals

4.3.1 Background

Whales used to be a very common sight in the Derwent estuary. The Hobart Town clergyman Robert Knopwood regularly wrote about them in his diaries, for example on 1 July 1804, he noted:

"*… Lt. Johnston and self went to Risdon by order of Lt. Govnr. Collins, and performed divine service there. We passed so many whales that it was dangerous for the boat to go up the river, unless you kept near the shore*" (Dakin, 1938).

Those days are unfortunately long gone, with past commercial whaling having brought the whale populations close to extinction. Thankfully, populations of Southern Right Whale (Eubalaena australis) and the Humpback Whale (Megaptera novaeangliae), which are the most common whales species in Tasmanian waters (**Figure 4.9**), have started to recover and have again become a frequent sight along the Tasmanian coastline during their annual migration (Marine Conservation Program DPIPWE, 2020a).

4.3.2 Whale records in the Derwent

The DPIPWE Marine Conservation Program records marine mammal sightings and strandings. Records are sourced from staff surveys, agency reports, and information received from the public via an all-hour Whale and Dolphin Strandings and Sightings Hotline (0427 WHALES (0427 942 537), or via Facebook https://www.facebook.com/whalestas.

Table 4.2 shows recorded numbers of whales within the Derwent estuary between 2003 and 2020. Sightings are recorded as independent spatial and temporal events for DPIPWE purposes, and records from before 2016 do not necessarily represent different individuals.

This is particularly so for humpback whales in 2014, where three to four individuals were repeatedly sighted over a period of several months. Southern right whales have visited the estuary most years since 2003, and in higher numbers than other whale species. On a few occasions, calves have also been observed, as occurred again in September 2018, when a cow and calf were spotted proceeding up the western shore. Humpback whales have also been sighted in the Derwent estuary in most years over the past decade, though in smaller numbers. Killer whales (*Orcinus orca*) are the third species of whale that visit the estuary. 2018 saw the first recorded visit by long-finned pilot whales in recent times.

Figure 4.9 Humpback whale in Tasmanian waters. Photo: Drew Griffiths 2019

Table 4.2 Number of records of marine mammals within the Derwent estuary between 2003 and 2020. Some individuals may have been counted multiple times prior to 2016 (Source: K. Carlyon, Marine Conservation Program, DPIPWE, 2020)

Year	Killer Whale	Humpback Whale	Long-finned pilot whales	Southern Right Whale	Total
2003	2	3		5	10
2004		1		3	4
2005		1		14	15
2006		1		4	5
2007				5	5
2008	1	3		3	7
2009		1		1	2
2010	6			9	15
2011		1		3	4
2012				7	7
2013	2			9	11
2014		18*		3	21
2015	6			3	9
2016		2			3**
2017	1	1		1	4 ***
2018		3***	5	3	11
2019		3			3
2020****				1	1
Total	18	38	5	74	137

* 3-4 individuals were repeatedly sighted, **includes one unidentified baleen whale, *** includes one unidentified toothed whale, ** unknown number observed on 13/9/18, ****data until July 2020.

Figure 4.10 shows the locations in the Derwent estuary where whale species have been observed since 2015. Some observation points indicate multiple animals (Source: K. Carlyon, Marine Conservation Program, DPIPWE, 2020).

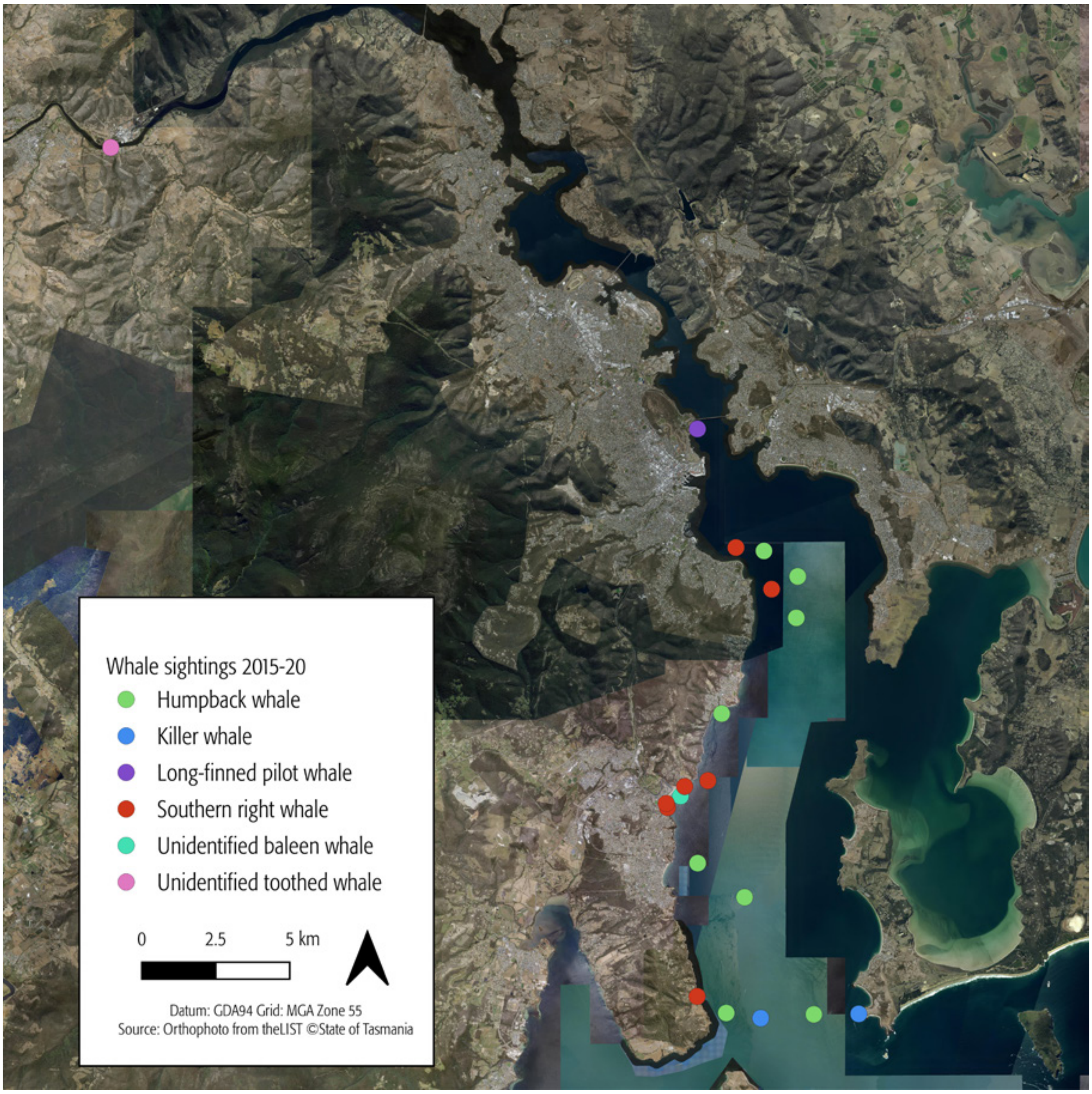


Figure 4.10 Whale sightings in the Derwent estuary 2015-20. The record from Sorell Creek may have been a long-finned pilot whale. Based on whale data from the Marine Protection Branch, DPIPWE

4.3.3 Whale watching

Despite their protection status under the Federal *Environment Protection and Biodiversity Conservation Act 1999* and Tasmania's *Threatened Species Protection Act 1995*, Humpback and southern right whales are still vulnerable. Current threats include interactions with well-meaning locals and tourists. The Marine Protection Program (DPIPWE) has developed guidelines for both dolphin and whale watching, to ensure human safety and to protect the welfare of the animals.

These guidelines include recommended approach distances of 300 m and 150 m for whales and dolphins, respectively (**Figure 4.11**) (Marine Conservation Program DPIPWE, 2020b).

The best time to see whales in Tasmania is between May and September as they migrate north to their breeding grounds in warmer waters off the coast of Queensland and Western Australia, though occasionally they do give birth around Tasmania, and when they head back to the Southern Ocean again between September and November.

4.3.4 Dolphins and seals

Bottlenose dolphins (*Tursiops aduncus*) and common dolphins (*Delphinus delphis*), are very common in the Derwent estuary at any time of the year, sometimes far upriver. These sighting are not often reported so accurate data on dolphin abundance is unclear.

Seals are also often observed in the Derwent, and occasionally they haul out on the foreshore. However, no regular haul-out or breeding sites occur in the estuary.

Five species of seals have been recorded in the Derwent, the Australian fur seal (*Arctocephalus pusillus*) and the New Zealand fur seal (*Arctocephalus fosteri*), plus rare visits from leopard seals (*Hydrurga leptonyx*), southern elephant seals (*Mirounga leonine*) and Australian sea-lions (*Neophoca cinereal*). DPIPWE do not typically record seal observations from the River Derwent unless a management action is required.

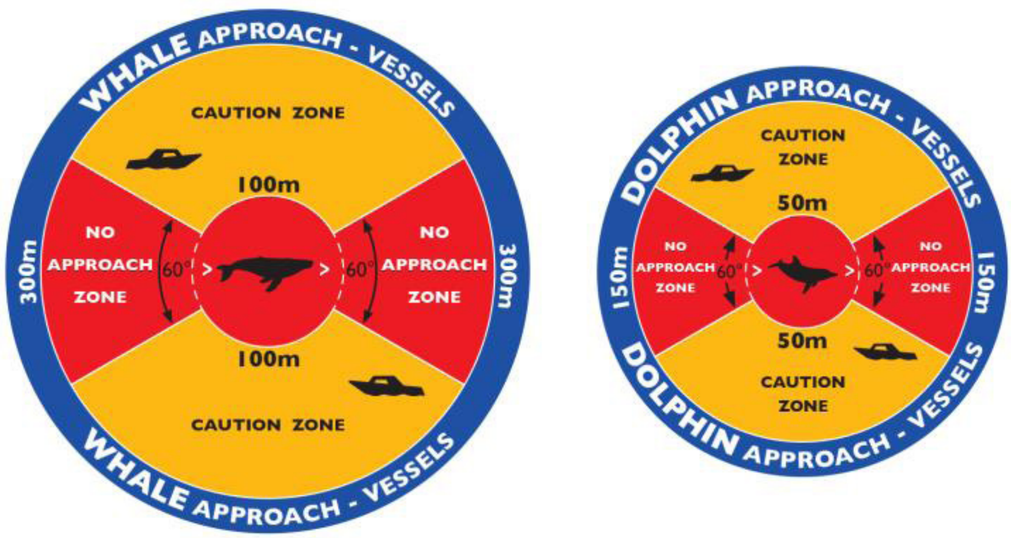


Figure 4.11 Recommended approach distances for vessels to whales and dolphins (Marine Conservation Program, DPIPWE).

5

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6

Appendices

Appendices

Appendix A – Sampling overview

The Derwent Estuary Program (DEP) coordinates monthly ambient water quality monitoring as a cooperative initiative between the Tasmanian Government, Nyrstar Hobart and Norske Skog Boyer. The principle objectives of this monitoring program are to:

- Coordinate and better integrate existing monitoring activities.
- Compile and interpret water quality data.
- Report on water quality conditions and trends.
- Provide water quality data to support informed assessment and management.
- Support scientific investigations into physical, chemical and ecological processes.

Currently, estuarine water quality sampling is conducted on the third Tuesday of each month at 29 sites between New Norfolk and the Iron Pot (**Figure 1.3**). Samples are collected by Norske Skog Boyer (upper estuary), Nyrstar (mid-estuary), and the Derwent Estuary Program with the Environment Protection Authority (EPA) (lower estuary and Ralphs Bay). At each site, field data is collected on site using calibrated sensors, which record temperature, salinity, pH and dissolved oxygen. Field turbidity was also recorded at all sites sampled by the DEP. In situ field measurements were collected at the surface (<0.5 m water depth), then at 1 m intervals to 10 m depth, at 5 m intervals between 10 m and the bottom, with a final measurement at 0.5 m above the seabed. Water clarity was also measured at each site using a Secchi disc.

Water samples are collected at most sites from the surface (~0.5 m below the water surface) and bottom (~0.5 m above the benthos) for laboratory analysis of combined ammonia+ammonium (total ammonia nitrogen, TAN), combined nitrite+nitrate (NO_x), total nitrogen (TN), phosphate (also referred to as dissolved reactive phosphorus, DRP), total phosphorus (TP), true colour, total suspended solids (TSS), total organic carbon (TOC, measured as non-purgable organic carbon) and total zinc. Depth integrated samples are collected using a Lund tube (Talling and Lund, 1957) for laboratory analysis of chlorophyll-a. Samples are placed in an insulated cool-box containing ice before taking them to the laboratory immediately upon completion of the sampling event. All laboratory analysis is conducted by the NATA-accredited laboratory Analytical Services Tasmania.

The following is a list of exceptions:

- All Nyrstar sites were also sampled for total cadmium, copper, lead, mercury and iron.
- Zinc data collected from Nyrstar sites prior to September 2011 have been omitted as samples were analysed at another lab and the data were not considered comparable.
- Sampling for the suite of laboratory analyses at Nyrstar sites NTB5, PWB, U3 and U5, and DEP sites G2 and KB, commenced in November 2010.
- DEP sites B5, C, RB, RBS, SC, CB, LB were sampled for in situ parameters and Secchi depth only.
- Norske Skog Boyer collected in situ physical and chemical data for surface and bottom (~0.5 m above the benthos) depths only, not full water column profiles.

Appendix B – Quality Assurance and Quality Control

Quality Assurance (QA) is the process whereby field sampling and laboratory activities are carried out in a way that ensures accurate and reliable results. The DEP monitoring program achieves this through the use of standard operating procedures that are used by all sampling teams. The DEP also coordinates regular inter-calibration exercises with sampling teams to ensure consistency of sampling method and functionality of physic-chemical multi-probes. All water samples are analysed by Analytical Services Tasmania (AST), a NATA-accredited laboratory, to ensure consistency of analytical method.

Quality Control (QC) is a set of activities or techniques used to ensure that quality assurance procedures are effective. Specific control samples are used to achieve this, including the use of an artificial seawater standard prepared by AST as the nutrients blank and deionised water as the metals blank. These blanks are handled as if they were collected from the field, that is, for nutrients filtered and transferred into a laboratory supplied sample vial and for metals transferred to another sample container. This process identifies any possible sources of contamination that may occur during sample collection. Trip blanks consist of sample bottles that are not opened, but are handled and stored in the same manner as other samples, and are indicative of sample changes that may occur due to storage and transport effects.

Appendix C – Nutrients

All nutrient concentrations were determined at Analytical Services Tasmania (AST) by flow injection analysis. This includes the following parameters, where bold terms are the terms generally used throughout this report:

Phosphate: PO_4, also referred to as dissolved reactive phosphorus (DRP), filtered sample (0.45 μm), mgP/L

Total phosphorus (TP): unfiltered sample, mgP/L

Nitrate: NO_3, filtered sample (0.45 μm), mgN/L

Nitrite: NO_2, filtered sample (0.45 μm), mgN/L

Nitrate + nitrite: NO_x, filtered sample (0.45 μm), mgN/L

Total ammonia nitrogen (TAN): combined ammonia (NH_3) + ammonium (NH_4), filtered sample (0.45 μm), mgN/L

Total Kjeldahl nitrogen (TKN): organic nitrogen (Norg) + TAN, unfiltered sample, mgN/L

Total nitrogen (TN): Determined as the sum of TKN and NO_x (mgN/L)

Dissolved inorganic nitrogen: NO_x+TAN (mgN/L)

Current reporting limits and measurement uncertainties are outlined in Table 7 (AST, 2020).

Table 7 Limits and measurement uncertainties (AST, 2020)

Water Analyte	Reporting limit concentration (mg/L)	Measurement Uncertainty
Total Ammonia Nitrogen (TAN, NH_3+NH_4)	0.005 mgN/L	±15% or ±0.005 mgN/L, whichever is greater
Nitrate (NO_3)	0.002 mgN/L	±15% or ±0.002 mgN/L, whichever is greater
Nitrite (NO_2)	0.002 mgN/L	±10% or ±0.002 mgN/L, whichever is greater
Nitrate + Nitrite (NO_x)	0.002 mgN/L	±15% or ±0.002 mgN/L, whichever is greater
Dissolved Reactive Phosphorus (DRP)	0.003 mgP/L	±20% or ±0.003 mgP/L, whichever is greater
Total Kjeldahl Nitrogen (TKN)	0.10 mgN/L	±23% or ±0.10 mgN/L, whichever is greater
Total Nitrogen (TN)	0.10 mgN/L	±23% or ±0.10 mgN/L, whichever is greater
Total Phosphorus (TP)	0.01 mgP/L	±28% or ±0.01 mgP/L, whichever is greater

Appendix D – Isotope analysis

Isotope analysis is the determination of isotope ratios (e.g. $^{13}C/^{12}C$, $^{15}N/^{14}N$) using mass spectrometry. Collected sediment samples were dried, ground and analysed using flash combustion isotope ratio mass spectrometry (*varioPYRO* cube coupled to an *Isoprime100* mass spectrometer) at the Central Science Laboratory, UTAS. Stable isotope values are reported in the internationally accepted delta notation (δX(‰)=((Rsample/Rstandard)-1) x1000), where X = ^{13}C or ^{15}N, and R = the ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$ of sample and standard) with respect to the international reference materials for carbon (Pee Dee Belemnite) and nitrogen (atmospheric air). Values are reported in permil and instrumental precision is 0.03% and 0.09% for total nitrogen and total carbon percentages, and 0.1‰ and 0.1‰ for delta values, respectively.

Appendix E – Data

DEP manages a long-term data sets on behalf of DEP Partners. Upon approval, data is available for research and other projects. Please contact the DEP for details www.derwentestuary.org.au/contact-us.

Appendix F – Maps

Maps throughout this document were created using the free Open Source QGIS software package (QGIS.org, 2020).

Base maps were reproduced using the Orthophoto dataset from theLIST ©State of Tasmania. Local Government Areas, CFEV Rivers and CFEV Sub-Catchments datasets from theLIST ©State of Tasmania. Landuse 2015 dataset from https://dpipwe.tas.gov.au/agriculture/land-management-and-soils/land-use-information ©State of Tasmania. Water Entitlements dataset from WIST ©State of Tasmania.

Mapping of monitoring sites has been undertaken using a hand-held GPS, and in some cases approximate locations. Consequently, spatial datasets should be considered as indicative only.

Isosurface (heat) maps were created using the free software Ocean Data View (Schlitzer, 2018) using the DIVA (Data-Interpolating Variational Analysis) gridding function (Troupin *et al*., 2012).

Acronyms

ACE	CRC Antarctic Climate Ecosystem Cooperative Research Centre
AMR	Antimicrobial Resistance
ANZECC	Australian New Zealand Environmental and Conservation Council
ANSTO	Australian Nuclear Science and Technology Organisation
ARC	Australian Research Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AST	Analytical Services Tasmania (Tasmanian Government)
AUSRIVAS	Australian River Assessment System
AWQ	Ambient Water Quality
BC	Brighton Council
BOD	Biochemical Oxygen Demand
BoM	Bureau of Meteorology
CAP	Derwent Estuary Conservation Action Plan
CCC	Clarence City Council
CCTV	Closed Circuit Television
Chl-a	Chlorophyll-a
CMR	Capture-Mark-Release
COD	Chemical Oxygen Demand
CoH	City of Hobart
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DA	Development Application
DCP	Derwent Catchment Project
DEP	Derwent Estuary Program
DEWC	Derwent Estuary Weed Collaboration
DIC	Dissolved Inorganic Carbon
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DIVA	Data-Interpolating Variational Analysis
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DoH	Department of Health (Tasmanian Government)
DOM	Dissolved Organic Matter
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DPIPWE	Department of Primary Industries, Parks, Water and Environment (Tasmanian Government)
DRP	Dissolved reactive phosphorus
DVC	Derwent Valley Council
EAC	East Australian Current
EMF	Environmentally Friendly Moorings
EMPCA	*Environmental Management and Pollution Control Act 1994*
EPA	Environment Protection Authority
ESC	Erosion and Sediment Control
EZ	Electrolytic Zinc
FST	Faecal Source Tracking
FRDC	Fisheries Research and Development Corporation
FRP	Filtered reactive phosphate
FSANZ	Food Standards Australia New Zealand
GCC	Glenorchy City Council
GIS	Geographical Information Systems
GPTs	Gross Pollutant Traps
IMAS	Institute for Marine and Antarctic Studies
IPS	Interim Planning Scheme
IPCC	International Panel on Climate Change
IPWEA	Institute of Public Works and Engineering Australia
IUCN	International Union for Conservation of Nature
KC	Kingborough Council
LGAT	Local Government Association of Tasmania
LiDAR	'Light Detecting and Ranging' technique
LIST	Land Information Services Tasmania (theLIST website: www.thelist.tas.gov.au)
LPSs	Local Provisions Schedules
MCP	Marine Conservation Program
MFDP	Marine Farm Development Plan
MAST	Marine and Safety Tasmania
MLE	Multiple Lines of Evidence
NESP	National Environmental Science Program
NHRT	National Handfish Recovery Team
NOx	Nitrate and nitrite
NRM	Natural Resource Management
NTU	Nephelometric Turbidity Units

NWQMS	National Water Quality Management Strategy
ODV	Ocean Data View
OM	Organic Matter
PAG	(Derwent estuary) Penguin Advisory Group
ppt	parts per thousand
PHL	Public Health Laboratory (Tasmanian Government)
POMS	Pacific Oyster Mortality Syndrome
POWB	Prince of Wales Bay
PWS	Department of Parks and Wildlife Service (Tasmanian Government)
RDC	Refractory Detrital Carbon
RDN	Refractory Detrital Nitrogen
RHMP	River Health Monitoring Program
RWUS	Rural Water Use Strategy (Tasmanian Government)
RWQ	Recreational Water Quality
SNDWG	Stormwater in New Developments Working Group
SD	Secchi (Disk) Depth
SPPs	State Planning Provisions
SPWQM	State Policy on Water Quality Management
SSMPs	Stormwater System Management Plans
STP	Sewerage Treatment Plants
SWTF	Stormwater Taskforce
TAC	Tasmanian Aboriginal Centre
TasPorts	Tasmanian Ports Corporation
TAS	Total Ammonia Nitrogen
TASVEG	Tasmanian vegetation map (Tasmanian Vegetation Monitoring & Mapping Program, DPIPWE)
TOC	Total Organic Carbon
TN	Total Nitrogen
TN MAR	Total Nitrogen Mass Accumulation Rate
TP	Total Phosphorus
TPAG	Tasmanian Penguin Advisory Group
TPS	Tasmanian Planning Scheme
TSS	Total Suspended Solids
UTAS	University of Tasmania
WHO	World Health Organization
WIMS	Water Information Management System
WIST	Water Information System of Tasmania
WQIP	Water Quality Improvement Plan
WSUD	Water Sensitive Urban Design
WWTP	Wastewater Treatment Plant


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