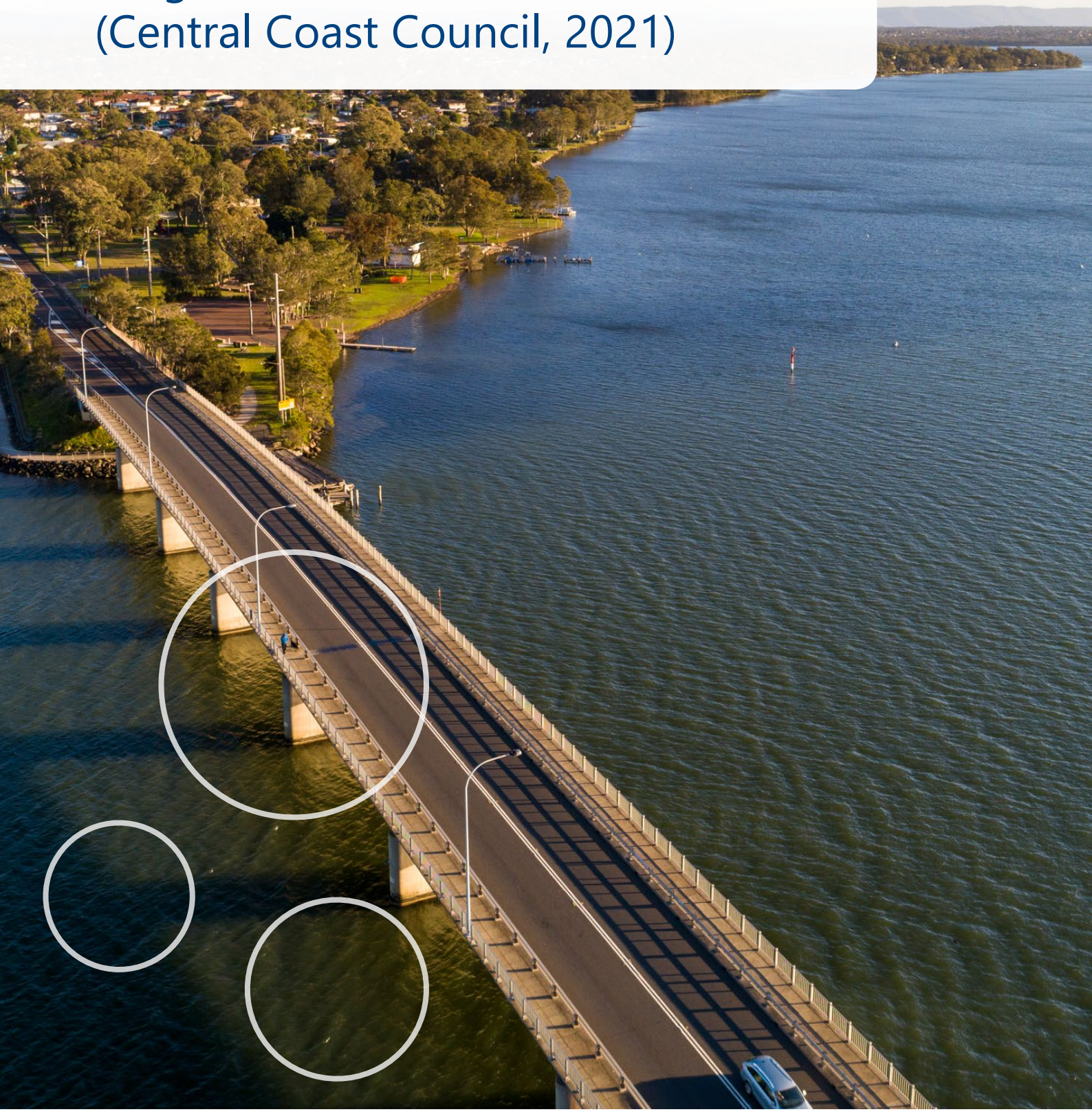
Appendix D

Tuggerah Lakes Coastal Management Program – Environmental Context (Central Coast Council, 2021)



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1. Introduction and overview

Tuggerah Lakes is located on the Central Coast of New South Wales, Australia and forms part of the traditional Country of our First Nations People. Whilst known by different common names, Tuggerah Lake, Budgewoi Lake and Lake Munmorah are collectively known as Tuggerah Lakes and are defined as a "**wave dominated estuary**" of the type **"intermittently closed or open lakes or lagoons" (ICOLLs)**. In 2020, the Tuggerah Lakes Expert Panel highlighted the historic confusion around the name and classification with reference to lakes, lagoons etc. For the sake of this report, the estuarine areas including the brackish feeder rivers and creeks, saltmarshes, low lying foreshores, water bodies and the entrance will be referred to as **"the estuary"**. The broader area of land including freshwater rivers and creeks, coastal wetlands, floodplains, valleys and the plateau will be referred to as **"the catchment"**.

The **Tuggerah Lakes Expert Panel Final Report (Glamore et. al., 2020**) details the environmental characteristics of the estuary including physical features and processes, habitat extent and health, catchment characteristics and pressures, and potential climate change impacts. Readers are encouraged to review the findings of the Tuggerah Lakes Expert Panel, which represents the most comprehensive recent summary of research and scientific understanding of the Tuggerah Lakes estuary and includes significant input from the local community.

This supplementary report accompanies the Stage 1 Tuggerah Lakes Coastal Management Program (CMP) Scoping Study and has been prepared to satisfy the requirements of the Coastal Management Manual and CMP Checklist and to explore the contemporary understanding of the complex and integrated processes, stressors and environmental conditions present in Tuggerah Lakes today.

2. Physical features and coastal processes

The Tuggerah Lakes estuary comprises three shallow, interconnected coastal waterbodies, namely Tuggerah Lake, Budgewoi Lake and Lake Munmorah which are open to the ocean via a heavily shoaled entrance located in the suburb of The Entrance. The entrance channel is naturally variable and has never been considered formally navigable. Tuggerah Lakes is the eighth largest estuary in NSW, occupying an area of approximately 81 square kilometres (OEH, 2013) in total comprising approximately 58.95 square kilometres for Tuggerah Lake, 13.88 square kilometres for Budgewoi Lake and 8.26 square kilometres for Lake Munmorah (OEH, 2013).

The typical water level resides between 0.2 and 0.4m AHD (above sea level) (WMA Water, 2014) with a normal storage volume of approximately 172,000 megalitres and under these conditions, average depths are 3.0m, 2.0m and 2.5m for Munmorah, Budgewoi and Tuggerah Lakes respectively (Glamore et. al., 2020).

The Tuggerah Lakes catchment is traversed by a network of large and small permanent and ephemeral tributaries and feeder streams including Wyong River and Ourimbah Creek which collectively make up 75% of the catchment (Cardno, 2008), as well as several smaller tributaries including Wallarah Creek, Tumbi Creek and Saltwater Creek. Wyong River and Ourimbah Creek form an important part of the **Central Coast Water Supply Network**.

The vast majority of inflow is derived from the catchment during rainfall events that are sufficient to produce overland flow. Recent estimates indicate an average annual flow in the order of 193,000 megalitres per annum (OEH, 2013). Tidal flows are estimated to exchange, on average, 1% of the lake volume every day (while the entrance is open), causing a gradual increase in lake salinity during dry periods. Oceanic water is only apparent in the channels of the entrance compartment during

flood tides, as wind-driven processes rapidly mix and disperse flood tide flows entering the lake basin (Glamore et. al., 2020). The flushing effect of the entrance alone reduces with distance from the entrance such that current estimates of average retention time are 220 days, 460 days and 520 days for Tuggerah Lake, Budgewoi Lake and Lake Munmorah respectively (OEH, 2013). It is envisaged that these will be further refined during the model calibration proposed in the CMP Forward Program (refer to **Section 5.3** in CMP Scoping Study).

The estuary is slowly infilling (approx. 1.42mm/yr) (Roy and Peat, 1973) with catchment derived sediment which is predominantly delivered via the major tributaries. This process is gradual, and despite common perception, is relatively imperceptible in most places. A recent bathymetric survey of the southern basin of Tuggerah Lakes found relatively little difference between 1975 and present day (DPIE, 2021).

Shallow deltas have formed at the mouth of each tributary, and to a lesser extent at the end of large stormwater drains, however much of the incoming sediment is fine-grained and is carried into the deeper basins where it is deposited as estuarine mud. The sediments along the eastern fringes of all lakes are sandy and of marine origin (i.e. quartzose), having mixed with muddier sediments and organic material over time. The basins are generally comprised of muddier material that is easily resuspended by wind and wave action, whilst the western fringes typically consist of bed material of catchment origin (i.e. lithic). This material is delivered by the larger tributaries and reworked along the shorelines over time.

Water circulation and flushing are primarily controlled by the mixing of freshwater runoff from the main rivers and creeks with oceanic water during flood events, and more gradually in response to above- and below-average rainfall periods over seasonal to annual timescales (Glamore et. al., 2020). Wind-driven mixing and wave action serves to break down any lateral or vertical water quality gradients and can cause significant variations in water quality over hourly to daily timescales (e.g. rapid increases in turbidity during windy days). Notably, mixing and flushing between zones is constrained as described below.

2.1. Anthropogenic impacts - a timeline of change

Under natural, pre-European conditions, the estuary was well vegetated, with significant infiltration of rainfall and evapotranspiration, relatively slower movement of water through the catchment, substantially lower nutrient loads (which were also generally less bio-available), expansive seagrass beds and higher energy, sandier shorelines (**Figure 1**).

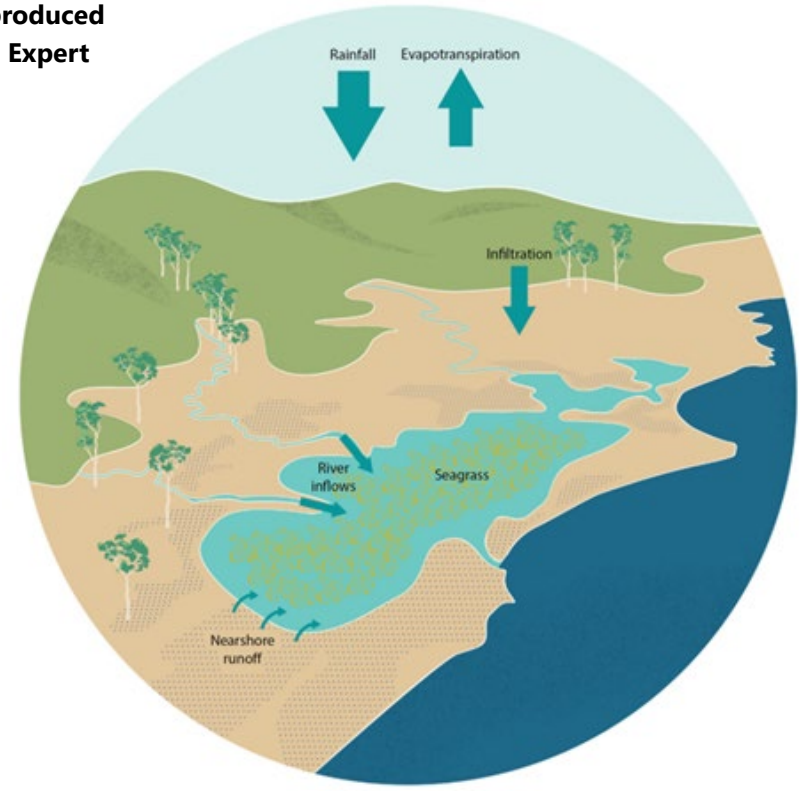
The history of natural and anthropogenic change is well documented (CSIRO, 1998; Scott, 2002; Bio-Analysis, 2006; Waddell, 2018; McCann, 2019; TLEP, 2020). 200 years of European settlement, industry and urban development in the Tuggerah Lakes catchment have all had significant, long-term impacts on the local ecosystem. Whilst this period of change brought great opportunity, it simultaneously placed ever increasing pressure on the natural environment. Like most urban estuaries, the major effects of the development have included:

- a loss of vegetation from land clearing
- altered water flows from the changed land use, and
- stormwater pollution (including natural and chemical pollutants and litter).

Before the area became densely populated, forests covered the catchments of Wyong River, Ourimbah Creek, as well as Wallarah, Spring, Tumbi and Saltwater Creeks. The period between the 1800s and 1900s marked a swift transformation from the natural to the cultivated landscape. People continuously cleared the land for agriculture and timber harvesting, which among other things, resulted in a marked increase in soil erosion. Loss of vegetation affects a range of important natural functions including infiltration, evapotranspiration, carbon storage, soil stability, soil chemistry, groundwater permeability, groundwater quality, watercourse planform, habitat connectivity and biodiversity.

As human activity continued and accelerated, the patterns of water flowing over the land and into the estuary changed further. Thick forests in the

Figure 1: A simple conceptual catchment model of natural conditions in Tuggerah Lakes (reproduced with permission from the Tuggerah Lakes Expert Panel).



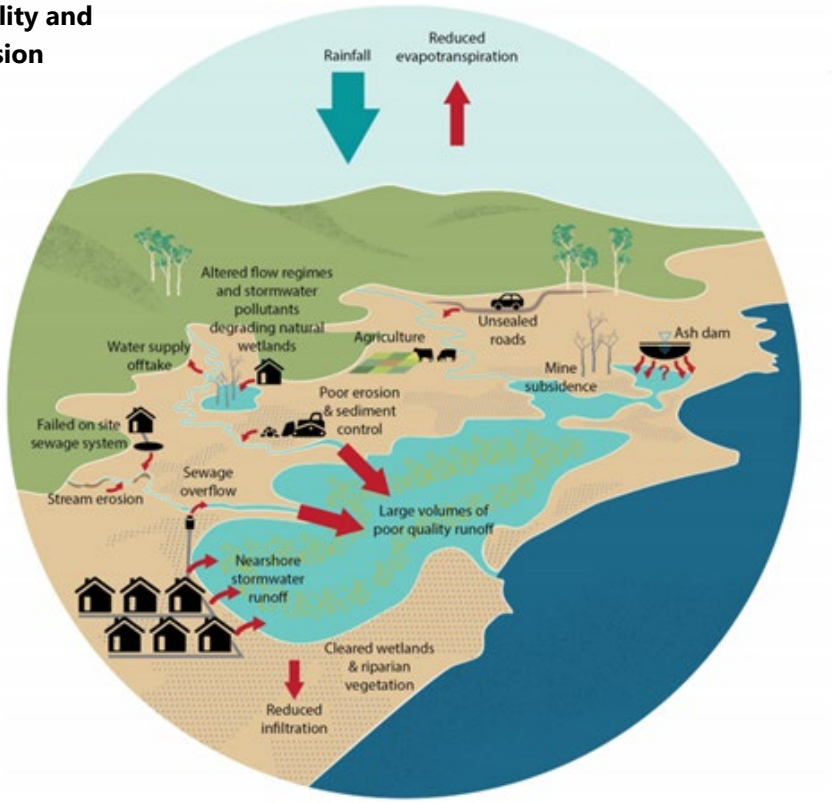
valleys transitioned to pastures, and the wetlands and woodlands of the floodplains and lowlands transformed into urban, industrial and commercial hubs. Water supply storage and offtake further altered hydrology whilst this intensive development increased the amount of hard surfaces – roofs, roads and pathways – significantly reducing infiltration, changing flow pathways and modifying the volume and seasonality of flows.

The growing industrial and commercial activity resulted in higher loads of organic and inorganic materials settling in the estuary than would have ever occurred naturally. This included sediment coming from erosion, sewage effluent, chemicals and nutrients from plant fertilisers, cleaning products and organic matter, e.g. animal manure or plant material such as grass clippings. These pollutants were harmful to the overall health of the estuary and their presence contributed to reduced water clarity and an ideal microclimate for excess macroalgae to grow. They also contributed to the increase of black ooze in the nearshore zones and reduced the available habitat for seagrasses through the middle of the estuary.

Whilst a better understanding of estuary processes, human impacts and drivers of change has been developed, a broad range of catchment improvements undertaken, and incremental improvements observed, coordinated plans, broad engagement, and transparent actions are essential to improve existing estuary management and plan for a sustainable future.

Figure 2 provides a conceptual model of the current and future pressures on the water quality and ecological health of Tuggerah Lakes.

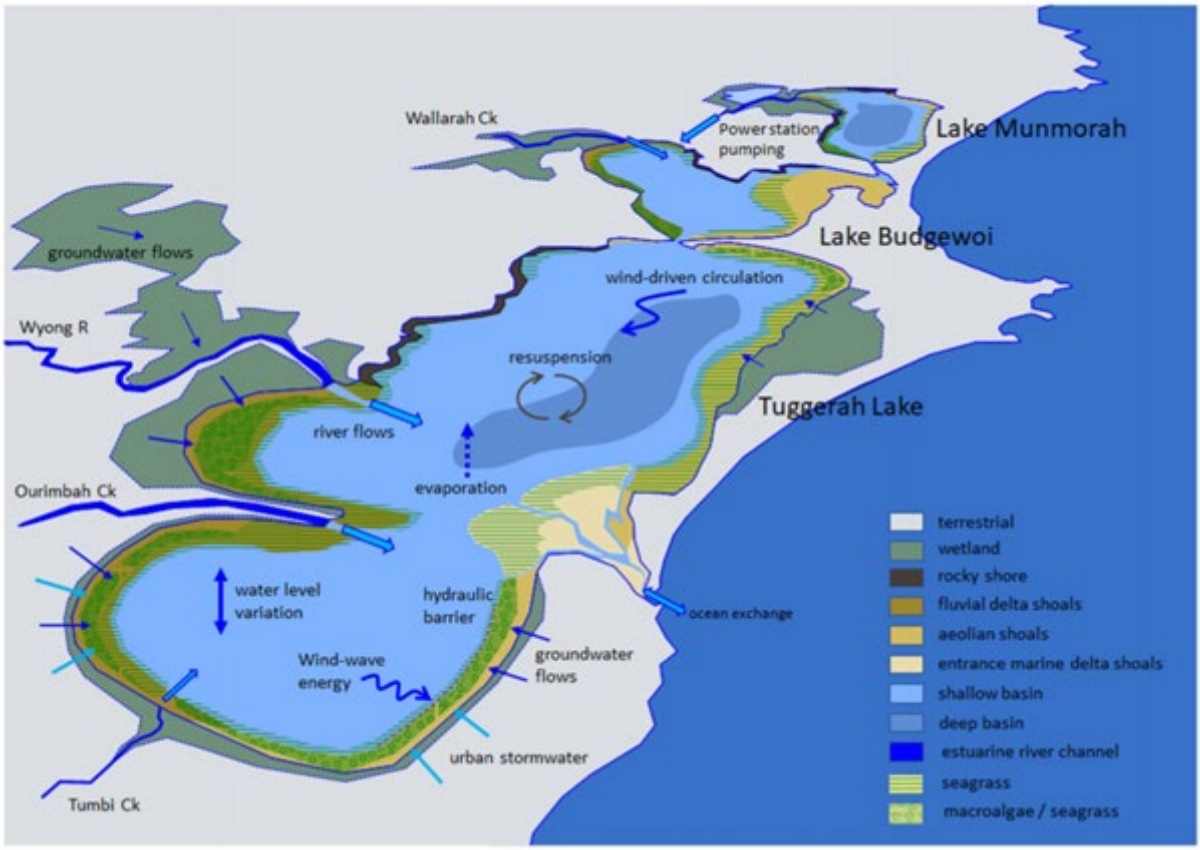
Figure 2: A conceptual catchment model of existing and future pressures on water quality and ecological health (reproduced with permission from the Tuggerah Lakes Expert Panel).



2.2. Functional zones and key ecological processes

Several functional zones have been identified within the estuary, namely fringing coastal wetlands, estuarine river channels, soft-sediment nearshore zones, rocky nearshore zones, open basin zones and the entrance compartment **(Figure 3**). Water quality and ecological health is controlled by the interaction between these zones.

Figure 3: Functional zones of Tuggerah Lakes (reproduced with permission from the Tuggerah Lakes Expert Panel)

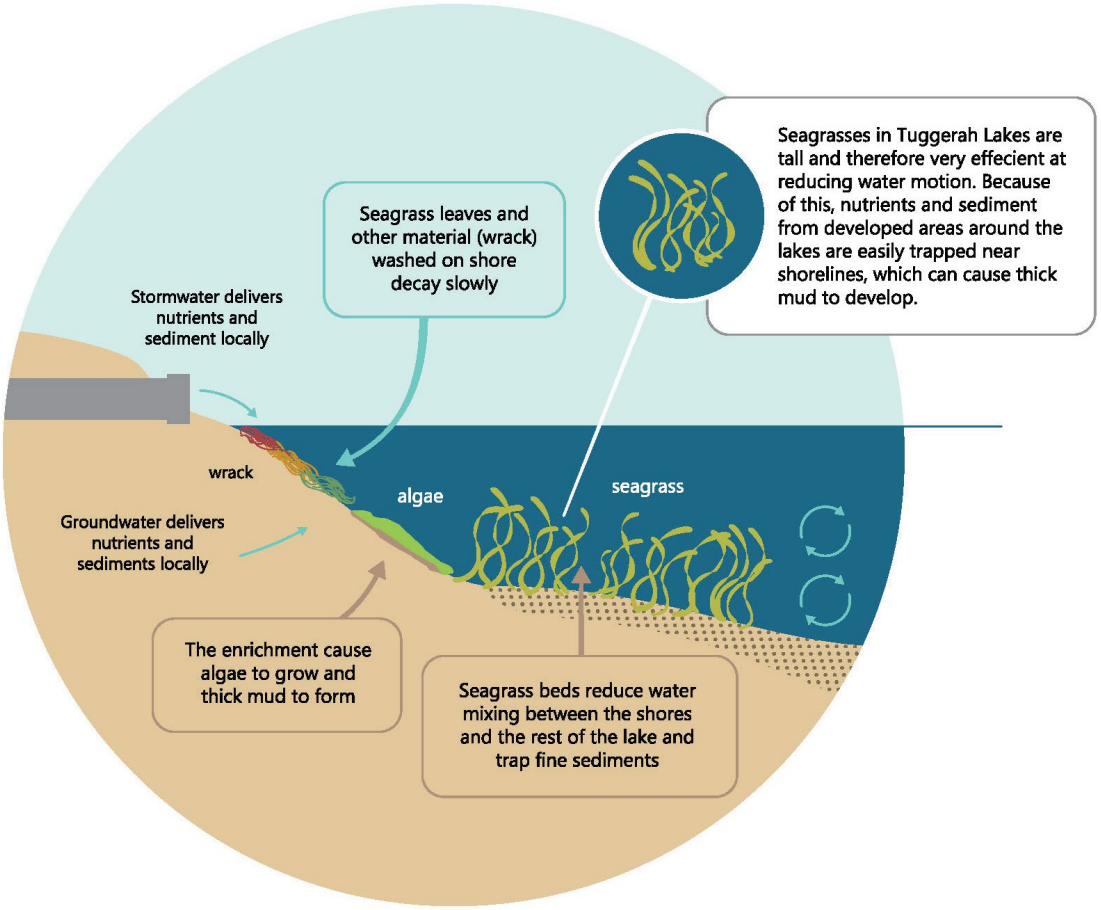


A key finding of recent research, modelling and in-situ observation is that a distinct, physical barrier is present between the nearshore zone (the fringing areas of water on the edges) and open basin zone (the middle areas) in many parts of the estuary (OEH, 2013, Glamore et. al., 2020). This phenomenon, described as "hydraulic decoupling", has increased in magnitude over time and is largely driven by historic landward migration of seagrass and macroalgae along with increased seagrass leaf length which effectively limits the natural rate of mixing between the zones (OEH, 2013). In addition, historic shoreline reclamation and modification, reduced natural water level variation, enriched groundwater and concentrated stormwater pollutant loads collectively contribute to poorer water quality, eutrophication and organic enrichment of the sediment in the nearshore zone as shown in Figure 4. Typically, this effect is more prevalent in urbanised areas where pollutant loads are greater and mixing is more heavily constrained.

The work of the Tuggerah Lakes Expert Panel (TLEP), alongside other large engagement programs coordinated by Central Coast Council (Community

Strategic Plan, Let's Talk Northern Lakes, Our Coast Our Waterways etc) and anecdotal community feedback have highlighted that much of the community concern regarding water quality, ecology and aesthetics of the estuary relate to processes occurring in the nearshore functional zone. The key concerns in this zone relate to wrack accumulation, ooze formation, algal blooms and odour issues. These processes are intricately linked and the TLEP's review of the data alongside other key research (DPIE, 2013) highlights several key factors influencing these processes which need to be managed in an integrated and holistic way to achieve better outcomes. Managing any one issue in isolation is unlikely to achieve an effective outcome for either the estuary or the community. Similarly, focussing on managing the symptom instead of the cause is not likely to result in long-term sustainable improvement.

Figure 4: Nearshore processes and organic "ooze" formation



3. Sediment compartments and estuary catchment

The coastal zone within the Central Coast Local Government Area (LGA) is identified under the CM Act as being part of three coastal sediment compartments: 1) Central Coast, 2) Newcastle Coast (part) and 3) Broken Bay (part). In addition, there are two estuaries identified under the CM Act within the Central Coast LGA - 1) Lake Macquarie and 2) Hawkesbury River (part); Tuggerah Lakes is not included.

The catchment of the estuary is vast, with recent mapping indicating an area of approximately 790 square kilometres (MHL, 2021) which takes in the plateaus of Kulnura and Somersby, the river valleys of Dooralong, Yarramalong and Ourimbah and the floodplains wrapping around the waterway from Lake Munmorah to Bateau Bay. The catchment includes the population centres of Tuggerah, Berkeley Vale, Lake Haven and Toukley and is the traditional land of our First Nations People.

A wide range of land use types are present in the catchment with varying levels of intervention and potential impact on the natural landscape. Land development to the west of the M1 Motorway typically comprises lower density rural and semi-rural holdings and low intensity agriculture whilst the floodplains to the east of the M1 are heavily urbanised with remaining fragments of wetland, riparian corridor and bushland parcels throughout.

The NSW Government recently undertook a reclassification of land use type for the Central Coast region as part of the Freshwater Riverine Monitoring, Evaluation and Reporting Program (DPIE, 2021) using the Australian Land Use and Management Classification Version 8 (October 2016) (ALUMv8) as a baseline. The revised method further reviewed and redefined the classifications to provide greater spatial resolution across the Central Coast and to link more closely to the potential to impact aquatic ecosystem health.

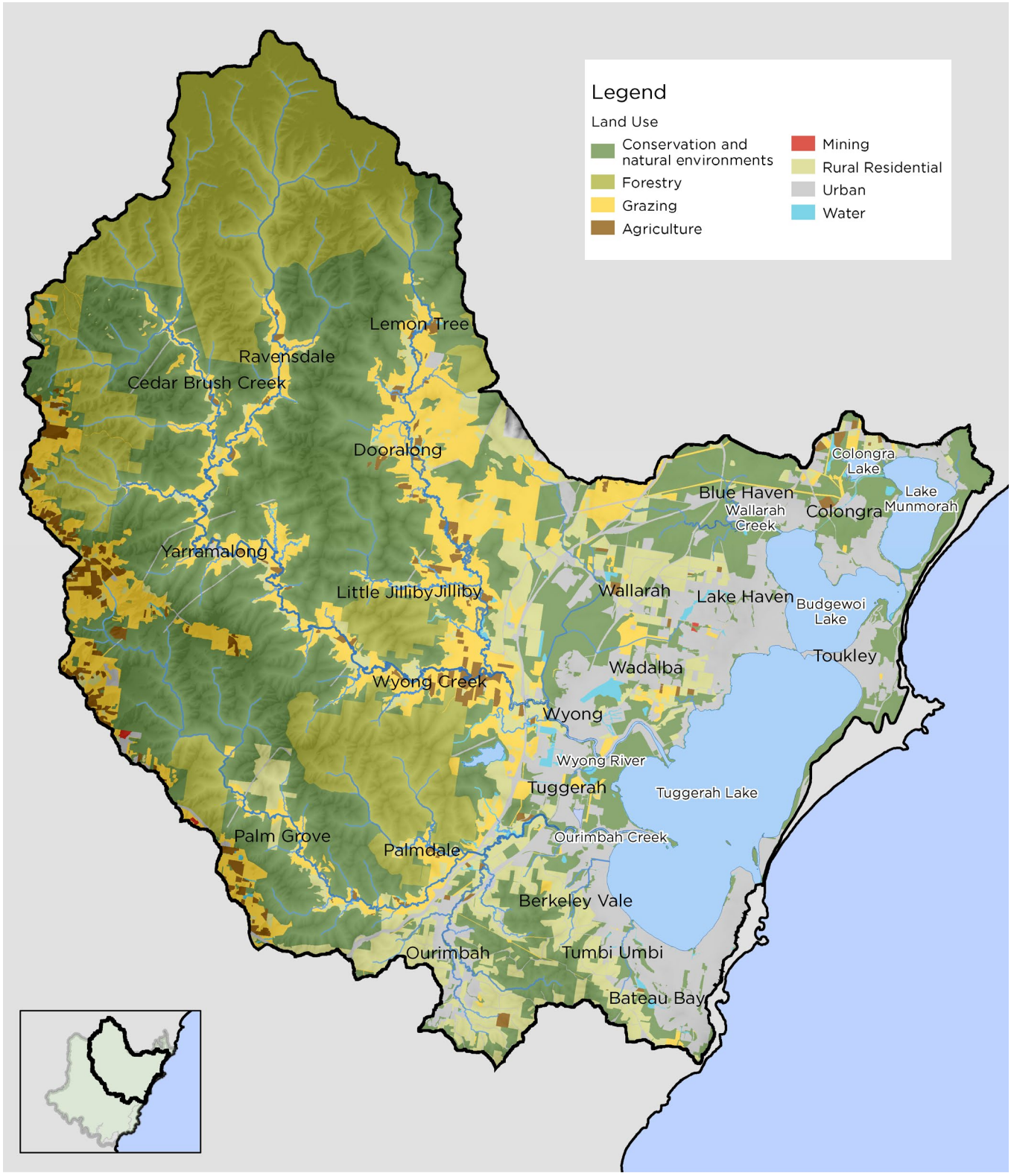
The seven proposed land use classes are as follows:

1. Conservation and natural environments
2. Forestry
3. Grazing
4. Agriculture
5. Mining
6. Rural residential
7. Urban

A map of the reclassified land use data set is provided in **Figure 5.**

Figure 5: Land use in the Central Coast Council LGA reclassified by potential for land use to impact aquatic ecosystems [Draft].

In recognition of the significance these areas play in the health and function of the estuary, the CMP will apply to the whole catchment area, not just the defined coastal zone.



4. Habitat condition and extent

The climate of the Central Coast is moist and temperate, with unpredictable and significant rainfall events. Rain usually falls as either east coast lows or as heavy spring/ summer thunderstorms. Winters are mild, especially on the coast, with only the occasional frost. Gosford, for example, has temperatures ranging from mean maxima of 18° C in winter to 28° C in summer.

Approximately 25% of the Central Coast LGA is National Park (**Central Coast Biodiversity Strategy**, Central Coast Council, 2020b) with Jilliby State Conservation Area making up a large portion of the Wyong River and Ourimbah Creek catchments and the other natural heritage areas in the region including Tuggerah State Conservation Area, Munmorah State Conservation Area, Colongra Swamp Nature Reserve and Wyrrabalong National Park.

The freshwater rivers and streams are important habitat for a range of species, including platypus, along with a range of macroinvertebrates and rainforest stream frogs, such as the stuttering frog. Riparian vegetation provides an important resource for a range of specialised aquatic and terrestrial fauna that feed along waterways (e.g. fishing bats, kingfishers, water dragons) or spend a portion of their lifecycle in the water. Riparian vegetation also provides leaf litter input to streams that forms the basis of the food chain in freshwater streams. Important freshwater streams on the Central Coast include the upper reaches of the Wyong River in Olney State Forest, the middle reaches of Ourimbah Creek in Ourimbah State Forest and the relatively undeveloped catchments of Wallarah and Spring Creeks (Central Coast Council, 2020).

Tuggerah Lakes supports a diverse and complex food web ranging from benthic microalgae living in the bed sediment and phytoplankton in the water column to the larger fish and birds that are permanent or intermittent residents of the estuary (Figure 6). The dominant macrophytes include seagrasses and seaweeds which are of ecological importance and underpin the ecological health of the system. Seagrasses are highly efficient carbon sinks, with recent research indicating these aquatic angiosperms are **40 - 50 times more efficient at storing carbon than their terrestrial equivalents** (Lavery, 2020).

Benthic organic matter including benthic microalgae forms the base of the food chain. Benthic microalgae live on the estuary bed and consume nutrients released from the sediment. They act as a nutrient source and sink providing a sustained food source for higher lifeforms (OEH, 2013).

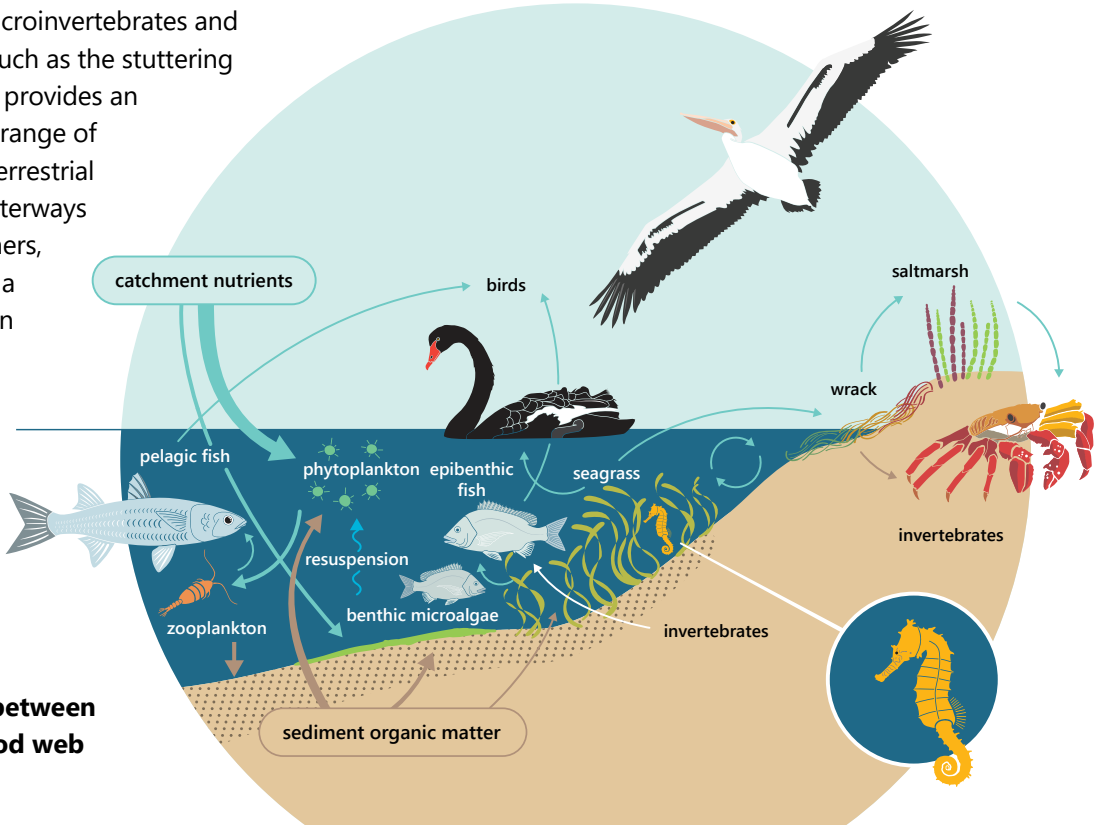


Figure 6: Interactions between the Tuggerah Lakes food web and nutrient cycling

4.1. Threatened and Migratory Species

The Tuggerah Lakes catchment extends from the Watagan Mountains in the west to the Pacific Ocean in the east and encompasses a diverse range of habitat types that are home to thousands of different flora and fauna species (Central Coast Council, 2020b). Of these, a large number are considered threatened under state and/ or federal legislation. The following table summarises the number of threatened species which have been recorded physically – either by sight or sound, within the Tuggerah Lakes estuary and catchment (NSW Government's BioNet Atlas, 2021).

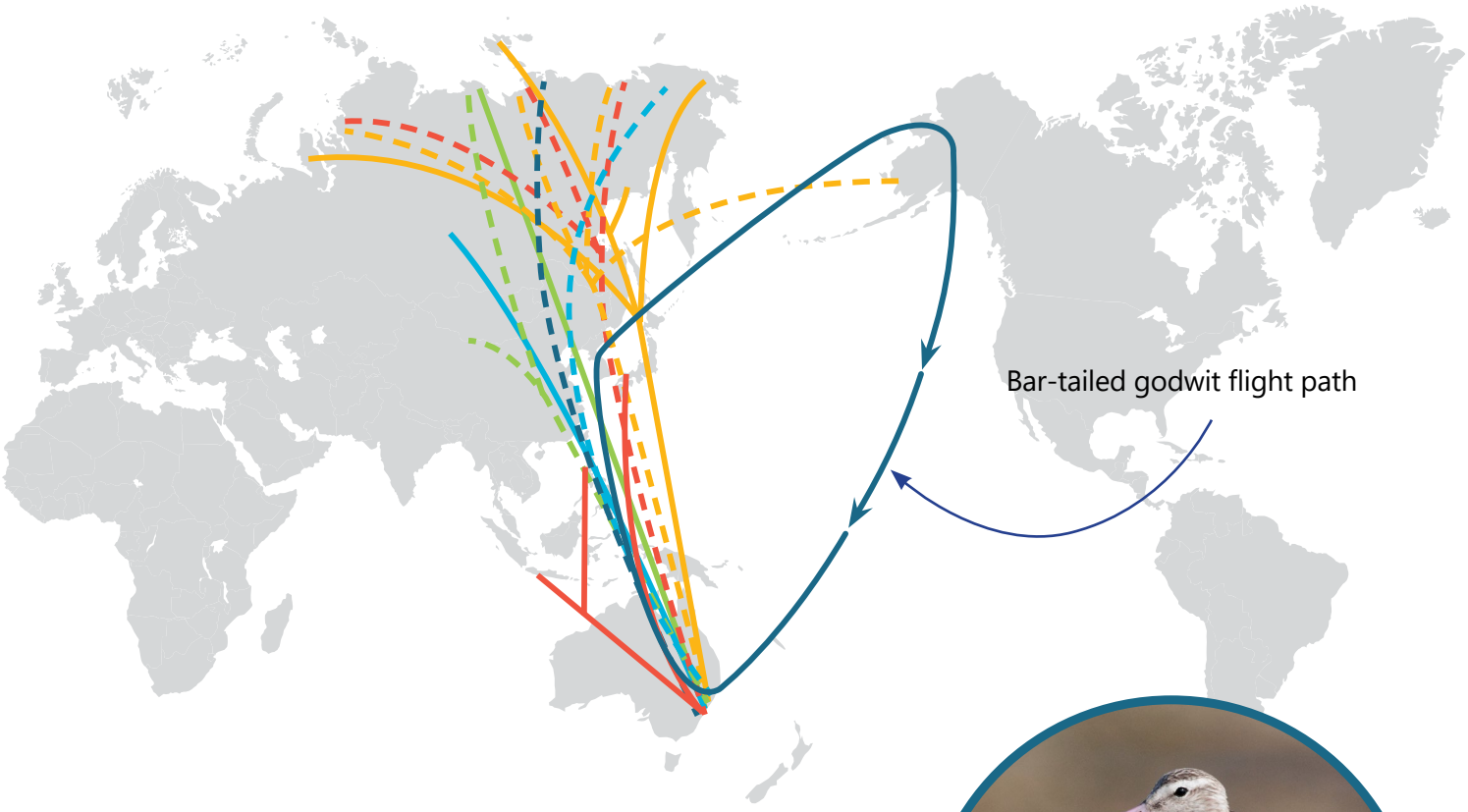
Table 6.1: Threatened Species records for the Tuggerah Lake estuary and catchment

Class	NSW Status	Commonwealth Status	Commonwealth Migratory Agreement
FLORA			
Plants	28	18	-
FAUNA			
Frogs	9	5	-
Birds	62	11	30
Insects	1	-	-
Mammals	20	8	-
Reptiles	6	4	-
Total Fauna	98	28	30

*Data for this table are compiled from NSW BioNet Atlas – May 2021. Marine/pelagic birds, seals and cetaceans removed from record count.

The estuary and catchment provides important habitat for locally threatened species and are also seasonally home to a number of threatened and/or migratory bird species. Some such as the Regent Honeyeater and Swift Parrot (both critically endangered in Australia) migrate between Australian states and territories following their preferred food sources – specific species of flowering gums. Other bird species that seasonally call the Tuggerah Lakes home are protected under bilateral migratory bird agreements between the Australian Government and China (CAMBA), Japan (JAMBA) and the Republic of Korea (ROKAMBA). The Bar-tailed Godwit is one of these protected bird species and has the longest migratory flight in the world, travelling up to 11,000 kilometres non-stop from Alaska to Australia/New Zealand in just over eight days (**Figure 7)**. Maintaining roosting and foraging habitat along these flight paths is critical to the survival of these species.

Our Lakes: important habitat for global birds



Longest flight in the world - bar-tailed godwits can fly up to 11,000 kilometres, non-stop, from Alaska to Australia/New Zealand in just over 8 days! Try flapping your arms like a bird for one minute, then imagine flapping your arms for 8 days!

Bar-tailed godwits breed in Alaska and then escape the cold winter by migrating to wetlands in the southern hemisphere such as Tuggerah Lakes. Juvenile birds make this trip at just 2 months of age! Bar-tailed godwits arrive and stay in NSW from September to March.

Tuggerah Lakes support important feeding habitat for annual bird migrations. Saltmarshes, mudflats and seagrass each provide habitat to rest and feed on molluscs, worms and aquatic insects.

Around March, bar-tailed godwits return to Alaska via important feeding grounds in China and Korea.

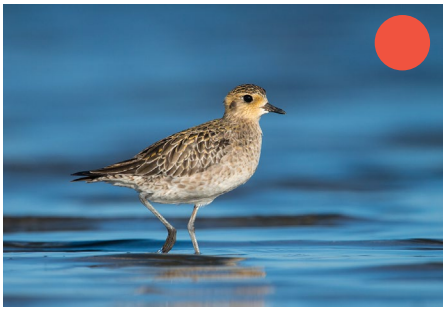
The bar-tailed godwit and its fellow shorebirds face enormous challenges for survival from pollution, the loss of habitat from coastal and estuary development, increased predation from cats and dogs and disturbance from foot and vehicle traffic.

Bar-tailed Godwit
Limosa lapponica
Length: 37-45cm

Red dots indicate which species are listed as Critically Endangered, Endangered or Vulnerable in NSW or Nationally (2021)

Check out other migratory birds known to visit Tuggerah Lakes and the Central Coast. See their amazing journeys, what they are doing here, when you might spot them and what size they are.

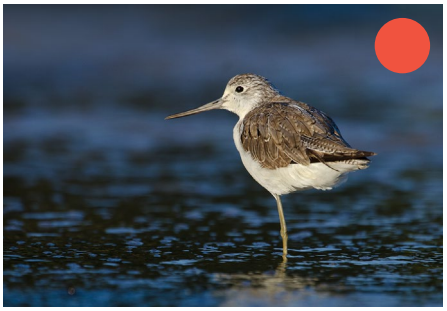
Red-necked Stint
Calidris ruficollis
In Australia from August - March
Length: 13-16cm
Non-breeding in Aus.



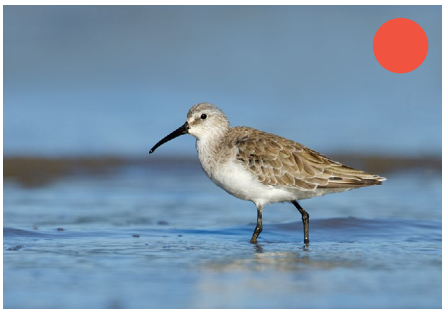
Pacific Golden Plover
Pluvialis fulva
In Australia from September - March
Length: 23-26cm
Non-breeding in Aus.

Little Tern
Sternula albifrons
In Australia from September - January
Length: 20-28cm
Breeding in Aus.

Sharp-tailed Sandpiper
Calidris acuminata
In Australia from August - March
Length: 17-22cm
Non-breeding in Aus.



Greenshank
Tringa nebularia
In Australia from August - March
Length: 30-35cm
Non-breeding in Aus.



Curlew Sandpiper
Calidris ferruginea
In Australia from August - April
Length: 18-23cm
Non-breeding in Aus.

Black-tailed Godwit
Limosa limosa
In Australia from August - March
Length: 38-44cm
Non-breeding in Aus.

Red Knot
Calidris canutus
In Australia from August - March
Length: 25-28cm
Non-breeding in Aus.

Great Knot
Calidris tenuirostris
In Australia from August - March
Length: 25-28cm
Non-breeding in Aus.

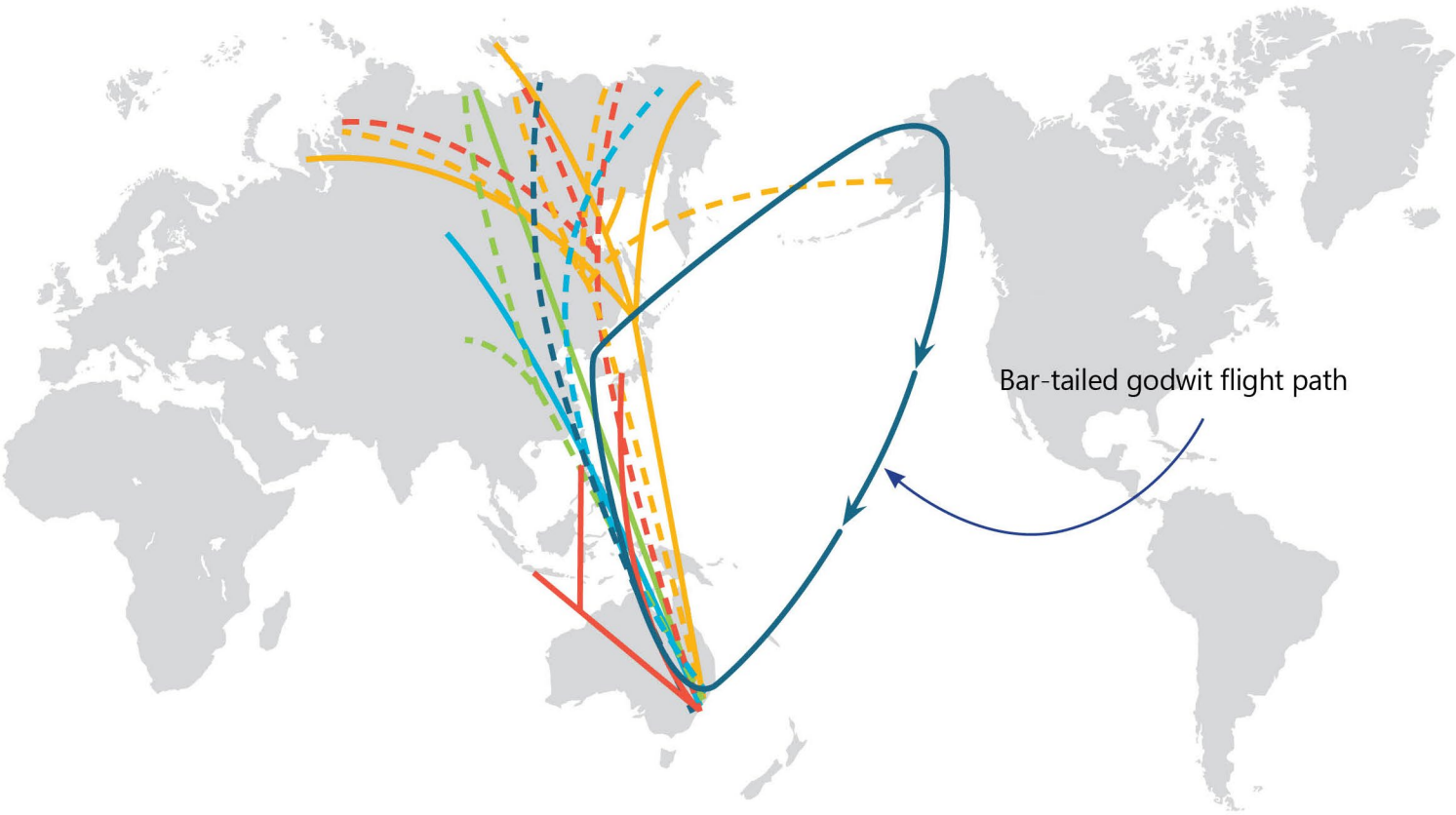


Figure 7: International flight paths of some Tuggerah Lakes migratory bird species protected under CAMBA, JAMBA and ROKAMBA international agreements.

Endangered Ecological Communities (EEC) are groups of naturally occurring native plants, animals and other organisms which have had their original extent significantly reduced. Twelve EECs have been mapped from the shorelines of the estuary to the uppermost reaches of the Tuggerah Lakes catchment including:

- Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Coastal Upland Swamp in the Sydney Basin Bioregion
- Duffys Forest Ecological Community in the Sydney Basin Bioregion
- Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Littoral Rainforest in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Low woodland with heathland on indurated sand at Norah Head
- Lower Hunter Spotted Gum Ironbark Forest in the Sydney Basin and NSW North Coast Bioregions
- Lowland Rainforest in the NSW North Coast and Sydney Basin Bioregions
- River-Flat Eucalypt Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions, and
- Sydney Freshwater Wetlands in the Sydney Basin Bioregion.

4.2. Coastal Wetlands

Coastal wetlands can be freshwater, brackish or saltwater and include marshes, swamps, lagoons and bogs. They are vegetated areas that are characterised by being waterlogged, either permanently or seasonally. A range of coastal wetlands are present in the Tuggerah Lakes catchment including the estuary itself, the surrounding saltmarshes and fringing swamp oak floodplain forests, the lowland riparian corridors and ephemeral freshwater wetlands that sprawl across the floodplain.

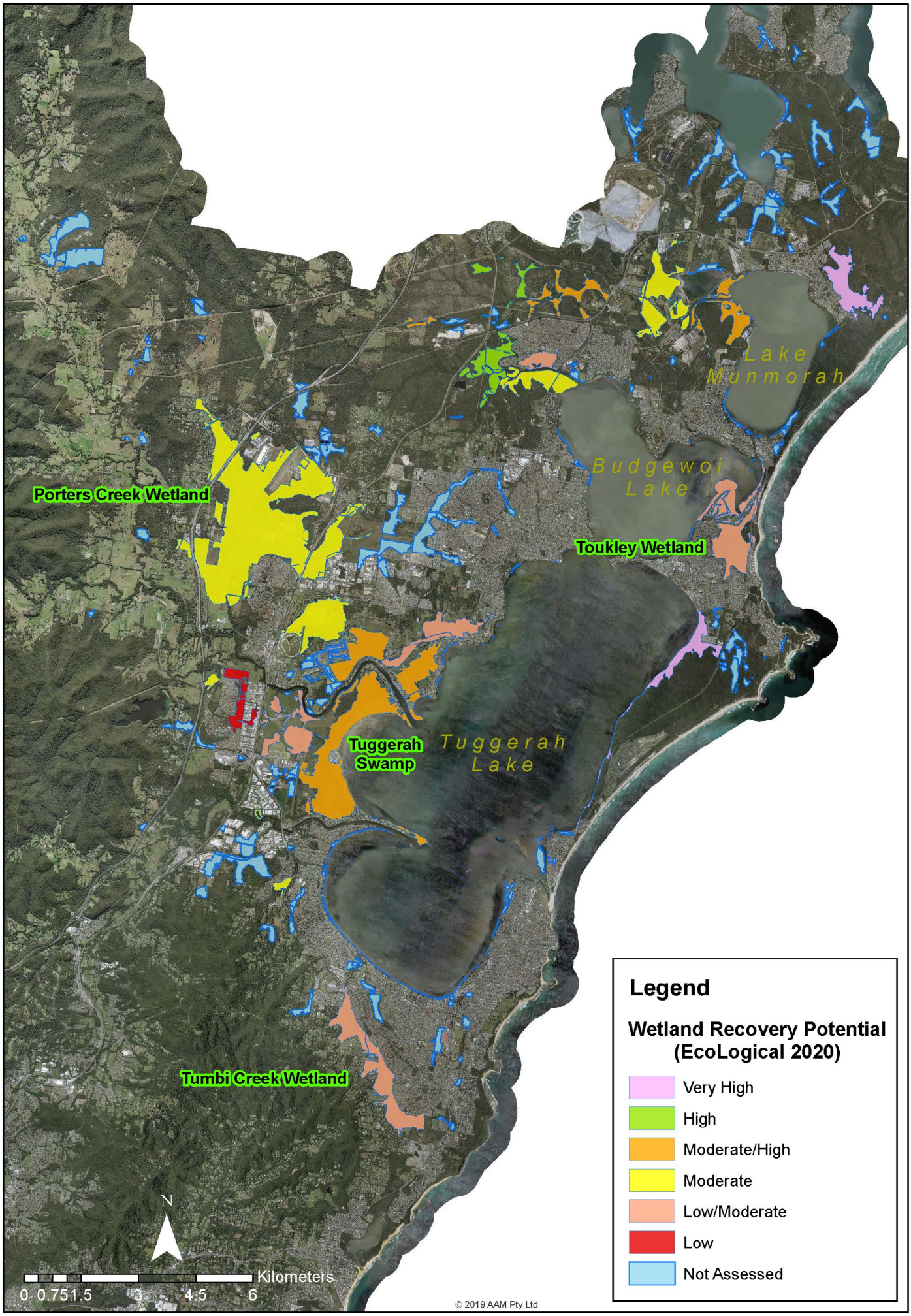
Natural wetlands play an important role in filtering water, maintaining water quality, stabilising lands, reducing flood impacts and are home to a wide variety of plants and animals. It is estimated that up to 75% of Australia's wetlands have been lost and many of the remainder are degraded. Wetlands are threatened by land clearing and filling, stormwater pollution, habitat degradation, weed invasion, increased pedestrian and vehicular traffic, feral and domestic animals, and littering.

The Tuggerah Lake catchment supports over 29 square kilometres of remnant natural wetlands, the largest of which being Porters Creek Wetland (7 square kilometres), Tuggerah Swamp (4 square kilometres), Toukley Wetland (1.7 square kilometres) and Tumbi Creek wetland (1.7 square kilometres). Over 40% of the remaining wetlands in the Tuggerah Lakes catchment are considered to have high to very high recovery potential (Australian Wetlands, 2009, Niche, 2020, EcoLogical 2020).

In 2020, Council commissioned a study to remap and assess the condition of 36 identified coastal wetlands in the Tuggerah Lakes catchment (Niche, 2020). In addition to refining the mapping, the study evaluated the condition, recovery potential and threats in each location, reviewed the efficacy of previous management actions (which have been extensive), and provided guidance on future management actions. This information will be used to update the Coastal Wetlands SEPP via a Planning Proposal and will inform the priorities and actions in Stage 3-5 of the CMP.

A map of wetland extant (remaining area) is provided in **Figure 8** with more detailed mapping available in Niche 2020, EcoLogical 2020.

Figure 8: Remaining Coastal Wetlands in the Tuggerah Lakes catchment.


Lake Munmorah
Budgewoi Lake
Porters Creek Wetland
Toukley Wetland
Tuggerah Swamp
Tuggerah Lake
Tumbi Creek Wetland
Legend
Wetland Recovery Potential (EcoLogical 2020)
Very High
High
Moderate/High
Moderate
Low/Moderate
Low
Not Assessed
N
Kilometers
0 0.751.5 3 4.5 6
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4.3. Coastal Saltmarsh

Coastal Saltmarsh is a very fragile plant community which on the shores of Tuggerah Lakes only grows within a limited elevation. Saltmarsh is a salt-tolerant, mostly treeless collection of plants consisting of low-lying succulents, rushes and sedges that grow at the water's edge where the soil moisture and salinity is maintained by surface and groundwater levels.

Coastal Saltmarsh is a fundamental component of the estuary ecosystem representing an important habitat for birds, fish and crustaceans to nest, breed and eat. In addition, saltmarsh stabilises the foreshore, filters water and naturally manages seagrass wrack. Historically, the foreshore zones of the Tuggerah Lakes were lined with Coastal Saltmarsh, Swamp Oaks (Casuarinas) and Tea Trees (Melaleucas), however foreshore modification, shoreline reclamation and other damaging activities have negatively impacted these vegetation communities and have interfered with the important coastal processes they provide.

Scientific understanding of the ecological value of Coastal Saltmarsh habitat has improved markedly over the past few decades and these important communities are now regarded as protected and significant ecological communities for the range of ecosystem service they provide including:

- Providing habitat and food for fishes, birds, insects and crustaceans that allow for bird watching and fishing in the estuary
- buffering against wind and water erosion, stabilising the foreshore and decreasing sediment entering the lake that makes it murky
- managing seagrass wrack by catching it, allowing it to dry, and naturally break down back into the ecosystem, naturally reducing unpleasant smells (Figure 9).
- filtering nutrients that are in runoff from the foreshore and stormwater that contain excess nutrients from lawn clippings, soaps and fertilisers
- capturing atmospheric carbon and storing it in the plant tissue as a carbon sink.

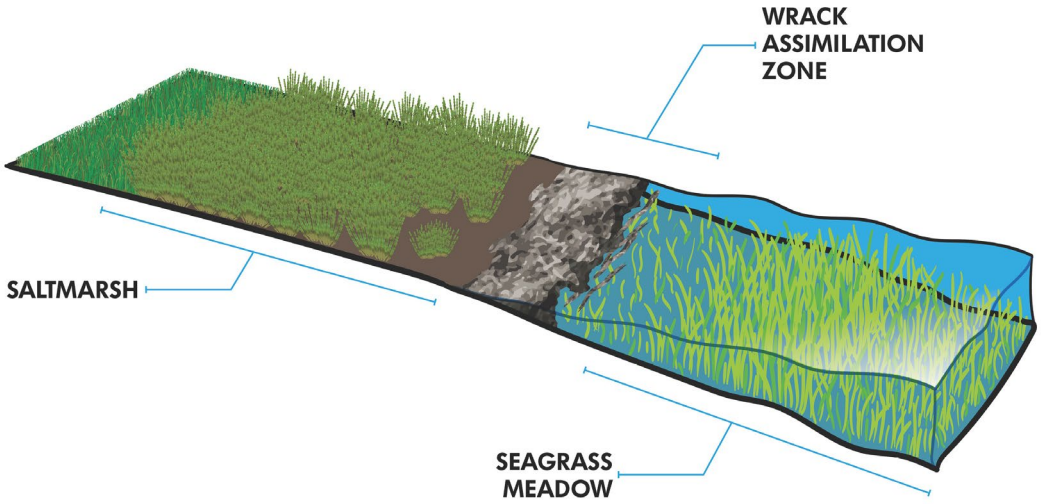


Figure 9: Wrack assimilation zone - where wrack washes on to shore to dry out on saltmarsh.

Historic estimates indicate that approximately 50% of the Coastal Saltmarsh EEC surrounding Tuggerah Lakes has been lost since European settlement (Bio-Analysis, 2006). Recent efforts to reinstate and rehabilitate saltmarshes around Tuggerah Lakes through both active reconstruction and passive restoration methods has seen more than 2.5 hectares of saltmarsh reconstructed and over 29 hectares rehabilitated. This activity is ongoing in recognition of the critical importance of these intertidal areas to both habitat and water quality.

The success of committed volunteer groups in restoring Coastal Saltmarsh should not be overlooked either – long-term dedicated groups have achieved incredible results along long stretches of shoreline and their commitment should be commended. The CMP should build on the efforts of these groups, integrating volunteerism and citizen science as key opportunities to build capacity, educate and work together towards common outcomes.

4.4. Seagrass

Three species of seagrass are found in Tuggerah Lakes, *Eelgrass Zostera muelleri subsp. capricorni*, Stackweed *Ruppia megacarpa* and Paddleweed *Halophila ovalis*. Seagrass beds are transient and will move over relatively short timeframes in response to ambient conditions such as light availability and salinity.

Seagrass provides an important habitat for recreational and commercial fish species, stabilises bed sediment, creates quiescent zones for juvenile fish and acts as an extremely efficient carbon sink (Lavery, 2020). In combination with algae, seagrasses are nutritionally important providing a substantial surface area for growth of epibiotic red, green and brown macroalgae, colonial bryozoans and calcareous polychaete worms as well as providing refuge for many adult and juvenile fish (OEH, 2011).

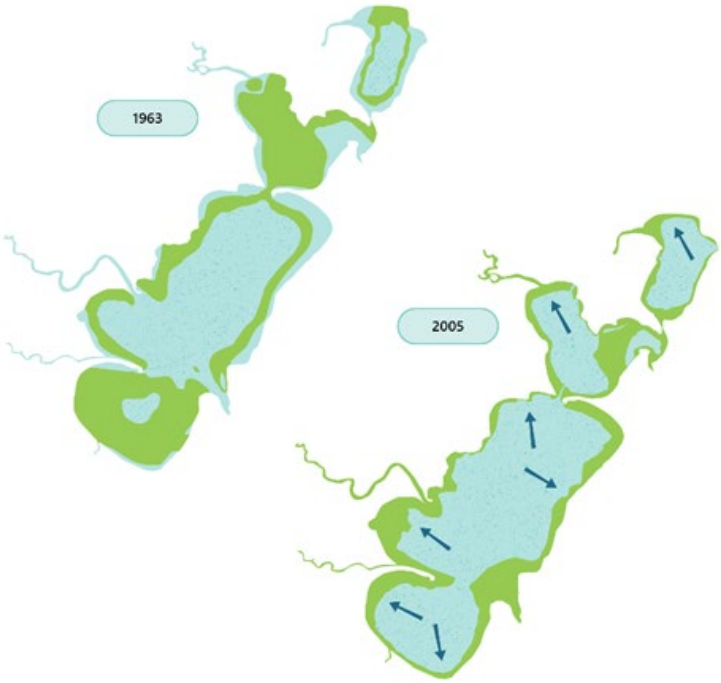
Despite their ecological importance, many aquatic macrophytes are considered nuisance species. Part of this negative perception is evident in the use of term "weed" for many of the common names and as a colloquial descriptor. The growth of microalgae, macroalgae (seaweed) and aquatic macrophytes such as seagrass is affected by a number of natural factors including temperature, nutrients, salinity, light and the presence of herbivores. Rarely do these natural factors act in isolation and it is difficult to separate their effects from human induced stressors arising due to rapid urbanisation of the catchment, recreational use of the waterway, and the high turbidity that results from the wind-driven resuspension of silt in the estuary (Glamore et. al., 2020).

Seagrass depth range is used as a system response indicator in the long-term water quality and ecological health monitoring program for Tuggerah Lakes. Despite an estimated loss of approximately 80% of seagrass extent (Bio-Analysis, 2006), mainly since the 1960s, the estuary still supports healthy and extensive communities of seagrass and macroalgae, which cover approximately 17.32 square kilometres (DPI, 2009).

Over recent decades, increased input of fine sediment from the catchment has resulted in increased turbidity in the water column and less favourable conditions for seagrass survival. This effect, paired with increased bioavailable nutrients, which contrary to popular belief has a negative effect on seagrass health, has resulted in a shoreward migration of seagrass as shown in Figure 10. Resuspension of benthic microalgae is a distinct physical and ecological feature of the estuary which results in temporary increase in pelagic microalgae and alongside sediment resuspension, clouds the water and ultimately limits seagrass growth and physical extent (OEH, 2013).

As a result of this process, seagrass beds in Tuggerah Lakes have migrated closer to the shoreline toward more favourable light conditions. In addition, research undertaken by the NSW Government in the past decade indicated that leaf length and biomass has significantly increased, whilst root density has decreased in response to ambient conditions which further exacerbates the nearshore-basin decoupling (OEH, 2011; OEH, 2013). Considering the low average depth of the estuary, Zostera leaf lengths observations between 0.44m and 0.63m could reasonably be expected to have a major impact on connectivity between functional zones.

Figure 10: Seagrass migration in Tuggerah Lakes.



4.5. Macroalgae / Seaweed

The main species of macroalgae or seaweed documented from Tuggerah Lakes include *Chaetomorpha linum* (rope weed), *Enteromorpha intestinalis* (green or bait weed), *Cladophora spp.* (goat weed), **Sargassum sp.** (bladder wrack), *Chara sp., Cystophyllum muricatum, Dictyota spp., Polysiphonia mollis, Gracilaria verrucosa, Lyngbya majuscula, Rhizoclonium implexum*, and *Lamprothamnium papulosum*. The species that are considered to be a nuisance in the lakes are those that occasionally bloom to form large floating mats and accumulate in the nearshore where ooze can develop. These include Enteromorpha, Chaetomorpha and Rhizoclonium (King, 2010).

Blooms of floating, detached filamentous algae are common during periods of low rainfall and warm weather and are regularly observed in nearshore areas.

4.6. Seagrass and macroalgal wrack

Seagrass wrack is a natural by-product which is generated as seagrass plants shed their leaves. Macroalgal wrack is typically made up of seasonal floating rafts of filamentous algae which grow amongst the wrack and bloom in the nearshore where conditions are optimal.

Wrack can gather and float in rafts near the surface and be blown ashore by the prevailing wind. Floating wrack provides a habitat and nursery ground for protected Eastern Garfish, and is an important part of the estuary's ecology, providing food and habitat for invertebrates, fish and bird species. Where shorelines are modified, wrack assimilation is significantly less effective and wrack can be trapped in the water column triggering a range of interrelated processes which can lead to organic sediment enrichment and in the worst case, the formation of mono-sulphidic black ooze. This is generally only observed along developed shorelines and enclosed bays where the other key characteristics are present (high nutrient input, fine sediment, benthic organic matter etc). Wrack alone is not a precursor to sediment degradation and can coexist with healthy sediments in many more natural locations (e.g. Budgewoi Sandmass, Tuggerah Nature Reserve). These complex processes are outlined in detail in OEH, 2011, OEH 2013 and Glamore et. al., 2020 and are important to clearly understand in order to properly manage the cause and not the symptom.

For a range of reasons, and predominantly in response to anthropogenic changes that have interrupted the natural wrack cycle, Council has been manually and mechanically collecting excess wrack from key locations for decades. Council's current approach to managing seagrass wrack is described in the **Tuggerah Lakes Estuary Management Plan: Summary of Implementation 2008 – 2020**. As the population has increased, demand for wrack collection has also increased placing a strain on existing capacity and resulting in largely reactive collection programs. Wrack management is hugely important to the local community from an aesthetic and recreational point of view. It has also been demonstrated to be an effective tool in improving nearshore water quality when completed in a strategic manner by taking advantage of seasonal prevailing winds (OEH, 2013).

As it currently stands, managing wrack in both a reactive and proactive/strategic way is not possible within the constraints of the available resources. Other physical constraints (depth, bed material, rocky shores, presence of saltmarsh, presence of seagrass beds and presence of ooze) also limit the efficacy of the current program and are not easily overcome. A review of wrack management will be a key feature of the CMP and a key touch point in the community and stakeholder engagement activities. It will be important for all parties to evaluate the challenges of developing and delivering an effective wrack management program holistically, and together formulate a new, collaborative way forward.

4.7. Estuarine invertebrates

Tuggerah Lakes supports a variety of invertebrate species which are important primary consumers including amphipods, shrimp, prawns, polychaete worms and bivalves (cockles and oysters). Terrestrial organic material and seagrass are minor contributors to first level consumer diets, whilst micro- and macroalgae provide the bulk of their energy needs (OEH, 2011) (Figure 11).

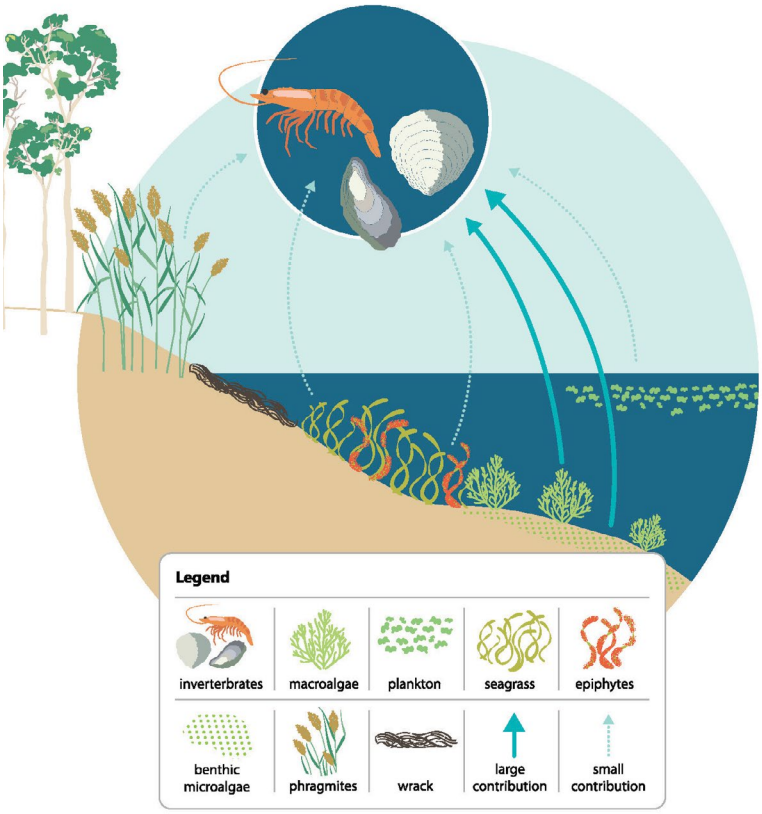


Figure 11: Invertebrate food web in Tuggerah Lakes.

4.8. Fish

A range of fish species are present in Tuggerah Lakes, many of which are commercially and recreationally important including Whiting, Tarwhine, Mullet, Hardyhead, Luderick, Leatherjacket and Trumpeter. In addition, species including Australian Bass rely on healthy connectivity of freshwater and brackish areas to live and reproduce.

Tuggerah Lakes is a commercial fishery with a significant average annual haul of 351 tonnes reported. As second level consumers, the fish in Tuggerah Lakes have a greater dependency on algal sources for nutrition (Figure 12), in comparison to the food web in Lake Macquarie which is more dependent on seagrass (OEH, 2011). Along with a suite of other evidence, this suggests that Tuggerah Lake is progressively more eutrophied than Lake Macquarie (OEH, 2011).

The difference between food webs in the two estuaries highlights what is likely to have been a gradual yet significant shift in Tuggerah Lakes in recent decades. Where seagrass becomes less abundant, algae tends to increase. The response of fish communities is a shift in abundance away from seagrass specialists towards detritivorous and pelagic species. Most species will remain present in the lake, but the relative abundance is altered.

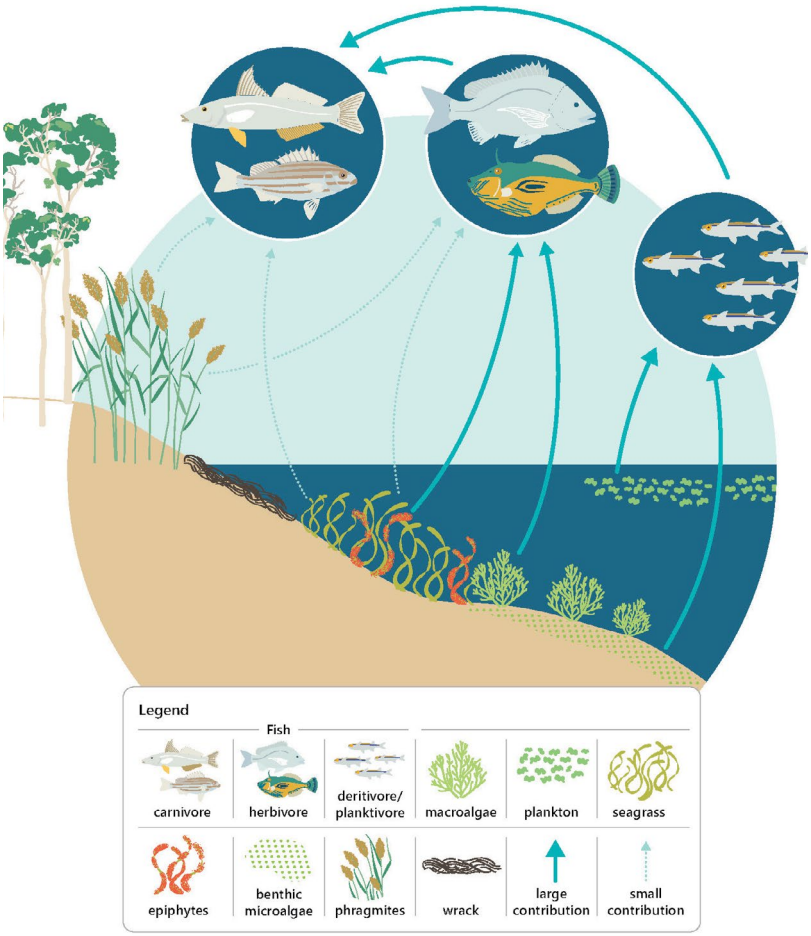


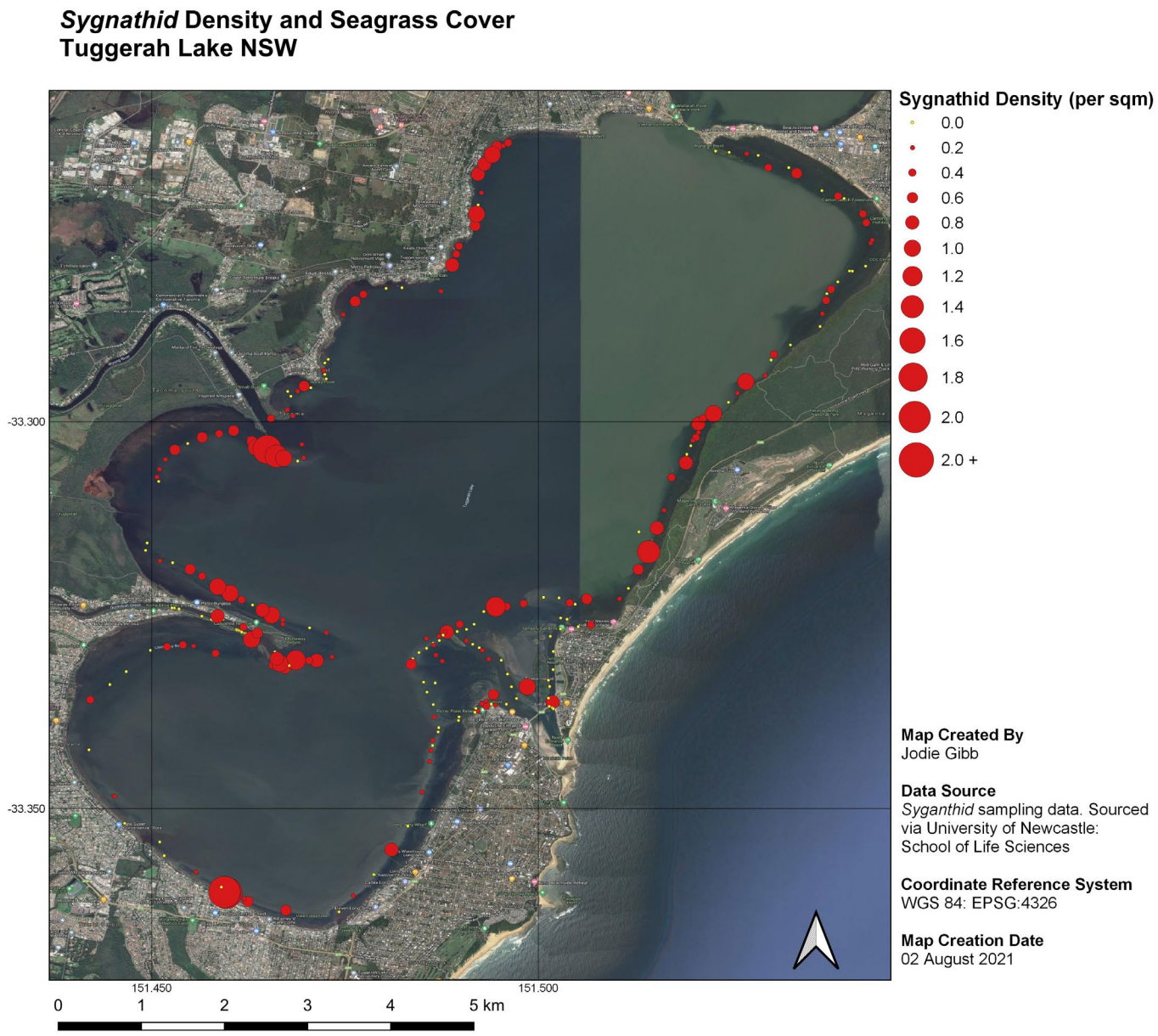
Figure 12: Fish food web in Tuggerah Lakes.

4.9. Protected Fish

A number of protected fish species are known to be present in Tuggerah Lakes. Historic records from the mid 2000's indicate the presence of six species of *Syngnathids* (seahorses and pipefish), including the elusive and endangered White's Seahorse. However, recent research undertaken by the University of Newcastle on behalf of Council has discovered only 3 species including Hairy Pipefish (most dominant), Double-ended Pipefish and Spotted Pipefish with no seahorses recorded.

Figure 13 shows the distribution of *Syngnathids* across over 241ha of mapped seagrass in Tuggerah Lake (UON, 2021). A handful of hotspot locations have been observed in the vicinity of Magenta, The Entrance, Killarney Vale, Chittaway Point and Tacoma and further research into population dynamics in these locations would be beneficial.

Figure 13: Preliminary abundance and distribution of Syngnathidae in Tuggerah Lake.



4.10. Birds

Tuggerah Lakes supports a diverse bird community both on the water and around the foreshores and has been recognised as a globally important bird area (Birdlife International, 2011). The Birding NSW Central Coast Group has recorded 379 bird species in the Central Coast Region between 1970-2010 and one of the most abundant species is the black swan, with over 6000 individuals recorded at one time (Carpenter, 2016). In the most recent report from the Birding NSW Central Coast Group, 63 bird species had been sighted on or around Tuggerah Lakes.

5.Water quality and ecological health

Council appreciates the importance of maintaining and improving water quality on the Central Coast and actively undertakes a range of programs to monitor and address both ecological and recreational water quality. These programs are long-standing and provide objective and scientifically valid information to inform the community and underpin management decisions. Without these feedback mechanisms in place, the capacity to understand the effectiveness of management actions and direct future decisions is compromised.

In addition to routine estuary monitoring programs (described in sections 5.1 and 5.5), both catchment modelling and catchment monitoring (DPIE; currently in draft) have been undertaken to identify priority catchments and assist in prioritising remediation action.

5.1.Estuary ecological health monitoring

Ecological health in the Tuggerah Lakes estuary is measured through an objective and scientifically rigorous monitoring, evaluation and reporting program. The program is designed to be consistent with the **NSW Natural Resources Monitoring, Evaluation and Reporting (MER) Protocols** and to address locally relevant issues. By following the MER protocols, waterway ecological health can be compared to other estuaries throughout NSW.

Sampling has been carried out monthly since 2011-12 in Tuggerah Lakes with the program expanding to all Central Coast estuaries following council amalgamation. Samples are collected and water quality is analysed at 16 locations in Tuggerah Lakes and includes a range of physical, chemical and biological indices including temperature, conductivity, salinity, dissolved oxygen, pH, turbidity, chlorophyll-a, fluorescent dissolved organic matter, total suspended solids, silica, phosphate, total dissolved phosphorus, total phosphorus, NOx, ammonia, total dissolved nitrogen and total nitrogen. Of those listed above, key pressure and response indicators including turbidity, chlorophyll-a and seagrass depth range are used to develop an annual grade for each site ranging from A – excellent to F – very poor. The grades are published annually in the **Central Coast Waterways Report Card** (Central Coast Council, 2020c) and periodically as part of the **Central Coast State of the Environment Report** (Central Coast Council, 2020d). This helps to raise awareness about the value, condition, trends and management actions underway for all Central Coast Waterways and links to ongoing estuary education and behaviour change programs.

5.2. Estuary ecological health results 2019-20

In 2019-20, Chittaway Bay was graded excellent, Lake Munmorah and the majority of sites in Tuggerah Lake were graded good and Budgewoi Lake and some fringing sites around Tuggerah Lake including Canton Beach, Ourimbah Creek and Tumbi Creek were graded fair **(Figure 14)**.

Figure 14: Results of the 2019-20 Water Quality Monitoring, Evaluation and Reporting Program. For reference:

A = Excellent: The indicators meet all benchmarks for more than most of the year. Equal to the best 20% of scores in NSW.

B = Good: The indicators meet all benchmarks for most of the year. Equal to the next 30% of scores in NSW.

C = Fair: The indicators meet some benchmarks for part of the year. Equal to the next 30% of scores in NSW.

D = Poor: The indicators meet few benchmarks for part of the year. Equal to the next 15% of scores in NSW.

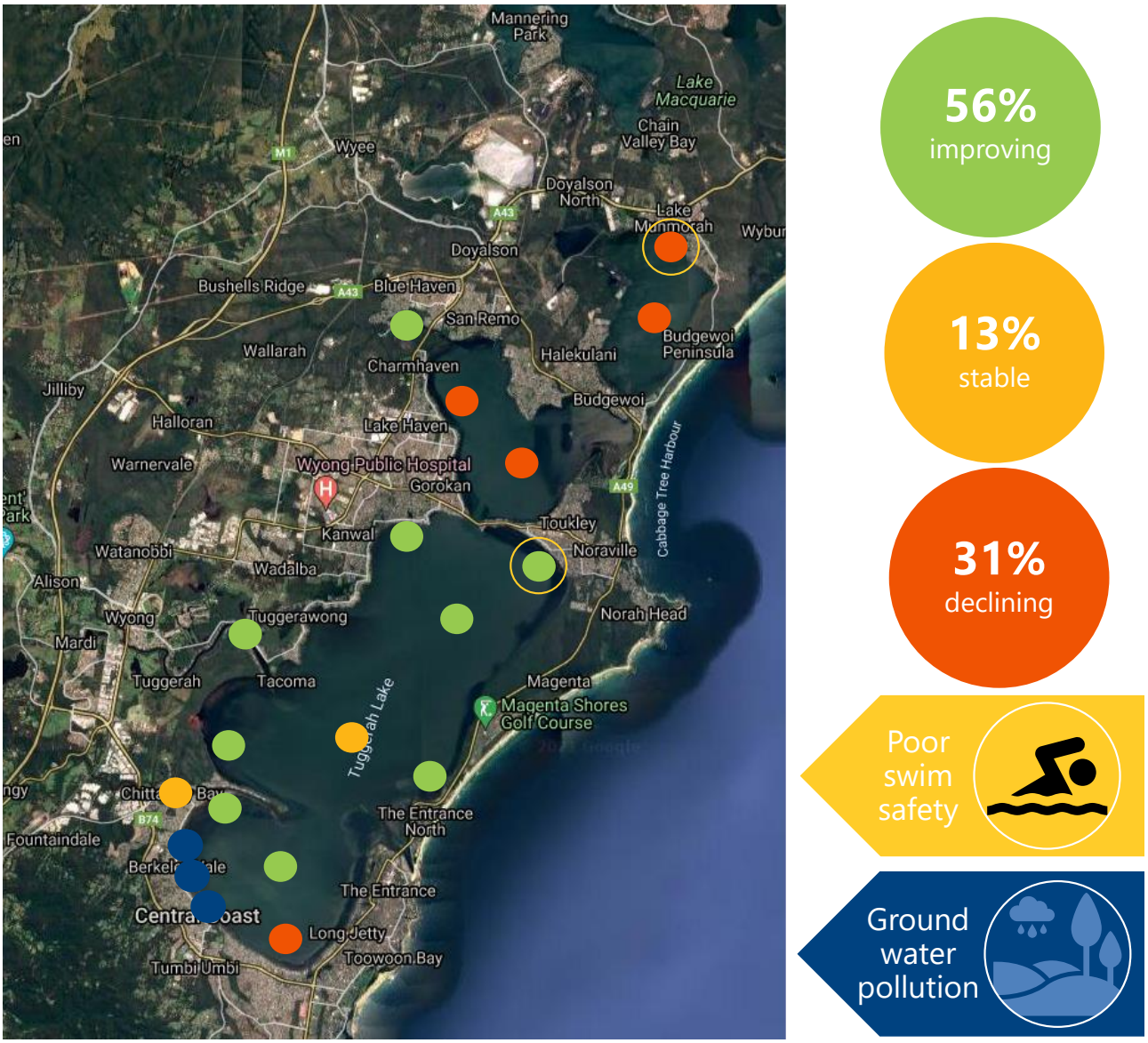
F = Very Poor: The indicators never meet benchmarks. Equal to the worst 5% of scores in NSW.

5.3. Estuary ecological health trends since 2011-12

Since 2011-12, 56% of sites have improved in ecological health, 13% have remained stable and 31% have declined (Figure 15). Where minor declines have been observed, further investigation should be prioritised through the CMP.

On average, ecological health and overall water quality has remained fair (C Grade) to good (B Grade) since the program began in 2011-12. Locally this can be compared to Lake Macquarie, which is routinely graded excellent; Brisbane Water which ranges from fair in the upper estuary to good/excellent in the main basins and tidal zones; and the smaller coastal lagoons which range from very poor (Avoca) though fair (Terrigal/Wamberal) and excellent (Cockrone). On a bioregional scale, Lake Illawarra and the coastal lagoons on the northern beaches typically receive similar grades to Tuggerah Lakes using comparable monitoring programs.

Figure 15: Water quality trends in Tuggerah Lakes over a nine-year period (2011-12 to 2019-20). Also noting locations with poor recreational water quality and poor groundwater quality.

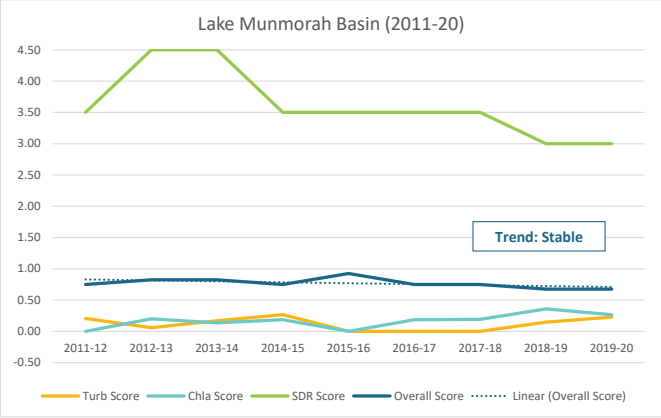


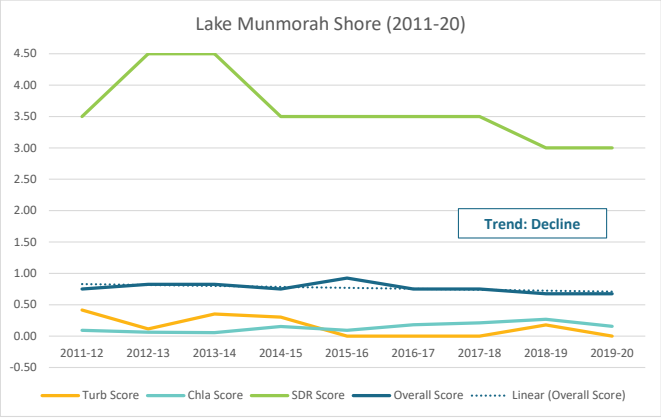
5.4. Site-by-site ecological health trends (2011-20)

The following graphs provide an overview of annual trends in water quality over time in Tuggerah Lakes. Improved or stable conditions have been recorded at 69% of sites including all sites in Tuggerah Lake excluding the Tumbi Creek shoreline site. Declining conditions were recorded at both Lake Munmorah sites, both Budgewoi Lake sites and the Tumbi Creek shoreline site. The creeks remained stable or improved noting that sampling in these locations has only been completed using this methodology since 2017 so it is more difficult to extrapolate long-term trends **(Figure 16).**

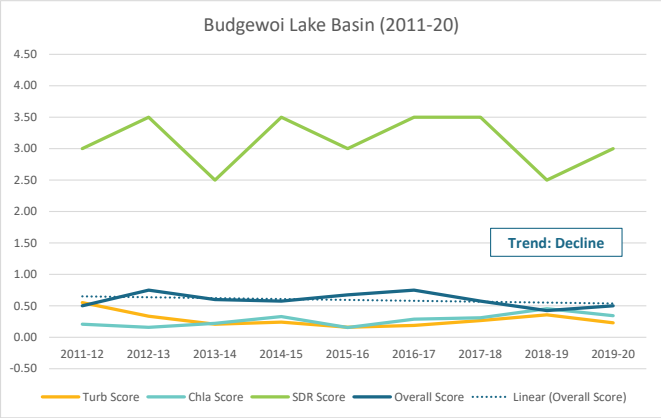
Figure 16: Annual trends for ecological health indicators for all sites between 2011 and 2020. Key "Turb Score" is the Turbidity Score, "Chla Score" is the Chlorophyll-a Score.

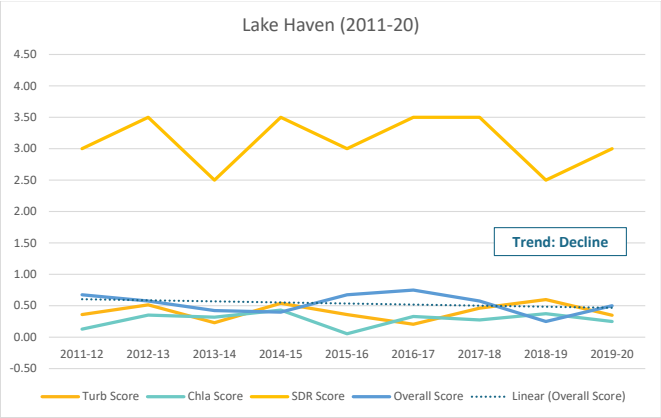
Lake Munmorah



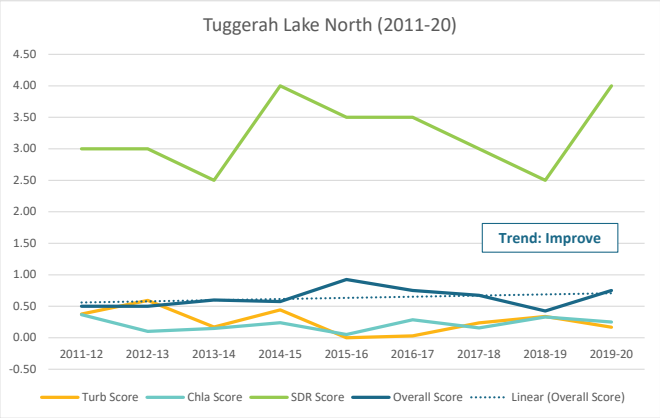


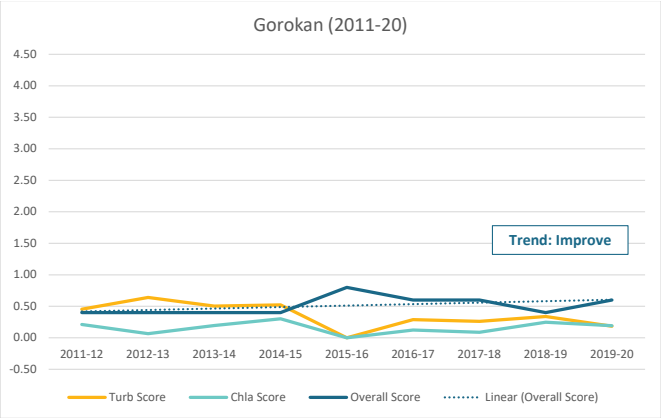
Budgewoi Lake

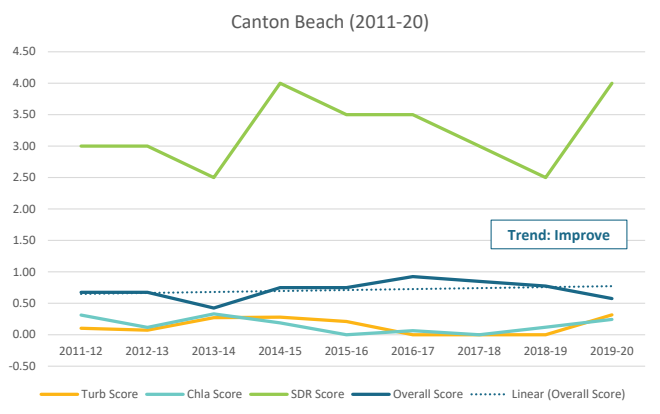




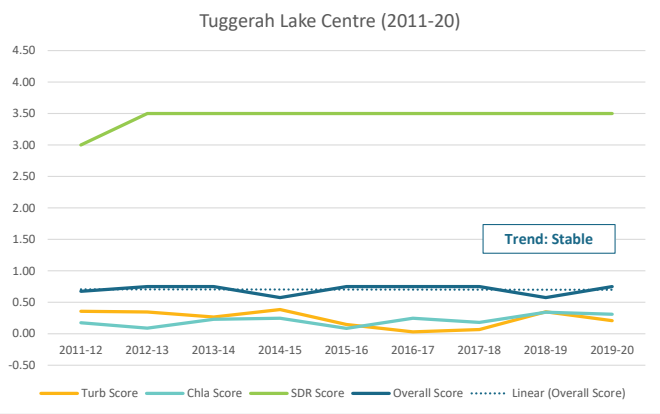
Tuggerah Lake North

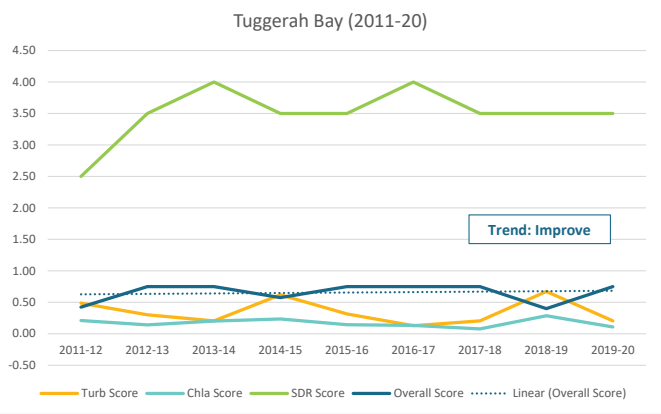




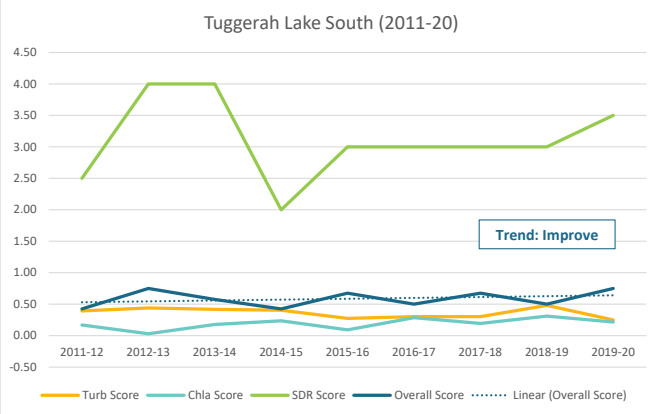


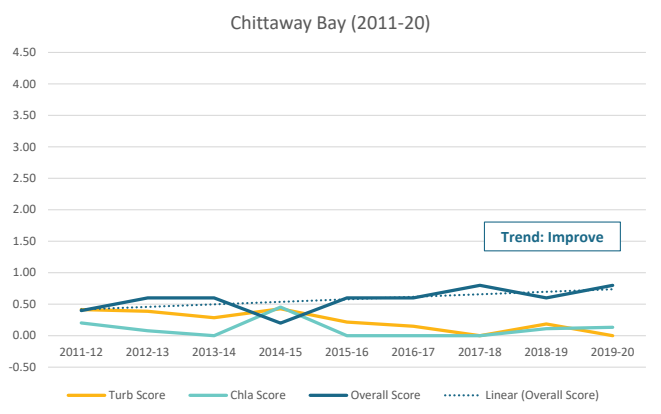
Tuggerah Lake Centre

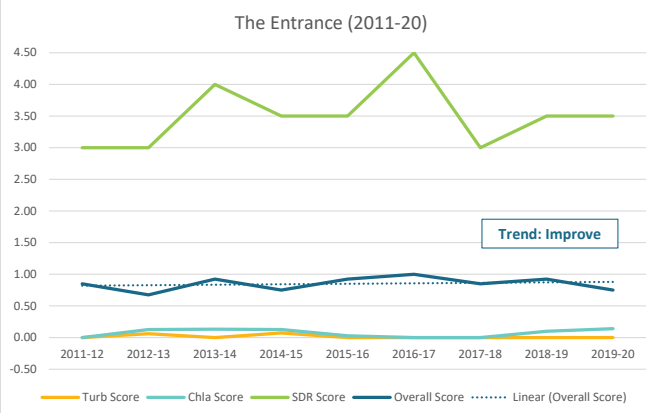


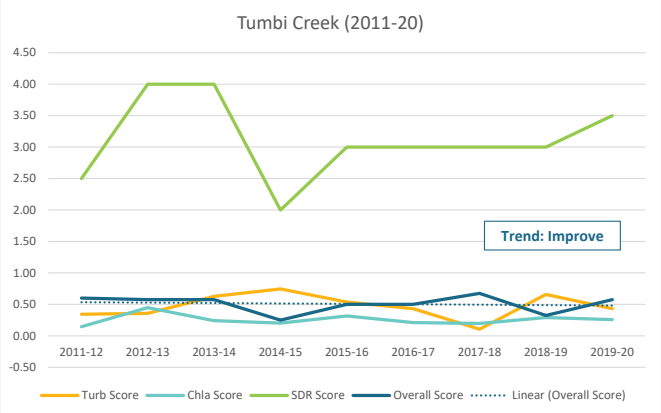


Tuggerah Lake South

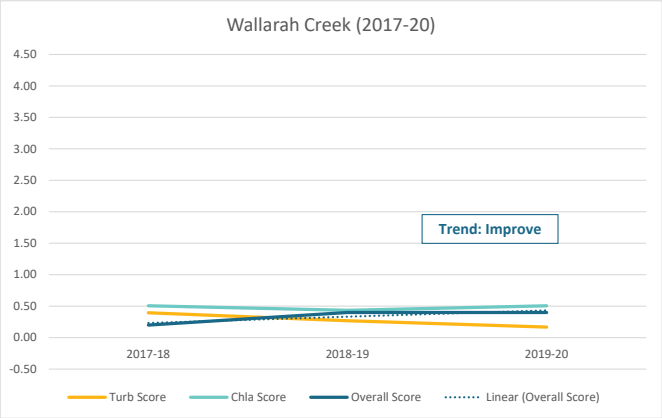


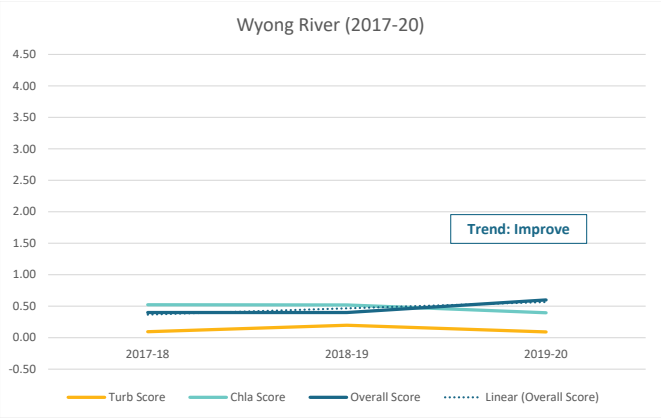


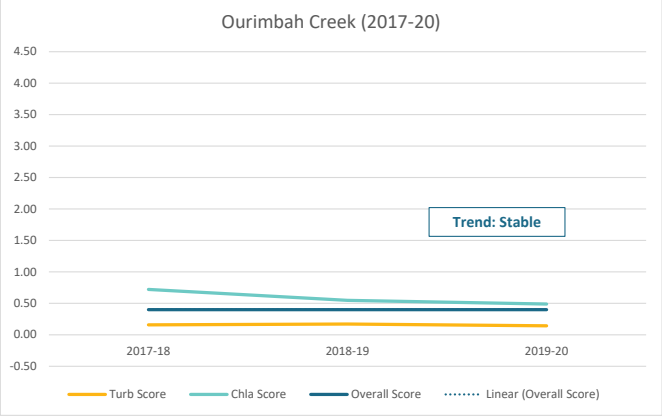


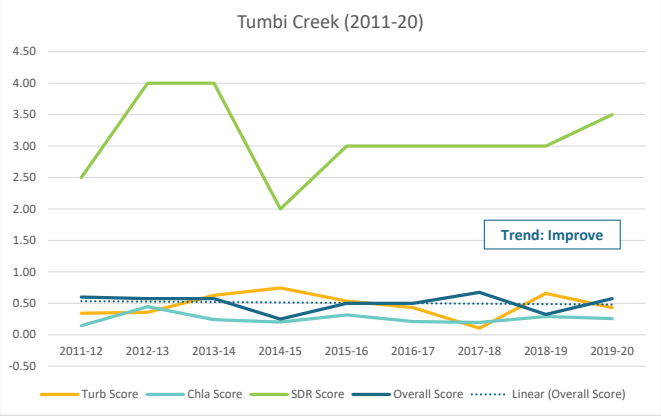


Creeks









Other more concerning trends over the past few decades include loss of seagrass and saltmarsh, declining condition and physical relocation of seagrass in response to persistent reduced water quality, poor mixing and circulation, nearshore eutrophication and sediment quality decline. Whilst the greatest impacts occurred during the 1980s and 1990s, recovery is slow and it is unclear what levels of future pressure the estuary can sustain. A trophic shift from a seagrass dominated system to a macroalgal/ phytoplankton dominated system is an extremely undesirable outcome and it is recommended that the current catchment models be reviewed and updated to identify sustainable catchment loads and to determine appropriate development controls.

5.5. Recreational water quality monitoring

The NSW State of the Beaches Report and the Beachwatch program is a separate program focused on water quality as it relates to recreational swimming guidelines and uses microbial contamination as the indicator. To monitor water quality for community swim safety, Central Coast Council undertakes routine recreational water quality monitoring. In Tuggerah Lakes, sampling is undertaken at the Entrance Beach, Canton Beach baths and Lake Munmorah baths alongside 29 other locations on the Central Coast.

Any beach, waterway, lake or lagoon in a developed or developing area will have less than optimum water quality for recreational purposes. This is particularly relevant for lake and lagoon sites where flushing is less frequent. The main impacts on water quality in developed or developing areas are stormwater run-off and sewer overflows and leaks. Poor water quality in urban areas is not a new phenomenon, and waste materials affecting waterways and the ocean is a common issue in both developed and developing countries. Monitoring programs, like NSW Beachwatch and Waterwatch, are undertaken to identify locations that experience water quality declines and to prompt audit investigations and improvement programs. Whilst Beachwatch offers a high level warning system to flag problem areas, more detailed catchment audits are required where persistent poor results are observed.

The designated swimming sites in Tuggerah Lakes, Canton Beach baths and Lake Munmorah baths routinely receive "poor" ratings in the **NSW State of the Beaches Report**. Whilst this is not uncommon for estuary sites that are assessed using this method, further catchment investigations at Canton Beach are recommended based on recent trends in the 95th percentile CFU rating.

North Entrance Beach, the Entrance Beach and the Entrance Ocean Bath all received "good" ratings in 2019-20 which has remained stable.

5.6. Groundwater monitoring

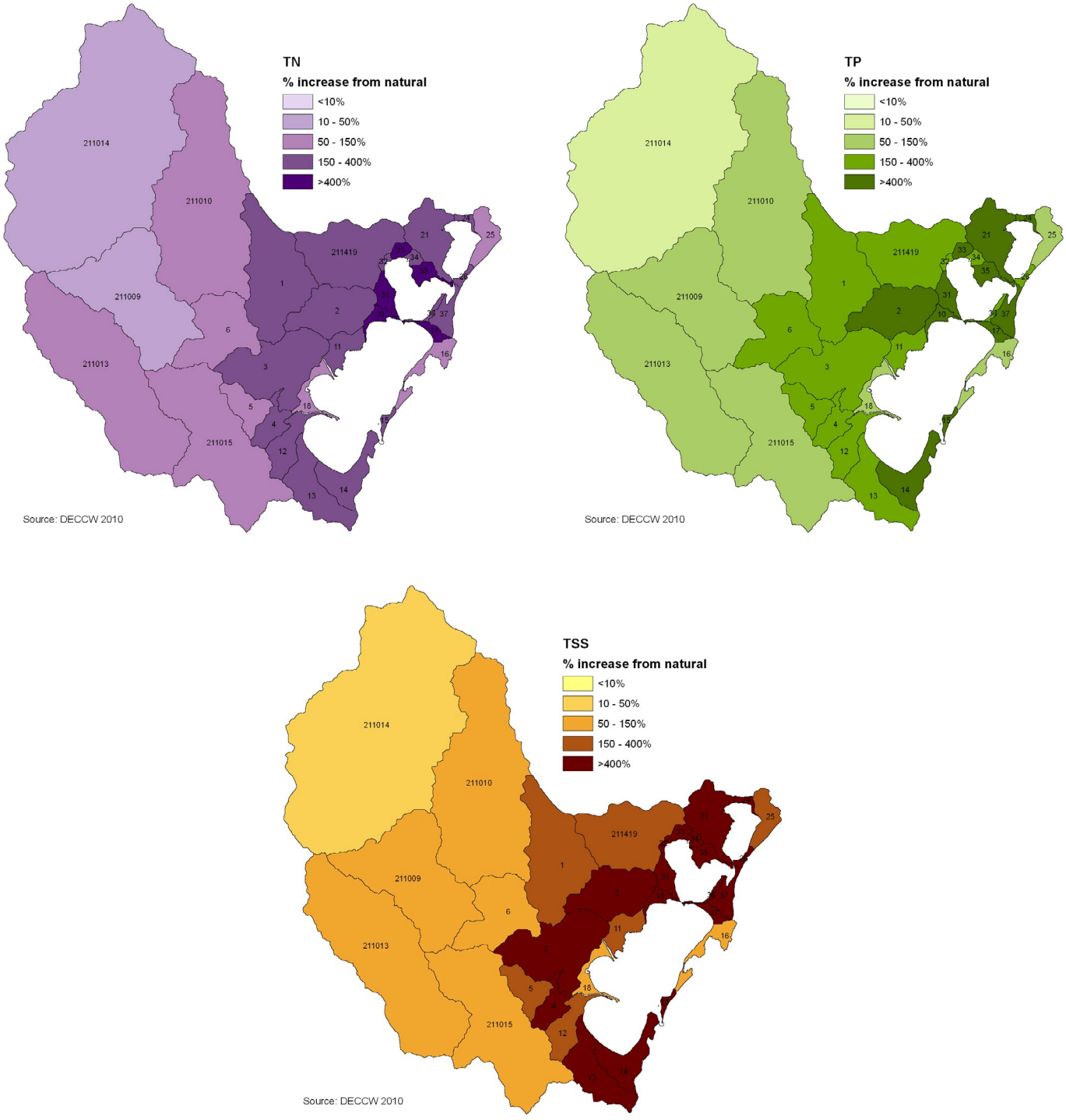
In response to a lack of data on the relative importance of groundwater on downstream water quality and ecological health, Council initiated a groundwater research study at Berkeley Vale in partnership with the NSW Government. The Berkeley Vale shoreline was subject to historic reclamation and exhibits long-term signs of nearshore eutrophication and organic sediment enrichment and presented an ideal location for further work.

Preliminary findings indicate that groundwater may supply a constant feed of nutrients to the nearshore zone of Tuggerah Lake following rainfall, 23% of the observed total dissolved phosphorous concentrations and 47% of the observed total dissolved nitrogen concentrations have been calculated as being contributed by groundwater (DPIE, 2021b). Groundwater discharge continues after surface water flows (i.e. stormwater) cease, as a result it is concluded that groundwater may be exacerbating eutrophic conditions along the Berkeley Vale shoreline. The current study is expected to conclude in early 2022 and will be used to inform CMP development. Further investigation of groundwater conditions and impacts are recommended elsewhere in the estuary.

5.7. Catchment modelling

In 2011-13, Council provided funding to the NSW Government to undertake a range of catchment modelling to understand catchment derived pollutant loads and to identify priority catchments. Figure 17 indicates the percentage increase from natural levels of Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS). The significantly elevated pollutant loads from fringing catchments (between 150% and 400% of background levels) is a major issue and driver of ecological decline, particularly when trapped in the nearshore zone.

Figure 17: Modelled pollution sources per sub-catchment.



5.8. Water quality expectations and future monitoring

Unfortunately, much of the discourse surrounding Tuggerah Lakes relates to community expectations of what good water quality means and what is achievable for Tuggerah Lakes both now and into the future. As the Tuggerah Lakes Expert Panel recently described, many of the issues are complex and inter-related, and undoing the damage already caused will be a long-term proposition that requires intergovernmental commitment and support, integrated evidence-based management, reliable funding and above all else, collaboration. An important step in the CMP will be to identify an appropriate water quality standard and integrate additional variables into the existing program to adequately capture and track community expectations. Notably, this should include an evaluation of sediment health, which for Tuggerah Lakes is equally as important as water quality and relates closely to the aesthetic and recreational values the local community hold. Other indicators that align with the key focus areas should be developed and implemented. Healthy Land and Water in South East Queensland provide some great examples of applicable indicators that link to biodiversity, ecological health and community values (social, economic, cultural).

6. Concluding remarks

We are fortunate that the ecological processes, key drivers of change and greatest risks to the future of Tuggerah Lakes are relatively well understood thanks to the extensive investment in science and research to date. Whilst further work can be undertaken to enhance this knowledge, fill remaining knowledge gaps and refine management techniques, the existing body of information forms a strong foundation upon which to build an effective, holistic and collaborative Coastal Management Program which shares responsibility and accountability across a range of stakeholders and sectors.

The challenges of existing urban impacts, aging infrastructure, future population growth, and climate change present real risks to the long-term health and viability of the estuary. Declining water quality in Budgewoi Lake and Lake Munmorah highlights the need to focus on sustainable planning and delivery both now and into the future in order to reverse this trend.

Conversely, the extensive work undertaken to implement the Tuggerah Lakes Estuary Management Plan through on ground action has resulted in real, measurable improvements in water quality and ecological health which is a promising result and demonstrates that a concerted, strategic effort to manage pressures and risks both now and into the future can result in a healthier estuary. It will be the role of the CMP to establish a clear vision for what this future will look like and to identify the pathways we will need to take collectively to achieve that.

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