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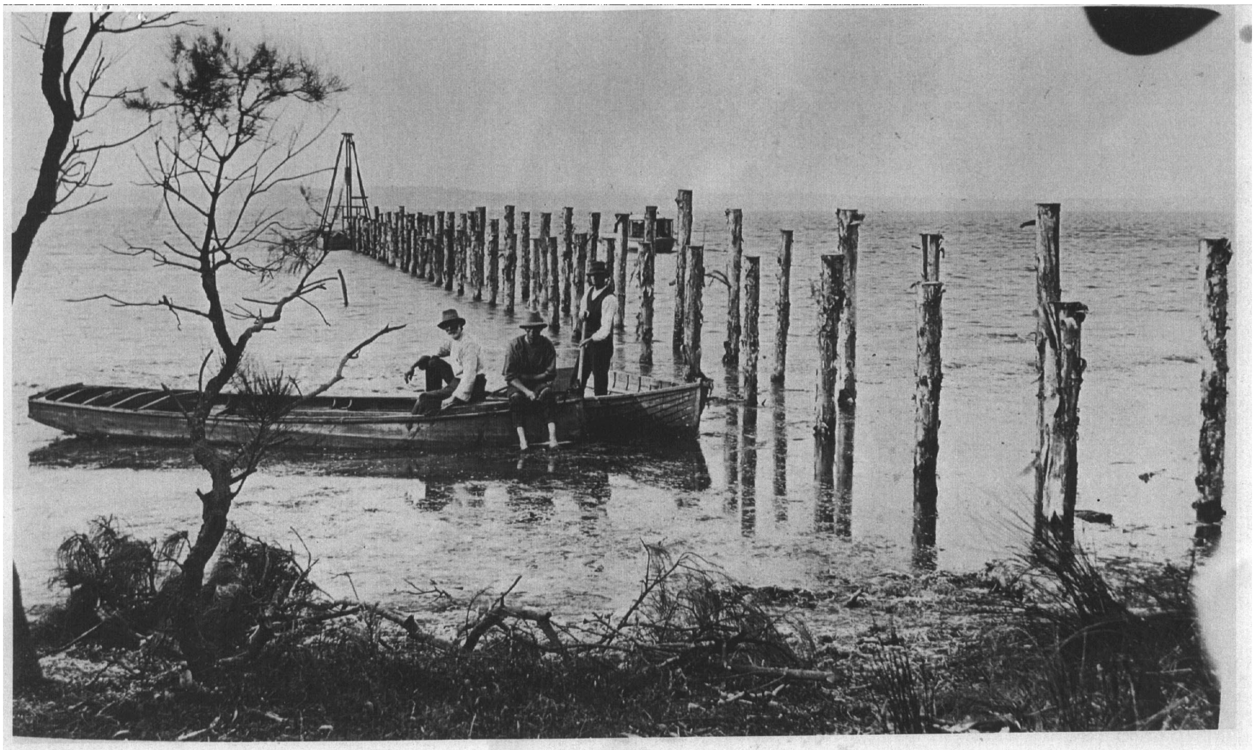
Ecological History of the Tuggerah Lakes
Final Report

By Anthony Scott



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CSIRO Land and Water, Canberra
Technical Report 18/99 June 1999

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Produced by CSIRO Land and Water and Sainty & Associates
for Wyong Shire Council.

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Front cover photo; Constructing the first 'Long Jetty', circa 1915. (supplied by *Wyong Historical Society)*

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Summary

The Tuggerah Lakes are on the Central Coast of NSW and consist of three interconnected coastal lagoons, Lake Munmorah, Budgewoi Lake and Tuggerah Lake. There has been rapid urban development over the last 20-30 years and this has resulted in a number of environmental pressures being placed on the lakes' ecology. One of the problems facing the managers of the Tuggerah Lakes is the lack of scientific data available that provides an indication of what the lakes were like in pre-development times. To overcome this problem, historical information was collected to provide an insight into the long term ecological changes of the lakes. This included historical documents, old newspapers and anecdotal records from residents who have lived in the area for up to 90 years. The historical information was then combined with more recent scientific studies of the lakes to provide a better understanding of the ecological changes to the lakes since European settlement.

Pressures and impacts

The evidence collected suggests that European settlement has placed a number of pressures on the ecology of the lakes, including;

- Rapid urban development around the lakes, with associated problems with sewage and stormwater disposal,
- Operation of a coal-fired power station which used lake water for cooling purposes,
- Land clearing and logging of the upper catchment, and resulting erosion problems,
- Dredging of the entrance channel to reduce flooding and maintain a permanent opening,
- Commercial and recreational fishing and prawning.

These pressures have impacted on the lake ecology in many ways, some more obvious than others. The most noticeable long term impacts are:

- Increased nutrient concentrations in water and sediment, particularly in the nearshore zone,
- Increase in abundance of macroalgae in the nearshore zone,
- Loss of seagrass in the centre of the lakes, particularly *Ruppia megacarpa,*
- Increased levels of organic ooze (and associated smells) in nearshore zone,
- Possible decrease in abundance of some species of fish and prawns,
- Loss of riparian vegetation and reclamation of surrounding wetlands,
- Decrease in abundance of jellyfish in the lakes,
- A reduction in the natural variation of lake parameters (such as salinity and water level) due to the policy of maintaining a permanently open entrance channel,
- Increased sedimentation, particularly near stormwater drains.

The pressures and impacts for the Tuggerah Lakes are very similar to those being experienced by other estuarine lakes along the NSW coast, in particular Lake Macquarie near Newcastle and Lake Illawarra near Wollongong.

Recent changes in pressures and impacts

In recent years two of the pressures on the ecology of the lakes have been greatly reduced. In the late 1980s and early 1990s the sewerage scheme for the Shire was completed, and this has virtually eliminated one of the major sources of nutrients to the lakes. Secondly, the Munmorah Power Station greatly reduced its operation in the mid 1990s and this returns the circulation patterns and water temperature of two northern lakes to their natural condition.

It has also become apparent that the 'health' of the lakes might have been slowly improving over the last four to five years. The growth of macroalgae in the nearshore zone, for instance, seems to have declined, and professional fishermen are starting to report increases in the abundance of the greasyback prawn. However, these anecdotal reports need to be tested by scientific monitoring of the lakes' ecology over a number of years to confirm that they are in fact a long term change rather than just part of a natural fluctuation in the system.

On a less positive note, is the ever expanding urban development around the lakes and the increasing quantities of sediment, nutrients and other pollutants associated with the runoff from these areas. Urban development is also accelerating the loss of riparian vegetation and reclamation of wetlands around the lakes. Controlling the impacts of urban development is probably the greatest challenge for those managing the Tuggerah Lakes.

Linking pressures with impacts

When attempting to link the major pressures on the system with observed changes in lake ecology, great care needs to be taken. Unless there is a very strong direct link between a particular pressure and how a part of the ecosystem operates, it can be a difficult task due to the extreme complexity of the ecological processes operating in the lake and the possibility of indirect secondary impacts going unnoticed. For the Tuggerah Lakes (and many other estuarine lakes along the NSW coast) this is further complicated by the high number of different pressures acting on the ecosystem at the same time. In addition, the natural variability of the system, over time periods of years and sometimes even decades, can make it difficult to determine what are natural fluctuations in the lake ecology and what are anthropogenic impacts.

However, by improving our understanding of the ecology, both in present times and in pre-European times, it should be possible to make more informed assessments of how the system has changed. This in turn should provide a better framework for the environmental management of the lakes, and assist with efforts to restore the lakes to a state closer to its original condition.

The value of collecting historical information

This study also demonstrates the value of using historical information to develop a better understanding of ecological systems such as the Tuggerah Lakes. Virtually all scientific studies undertaken on these lakes have occurred since the early 1960s and there are few scientific records prior to this time. To develop a better understanding of the ecology before that date, the historical records were found to be a very useful source of information. It is hoped that other ecological studies will utilise this valuable source of information.

1 Introduction

1.1 Objective

Only forty years ago, the Tuggerah Lakes, on the Central Coast of New South Wales, consisted of a few small villages and towns which catered for the annual influx of visitors during the summer holidays. However, over the last few decades these towns have been transformed into large urban centres, with an associated population increase from 13,000 in 1954 to over 100,000 in the 1990s. This rapid development has resulted in a number of environmental pressures, and in the late 1980s - early 1990s the Tuggerah Lakes suffered from eutrophication, with macroalgae blooms being common within shallow nearshore habitats.

Management actions to alleviate the excessive macroalgal growth resulted in the ‘Lakes Restoration Program’ in the late 1980s and early 1990s. However, this Program was only partially successful.

It is now clear that to develop long term management plans for the lakes, a better understanding of their ecology is required. However, one of the problems facing the managers of the Tuggerah Lakes, is that there is very little scientific data available that provides an indication of what the lakes were like in pre-development times, since most scientific studies have been undertaken in the last 30-40 years.

The objective of this study was to:

Collect information about the ecological changes that have occurred in the Tuggerah Lakes since European settlement in the early 19th century.

Since there were very few scientific studies of the Tuggerah Lakes prior to 1960, most of the key information used to develop a long term picture of ecological changes was of a qualitative nature. The most valuable source of information available was the collective memories of local residents, and in particular the retired professional fishermen. These people could provide information about the lakes prior to the 1960s, and in some cases as early as the 1920s, when the impact of European settlement was still minimal. Other sources of information included articles in old newspapers, old photos and maps, and other historical documents.

The historical information was then combined with the results of more recent scientific studies, to provide a better understanding of the long term ecological changes to the lakes.

1.2 Interpretation of historical information

In the absence of quantitative scientific data, anecdotal records (both written and oral) can provide an alternative source of information. However, such information has often been criticised by scientists for inaccuracy, subjectivity and selectivity. These short-comings can be minimised by careful design of both the data collection and the analysis. When assessing anecdotal records for instance, it is unwise to rely on the recollections of just one individual, but if it is corroborated by many others then the evidence is much stronger. Anecdotal records might also be supported by historical documents such as diaries, letters or newspaper articles. For ecological history, the evidence gathered from anecdotal records is further strengthened if it follows ‘scientific logic’.

Sometimes observations reported by locals might appear to be in conflict, for example, in the perceived abundance of ‘weed’ in the Tuggerah Lakes. However, variability is a natural feature of most ecosystems, including the Tuggerah Lakes, and some differences in observations should be expected. For instance, one person might be recollecting a large quantity of weed at one end of the lake system during a specific year, while another person might remember very little weed but at a different location (spatial variability) or in a different year (temporal variability). This can be confounded further by the difficulty many people have at recollecting the exact year of a particular event or observation.

There can also be a difference in opinion depending on what one's past experiences have been. For instance, an older local who experienced the large growth of stackweed in the 1920s might think that the weed growth in the 1970s was minimal. However, another person who first arrived at the lakes in the 1940s when there was very little weed present, might describe the weed growth in the 1970s quite differently. Differences in perception, depending on one's past experiences, was also evident when collecting information on the abundance of fish in the lakes.

In summary, when interpreting the anecdotal information, one cannot expect all memories to be completely consistent due to different perceptions and also due to the large natural variability of the lakes both over time and at different locations. However, despite this, there were many topics for which most people interviewed had very similar recollections and a great deal of consistency was obtained. This has provided some valuable information about the past ecology of the Tuggerah Lakes and has enabled us to piece together a picture of what the lakes were like earlier this century when the impact of European settlement was still minimal.

1.3 The Tuggerah Lakes

The Tuggerah Lakes are on the Central Coast of NSW and consist of three interconnected coastal lagoons, Lake Munmorah, Budgewoi Lake and Tuggerah Lake (Figure 1). The three lakes cover a total area of 77 sq km and have a perimeter of 105 km. The largest of the lakes is Tuggerah Lake with an area of 54 sq km (IDC 1979). The lakes are shallow, the average depth being 1.9 metres.

There is only limited interchange of water between the lakes and the sea through a narrow channel at The Entrance, and hence tides in the main body of the lakes are negligible. Tidal exchange has been estimated at approximately 1% (IDC 1979, Hunter 1995) but would vary with the size of the entrance channel. The average water level in the lakes is about 0.2 m above sea level, and the highest flood level in the lakes is reported to have been approximately 2.0 m above sea level (Lawson and Treloar 1994, PWD 1992).

The total area of the catchment serving the lakes is 671 square kilometres (IDC 1979). Freshwater flow into the lakes comes mainly from Wyong River (catchment of 347 sq km), Ourimbah Creek (141 sq km) and to a lesser extent Wallarah Creek (32 sq km).

Salinity in the lakes is affected by freshwater input from catchment runoff and precipitation, by salt water input from the ocean and by evaporation. Salinity variation is normally in the range 17-28ppt (compared with ocean water at 35ppt). There are local variations within the lakes due to proximity of freshwater inflow or due to ocean influence. During extended droughts salinity over 40 ppt has been recorded but in times of heavy rainfall can be as low as 5 ppt.

The lakes contain a diversity of aquatic plants and animals, support tourist and fishing industries, and are also an important aesthetic and recreational resource for residents.

Table 1 Physical characteristics of Tuggerah Lakes and the catchment

Lake	*Surface (km^2)*	*Shoreline (km)*	*Volume (10^6 m^3)*	*Mean depth (m)*	*Catchment area (km^2)*
Tuggerah	58	60	91	1.6	600
Budgewoi	11	30	18	1.6	42
Munmorah	8	15	14	1.8	29
Total	**77**	**105**	**123**	**-**	**671**

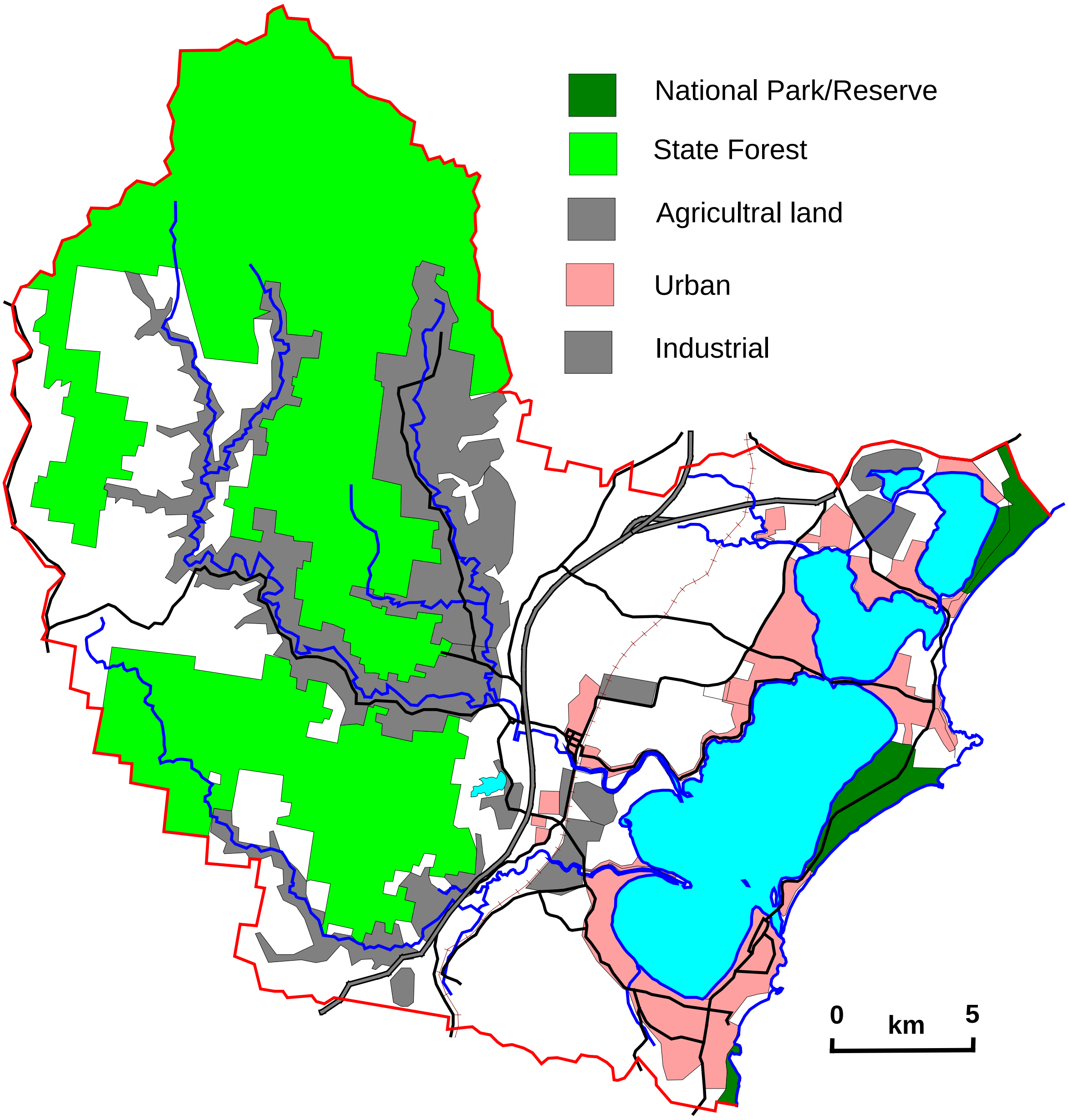
Coastal Lagoons

Coastal lagoons are areas of relatively shallow water that have been partly or wholly sealed off from the sea by the formation of a depositional barrier of sand (Bird 1984). For the Tuggerah Lakes the sand barrier runs from north of Lake Munmorah right down to The Entrance, and incorporates a former offshore island at Norah Head. Similar coastal lagoons include Wallis Lake, Myall Lakes, Lake Macquarie, Lake Illawarra, St Georges Basin and Wagonga Inlet in NSW, and the Gippsland Lakes in Victoria.

Coastal Lagoons often have three zones; a freshwater zone close to the mouths of rivers, a salt-water tidal zone close to the entrance, and an intervening transitional zone of brackish (moderately saline) but relatively tideless water. The proportions of each zone vary from one lagoon system to another; the Myall Lakes consist largely of the freshwater zone, Lake Illawarra and the Tuggerah Lakes largely of the intermediate zone, and Wagonga Inlet largely of the saltwater tidal zone. The extent of each zone depends largely on the proportion of freshwater inflow to the lagoon system, and on the size of the entrance channel to the sea (Bird 1984).

Three of these lagoon systems (Lake Illawarra near the industrial city of Wollongong, and Lake Macquarie and Tuggerah Lakes on the New South Wales Central Coast) have been studied extensively. These lakes all support some commercial fishing and prawning, but are in regions of rapid urbanisation and have been subject to nutrient input from sewage and catchment runoff. They are also subject to high levels of recreational use. The proximity of major population centres and the coal deposits of the Sydney basin has made these lakes suitable sites for coal-fired power stations. Condenser cooling water is drawn from the lakes and the heated water discharged back into the lakes, which then act as a cooling field (King and Hodgson 1995).

Figure 1. Landuse in the Tuggerah Lakes catchment



2 Settlement of the Tuggerah Lakes

The ecological history of the Tuggerah Lakes over the last 200 years, is closely linked to the pattern of European settlement, both around the lakes and also within the upper catchment. As settlement spread throughout the district, activities such as the clearing of land, logging, fishing and urban development have all had impacts on the ecology of the lakes.

2.1 Aboriginal settlement

The first evidence of human habitation in the coastal environment of the Tuggerah Lakes is provided by aboriginal middens, shell and other food remains, and artefacts. In the coastal escarpment, rock engravings and painting sites provide further clues to the hunting and gathering activities of the pre-European population (King and Hodgson 1995). The Wyong District was occupied by three aboriginal language groups, the Kurringgai, Darkingung and Awabakal tribes. Bennett (1968) estimated that the peak population in the Central Coast would have been about 360 people. However, the arrival of Europeans brought new diseases and also an inevitable clash of cultures.

As early as 1828 it was reported that only 65 aborigines belonging to five family groups remained in the district (Bennett 1968), and by 1875 the last full blooded aboriginal of the Wyong district had died.

<u>Ecological Impacts:</u>
With a peak population of only 360 people spread throughout the Central Coast District, the ecological impact of their hunting and gathering activities would have been negligible compared with the impacts in the last 200 years caused by European settlement.

2.2 The first European settlers (1820s – 1870s)

The first European landholders in the Wyong Shire acquired their land in the mid to late 1820s. However this was only a handful of people and in the 1830s much of the district remained unexplored. When the 1828 census was taken, there were only 15 households in the Gosford and Wyong districts. (Strom 1984).

While some settlers were establishing farms and raising cattle, others were felling timber and hauling it out of the valleys with teams of bullocks. Most of the cedar had already been taken by the 1850s and attention turned to other types of timber. The timber industry steadily expanded, and in 1855 a sawmill started operation in the Ourimbah valley. During this time, all timber and produce was transported to Sydney by boats which travelled regularly along the coast.

By the 1870s, farms had been developed throughout much of the Tuggerah Lakes district, including Norah Head, The Entrance, Budgewoi, Warnervale, Kanwal and Gorokan. However, despite the increasing number of farms in the district and the establishment of small villages, it is clear that much of the area remained forested and that settlement was still relatively sparse. The earliest settlers practised mixed farming, including the grazing of sheep and cattle, dairying, pigs, poultry, and crops such as wheat, corn and potatoes.

Commercial fishing on the lakes became established in the late 1850s, initially at Canton Beach (near Toukley) by a group of Chinese fishermen, who were smoking the fish and exporting it to China or sending it to the goldfields.

Ecological Impacts:
In the 1820s and 1830s the clearing of small areas of land for cultivation, and the selective cutting of cedar in the valleys of the upper catchment, would have been the first ecological impacts of European settlement in the district. However, during this period these activities were on a relatively small scale and any impact on the Tuggerah Lakes would have been quite small. The quality of water reaching the Tuggerah Lakes from the upper catchment would have remained high.

From the 1850s onwards, as logging and clearing slowly expanded throughout the catchment, the Tuggerah Lakes would have experienced an increase in the rates of sediment and nutrients entering via the Wyong River and Ourimbah Creek. Around the lakes themselves however, there was still very little disturbance of the land and hence very little impact from these areas.

The only other significant impact on the ecology of the lakes during this period would have been caused by the commencement of commercial fishing in the 1850s.

2.3 Development accelerates after the opening of the railway (1880s – 1950s)

The opening of the Great Northern Railway in the period 1887-89 was the single most important factor in the development of the district. Timber could now be transported rapidly and efficiently to Sydney and the industry started to boom. This led to the development of the Wyong township as large quantities of timber were hauled into the yards at the railway station.

Agriculture also expanded rapidly, as the railway now allowed fresh farm produce to be sent to the Sydney markets. By the 1890s citrus farming was expanding into the district and became an important industry in the Yarramalong, Dooralong and Ourimbah Creek valleys. By 1930 there were 7.833 acres of orchards in the Gosford-Wyong district which were supplying over one-third of the citrus fruit production in NSW (Lowndes 1932). Dairying was also expanding, and in 1907 a butter factory was opened at Wyong.

In the 1920s the timber industry started to decline and mixed farming became the major focus for the district. In 1926 the butter factory commenced the supply of milk to Sydney and in the 1930s and 40s the industry was flourishing with two hundred farmers sending their milk to the factory for processing. Poultry farming also became popular, particularly at Kanwal and Warnervale, and the district became one of the largest egg producers in the state.

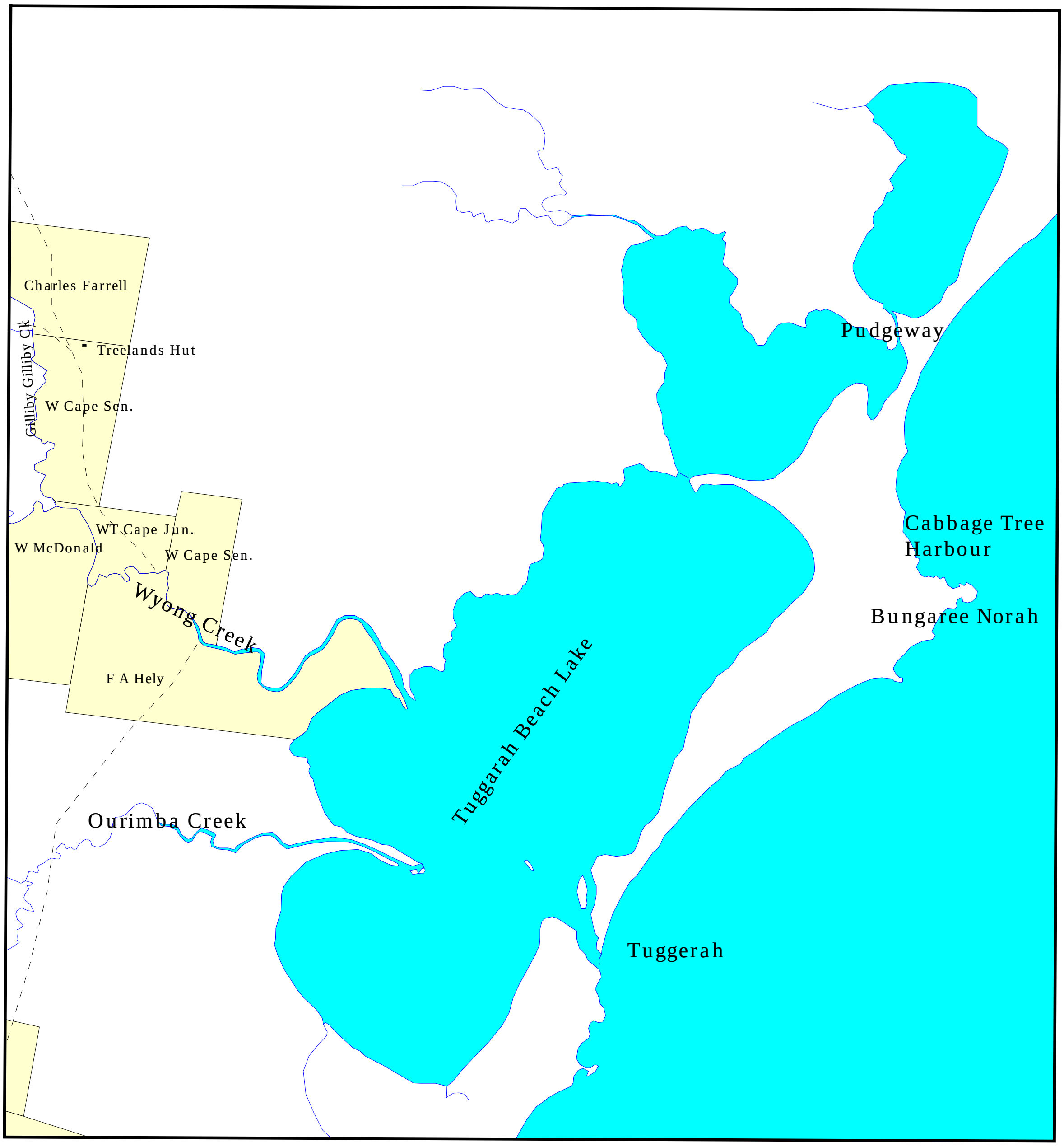
The railway was also used to transport the fish caught by an increasing number of professional fishermen now living at the mouth of the Wyong River (Tacoma).

Throughout the first decades of the twentieth century the Central Coast evolved as a favourite holiday destination, particularly The Entrance where a number of guesthouses were built. By 1920 subdivisions were being made at The Entrance with a high proportion of the lots devoted to future holiday home accommodation. Other subdivisions occurred around the lakes, including Rocky Point, Wyong, Budgewoi and Gorokan.

The Depression years, quickly followed by World War Two, slowed all development in the district, particularly the timber industry.

After World War Two, development resumed, although by 1954 the resident population of the Wyong Shire had only increased to 13,100 and the region was still regarded as a holiday destination rather than an urban centre.

Figure 2a. Tuggerah Lakes in mid-1830s

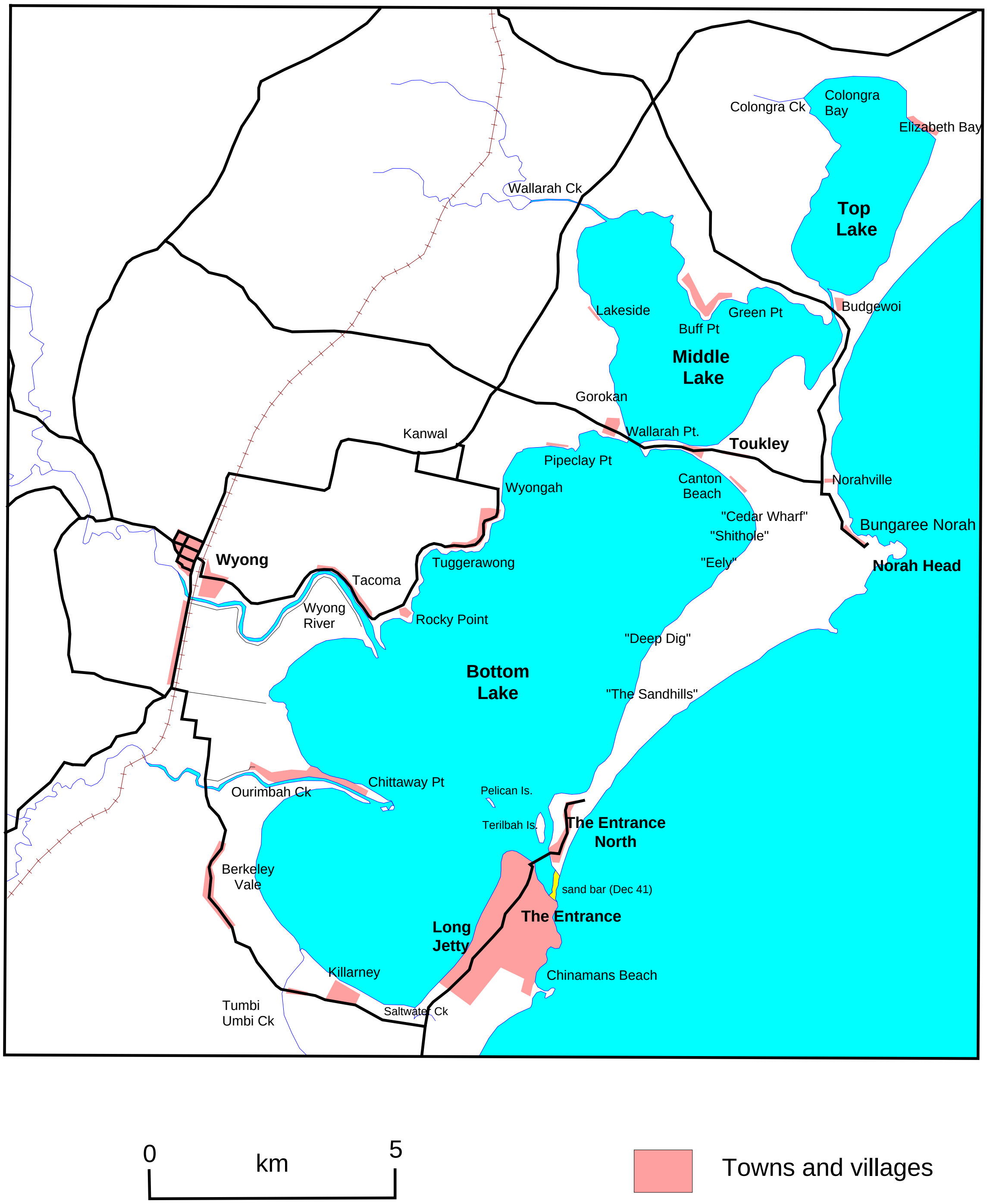


Details of some early land grants from an 1834 survey map drawn by Larmer (and reproduced by Stinson 1984).

A map of the colony of NSW, first published by Robert Dixon in 1837, shows another property owned by Larnock, on the north side of the Wyong River next to the shores of Tuggerah Lake.

Other properties included a station owned by Charles Bloodsworth on the west side of Jilliby Creek, 640 acres at "Pudgeway" owned by John Slade, 640 acres at The Entrance owned by Henry Holden, and Robert Henderson’s 2,000 acres at Norah Head.

Figure 2b. Tuggerah Lakes in 1941



Ecological Impacts:
The main impacts on the Tuggerah Lakes during this period would have been caused by increased sediment and nutrient loads entering via the creeks and rivers. (Although erosion is a natural geological process, most of the sediment is the result of man's activities on the land, which accelerate the process far beyond background levels.) The highest loads probably occurred in the early 1900s when large areas of land were being cleared for the rapidly expanding agricultural industries, and the logging industry was at its peak.

Other impacts during this period would have included:

- The development of small towns and villages around the lake shores with associated land clearing, street runoff and waste disposal problems;
- Expansion of commercial and recreational fishing activities;
- Hunting of waterbirds.

2.4 Urban development (1960s – 1990s)

During this period the focus of the district shifted from agriculture and timber to urban development, while tourism continued to play an important role.

The dairy industry started to decline in the 1970s and 80s as land prices climbed and farmers sold their properties to wealthy investors from Sydney. In 1982 there were only 12 local dairy farms remaining and by the mid 1990s the last dairy farm in the district had ceased operation. Citrus farming also declined in importance, due to the high land prices and a declining price for oranges.

In recent years hobby farms, consisting primarily of grazing land, have become an important land use. In the valleys along the alluvial flats, turf farming has also become an important industry. Closer to the Tuggerah Lakes, rural land is being converted into residential areas.

In the 1990s the timber industry continued in the State Forests of the upper catchment, but at a reduced intensity compared with its peak period in the early 1900s.

Urban development accelerated in the 1960s with the construction of the Munmorah Power Station and the associated coal mines. The social structure of the coastal communities started to change, with the holiday-makers being replaced by a permanent residential population living in urban centres.

In the 1970s the Central Coast became the fastest growing urban district in south-eastern Australia. The Wyong district was an important contributor to this growth.

Urban development continued through the 1980s largely due to the extension of the Sydney-Newcastle freeway and the electrification of the Gosford-Newcastle railway. This enabled people to live in the Wyong Shire and commute to Sydney for work. By 1990 the population had risen to 102,000. This population growth has continued through the 1990s with new residential areas being developed around the western shores of Budgewoi Lake and southern shores of Tuggerah Lake, and also extending westward through Warnervale, Wyong and Tuggerah.

Ecological Impacts:
During this period (1960s to 1990s) there has been a rapid increase in the ecological impacts on the Lakes from urban development. These have included;

- High nutrient loads entering the lakes from septic systems in the 1960s, 70s and early 80s.
- Nutrients and other pollutants from urban runoff, particularly during storms.
- Reclamation of surrounding wetlands for industrial, recreational and housing developments.
- Loss of riparian vegetation around the lakes due to housing developments.
- Dredging and reclamation activities along the shorelines of the lakes.

While impacts from urban development were increasing, impacts from the agricultural and timber industries in the upper catchment were probably declining.

In the last few decades many agricultural activities such as dairying and citrus growing have declined and land clearing in the upper catchment has slowed. This would have resulted in less disturbance to the land and hence less erosion. There is also an increased awareness of erosion control in the farming districts through the introduction of ‘catchment management’ principles and better protection of riparian lands. Logging still occurs but at a much reduced rate, and erosion control measures have been introduced to help reduce the quantity of sediment reaching streams.

Overall, the present rates of sediment and nutrients reaching the lakes from the valleys and hills of the upper catchment have probably declined from the peaks that would have been experienced during the late 19th and early 20th century when there was little consideration for erosion control and the timber and farming industries were rapidly expanding.

Other impacts on the Lake system during the 1960s to 1990s have included;

- Operation of the Munmorah Power Station from the late 1960s onwards, which increased the water temperature and changed water circulation patterns in the northern two lakes.

- Commercial and recreational fishing activities (both within the lakes and offshore).

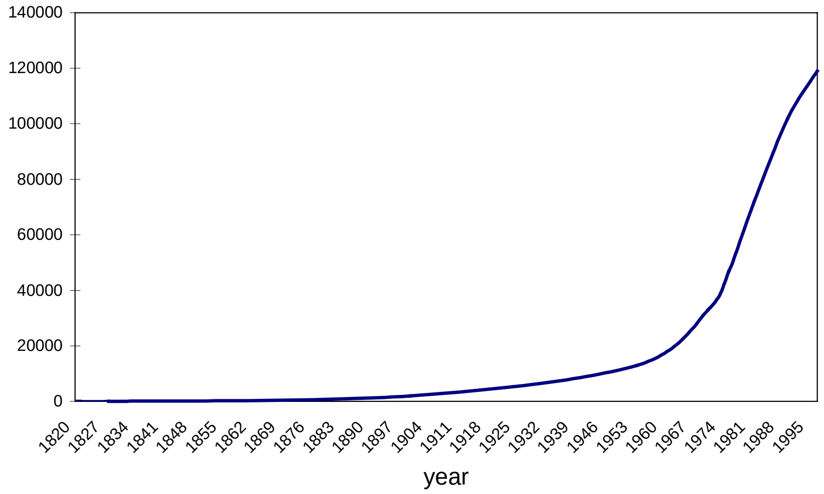
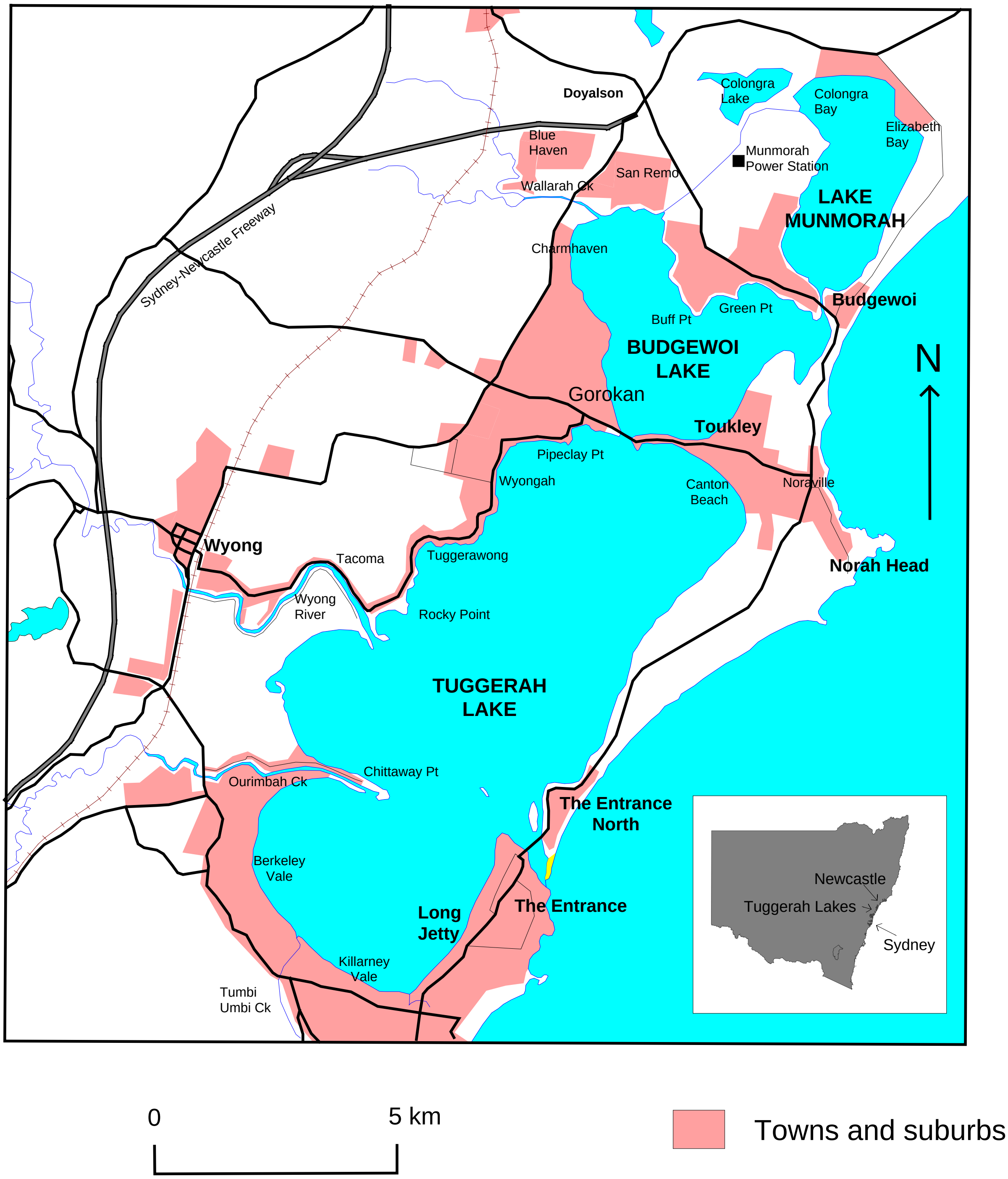


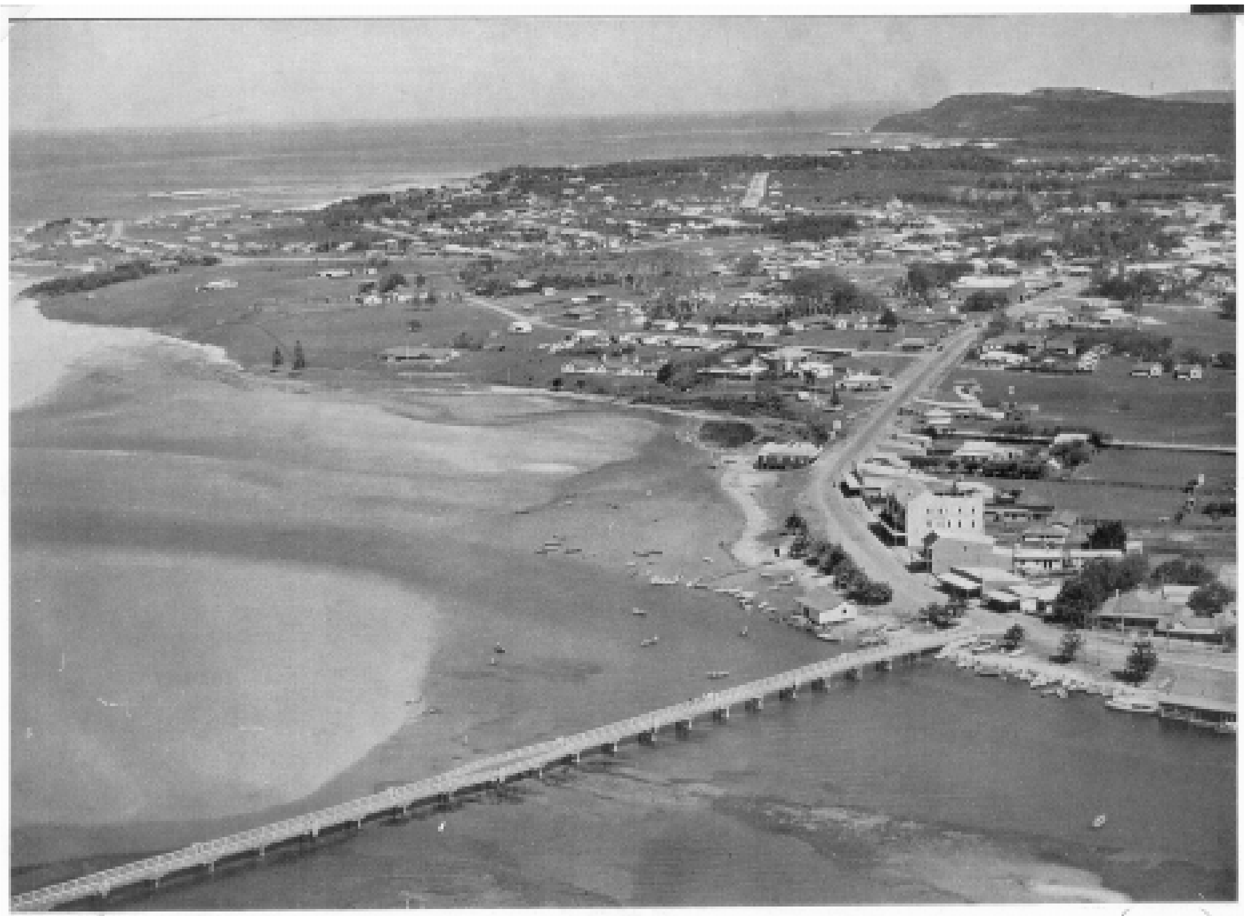
Figure 3. Population of Wyong Shire, 1820 to 1997

Figure 4. Tuggerah Lakes in 1998



Tuggerah Lake near Long Jetty, 1927. (Photo; Mitchell Library)

Deave's Point (now called Green Point) on Budgewoi Lake in 1935 (photo; Eileen Brown)



The Entrance in about 1937. The sand bar in the upper left hand side of the photo indicates that the channel might have been closed off at this time. *(photo from Wyong Historical Society)*

Aerial photo of Toukley, probably taken in the late 1930s or early 1940s. *(contributed by Graeme Wagstaff)*

3 Aquatic plants and algae

Many local residents and fishermen use the term ‘weeds’ when referring to both the algae and the aquatic plants that grow in the Tuggerah Lakes and often no distinction is made between them. These are in fact two quite different groups of organism, and each will be discussed in further detail below.

In biological terms, the aquatic plants and the algae are both defined as primary producers since they obtain their energy from the sun through photosynthesis. Primary producers play an important role in the ecology of lakes since they produce oxygen gas (as a result of photosynthesis) and also provide food and shelter for aquatic animals.

Both the algal and aquatic plant populations in the Tuggerah Lakes show a high degree of natural variability, both temporally and spatially. Temporal variability is both on a regular seasonal basis and also a less predictable yearly basis.

3.1 Aquatic plants

The aquatic plants of principal interest in the Tuggerah Lakes are the seagrasses, which grow under the water on the lake bottom. Other aquatic plants include emergent species along the lake edge such as *Paspalum vaginatum, Phragmites australis* (Common reed), *Juncus kraussii* (Sea rush) and various saltmarsh species.

Seagrasses generally grow below the high tide level in the sheltered shallow waters of estuaries. They are flowering plants and are found in soft sediments like sand or mud. Like any plant, seagrasses need light to grow and are usually restricted to the upper two metres of water where there is sufficient light. In form, many seagrasses grow from rhizomes, or underground stems.

The dominant seagrasses in the Tuggerah Lakes are *Zostera capricorni* (eelgrass or ribbonweed), *Ruppia megacarpa* (stackweed) and *Halophila ovalis* (breamweed or paddleweed).

Table 2. The three dominant seagrasses of Tuggerah Lakes

Common name	*Scientific name*	*Features*
Ribbonweed or eelgrass	*Zostera capricorni*	• Narrow strap-like leaves up to 50cm long and 0.5 to 2 cm wide • Exhibits a fast leaf growth during spring and summer and leaf loss in autumn. In winter the rhizomes remain buried in the substrate • Propagation of *Zostera* is almost entirely vegetative through the spread of the rhizomes. • Thrives in waters of high salinity but can tolerate waters of reduced saline content. • Can persist in currents of several knots • In Tuggerah Lakes, tends to favour the sandier sediments. • Black swans feed on the stolons
Stackweed or seatassel	*Ruppia megacarpa* (previously called *Ruppia spiralis*)	• Slender stems with numerous branches, usually 20-30 cm long but sometimes up to 2 metres long. • Narrow leaves less than 2mm wide and 2-20cm long. • *Ruppia megacarpa*, in comparison to *Zostera*, is often associated with estuarine waters of reduced salinity. • Intolerant of strong currents, favouring sheltered bays. • Favours areas with muddy sediments. • Note; *Ruppia megacarpa* is sometimes not classified as a seagrass since it also grows in non-marine brackish waters
Bream weed or paddleweed	*Halophila ovalis*	• Paired oval leaves 1-5 cm long and 0.5 to 2cm wide. • In Tuggerah Lakes, generally restricted to shallow sandy areas to a depth of approximately 1 metre.

Information derived from Higginson (1965) and West (1983)

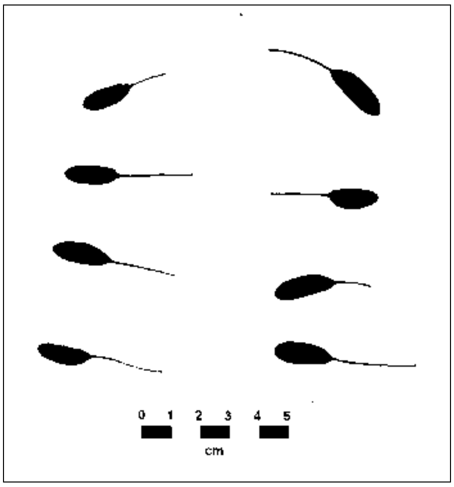


Figure 5a. Bream weed or paddleweed *(Halophila ovalis)*

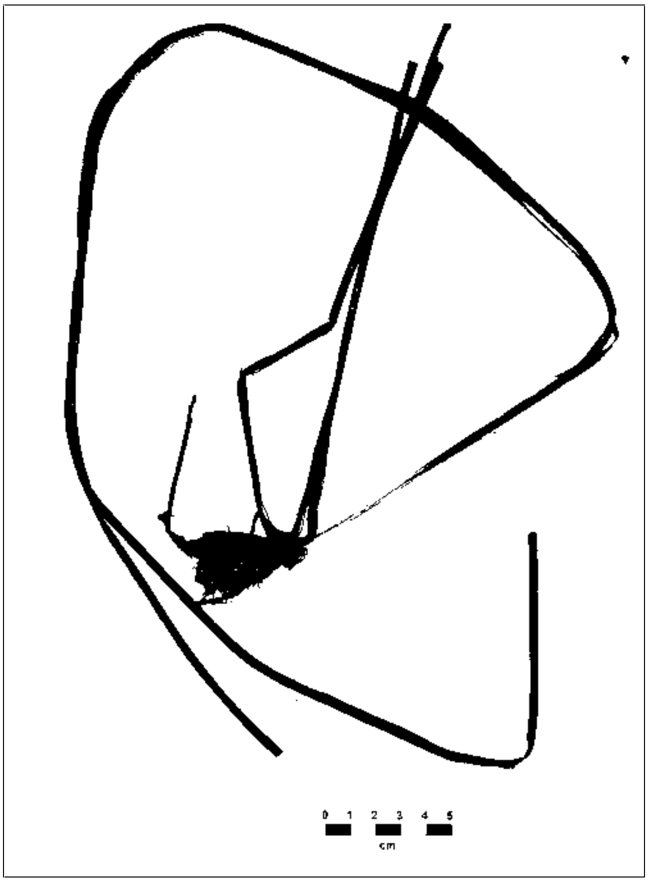


Figure 5b. Ribbonweed *(Zostera capricorni)*

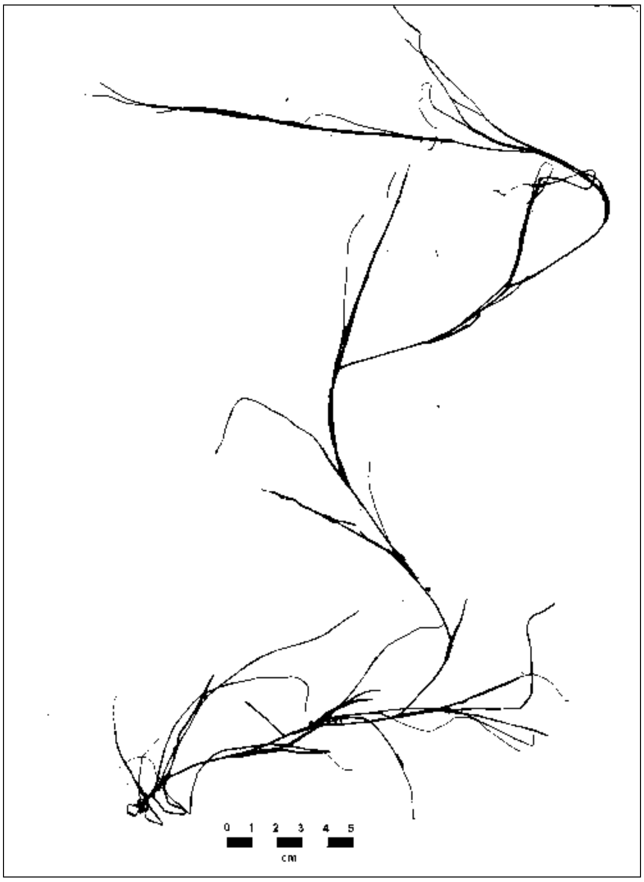


Figure 5c. Stackweed *(Ruppia megacarpa)*

Seasonal variations in the abundance of seagrass can be 50% or more. This can be related to changes in light availability and water temperature which in turn affect the rate of photosynthesis of the plants. Other important factors include water turbidity, salinity and biological interactions (see Table 3). For instance, if storms and strong winds keep the lake turbid, plants in deeper water might die back due to the reduction in light.

Ruppia has a smaller root system than *Zostera* and tends to grow better on fine sediments. The small root system also makes it more susceptible to damage from storms. *Zostera* has a bigger root system and tends to do better where the water is turbulent – either from wind or water current.

Halophila is less conspicuous than the other two seagrasses, consisting of small paired leaves, and is generally found in shallow sandy areas. It is considered a pioneer species in denuded areas (West 1983) often to be followed by *Zostera*.

West (1983) reported that along the NSW south coast, coastal lagoons which are regularly open to the sea contain beds of *Zostera* and *Halophila ovalis* at the entrance delta and in shallow water around the fringes. *Ruppia* is also sometimes present in the very shallow water and at creek entrances where the salinity is lower. If there are long periods (of up to several years) when the lagoon entrance does not open, salinity can fall due to rainfall and freshwater inflows, and the much of the *Zostera* and *Halophila* stands are replaced by *Ruppia*.

Without the presence of seagrasses in the Tuggerah Lakes, the whole ecological balance would be upset, and there would not be the abundance or diversity of fish and bird life. "

<u>Effect of salinity on seagrasses</u>
Growth studies undertaken at Sydney University showed that Ruppia will grow happily in water of salinity 0.35 to 35 ppt, although the relative growth rate was 4 times higher towards the brackish end of the spectrum. Zostera, on the other hand, had its highest growth rate at the marine end of the spectrum. (Ross Higginson, May 1999)

3.2 Algae

Algae are a natural part of the lakes' ecology and together with the seagrasses are the main primary producers. They form an important food source for many species of aquatic animals. The algae can be broadly divided into two main groups, the microscopic free floating algae collectively called phytoplankton, and benthic or attached algae (Cheng 1984).

<u>Phytoplankton</u> is the dominant primary producer in the open water of the lakes and is an important food source for zooplankton and filter feeders . It exhibits seasonal changes in species composition and abundance. The factors controlling these changes include nutrient availability, light, temperature and biological interactions. Under certain conditions, usually associated with high nutrient levels, massive phytoplankton crops can develop, forming 'algal blooms'. Tuggerah Lakes has not yet had any problems with blooms of phytoplankton.

<u>Benthic algae</u> includes both microscopic algae growing on the mud surfaces on the lake bottom, and also the algae that grows on the surfaces of seagrass leaves (which is referred to as epiphytic algae). Other benthic algae consist of large complex structures that form tangled mats lying over the seagrass beds or on the mud in the shallow waters of the littoral zone. These are called <u>macroalgae</u> and include filamentous green algae such as *Chaetomorpha*, *Rhizoclonium*, *Cladophora* and *Enteromorpha* (King and Hodgson 1995). Local fishermen often refer to macroalgae as 'wool'.

Macroalgae occur throughout the year but in spring and early summer they may proliferate. If nutrient levels are high, large quantities of detached macroalgae will form floating mats, particularly in sheltered shallow localities. Such blooms of macroalgae have been a problem in the Tuggerah Lakes on a number of occasions.

Since algae extract nutrients from the surrounding water, the ultimate limiting factor for their growth is the nutrient status of the lake water.

Macroalgae in the Tuggerah Lakes

The nuisance algae in Tuggerah Lakes are mostly green algae, baitweed (*Enteromorpha*) and more particularly the finer filamentous types (*Chaetomorpha* and *Rhizoclonium*). These algae are attached at least initially, to the substratum which is often the leaves of seagrasses. Later they may form large floating surface mats which can be buoyed up by the oxygen produced during photosynthesis. A further macroalga common in the lakes is *Gracilaria verrucosa*. This is a more robust red alga and it is not implicated as a nuisance species. The three green algae are naturally occurring in the Tuggerah Lakes and are also widely distributed in other estuarine and marine localities around Australia. As elsewhere, it is their excessive growth and subsequent accumulation and decay with the production of objectionable odours that is a major cause for complaint. *(Adapted from King 1988)*

3.3 Seagrass and macroalgae – getting the balance right

Beds of seagrass are valuable fish habitat in the Tuggerah Lakes. These act as a host for epiphytic algae and small marine animals (such as protozoans) by providing a surface area on which they can grow. In turn, some species of aquatic invertebrates and fish (such as mullet, luderick and garfish) graze on these. The seagrass beds also provide shelter for small fish and crustaceans from larger predatory fish. Macroalgae is another source of food for some aquatic animals inhabiting the lakes.

The unvegetated sand and mud flats around the edges of the lake also play an important role in the ecology of the lake system by providing habitat for a range of other marine animals such as worms and shellfish, and also some fish species such as whiting and flathead.

The greatest biodiversity of marine life in Tuggerah Lakes will occur when there is a combination of both vegetated areas (both seagrass beds and macroalgae), and also some unvegetated areas (both sand and mud flats).

However, if nutrient levels in the water are high, excessive growth of macroalgae can occur. This can reduce (or eliminate) seagrass beds and also cover the sand and mud flats. If the lakes become dominated by macroalgae, the biodiversity is likely to be reduced.

Excessive growth of macroalgae can also restrict commercial fishing activities as well as some recreational uses of the lakes. Decomposition of large quantities of dead seagrass and algae washed up along the shallow edges of the lakes also gives off offensive odours and creates a thick layer of organic ooze which can cover the sandy bottom.

3.4 History of 'weed' growth in the Tuggerah Lakes

Much of the information on 'weed' growth in the Tuggerah Lakes prior to 1960 was collected from interviews with local residents and fishermen (Scott 1998). These interviews provided valuable information back to the 1920s. Prior to 1920, there are only a handful of historical records in annual reports of the State Fisheries Department. From 1960 onwards anecdotal records could be supplemented with the results of scientific surveys.

In the following sections, summaries of the key periods of weed growth and other important issues related to the weed abundance in the lakes, are presented. For a more complete set of references and anecdotal records, refer to the earlier reports (Allison and Scott 1998, Scott 1998, and Scott 1999).

3.4.1 'Weed' and 'slime' in the 19th century

There are very few historical references to weed growth in the Tuggerah Lakes prior to 1920. In the annual reports of the Fisheries Department from the 1880s and 1890s there are some passing comments about 'slimy weed' interfering with netting, and to the presence of small fish in the weed around the edge of the lake.

The only other useful information prior to 1920 are a number of reports, dating as far back as the 1830s and 1840s, that describe 'thousands' of black swans on the lakes (Scott 1999). Since seagrasses, such as *Zostera*, constitute the bulk of the food for these birds, these reports indicate that aquatic plants were present in the lakes prior to any European settlement.

Slimy weed in 1888
The lakes themselves are in a very dirty state owing to a slimy weed which is very destructive to the nets. I do not expect improvement until a flood occurs. (1888 Fisheries Annual Report)

Weed in the shallow water - 1891
The sea entrance, Ourimbah Creek, Wyong Creek, and the big flat on the eastern side of Budgewoi Lake, which were swarming with young fish, especially mullet, in fact young fish were very plentiful all round the shores of the Lake, where the nets could not disturb them owing to the shallow water and the weeds. (1891 Fisheries Annual Report)

Less weed and slime - January 1898
The young fry are first seen in shallow water on the flats of rivers or lakes and bays. I have seen large shoals of small fish, from ½ to 1 inch, in drains and round the edges of the lake behind the weeds, and the water has been so hot that I could scarcely bare to wade in it. Still the young fish seemed to enjoy it. …. At present the waters are in fair condition, there not being so much slime and weeds on the bottom; but the weather is very much against getting good hauls. ….. (Memo from Charles Gordon, January 1898, Fisheries Annual Report for 1897)

3.4.2 Stackweed in the 1920s and early 1930s

A number of the older people interviewed during this project reported that Budgewoi Lake was covered in large quantities of stackweed (*Ruppia megacarpa*) during the 1920s and early 1930s (Scott 1998). The stackweed grew in the deeper parts of the lake and came right up to the surface, reaching lengths of up 3 metres. The southern part of Tuggerah Lake (south of Chittaway Point) also had large quantities of stackweed during this period. However, the eastern shore of Tuggerah Lake, from Long Jetty north to Canton Beach was clean and sandy during this time.

During the 1920s and 1930s, Lake Munmorah did not experience a growth of stackweed and all reports indicate that the lake only contained small patches of ribbonweed.

Weed in the 1920s
The main lake was very weedy on the western side but the eastern side had clear sand flats, where prawning was done..... The Middle Lake, now known as Budgewoi, was a very weedy lake ...... The Top Lake, known as Munmorah Lake, was clear of weed. (Arthur Clouten)

The weed in the 1920s and early 30s
When I started as a child, the whole of Middle Lake was solid weed, you couldn't get through it in a boat. There was a channel around to the jetty at Toukley and another through the middle of the lake and the rest was solid weed. (Pat Clifford)

There was always weed in some areas
The Lakes have always had some weed, even in my father's time - but this was generally confined to the shallows on the southern and western shores of the bottom and centre lakes - especially the centre where I have seen these areas very heavily infested indeed. (Resident since 1891, interviewed in 1963 by Electricity Commission)

3.4.3 Little weed in the 1940s

During the late 1930s and early 1940s the stackweed in Budgewoi and Tuggerah Lakes is reported to have died off. Although difficult to interpret, aerial photos taken in 1941 appear to confirm that weed growth was minimal during this time. The recollections of residents and holiday makers visiting the area in the 1940s, were of weed-free lakes with sandy foreshores. A number of photos from this period also show sandy beaches with little weed (see photos in this report and in Scott 1998).

It is possible (but not confirmed) that this loss of stackweed was associated with a succession of dry years during this time. During the period 1935 to 1941 every year had below average rainfall and this might have resulted in a sustained increase in lake salinity, which in turn would have reduced the growth rates of stackweed.

<u>*No weed in 1940s*</u>

In 1938 the entrance to the sea blocked. So no sea water, and all weed and shell life died by 1941. The lake foreshore became hard sand, fish became very scarce and fishermen had to catch under-size fish to exist or go to other estuaries. (Arthur Clouten)

3.4.4 Stackweed returns in 1950s and early 1960s

It wasn't until the early 1950s that fishermen reported substantial areas of 'weed' beginning to appear again. By the early 1960s there were large areas covered in stackweed, in particular the centre of Budgewoi Lake and the south-western parts of Tuggerah Lake. The weed became so prolific in the early 1960s that fishermen had difficulty using hauling nets (Scott 1998).

The first survey of aquatic plants in the Tuggerah Lakes was undertaken in late 1962 by Higginson (1965) and his results confirm the large growth of stackweed in Budgewoi and Tuggerah Lakes. Subsequent surveys by Higginson and the Electricity Commission indicate that the stackweed was still present in May 1963 but had disappeared by August 1965 (IDC 1979). Newspaper reports from 1965 and 1966 also indicate that the weed growth eased around about this time (Allison and Scott 1998).

However, all anecdotal accounts and surveys of Lake Munmorah during this period indicate that this lake was relatively free of 'weed' apart from some beds of ribbonweed.

<u>*Fishing Inspector's comments*</u>

..the Fisheries Inspector stationed at Lake Macquarie between 1949-1952 and then at Tuggerah Lakes from 1956-1965. ..has talked with the old professional fishermen of the Lakes who claim the growth of stackweed (Ruppia) in the twenties was so severe it hampered fishing and movement of boats on the Lakes. The Inspector also recalls the decline in weed cover of the late forties such that by the mid fifties Canton Beach was clean sand. Following this there was a rapid growth of weeds culminating in the severe problem of 1960-1962. (extract from the Interdepartmental Report on the Tuggerah Lakes, published in 1979)

<u>*Stackweed returns to Tuggerah Lake and Budgewoi Lake*</u>

From 1939-54 ...there was a little bit of ribbonweed but no stackweed. And that is when there were no fish and prawns in the lake too. In 1958 there was stackweed in the lake again. By 1962 .....the stackweed was right across from Chittaway, and Budgewoi was full of stackweed too. The stackweed was to the top of the water and you could not use a hauling net so we used a meshing net in between the weed. But the Top Lake was bare at that time. (Arthur Clouten)

Seagrass and algal distribution in 1962/63

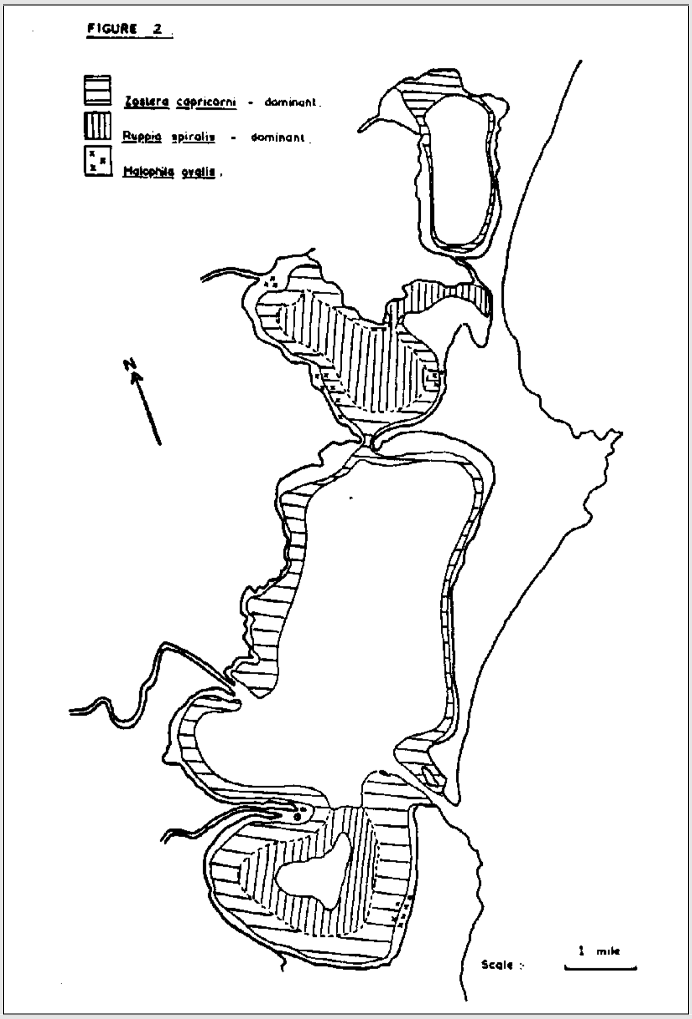


Figure 6. Seagrass communities in the Tuggerah Lakes in 1962-63. (plant distribution was compiled by Ross Higginson from aerial photos taken in November 1962 and supplemented by skindiver transects in early 1963)

<u>*Additional comments by Ross Higginson*</u>
The map shown in Figure 6 is a simplified version of the plant distribution in 1962/63 and shows the dominant seagrass in each region of the lake. Studies reported later (Higginson 1968) show the structure of these seagrass communities, and to illustrate this, the list of species present within the two most dominant communities together with an estimation of their abundance are presented below;

***Zostera* community**	abundance
Zostera capricorni	*90.3%*
Enteromorpha clathrata	*1.0%*
Polysiphonia mollis (epiphyte)	-
Other macroalgae including – *Gracilaria verrucosa* (February), *Cystophyllum muricatum* (April), *Dictyota dichotoma* (March) and *Cladophora* sp. (June)	8.2%
Velacumantus australis (whelk)	-
Spirorbis sp. (tubeworm)	-

***Ruppia* community**	abundance
Ruppia megacarpa	*78.6%*
Chaetomorpha linum	*14.6%*
Lyngbya complex	6.6%
Potamopygus procinctus (gastropod)	-
Notospisula cretacea (bivalve)	-

At this time both macroalgae and *Ruppia* were considered a nuisance by those using the lake. The Lyngbya complex (probably *Lyngbya majuscula*) was a light-green, very slimy mass that sometimes became smelly. It was capable of preventing an outboard motor from operating. *Ruppia* was growing to the top of the water-line in Budgewoi Lake and at Chittaway Point, and was so thick that it was impossible to drag a fishing net.

Decline in Ruppia in August 1965

The decline in Ruppia distribution in Budgewoi Lake in August 1965 was caused by excessive water turbulence (storm-driven) that physically separated the Ruppia roots from the sediment. Ruppia tends to grow in finer sediments, and together with its finer root system, is more easily separated from the substrate during times of high turbulence. Zostera, on the other hand prefers to grow on sandier sediments and, together with its much stronger stoloniferous root system, can withstand turbulent water movement much more than Ruppia. During the same storm in August 1965, the leaves of Zostera were torn off the rhizomes and were then deposited around the edges of the lakes, particularly Budgewoi and Tuggerah Lakes. (Ross Higginson, May 1999)

3.4.5 Hauling nets keep eastern shores free of weed

Anecdotal reports (Scott 1998) indicate that the eastern shores of Tuggerah Lakes, from Long Jetty in the south right up to Canton Beach, remained clear of weed until the 1960s and many locals believe that this was due to the continuous hauling of prawning nets across the shallow near-shore areas during the summer months. Hauling nets were used for prawning by professional fishermen until about 1962 when running nets were introduced, and a few years later snigger trawling. Amateur prawners also used small 20ft hauling nets.

The hauling nets would 'rake up' any loose weed along the shorelines. There are also reports that early this century the fishermen used scythes to remove weed beds that were interfering with the hauling of nets.

The surveys by Higginson and the Electricity Commission (Higginson 1965, IDC 1979) confirm that on most occasions in the early to mid 1960s there was little 'weed' in the shallows along the shoreline of Tuggerah Lakes, but do show a band of ribbonweed in deeper water. Surveys from the 1970s onwards, indicate that stackweed had established in the previously bare shallows between the ribbonweed and the shoreline. King and Holland (1986) surveyed the vegetation of the Tuggerah Lakes in 1985 and also observed this trend.

Whether the increased growth of 'weed' around the shoreline has only occurred after the use of prawn hauling nets ceased, or whether it is due to some other factor, such as increased nutrients or mud from urban runoff, is difficult to determine. However, comments in the diaries of Arthur Clouten, a professional fisherman in the early 1960s indicate that fishermen had to stop using hauling nets because of the increased weed growth, rather than the reverse (Scott 1998).

Prawn hauling keeps shores clean of weed

My dad got the big catches of prawns with a prawn hauling net from the shore, a net of 6 strips of 25 yards each (150yds total). And that type of net used to keep the shallows clean of weed. ..... This hauling effect would be occurring each prawning season all along the eastern shore of Tuggerah Lake. ....These days there is no cleaning effect because they are not hauling the net across the shallows. (Trevor Spiers)

Using a scythe to remove weed

My grandfather used to use a scythe to remove any weed that was in the way of the net because the fish could lay under the weed, and the net would go over the top. (Elizabeth Denniss)

3.4.6 Little 'weed' in Lake Munmorah until the late 1960s

As mentioned previously, anecdotal reports of Lake Munmorah prior to the late 1960s indicate that there had only ever been a few small patches of 'weed'. However in the late 1960s or early 1970s, locals reported that 'weed' started appearing in locations where it had not been observed previously, in particular in the shallows along the shoreline. This trend is confirmed by aquatic plant surveys in the 1970s and 80s (IDC 1979, King and Holland 1986).

It is not entirely clear what caused the change in abundance and distribution of 'weed' in this lake, although it was probably associated with the increasing rates of nutrients entering the lake from urban runoff (particularly from septic tanks) as residential development around the shores accelerated during the 1960s and 70s. In 1967 the Munmorah Power Station commenced operation and this caused a small increase in water temperature in Lake Munmorah and changed the water circulation patterns between Budgewoi and Munmorah Lakes. Whether these impacts also had an effect on the growth of seagrasses and algae in Lake Munmorah is unclear.

Munmorah free of weed
The Top Lake was always a clean lake, you didn't see much weed, but the weed has grown into it now. I think the weed grows when you get soil, and a lot of soil has been washed into all these areas, so I think there is more weed now. (Clarrie Wynn)

Lake Munmorah in the 1940s
It was a beautiful lake, clean, sandy shores. Near the camping ground it was all nice white sand. You wouldn't have got a bucket full of weed from around the whole lake. It was all sand right the way round, except the western side which was gravel. There is more weed and mud now. (Mick Asquith)

Lake Munmorah was the 'cleanest' lake
I remember in the early 1960s that Lake Munmorah was by far the 'cleanest' lake from a vegetative point of view. (Dr Ross Higginson)

3.4.7 Early references to algal growth (1880s to the 1960s)

There are very few historical references to algae in the Tuggerah Lakes apart from a few passing comments in the annual fisheries reports of the 1880s (see section 3.4.1). One of these refers to a 'slimey weed' and another refers to 'slime'. Slime is a term often used by fishermen to describe macroalgae, although 'slimey weed' could also refer to seagrass with epiphytic algae growing on its leaves.

Evidence from the 1920s onwards, is largely based on anecdotal reports from retired fishermen. They recall that 'wool' and 'slime' have been present in the Tuggerah Lakes ever since they first started fishing. These reports indicate that macroalgae ('slime' and 'wool') have always been present in the Tuggerah Lakes, but like the seagrasses have varied greatly in abundance and distribution from year to year.

More recently, a map of weed distribution produced in October 1962 by the Electricity Commission (IDC 1979) showed *Chaetomorpha* in the shallows of Tuggerah Lake from Saltwater Creek in the south, around the western shoreline and up to Wyongah in the north of the lake. The same map showed a small amount immediately north of The Entrance North in Tuggerah Lake, and another small patch just north of the large sandbar in Budgewoi Lake. *Cladophora* was also present in the south of Tuggerah Lake and near the sandbar of Budgewoi Lake. Higginson (1965, 1968) also recorded a variety of macroalgal species in association with seagrass beds during his surveys in 1963. In 1971 Higginson published a paper in which he concluded that the eutrophication process had commenced, resulting in excessive growth of both algae and seagrasses. He attributed this to the increased nutrient inputs from erosion in the upper catchment and the entry of sewage pollution from urban areas.

Red wool

There is a sort of weed that we call 'red wool'; it comes in the spring or towards the latter end of winter. And then you can't haul a net, you can't do anything. It grows on the bottom. It does not float. It comes periodically, some years it is there other years it isn't. I remember in the 1930s we couldn't get the fish in the nets up because there was so much of the stuff. (Pat Clifford) (Note; The species being referred to is most likely to be *Gracilaria verrucosa*)

3.4.8 'Weed' problems continue from the late 1960s until the early 1990s

In the late 1960s and 1970s, people started to report that 'weed' (seagrass and macroalgae) was growing in shallow areas where they remembered it as always being sandy and free of weed.

From the mid 1970s onwards, there are an increasing number of newspaper reports that document the increasing problems with algal growth along the beaches of the lakes (Allison and Scott 1998).

In 1978, Ernie Quinton, a boat hire operator, led a community campaign to remove large amounts of macroalgae from Canton Beach (Allison and Scott 1998).

Concern about the algal growth led to the Public Works Department commissioning Cheng and Associates to undertake a study of macroalgae at Canton Beach and Long Jetty, commencing in December 1978 (see section 3.4.9).

Problems with weed growth, and in particular macroalgae, continued through the 1980s. In the late 1980s and early 1990s the algal growth became significantly worse, with reports of large amounts of 'slime', 'fungus' and floating mats of macroalgae. Once again, the algal growth was primarily along the shallow edges of the lakes where there had once been sandy beaches. These algal blooms coincided with the appearance of bad smells and a black 'ooze'.

During the same period, from the 1960s to the 1990s, some of the professional fishermen believed there had been a decline in seagrass beds in the deeper central parts of Tuggerah and Budgewoi Lakes (Scott 1998). In particular they reported a decline in the amount of stackweed. These reports are confirmed by the weed surveys undertaken in the 1960s, 70s and 80s (IDC 1979, King and Holland 1986, King and Hodgson 1995).

3.4.9 Algal studies in the 1970s and 1980s

Dominic Cheng undertook a number of algal studies in the Tuggerah Lakes during the 1970s and 1980s (Cheng 1979, 1980, 1984, 1985, 1986a, 1986b, 1987). His first survey was in the littoral shallows of Canton Beach and Long Jetty in the period December 1978 to June 1979 (Cheng 1979), and his results are summarised below;

Both areas contained the two seagrasses *Zostera capricorni* and *Ruppia megacarpa*, and a variety of algal species, including the two filamentous green algae *Chaetomorpha linum* and *Enteromorpha intestinalis*. These two species formed large floating mats, up to a metre thick and many metres across, and appeared to be the subject of most of the complaints by fishermen and holiday-makers.

During the summer months of 1978-79, at Canton Beach and Long Jetty, seagrasses and algae in the littoral shallows formed almost continuous carpet covers extending from the edge of the lake to considerable distances off shore. At Canton Beach the width of the weed belt ranged from 120 metres off Dunleigh St, at the north-western end, to over 300 metres off Crossingham St, further east. The results of transect studies by Cheng at Canton Beach indicated that filamentous algae covered about 70% of the weed belt, either as large algal mats or in association with seagrasses. At Long Jetty the percent cover of filamentous algae was lower, at about 33%.

The lake floor within the weed belt was usually covered by a fine black sediment near the lake edge and gradually changed to clean sand towards the outer fringe.

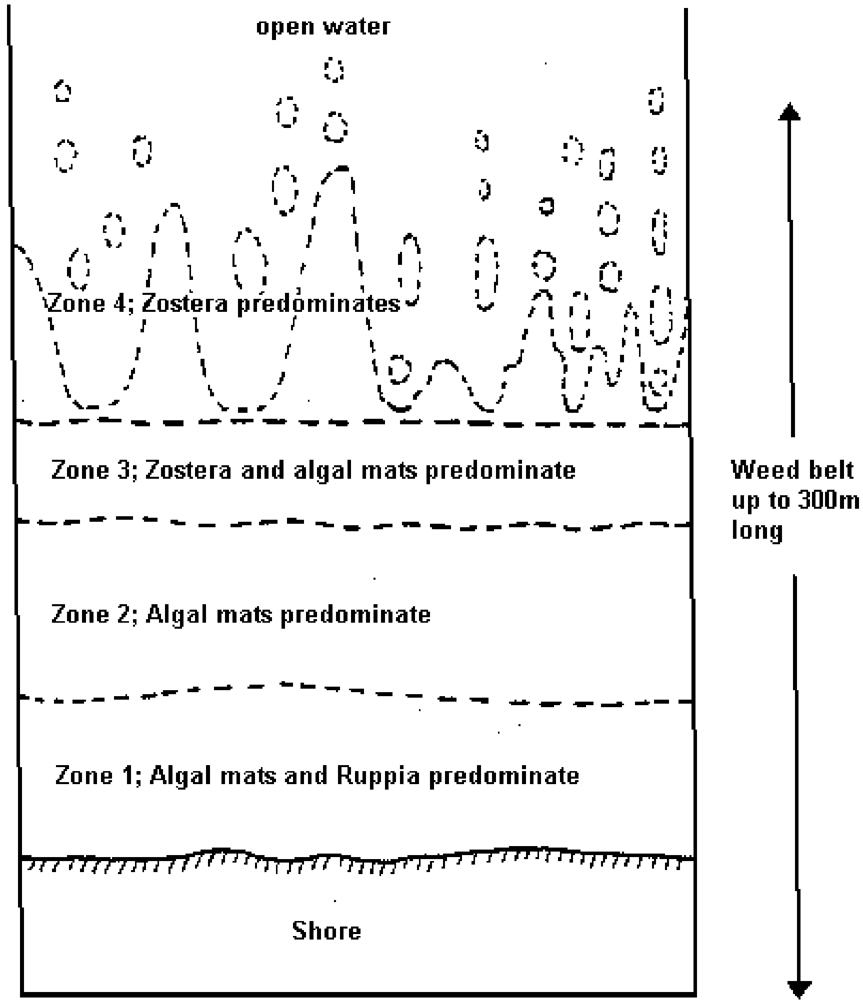


Figure 7. Zones of seagrass and algae observed by Cheng at Canton Beach and Long Jetty in his 1978-79 surveys

3.4.10 Causes of excessive algal growth in littoral zones.

In his first study, Cheng (1979) provided an explanation of why there was excess algal growth in the littoral zone despite the nutrient concentrations of the open water being quite low. This explanation is summarised below.

The quantity of algae present in a water body is largely determined by the availability of light and nutrients. When light is not limiting, such as in the shallow waters around the edge of the Tuggerah Lakes, it is generally accepted that nutrient availability, especially compounds of nitrogen and phosphorus, controls to a very large degree the size of the algal crop present. Indeed, increased algal growth is usually a major symptom of eutrophication (the nutrient enrichment of water)

Water quality analyses from the open waters of Tuggerah Lakes indicated that the concentrations of phosphorus and nitrogen were quite low, and well below eutrophic levels. Measurements of chlorophyll-a (which indicates the amount of phytoplankton present), confirmed this.

Concentrations of nitrogen, phosphorus and chlorophyll-a in the Tuggerah Lakes

Dissolved phosphate	3 ug/L
Total phosphorus	5 ug/L
Total phosphorus concentration in eutrophic lakes	> 30 ug/L
Nitrate nitrogen	20 ug/L
Total inorganic nitrogen	30 ug/L
Total inorganic nitrogen in eutrophic lakes	> 500 ug/L
Chlorophyll-a (Tuggerah Lake)	2.7 ug/L
Chlorophyll-a (Budgewoi Lake)	2.3 ug/L
Chlorophyll-a (Munmorah Lake)	3.1 ug/L
Chlorophyll-a in eutrophic lakes	>10 ug/L

At first glance, the presence of the large standing crops of seagrasses and filamentous algae in the littoral shallows of Canton Beach and Long Jetty appeared to be a contradiction to the results of water quality monitoring of the lake. However, the routine water quality monitoring was carried out in the open waters of the lakes and did not include measurements of the littoral shallows where the weed problem was most severe.

In the littoral zone, the seagrasses and algae were found to be receiving high concentrations of nutrients from urban stormwater. This included seepage from septic tanks and urban runoff from roads and gardens. Under wet weather conditions, Cheng reported that discharges from stormwater drains along Canton Beach contained total phosphorus concentrations averaging 180 ug/L (and dissolved phosphorus of 40 ug/L). Some stormwater drains had total phosphorus concentrations above 1000 ug/L. The nitrate-nitrogen figures were also high, averaging 1440 ug/L with a maximum of 3600 ug/L.

Therefore, during wet weather, when large volumes of urban runoff were flowing into the littoral shallows of the lakes, there was a significant input of nutrients, both in dissolved form and attached to sediment.

The nutrients entering the littoral zone via urban stormwater were eventually deposited or incorporated in the sediment, where it slowly accumulated. Analyses of sediment samples confirmed that the nitrogen and phosphorus concentrations were very high. This store of nutrients in the sediment was sufficient to maintain a large quantity of algal matter, even without further inputs from the catchment.

In summary, although the open waters of the Tuggerah Lakes have relatively low concentrations of nutrients, the concentrations in the littoral shallows can be very high due to inputs from the surrounding urban areas.

Nutrient concentrations - separation of nearshore zone and main water body

There is a significant degree of separation between the nearshore zone and the main water bodies of the lakes. The significantly different concentrations of nutrients, and also differences in oxygen levels and temperature is evidence of this (Cheng 1979, 1984, 1995) This separation is enhanced by the presence of seagrass beds which reduce the circulation of water in the nearshore zone, and has two important consequences for management (Walkerden and Gilmore 1996);

1. The main water bodies have low nutrient concentrations and show little sign of eutrophication, while the near shore zones have higher nutrient concentrations and are more eutrophic.

2. Different areas of the catchments are the primary sources of nutrients for each region. Pollutants from the immediate catchment of the lakes dominate inputs into the nearshore zone. These are carried to the lakes by local surface runoff and local groundwater seepage. It was in these areas that septic sewage systems predominated in the 1960s and 70s. Pollutants from the wider catchment, carried by the main rivers and creeks, dominate nutrient inputs to the main water bodies.

3.4.11 Less macroalgae in mid to late 1990s?

Interviews with residents indicated that in the late 1980s and early 1990s there were large quantities of macroalgae growing in the shallow areas around the edges of the lakes (Scott 1998). But in the last 3 or 4 years residents reported a decline in this growth. Walkerden and Gilmore (1996) reported a similar finding from a series of workshops with community representatives, Councillors, and staff officers of government agencies. They concluded that macroalgae was dominant from about 1982 until 1992 when there was a sharp decline in abundance.

Possible explanations for this decline are;

- A natural biological cycle is at work, although there are no obvious natural variations in the climate or lake environment that might have caused its disappearance in the early 1990s

- The removal of sewage inputs to the lake. Septic systems were replaced by a reticulated sewerage system and full implementation was in place in the late 1980s. The routing of all treated effluent to ocean outfalls was implemented in 1988. The decline in macroalgae a few years later might simply reflect a lag in response to these improvements.

- The implementation of measures to reduce the impacts of urban runoff. In the late 1980s, artificial wetlands (‘stormwater treatment zones’) were added to over 200 streams draining into the lakes. However Walkerden and Gilmore (1996) reported that preliminary monitoring carried out by Wyong Council indicates that these wetlands are only making a marginal contribution to the management of nutrients.

- The physical removal of ooze from shallow nearshore zones during the Lakes Restoration Project may have reduced the pool of nutrients available for algal growth. The Restoration Project, which took place from around 1988 to 1993, with much of the work occurring in 1992, involved removing ooze from 15 km of the lake edge and placing it behind clay bunds (walls) created at the edge of the lakes. Not only did it remove nutrients but it deepened the nearshore zone, allowing better circulation of water. However only 15 km out of a total of 105 km of shoreline were treated.

- Changes to the entrance channel which improved flushing of the lakes. The entrance channel was almost closed in 1979, and again in 1980, 1981, and 1986. In the early 1990s however, floods in February 1990 (1.6 metres) and again in 1992 (1.2 metres) would have helped scour out the entrance channel (Lawson and Treloar 1994). In addition, dredging at The Entrance was undertaken in the early 1990s as part of the Lakes Restoration Programme. This might have improved conditions in Tuggerah Lake, particularly near The Entrance, but would not explain the improvements in other parts of the lakes where the tidal flushing would have less effect, particularly in Budgewoi and Munmorah Lakes.

- The reduction in output of Munmorah Power Station in the late 1980s followed by the closure of two of the four generating units in the early 1990s. This resulted in lower water temperatures in Lakes Budgewoi and Munmorah. However the Power Station had very little effect on Tuggerah Lake where the reduction in algal growth was also observed.

A number of these explanations are plausible, and possibly it was due to a combination of effects. Without a doubt however, the removal of sewage inputs through the replacement of septic tanks with a reticulated sewerage system has virtually eliminated one of the major sources of nutrients in the shallow nearshore zone of the lakes where the macroalgae was growing.

The recent trends in seagrass growth were more difficult to ascertain. Most of the professional fishermen interviewed by Scott (1998) reported that there is still very little stackweed compared with the early 1960s (or the 1920s) although a few thought there might have been a very slight increase in the last couple of years. On the other hand ribbonweed still appears to be plentiful, with many people still reporting quite large quantities being washed up on the shore.

The overall feeling of both the residents and fishermen who were interviewed was that the health of the lake had somewhat improved in the last 3 or 4 years with less ‘slime’ or algal growth along the lake shores.

Seagrass survey in the summer of 1985

King and Holland (1986) surveyed the seagrasses of the Tuggerah Lakes in the summer of 1985.

Seagrasses were recorded as covering 19.11 km^2 or 25% of the area of the lakes. *Zostera capricorni* was the most widely distributed seagrass occurring over 12.26 km^2 or approximately 16% of the lake area.

Lake	***Zostera***	**Halophila**	***Ruppia***	**Total area**
Tuggerah Lake	9.58 km^2	6.43 km^2	5.48 km^2	12.69 km^2
Budgewoi Lake	1.19 “	2.49 “	2.22 “	4.03 “
Lake Munmorah	1.49 “	1.48 “	0.54 “	2.39 “
Total	12.26 “	10.40 “	8.24 “	19.11 “

The areas of seagrass recorded were lower than those found by Higginson in the 1960s (Higginson 1965, 1968). He recorded in 1963, 1965 and 1966 seagrasses covering 42%, 31% and 28% of the lake area respectively.

Not only has the area occupied by seagrass decreased but also the relative importance of the different species has changed. Higginson’s survey in May 1963 (Higginson 1965) showed Lake Budgewoi almost filled with seagrass (76.2% of lake covered compared with 36% in the present study). The whole central region was occupied by *Ruppia* (42% of lake area). *Ruppia* was also dominant in deeper water in the southern part of Tuggerah Lake so that approximately one-third of the beds were *Ruppia*-dominated communities. By 1966 there was no *Ruppia* in the lake system (Higginson 1968).

The results of the 1985 survey by King and Holland showed that *Ruppia* had again become established in Tuggerah Lake but it was not found in deeper water; rather in shallow areas inshore of the *Zostera* beds. The places where *Ruppia* was dominant were west of Chittaway Point and just south of Toukley in Tuggerah Lake, and on Budgewoi Flats. The central portion of each of the three lakes was devoid of seagrasses.

3.5 Weed growth – long term changes

Early historical reports indicate that aquatic vegetation has been present in the Tuggerah Lakes system for over a century and almost certainly for a lot longer.

For the first fifty years or so of this century, the vegetation seems to have fluctuated both in area and in species composition. This variability is both on a regular seasonal basis and also a less predictable yearly basis. *Ruppia* in particular fluctuates greatly in its abundance, probably in response to salinity changes.

However, Batley *et al* (1990) and King and Hodgson (1995) concluded that some long term trends were also evident. They concluded that seagrass abundance around the near shore perimeter of the lakes had increased from the mid 1960s, and at the same time decreased in the centre of the lakes. They also concluded that since the early 1980s there had been a marked increase in the amount of macroalgae in shallow nearshore waters where it can constitute the bulk of plant matter in some localities.

The period of greatest change in aquatic vegetation coincides with the development and increasing human occupation of the catchment including long periods initially when housing developments were not sewered. Throughout the world, residential and industrial development of catchments have been identified as primary factors in bringing about nutrient enrichment (or eutrophication) of lakes that drain such catchments (Wood 1975; Cullen 1986; AWRC, 1983; Garman, 1983). Coincident with these changes in the vegetation there has been increasing reports of "black ooze" in the lake shallows with consequent further degradation of the lakes' recreational amenity and aesthetic appeal.

More recently, in the mid to late 1990s, there appears to have been a decline in the algal growth. Throughout the 1970s and 80s, the Wyong Shire was progressively sewered, and this project was finally completed in the early 1990s. This, along with other initiatives for reducing nutrient inputs (such as natural filters along stormwater drains and protection of riparian land in the upper catchment), should in the long term see a continuing reduction in eutrophication problems in the Tuggerah Lakes.

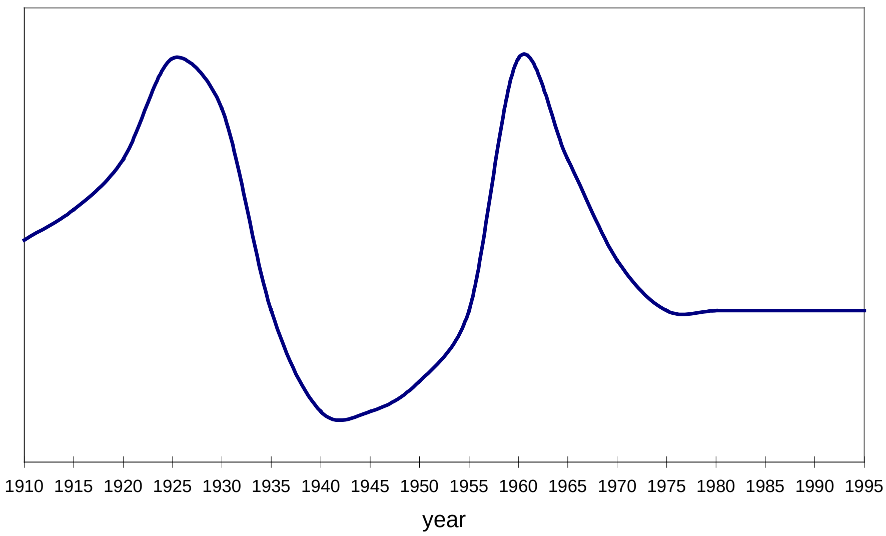


Figure 8.   Trends in seagrass abundance in Tuggerah Lakes

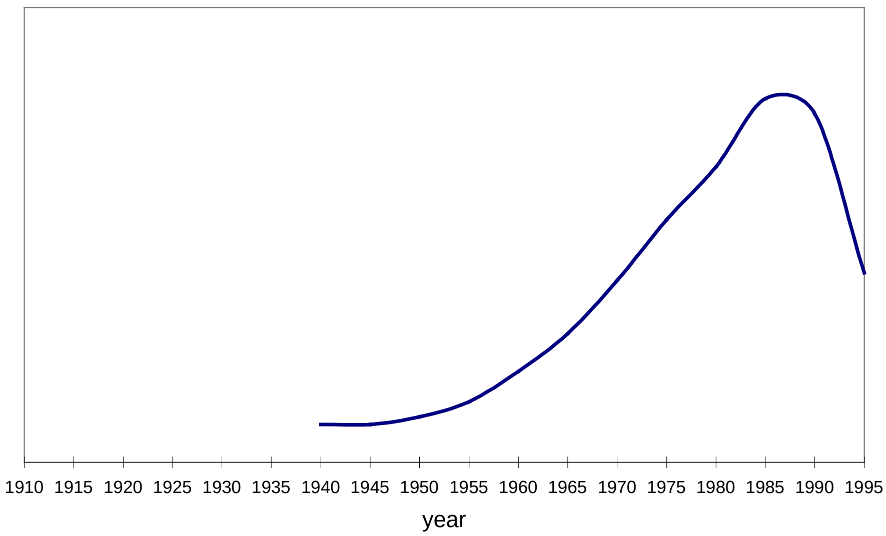


Figure 9. Trends in macroalgae abundance in Tuggerah Lakes

Researchers from the Electricity Commission and the University of Sydney collecting samples of seagrass and sediment during survey work in 1963. (photo supplied by Ross Higginson)

Canton Beach in May 1998. A tractor pulling a weed harvester can be seen in the background.

Table 3. Factors which can impact on the growth of seagrasses and algae in Tuggerah Lakes

Factors	*Effect*
Light	Increased availability of light increases the rate of photosynthesis and hence plant growth. Light is most intense in summer.
Temperature	Increased water temperatures in summer can lead to enhanced growth of seagrass and algae. However the growth of many species reaches a maximum at about 25ºC (King pers. comm.) and will decline sharply at temperatures above 35ºC.
Turbidity	Increased water turbidity, such as during a flood, reduces the available light and generally reduces plant growth, particularly for submerged species. Floating species will be favoured by high turbidity. Increased sediment loads entering the lake from erosion in the upper catchment and from urban runoff would have increased turbidity during wet weather above pre-European levels.
Salinity	This can have a major impact on the species composition. High salinity will favour marine species such as *Zostera*. Low salinity, such as after heavy rainfall, will favour species such as *Ruppia* which grow best in brackish water.
Turbulence	Seagrasses which have a strong root system (such as *Zostera*) will survive areas of high turbulence better than those with a weak root system which are easily dislodged (such as *Ruppia*). Turbulence can be associated with tidal flow near the entrance channel, or with the currents and waves generated by strong winds
Availability of nutrients in water	Increased nutrient supply in the water column tends to favour algal species over seagrasses. Algae can take up nutrients from the water where as seagrasses obtain nutrients from the sediment. Availability of nutrients in Tuggerah Lakes has increased significantly from pre-European levels. These nutrients originate from a variety of sources, including the erosion of streambanks in the upper catchment, urban stormwater and sewage.
Biological interactions	Swans, fish and other aquatic animals graze on both algae and seagrasses. This can cause seasonal fluctuations in abundance.

3.6 Eutrophication in coastal areas of Australia

Eutrophication results from the supply of excessive plant nutrients to an aquatic ecosystem leading to enhanced plant growth. Coastal eutrophication is recognised as a worldwide problem in areas affected by agricultural and urban runoff (McComb 1995, GESAMP 1990, Nixon 1990). Table 4 lists some coastal areas in Australia which have shown signs of eutrophication.

Table 4 Coastal areas in Australia showing eutrophication

State	Waterbody	Seagrass loss	Growth of macroalgae	Phytoplankton blooms	Toxic algae
NSW	Avoca Lagoon			✓	
	Botany Bay	✓			
	Clarence Estuary	✓			
	Harbord Lagoon			✓	
	Lake Illawarra	✓	✓		
	Lake Macquarie	✓		✓	
	Tuggerah Lakes	✓	✓		
	Tweed Estuary	✓			
QLD	Great Barrier Reef Lagoon		✓		
	Moreton Bay			✓	
VIC	Gippsland Lakes			✓	
	Port Phillip Bay		✓		✓
	Western Port	✓			
SA	Gulf St. Vincent	✓			✓
	Port Lincoln	✓			
WA	Albany Harbour	✓			
	Cockburn Sound	✓			
	Peel-Harvey Estuary		✓	✓	
	Swan River Estuary			✓	
TAS	Derwent Estuary			✓	✓
	Huon Estuary			✓	

(source; Brodie 1995)

The principal nutrients involved in eutrophication are nitrogen (N) and phosphorus (P) but others such as organic carbon, silicon, iron, molybdomen and manganese may play a supplementary role.

Eutrophication is initiated by an increased nutrient supply leading to increases in the growth of seagrasses that are already present in the system. However if the supply of nutrients exceeds the capacity of these plants to use them, algal epiphytes, which can utilise nutrients directly from the water column, begin to flourish. The algal growths smother the seagrasses and prevent light from reaching their leaves. The consequent decrease in seagrass growth provides further opportunity for the growth of algae. Eventually large colonies of macroalgae are formed which break up into drifting mats that accumulate in sheltered areas where they become self-sustaining. The rapid growth of green macroalgae is the most common response to nutrient enrichment in shallow marine systems (Harlin 1995, Kinney and Roman 1998). If eutrophication is severe, blooms of planktonic algae might also occur in the open water, and are often dominated by blue-green species.

For the process of eutrophication to be sustained, the rate of nutrient input has to exceed the rate at which nutrients can be removed by sedimentation within the system or the loss of nutrients through outflows.

Eutrophication commonly occurs where there has been marked increase in human population or in the use of fertilisers in the catchment of the water body. There are many examples throughout the world, three notable ones being the Peel-Harvey Inlet in Western Australia (McComb and Lukatelich 1986; 1995; Gordon and McComb 1989), Lake Laguna in the Philippines (Anonymous 1978) and the Norfolk Broads in the United Kingdom (Phillips *et al* 1978; Moss 1987).

The Tuggerah Lakes have a number of characteristics that make them particularly susceptible to eutrophication (Batley *et al* 1990). There is only a very small amount of tidal flushing of the lake system due to the small entrance channel, and at times this channel becomes completely blocked. The catchment of the lakes is quite small and there is a relatively low flow of fresh water entering the lakes from creeks and rivers, except during very large rainfall events. (This has probably been accentuated by the extraction of freshwater from Ourimbah creek and Wyong River for drinking water supply.)

The lack of flushing allows a local buildup of nutrients and resultant plant growth in the large areas of warm, shallow water around the edges of the lakes.

Loss of seagrass beds in coastal Australia

One of the most common features of the effects of eutrophication in coastal waters around Australia has been the loss of seagrass beds. Shepherd *et al* (1989) reviewed 12 well described cases of major seagrass loss following enhanced nutrient or sediment supply. In Cockburn Sound (WA) there has been an increasing urban and industrial development of the adjacent coast since 1954, and increased inputs of industrial wastes and sewage during the 1960s led to a 97% loss of seagrass beds by 1978 (Cambridge and McComb 1984). The loss was attributed to excessive growth of epiphytic algae leading to substantial reductions in ambient light reaching the leaf surfaces.

In coastal NSW, substantial changes in seagrass beds have been documented in Lake Illawarra, Botany bay, Tuggerah Lakes, lake Macquarie and the estuaries of the Georges, Clarence and Tweed Rivers (Brodie 1995). Although anthropogenic factors have been implicated in nearly all of these cases, the high natural variability in seagrass area and growth, both on a seasonal and a yearly basis, often makes it difficult to confirm (King and Hodgson 1986).

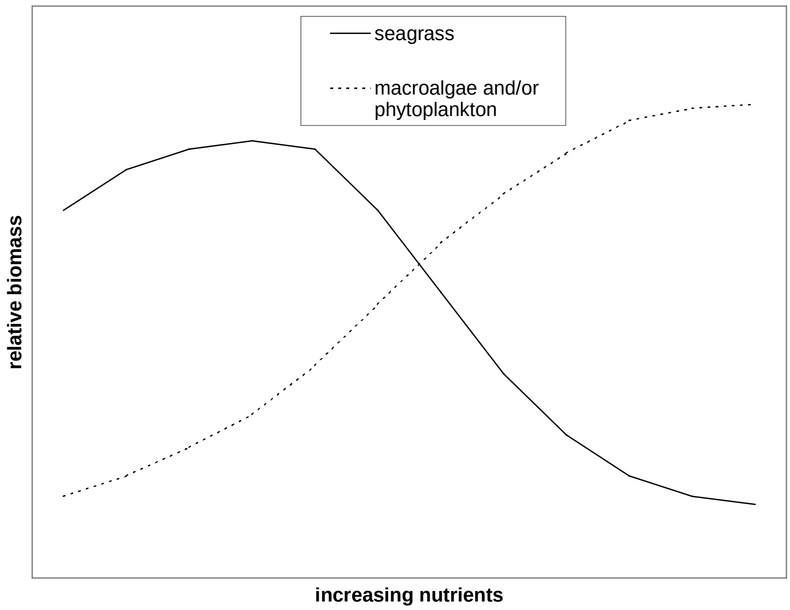


Figure 10. Generalised shift in biomass of major plant groups with increasing nutrient input to shallow marine systems.

Eutrophication can also lead to a reduction in species diversity of secondary producers (aquatic animals that feed on seagrasses and algae). As eutrophication proceeds, increased sedimentation of organic material may occur which promotes benthic feeders and increases decomposition processes (benthic respiration). This in turn leads to greatly reduced oxygen levels in the sediments (hypoxic conditions).

The reduced oxygen levels cause stress in many benthic organisms and, as oxygen levels decline further to a point where virtually no oxygen is left, many species of benthic organism die, leaving only bacterial mats and a few other hardy species. Thus, for secondary producers an overall reduction in species diversity is a typical response to eutrophication.

4 Changes along the shoreline

There is strong anecdotal evidence that 40-50 years ago, many sections of the shoreline consisted of clean sandy beaches (Scott 1998). This was particularly so for the eastern shores of Tuggerah and Budgewoi Lakes, and most of Munmorah Lake. Most of the beaches had some washed up weed (also called wrack), although this varied greatly depending on the exact location and the season. Some areas naturally accumulated wrack (probably due to prevailing winds) where others were mostly free of wrack.

Although the presence of loose weed along the lake edge is a natural part of the lake ecology, particularly in autumn when the ribbonweed is dying back and losing its leaves, most of the people interviewed believe that they have observed an increase in the quantity drifting ashore. This increase appears to have started in the 1960s and continued through the 1970s, 80s and early 90s. The increase in wrack coincides with an increase in the growth of ‘weed’, and particularly macroalgae, in the shallow littoral zone of the lakes. At the same time there were an increasing number of complaints about bad smells, presumably caused by the large masses of rotting weed along the lake edge.

Residents also observed a slow change along many parts of the shoreline, from clean sand to increasing amounts of black mud and organic ooze. Most people felt that the increased quantities of mud and ooze appeared when the amount of rotting ‘weed’ increased. This view is supported by a number of scientists (Batley *et al* 1990; Higginson 1970, Cheng 1979).

In the late 1970s, Cheng (1979) undertook some experiments that clearly showed the relationship between rotting weed, (in particular damp rotting macroalgae) and the black ooze that was forming along the beaches. These changes were accompanied by the production of a foul odour, of which hydrogen sulphide was noticeably a major component.

Batley *et al* (1990) also reported an increase in organic matter in the sediments near the lake shore, and observed that the layer of organic ooze could vary from ankle deep to knee deep. They attributed this to the increased amount of weed (seagrass and macroalgae) being washed onto the shore, and also in some areas to sediment from stormwater drains and creeks. A number of residents also support the view that there has been significant amounts of siltation near stormwater drains (Scott 1998).

Although there used to be sandy beaches around many parts of the Tuggerah Lakes, some other areas have always had a certain amount of weed and mud along the shoreline. This includes the south-western part of Tuggerah Lake and the Charmhaven area in Budgewoi Lake. Some local residents however, reported an increase in the depth of mud and organic ooze even in these areas, and they associated this with the increased amounts of macroalgae and washed up ribbonweed during the 1980s and early 90s.

There was mixed opinion about whether the amount of wrack and associated organic ooze has remained constant over the last 2-5 years or decreased (Scott 1998). Quite a few felt it might have declined from a peak in the late 1980s and early 1990s.

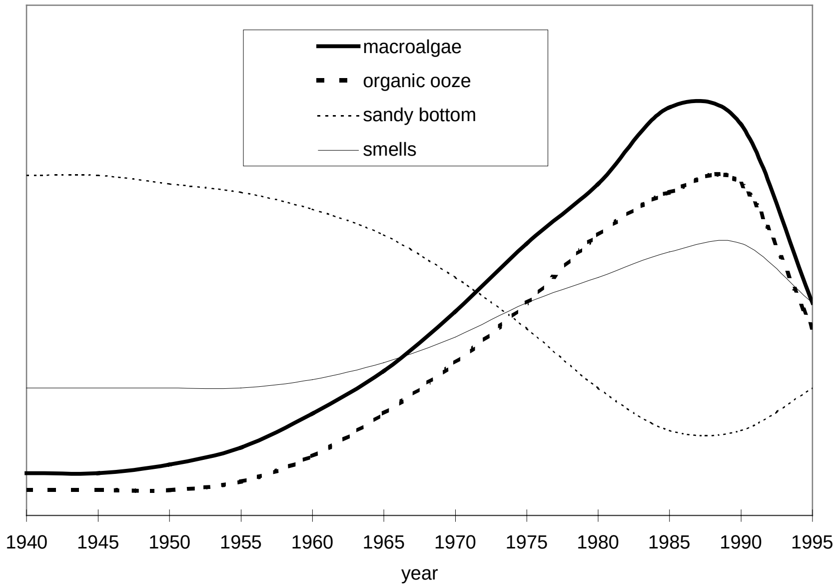


Figure 11. Relationship between macroalgae, ooze, sandy bottom, and smells around the shores

<u>*Foreshores - the sand has gone*</u>

There's a big change in the foreshores, the sand is all gone, there are very few places around the lake that have sand on them now, it's nearly all weed and silt, where years ago you could go ashore anywhere and it was a good hard sandy bottom, today it's silted. (Mick Asquith)

<u>*Dead weed would dry out*</u>

One difference in those days with the weed was that when the lake flooded the dead weed would be washed up 100 feet back from the normal edge of the lake, so it wouldn't be sitting on the water's edge rotting but would be further up the bank drying out. (Gordon Bennett)

<u>*Effects of hauling and urban development*</u>

There are a lot of places there now where the haulers used to come ashore, but don't now because in between some of the jetties it has become too shallow and other areas are now closed to hauling. And all the weed that is washed up is making the ooze. ... And there is more pollution too, in those days there wasn't the whole of Berkeley Vale emptying their rubbish into the lake. You would be surprised how much rubbish is out there, and the septic tanks didn't help either. The increase in nitrogen etc from the septic tanks would have boosted the weed growth along the shores. And now there is all this ooze. The pollution all ends up in the lake and can't leave because there is very little flushing of the lake. The only sea water that comes into the lake is through that narrow channel, and that has to supply three lakes. (Peter Clifford)

<u>*Rotting weed brings the mud*</u>

I can remember when from Killarney right around the east edge of the lake to Toukley it was all sand. And when the weed came, then the mud came. It is the weed that brings the mud. It is the rotting weed in the sediment. And it seems to fertilise itself. (Pat Clifford)

Canton Beach in the late 1940s (photo from Wyong Historical Society)

Summer holiday at Canton Beach in about 1954 (photo from Judy Allison)

Canton Beach in May 1998. The beach was extended about 30 metres further into the lake during the Lakes Restoration Project in the early 1990s.

Production of foul odour and organic ooze from decomposing weeds.

Experiments were undertaken by Cheng (1979) to determine if the decomposition of aquatic weeds (macroalgae and seagrasses) washed ashore led to the production of organic ooze and foul odour at Tuggerah Lakes.

It was found that if a mass of seagrass or algae was allowed to decompose over a layer of clean wet sand, in a matter of days a layer of black organic ooze would begin to seep from the weed/sand interface while black streaks of anaerobic sand would appear in the sand layer. These changes were accompanied by the production of a foul odour, of which hydrogen sulphide was noticeably a major component.

Similar changes occurred regardless of the weed species tested, which included the seagrasses *Zostera capricorni* and *Ruppia megacarpa* and the algae *Chaetomorpha linum* and *Enteromorpha intestinalis* although the algae appeared to decompose more completely and at a higher rate than the seagrasses.

It was noted that moisture was important for the decomposition process as algae or seagrasses left dry on a tray did not decompose readily and no foul odour was produced by the dried plant matter.

The experiment clearly showed that foul odour can indeed be produced by decaying weeds and the process contributes to the transformation of a clean sandy beach to a black foul smelling anaerobic sediment.

The experimental findings were supported by field observations at Canton Beach. It was observed on numerous occasions that foul odour of the kind similar to that produced under experimental conditions and the kind experienced by the local residents largely originated from the weed-covered littoral shallows and especially the edge of the lake shore where masses of decomposing algae and seagrasses accumulated. On the other hand, clumps of algae and seagrass pieces dumped or washed onto higher ground dried into light clumps without any foul odour.

5 Aquatic fauna

Tuggerah Lakes have been a popular commercial and recreational fishing area for more than a century. Not only has it been one of the most important producers of estuarine fish in NSW, but has also attracted many tourists to the area each year.

However, recreational fishermen have reported a decline in angling success in the last 20-30 years (Scott 1998). Commercial fishermen on the other hand, had mixed feelings, some agreeing that there had probably been a decline but that it was a coast-wide effect rather than just Tuggerah Lakes, while others believed that the fluctuations were just part of a long term natural cycle. In this section the anecdotal evidence of recreational and commercial fishermen are presented, along with the official catch statistics collected by NSW Fisheries for over 100 years.

5.1 Finfish – anecdotal evidence

Some of the earliest historical records of the Tuggerah Lakes include descriptions of an abundance of fish (see Scott 1999). In 1842 for instance, John Mann observed a large canoe-full of fish at a corroboree on the edge of the lake.

The abundance of fish in Tuggerah Lakes attracted a group of Chinese to Canton Beach in the 1860s, and they smoked and dried fish for export. In the 1880s, professional fishermen from the South Coast set up camp at Saltwater Creek in the south of Tuggerah Lake and also at Canton Beach. After the opening of the railway most of the fishermen moved to Tacoma.

Early this century, the abundance of fish was one of the main attractions for holiday makers from Sydney and Newcastle, and there are a number of newspaper articles and tourist brochures that refer to this (Allison and Scott 1998, Scott 1999). Since there were few shops to buy fresh food, most people were catching fish on a daily basis and this was reported to be quite easy. You were regarded as a ‘dud’ if you couldn’t catch fish (Scott 1998).

Early this century professional fishermen were also obtaining good catches and sometimes they were restricted from catching more fish by the limit on how many they could process (often caused by a lack of ice or boxes for transport).

However, there were occasions when the fish were scarce and professional fishermen would travel up the coast to other estuaries, particularly in winter time when the fish would leave the shallower and colder Tuggerah Lakes.

There was also a period in the early 1950s when many fishermen left the industry for a short while, but this was a result of the minimum legal sizes for both fish and prawns being increased, and not necessarily any decrease in abundance of fish.

All reports of fishing, both from professional fishermen and from recreational fishermen, describe good catches of fish during the mid 1950s and the 1960s. Arthur Clouten, a professional fisherman, reported increased weed growth and shell life throughout the 1950s after a period in the 1940s when there had been very little (Scott 1998). This provided good habitat for the fish and catches were large.

More recently, nearly all recreational fishermen reported a big decline in fish abundance over the last 20-30 years (Scott 1998). The professional fishermen, however, explained that the numbers of fish can vary greatly from year to year and the recent decline in numbers might be part of a natural cycle. They also explained that it depends on the species of fish, since one species might decline in abundance while another increases. For instance in the last few years they have been catching large quantities of blue swimmer crabs but very few bream. In a few years time the crabs might be scarce but some other fish species might have become more common.

However, some of the professional fishermen did agree that there might have been a gradual long term decline in abundance of fish in the Tuggerah Lakes, but felt that this might simply reflect a general decline on a coast-wide basis rather than anything specific about the lakes themselves. A few also felt that some sort of decline was to be expected when a natural resource is harvested, and this was due to recreational fishing just as much as professional fishing.

One factor which has a very big impact on the quantity of fish in the lakes is the depth and size of the channel at The Entrance. For instance, in the early 1990s, after the channel was dredged, fishermen were catching large quantities of whiting. A large channel allows greater quantities of spawn and small fish to enter the lake and this is one of the arguments for providing a deeper, more permanent channel. Some argue that the long term decline in abundance of fish is associated with the channel generally being shallower in recent decades, and that this is due to there being fewer major floods, which used to periodically scour out the channel.

Abundance of fish at corroboree in 1842
The site of the camp was prettily situated on the bank of Wyong Creek, which hereabouts joined the lake. A bark canoe, paddled by a very old grey-bearded man, now silently approached, and drew up close to our camp; the canoe was so deeply laden with fish of all sorts as to be a few inches only above the water. The old man, by name "Jew Fish", at once commenced to throw the fish onto the shore. There was no rush or scramble for them; in fact no-one seemed to pay attention to this. (Observations of John Mann who attended an aboriginal corroboree at the mouth of the Wyong River in 1842; reprinted by Stinson, vol 1, 1979)

Fishing in the late 1920s and early 30s
Dad used to take his holidays at Xmas time, and he had a boat called 'Buzz-Buzz'. ....we used to go out and camp on the lake for a fortnight. We'd just fish and sleep and swim. Now fish in those days, you'd have no trouble in catching them for a feed. .....We'd wake at daybreak, get into the boat, go out about 200 yards, anchor, throw our lines over, and we'd start fishing. And in 5-10 minutes we'd have fish coming into the boat. I would be up in the cabin with a little stove, and as soon as they came out of the water they'd go into the pan. ....Today it is nearly impossible. (Mick Baker)

Fishing at The Entrance in the 1950s
When my wife & I were fishing in the 50s we used to go to Pelican Island, generally to the south of Pelican Island. Almost all the time we would come home with enough fish for 2 or 3 meals when we fished in that area. It would be mostly flathead and bream and the occasional whiting, we used to use the nippers for bait. We also caught blackfish. The biggest flathead I ever caught was 5¼ pound. The majority were pan size, anything smaller we'd throw back. Bream were never terribly big. The ones we would keep were only just legal length, about 9-10 inches . (Doug Duffy)

Drastic change in fishing since the 1960s
Bream, flathead, blackfish, eels, prawns, mullet, garfish, these were plentiful in the 1940s, 50s and early 60s. This has changed drastically since the 60s, fish are so few these days. (Ray Holmes)

Anyone could catch fish at one time, but not now
Whether the fishing has declined or the people aren't as good at fishing I don't know. I know people who can still catch fish. But anyone could catch fish at one time, anyone. (Gordon Bennett)

Decline in fishing
The fish aren't as they used to be but there still is fish in the lake. Even the ocean has less fish now. There's so many people now and big fishing boats trawling the seas. (Henry Denniss)

<u>*The good times are scarcer*</u>
The fish come in cycles and there are highs and lows. But the highs might be getting scarcer and the lows might be getting a bit longer. (Peter Clifford)

Table 6. Factors impacting on fish and prawn populations in Tuggerah Lakes

Impact	*Effect*
Commercial fishing	- Between 100,000 and 650,000 kg of finfish have been harvested from the lakes each year. - Between 10,000 and 350,000 kg prawns have been caught each year. Recently the catch has been in the range 10,000 to 70,000 kg.
Recreational fishing	- Henry and Virgona (1980) estimated that 66,000 kg of finfish were caught each year. - Montgomery and Reid (1995) estimated that 12,000 kg of prawns were caught each year during the early 1990s. (In earlier decades this might have been much higher).
Power Station	- Larvae of fish and prawns were susceptible to mechanical or thermal injury when passing through the cooling system. Many fishermen blamed the decline of the greasyback prawn on the power station. - Reversal of flow in Budgewoi channel trapped the prawns in Lake Munmorah and prevented the king and school prawns from leaving the lake to spawn at sea. Instead, the high circulation rate would draw the prawns into the inlet channel where they were caught by the professional fishermen. - High mortality of some species of plankton when passing through the cooling system; this might have impacted on planktivorous fish. - Improved recreational fishing at the outlet as a result of dead or injured fish larvae, prawn larvae, and plankton which have passed through the cooling system, providing a readily available food supply. *(see section 9 for further details on the impacts of the power station.)*
Increased nutrient loads entering lakes	- Eutrophication can lead to a loss of seagrass beds, which are an important habitat for both young and adult fish.
Maintaining a permanently open entrance to the lakes by dredging.	- This prevents the channel from closing up and hence provides permanent access for marine fish. On the other hand it also reduces the size of floods by continuously releasing the rainwater and this prevents the deep scouring of the channel by large floods which used to occur earlier this century. After large floods the deeper and wider channel greatly improved access for fish and prawns, thus increasing their abundance in the lakes.
Dredging the shallow nearshore zone	- This occurred around some parts of the lakes during the Lake Restoration Project in the late 1980s and early 1990s. The shallow sand and mudflats are important nurseries for young fish.

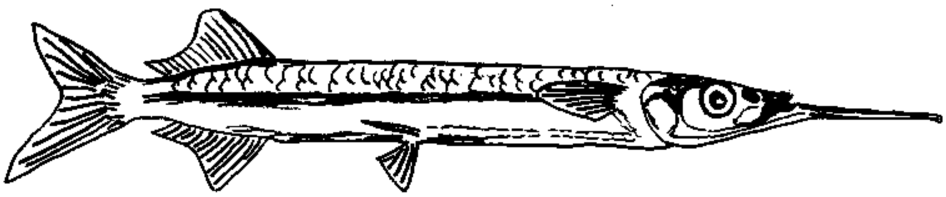


Figure 12. River garfish

Fishing the Tuggerah Lakes, near Toukley, in 1914 (photo; Wyong Historical Society)

5.2 Finfish – assessing the catch statistics

Catch statistics summarising the commercial fisheries of New South Wales are available in annual reports published by NSW Fisheries from 1883 onwards. Records prior to this date were destroyed in a fire in 1882 (Henry and Virgona 1980). For the Tuggerah Lakes, the early reports (prior to 1940-41) provide information on the total quantity of fish and prawns caught as well as additional information on the types of nets used, the number of licensed fishermen and boats, and on occasions they describe the conditions of the lakes, in particular whether the entrance channel was open or not. From 1940-41 the format of the reports changed and they started to provide catch statistics for each species.

5.2.1 Limitations to the catch data.

The annual fish catch data contained in the annual Fisheries reports have a number of limitations which restrict the amount of analysis and interpretation that can be undertaken. The main limitations are described below;

1) Most data prior to 1941 was collected from the agents at fish markets in Sydney and Newcastle, although the fishing inspector also obtained monthly returns from the local railway stations (Tuggerah, Wyong, Wyee). On occasions, the fishing inspector also included an allowance for fish sold locally. Sometimes there are small discrepancies between the data from the markets and the data collected by the inspector. From 1941 onwards, the data was collected from the monthly returns submitted by each licensed fisherman. Unfortunately this data tended to be unreliable as many fishermen would deliberately understate their catch and others would not submit a return at all. (see addendum to the 1955-56 Fisheries annual report). In some years there has also been a significant trade of fish on the black market (ie not through the Co-ops and Fish Markets) and this fish would not be reported by the fishermen.

2) During the period 1940-41 to 1954-55 the inshore ocean catch was not reported separately from the estuarine catch. For the Tuggerah Lakes this is not a major problem since there was only a small amount of ocean fishing occurring from this district. However, there are some oceanic species, such as tailor and snapper that might include a significant proportion of outside catch in their data for these years, and care should be taken when interpreting this data.

3) It is difficult to determine from the data if fluctuations in fish production are due to changes in fish stocks or fishing effort. A sudden drop in the catch of mullet, for instance, might be caused by either a decrease in abundance or a drop in market price (and hence less fishermen targeting the species). Other species, such as silver biddy, might not have been targeted in previous years, and the increase in the quantity caught simply reflects the change in market demand.

4) Fishing practices and gear have changed. For instance, the boats are now faster, the nets are lighter and require less maintenance. In early days, crews of 4 - 6 fishermen were needed to haul the nets in by hand and they would also need a couple of days per week for net maintenance. Today many fishermen work by themselves, have motorised winches, and can work 7 days a week if they wish.

5) Changing regulations can greatly influence the type and quantity of fish that can be caught. The restrictions on minimum fish sizes, mesh sizes, net lengths and the types of nets, have all changed from time to time. For instance, the minimum legal prawn size was increased from 3 inches to 4 inches at the end of 1951 and this greatly reduced the catch for that season. The areas within the Tuggerah Lakes that are closed to commercial fishing have also changed periodically and this too can affect the fish catch.

6) There is a significant fraction of the total fish and prawn catch taken by recreational fishermen and little data is available regarding this. There is also no information about how it might have changed over the years.

As long as these limitations are kept in mind, the annual catch data can still provide some valuable information. A summary of some trends for the Tuggerah Lakes are provided below.

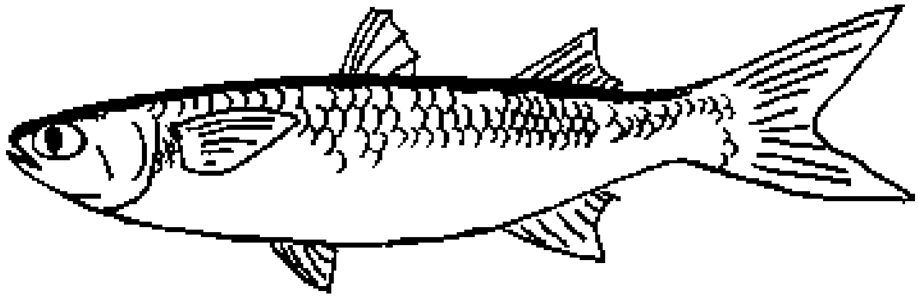


Figure 13. Sea mullet

5.2.2 Total finfish catch

Over the last twenty years annual production has fluctuated between 150,000 to 500,000 kg, which ranked the Tuggerah Lakes in the top ten estuaries along the NSW coast. In 1996/97 the finfish production was at the lower end of this range, with 218,000 kg.

Figure 14 presents the official production figures for the period 1886 to 1996/97, which were obtained from the Fisheries Annual Reports. This graph shows an initial increase up to 1915 when the record annual production for the lakes of 635,000 kg was achieved. This increase in production in the early 1900s probably reflects an increase in the number of fishermen and boats working on the lakes (Figure 15) as the industry expanded, the gradual improvement in fishing techniques (such as the introduction of motorised boats) and improvements in the transport of fish to market via the railway.

In the 1920s and 1930s the annual catch fluctuated between 200,000 and 630,000 kg and then suffered a sharp decline in the 1940s (unfortunately the data for the years 1942-43 and 1943-44 are not available). A decline in abundance of some fish species during the period 1945-47 was also observed in Lake Macquarie and recovery of stocks was reported as slow (Thomson 1959). The total catch in Tuggerah Lakes dropped to its lowest point in 1951-52, which coincided with increases to the minimum legal size for a number of species, including mullet. The fish catch then rose steadily until the mid 1960s but did not reach the levels attained earlier in the century.

Through the 1970s and 80s the catch fluctuated considerably, and then reached a peak in the late 1980s followed by another decline in the 1990s. A similar trend has been observed for estuarine production on a coastwide basis from 1954-55 to 1991-92 (See Figure 32 of Pease and Grinberg, 1995).

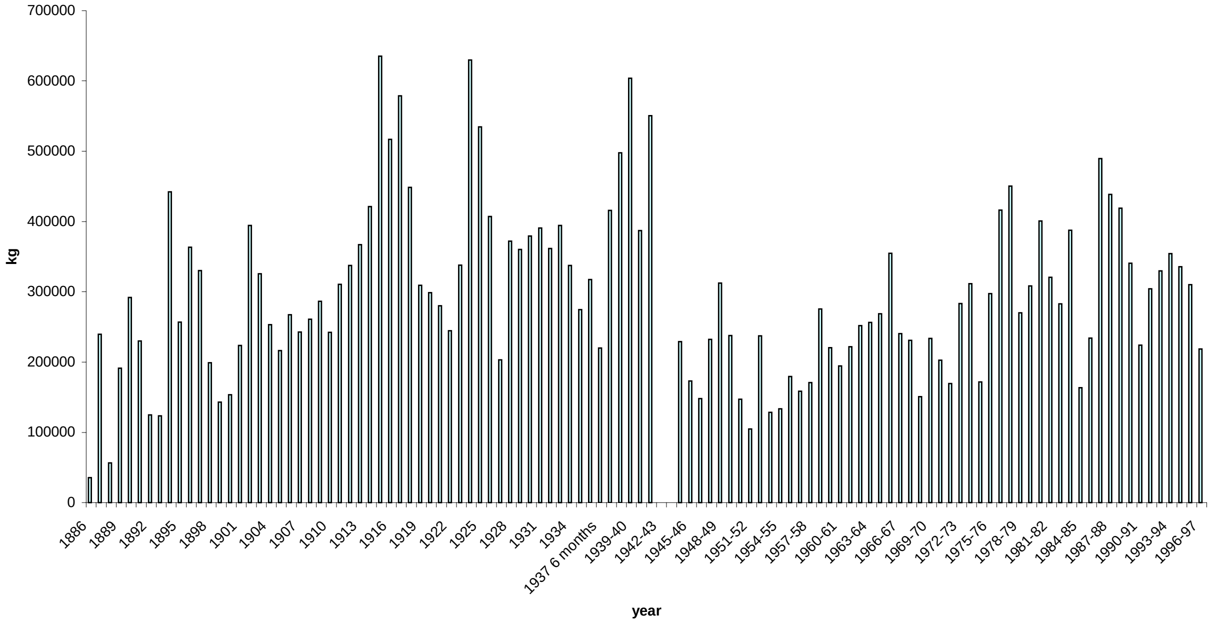


Figure 14. Tuggerah Lakes finfish catch 1886 to 1996-97

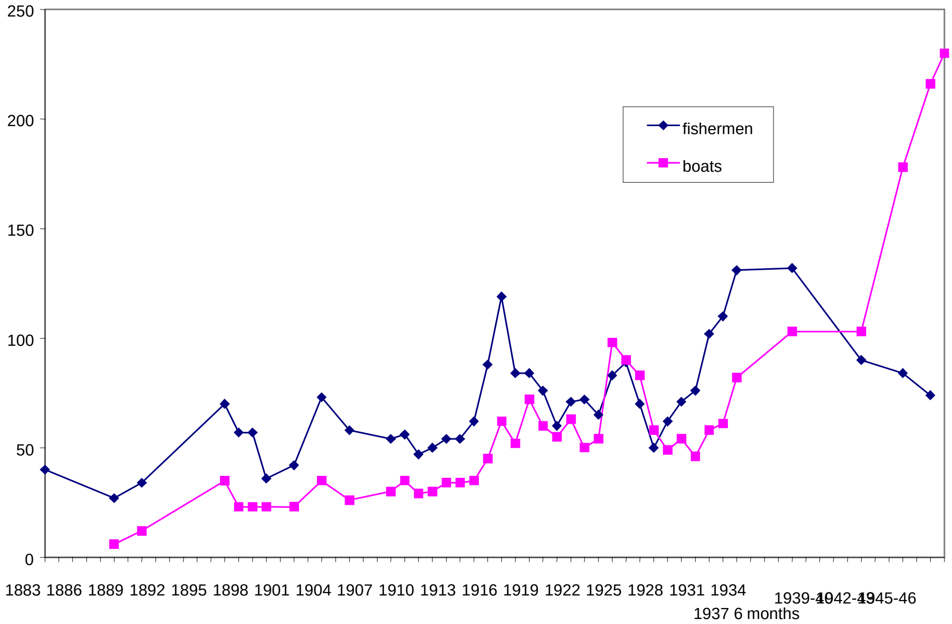


Figure 15. Number of licensed fishermen and boats on the Tuggerah Lakes between 1883 and 1946-47. (In 1998 the number of licensed fishermen using the Tuggerah Lakes on a regular basis was 44 (Tuggerah Fishermen's Co-op, pers. comm.))

5.2.3 Trends for the major finfish species caught

The types of fish caught commercially in the Tuggerah Lakes changes from year to year depending on conditions within the lake, in particular the amount of weed (seagrass and algae) and the size of the entrance channel. However, on a long term basis, there has been little change. The same species made up the bulk of the catch one hundred years ago as they do today, as shown in Table 6. The major species continue to be mullet, blackfish and bream. In some years mullet can account for up to 70% of the catch.

One species that does appear to have declined in importance is the garfish. In the 1890s and 1900s this fish was generally ranked between 3rd and 4th in quantity caught. In 1890 it was estimated to make up 15% of the total catch. In the 1990s however, garfish was only 0.3 to 1.6% of the catch, which ranked it between 5th and 9th most plentiful species caught.

Table 6 Common fish species caught commercially in Tuggerah Lakes

Ranking	1890	1901	1903	1905	1908
1	Mullet (30%)	Mullet	Bream	Mullet	Mullet
2	Blackfish (20%)	Bream	Mullet	Blackfish	Blackfish
3	Bream (15%)	Blackfish	Blackfish	Bream	Bream
4	Garfish (15%)	River Garfish	Garfish	Garfish	Garfish
5	Jewfish (10%)	Flathead	Whiting	Whiting	Whiting
6	Whiting (5%)	Whiting	Flathead	Flathead	Flathead
7	Flathead (5%)			Snapper	Snapper
8				Jewfish	Sole
9					

Ranking	1940-41	1947-48	1957-58	1965-66	1979-80
1	Mullet (67%)	Mullet (44%)	Mullet (34%)	Blackfish (40%)	Mullet (73%)
2	Bream (18%)	Bream (14%)	Blackfish (28%)	Mullet (33%)	Bream (8%)
3	Blackfish (4%)	Whiting (11%)	Bream (12%)	Bream (9%)	Flathead (5%)
4	Leatherjacket (2%)	Snapper (6%)	Garfish (9%)	Leatherjacket (6%)	Whiting (3%)
5	Flathead (2%)	Leatherjacket (6%)	Flathead (8%)	Flathead (5%)	Blackfish (3%)
6	Whiting (2%)	Flathead (4%)	Leatherjacket (4%)	Garfish (4%)	Silver Biddy (3%)
7	Garfish (1%)	Tailor (4%)	Whiting (1%)	Whiting (1%)	Garfish (2%)
8	Tailor (1%)	Blackfish (3%)		Tailor (1%)	Tailor (1%)
9	Snapper (1%)	Garfish (3%)			

Ranking	1992-93	1996-97
1	Mullet (44%)	Mullet (46%)
2	Bream (22%)	Bream (15%)
3	Blackfish (13%)	Flathead (14%)
4	Flathead (9%)	Whiting (8%)
5	Whiting (3%)	Blackfish (7%)
6	Silver Biddy (3%)	Silver Biddy (4%)
7	Tailor (1%)	Garfish (2%)
8		Tailor (1%)
9		

(Note: % of total catch is shown in brackets when this data is available)

Figures 16 to 24 show the catch data for some of the more important fish species from Tuggerah Lakes. Bream (Figure 16) and flathead (Figure 17) show considerable variation throughout the period, with peak catches reported in the 1990s. The garfish catch (Figure 18) shows a peak in the late 1960s and 70s followed by a decline, particularly in the 1990s. The blackfish catch (Figure 19) was very low in the 1940s and 50s and increased dramatically in the 1960s and 70s, presumably when there was an increase in abundance of plant growth in the lakes (the principal food of blackfish is seagrasses and algae). Another increase in catch occurred in the late 1980s and early 90s when there was a large amount of algae present. Mullet (Figure 20) shows a significant increase in catch from the late 1970s onwards. Sand whiting (Figure 23) shows a sudden increase in catch in the late 1970s and early 80s and another peak in the 1990s. The abundance of this species tends to increase when the entrance channel becomes larger. The trumpeter whiting catch (Figure 24) is generally very low, but sudden peaks occur from time to time, such as the late 1950s and once again in the 1990s.

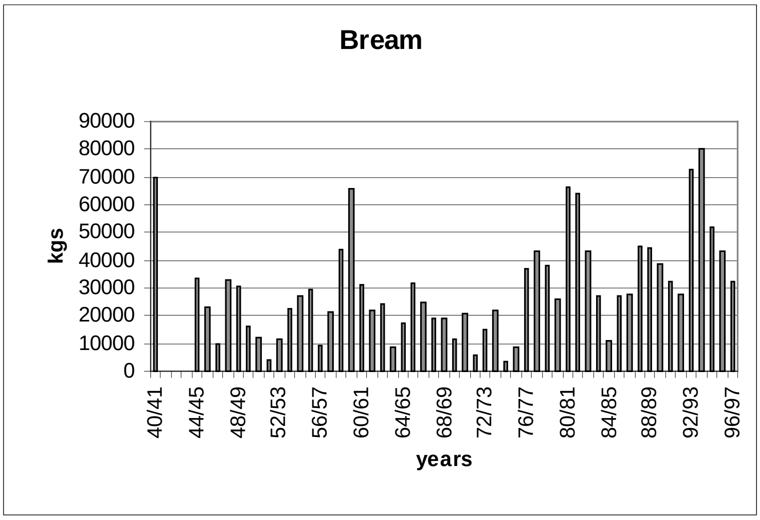


Figure 16. Catch data for bream, 1940/41 to 1996/97

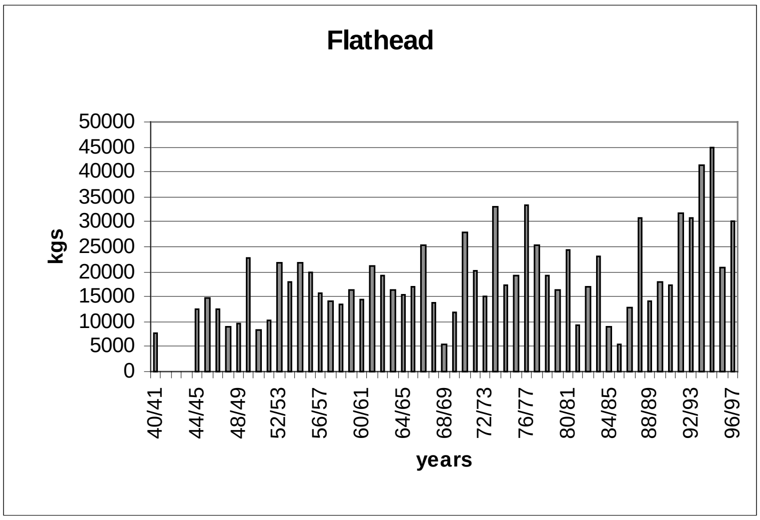


Figure 17. Catch data for flathead, 1940/41 to 1996/97

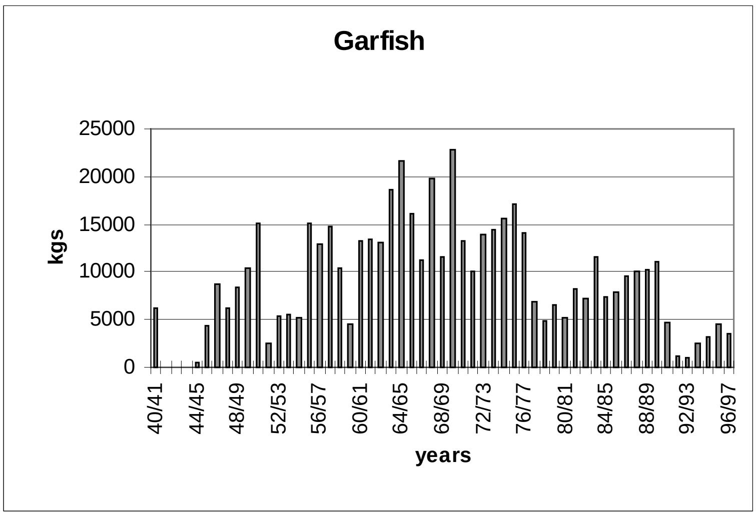


Figure 18. Catch data for garfish, 1940/41 to 1996/97

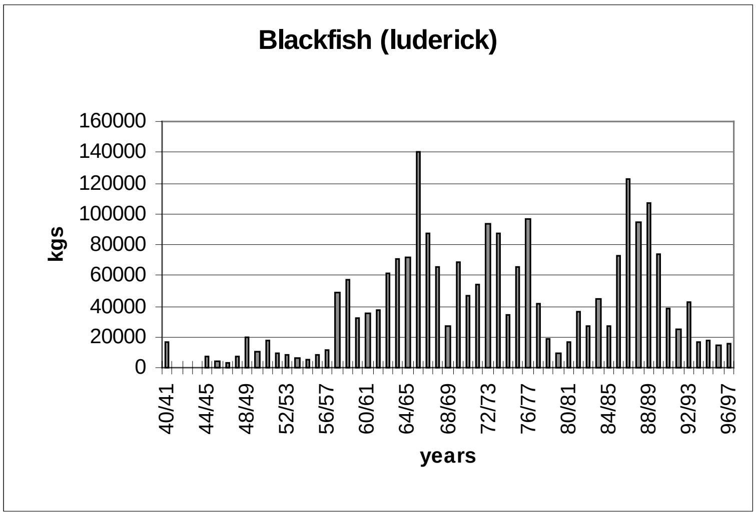


Figure 19. Catch data for blackfish, 1940/41 to 1996/97

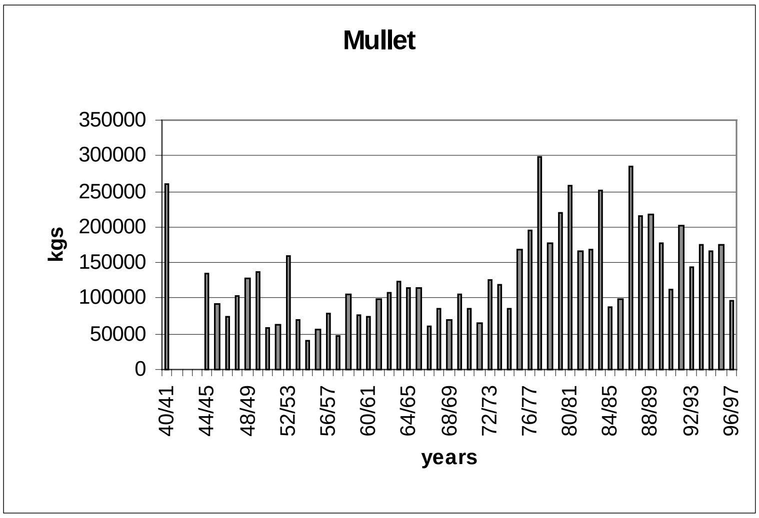


Figure 20. Catch data for mullet, 1940/41 to 1996/97

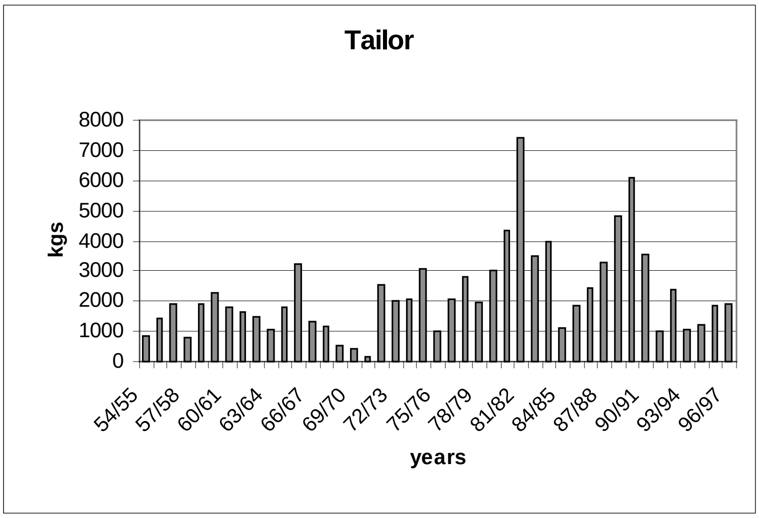


Figure 21. Catch data for tailor, 1954/55 to 1996/97

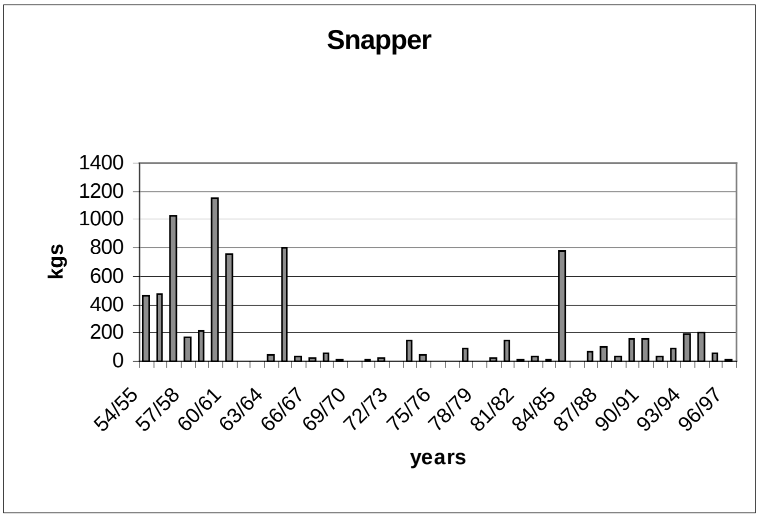


Figure 22. Catch data for snapper, 1954/55 to 1996/97

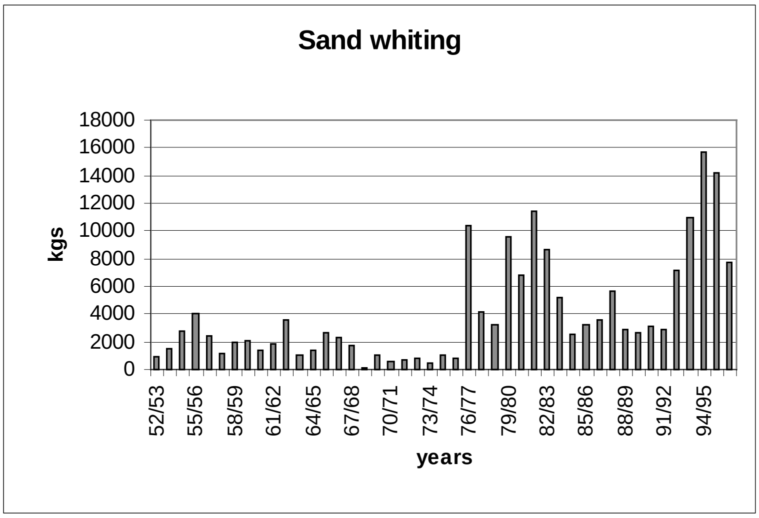


Figure 23. Catch data for sand whiting, 1952/53 to 1996/97

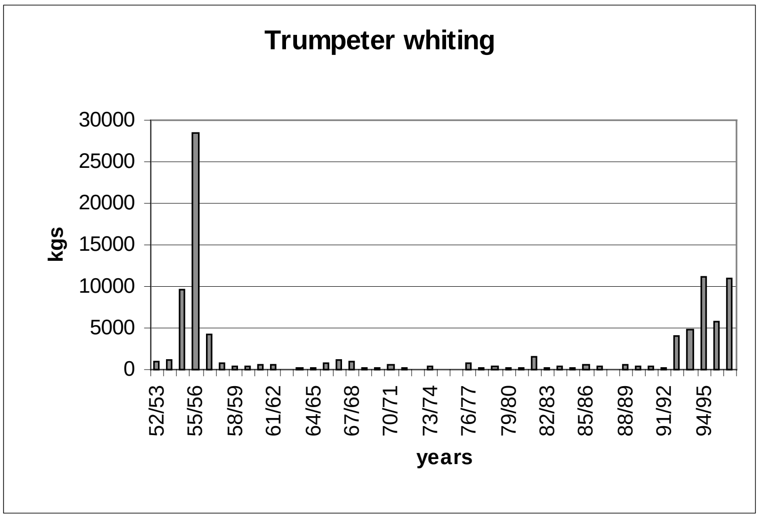


Figure 24. Catch data for trumpeter whiting, 1952/53 to 1996/97

5.3 Prawns – anecdotal evidence

In the late 19th century the Chinese fishermen were catching and drying prawns for export. When the Chinese left the lakes, very little prawning occurred until about 1904 when professional fishermen started to send fresh prawns to the markets in Sydney. By the 1930s and 40s prawning had become an important summer activity for many of the fishermen. Prawning had also become a popular past-time for holiday makers around the lakes and there are a number of references to prawning at locations such as Canton Beach and Long Jetty (Scott 1998, Scott 1999).

For the holiday makers at The Entrance, Long Jetty, Canton Beach and the camping reserve at Budgewoi, prawning was a major attraction of the area. In the summer holidays everyone would go prawning at night time (when conditions were right), and catch a kerosene tin-full of prawns (a kerosene tin was 4 gallons or about 18 litres). The prawns would be caught with a 20 foot drag net or with scoop nets, and would be cooked in a big pot on the beach, then eaten. Everyone described a plentiful supply of prawns in the 1920s, 30s and 40s.

At daytime, some people described catching prawns for bait simply by going down to the sandbars at The Entrance with a metal rake and raking through the sand. This would expose enough prawns to use for bait during the day.

It was reported that the professional prawners also caught large quantities of prawns during the 1920s, 30s and 40s, although there were also occasions when they were not so abundant. The numbers of school prawns and king prawns dropped if the channel at The Entrance was closed for a year or two and spawn could not drift into the lakes. However during these times, the greasyback prawns would increase in abundance since they breed within the lakes and do not require access to the ocean.

For the holiday maker, prawning continued to be a great attraction of the lakes with good catches throughout the 1950s and 60s.

For the professional fishermen, the prawns were available in good quantities throughout most of the 1950s and 60s, but they had to contend with many changes in the regulations governing net sizes, prawn sizes and prawning techniques. At one stage in the early 1950s, the minimum legal prawn size was increased from 3 inches to 4 inches and the mesh size from 1 inch to 1¼ inches. At the same time the legal sizes on many fish species were also increased and some fishermen left the industry for a short period to work on the construction of Wangi Power Station on Lake Macquarie.

In the last 20-30 years there have been many fluctuations in prawn catches, with both good and bad seasons. However, despite the yearly fluctuations in numbers, most recreational and professional fishermen described an overall decline in prawn catches over the last few decades.

There were a number of reasons suggested. One reason suggested for the decline in greasyback prawns (which breeds within the lakes) was that the spawn was sucked into the Munmorah Power Station and killed by the heat. In the last few years the Power Station has reduced its operation and is now on standby only, and some fishermen expect to see the greasyback prawns increase in numbers again. The reason suggested for declines in king and school prawns (which breed at sea) was that the entrance channel was no longer scoured out by large floods and hence was not deep enough to allow the spawn to enter the lake. Many feel that a deeper, more permanent entrance would solve this problem.

Some people also felt that the introduction of daylight prawning in the 1960s had slowly reduced the abundance of prawns in the lake and a few believed that the decision to remove a size limit (in 1959) meant that very small prawns were now being caught, not allowing them any opportunity to spawn.

On a positive note, the inlet channel of the Power Station provided a good site for catching very large adult king and school prawns. The king and school prawns in Munmorah Lake could not get out through the Budgewoi channel due to the strong current of recirculating water from the Power Station, and hence could not leave the lakes to spawn at sea. They remained in Lake Munmorah, continuing to grow and were eventually drawn into the inlet channel, where fishermen were allowed to place nets.

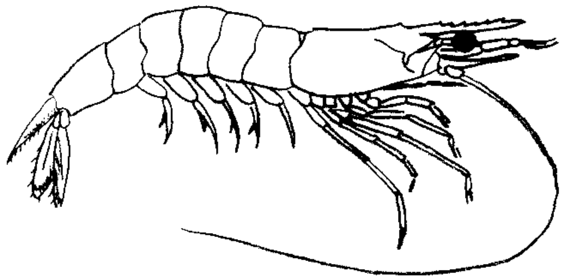


Figure 25. Greasyback prawn

<u>*Prawning in the 1930s*</u>
Lots of times in those days the fishermen all went prawning in the summertime because prawns were the much more profitable thing. I mean at Canton the whole beach would be taken up with prawners. In those days they hauled the prawn net, they didn't do it the way they do now, and every 150-200 yards there would be a prawn crew and they would shift the net out, they then drew them in and they would cook them and put them on racks to cool off during the night, then they would be put on the train in the morning and taken to market in Sydney by midday. That was in the 1930s. (Clarrie Wynn)

<u>*Prawning at Peel St, Toukley in the 1940s, 50s and 60s*</u>
We used to get wonderful prawns just out here (Peel Street)*, the catches were good, that was the 40s, 50s and 60s. There would be lots of people prawning down here, and it would be a great atmosphere, a small fire on the beach and lots of lights out in the water. You'd get a good catch but of course not every night because of the cycles with the moon and other things.* (Bill Hansen)

<u>*Power Station killed the greasyback prawns*</u>
We used to get a lot of greasyback prawns in the lakes. The school and king prawns breed at sea and the spawn comes back in, but the greasybacks breed in the lakes. Before the power station (pre 1967) *we used to get cycles of them. You got plenty of prawns. Then they put the power station in. The spawn goes through and is cooked there and we got no greasybacks. The power station is off now and the greasybacks are coming back. This year* (1998) *we had the most in years and years.* (Arthur Clouten)

<u>*King and school prawns scarce but greasybacks have picked up*</u>
School prawns have been scarce in the last three years. King prawns have also been in decline. I do not know the reason for this; some think it is because of the lack of flood rains. Greasyback prawns have picked up in the last few years because of the closing down of the Power Station. Greasyback prawns breed in the Top Lake. When the power station was working the prawns got sucked through the cooling system and were killed. (Gordon Denniss, 1998)

5.4 Prawns – assessing the catch statistics

The total prawn catch is shown in Figure 26. Prawns were caught and dried by Chinese fishermen in the mid to late 19th century, but there are no records of the quantities. The first records in the Fisheries Annual reports are in the early 1900s when fishermen started to send fresh prawns to the Sydney and Newcastle markets. Prawning increased in popularity through the 1920s and 30s and the official catch reached a peak in the 1940s. There was a sharp decline in the prawn catch in the early 1950s which coincides with a general decline along the NSW coast and the introduction of stricter regulations. Apart from a couple of exceptional years, from the 1950s onwards the official prawn catch has not been able to reach the peaks of the 1940s.

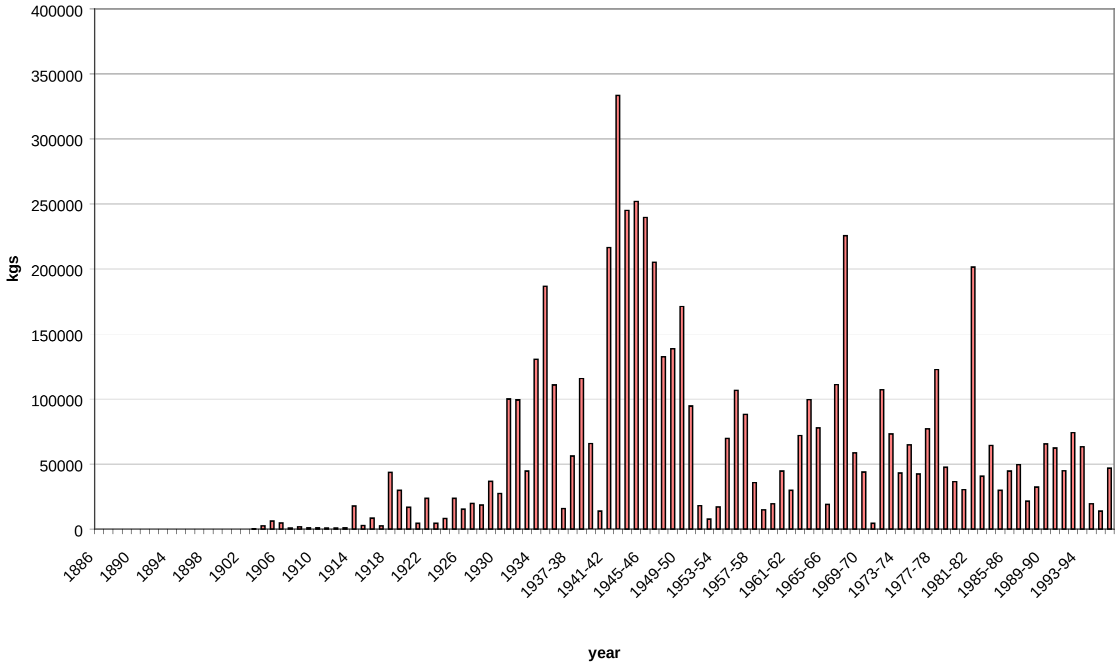


Figure 26. Annual prawn catch for Tuggerah Lakes – from NSW Fisheries data

5.5 Assessing the recreational catch of finfish and prawns

Henry and Virgona (1980) reported that in the late 1970s the amateur fishermen were concentrated in five small areas. These were the Munmorah Power Station inlet and outlet, Budgewoi Creek, Toukley Bridge, and The Entrance. Relatively little angling occurred in the main body of the three lakes.

During winter many fish would congregate in the warm water of the Power Station outlet and this location would attract up to 80% of amateurs. With the reduction in operation at the Power Station during the 1990s, the inlet and outlet have declined in popularity, and The Entrance is once again the most popular location for recreational fishing.

The most popular location for recreational prawners is also at The Entrance, with smaller numbers at other locations such as Canton Beach, Long Jetty and Budgewoi.

Estimates of the recreational fishing catch suffer from all the problems associated with commercial fish catch statistics. In addition, there is no formal reporting of catches, and so data must be obtained by surveying the recreational anglers. Henry and Virgona (1980) undertook such a survey in 1978/79 and estimated that the number of anglers varied from 170 to 1,000 per day, the peak being in January during the summer holidays. Although the total amount of time spent by recreational anglers was estimated to be 10 times greater than the commercial fishermen, the amateur catch was estimated to be only 66,000 kg compared with a commercial catch of almost 300,000 kg. The main species caught by recreational anglers during Henry and Virgona's survey are shown in Table 7.

Table 7 Tuggerah Lakes Amateur Fish Catch – main species caught (by weight)

Power Station Inlet	*Power Station outlet*	*Budgewoi Creek*	*Toukley Bridge*	*The Entrance*
Bream (86%) Blackfish (10%)	Blackfish (49%) Bream (33%) Mullet (8%) Flathead (7%)	Blackfish (51%) Bream (40%)	Tailor (76%) Bream (12%)	Whiting (28%) Flathead (27%) Mullet (14%) Blackfish (13%) Bream (9%) Tailor (7%)
Total = 5,400 kg	Total = 21,500 kg	Total = 15,300 kg	Total = 3,000 kg	Total = 17,900 kg

Data from Henry and Virgona (1980)

A survey of the recreational prawn catch over the seasons 1991/92, 1992/93 and 1993/94 estimated it to be 12,000 kg per year (Montgomery and Reid 1995, cited by NSW Fisheries 1997). This was equivalent to only 17% of the commercial prawn catch. The recreational catch was made up of equal proportions of eastern king prawns and school prawns.

5.6 Other marine species

5.6.1 Jellyfish

Many local residents and fishermen commented on the very large numbers of jellyfish (or 'blubber') that used to be in all three lakes (Scott 1998). The three types most commonly mentioned were the 'saucer blubber' (possibly *Aurelia coerulea*) , 'sausage blubber' (possibly the comb jelly *Neis coardigera*) and the 'man-of-war' (a term often used by locals when referring to *Catostylus mosaicus*)

Sometimes the professional fishermen would have problems hauling in their nets due to huge quantities of jellyfish caught in them, and this appears to have always been problem, with reports as far back as late last century. The jellyfish appear to have been plentiful until about the early 1970s, but in the last 20 years very few have been seen. Many fishermen believe that the jellyfish declined in numbers a few years after the Munmorah Power Station commenced operation in 1967.

The decline in numbers of the jellyfish *Catostylus mosaicus* in Tuggerah Lakes has also been observed by some scientists (Thresher *et al* 1993, J Bell, pers comm 1990). Possible causes for the decline in jellyfish abundance are presented in Table 8.

Table 8. Possible causes for decline in abundance of jellyfish

Part of a long term natural cycle and the decline is not permanent	
Power station effects	- entrainment of adults on screens - death of larvae while passing through cooling system - chemicals (such as chlorine) killed adults and/or larvae - Food supply (plankton) killed while passing through cooling system (see Thresher *et al* 1993)
Small size of entrance channel restricting the numbers that can move into the lakes	
The decline is part of a coast-wide effect and not isolated to just the Tuggerah Lakes	

Blubber prevent fishing – 1892
In June, blubber became very thick at all parts of the lakes, and, as this pest showed no signs of a decrease, fishermen began to leave, no less than five boats with some of the best fishermen going to Lake Macquarie. With the exception of Munmorah Lake, where fish were very scarce, blubber has been plentiful in the lakes throughout the year. (1892 Fisheries Annual Report)

Jellyfish hinder Professor Dakin's Research – 1940s
Another difficulty, accentuated by the opening of the lakes to the sea, was the seasonal influx of Coelenterates. Finally two types of cones which had the same diameter as the net and which fitted over the mouth of the net were used. …. The current set up by these cones as the nets were pulled through the water served, to a certain extent, to force the jelly fish out of the course of the net, and the holes and wire mesh permitted the net to catch smaller organisms. The method was quite successful when dealing with the large medusa, Catostylus mosaicus, but when the Ctenophores came into the lakes, all our efforts were practically useless. The surface waters were almost solid Ctenophora, which were so soft that the cones merely broke them and the nets became coated with a thick gelatinous slime.….(Morris and Bennett (1951); a scientific paper reporting on prawn research in Tuggerah Lakes in the 1940s by Professor Dakin of Sydney University.)

Jellyfish - they used to come in like sago
I haven't seen it (jellyfish) *for twenty years. They reckon that when the Power Station started* (in 1967) *they put something in the water and that killed the blubber but I don't really know. I remember standing on the bridge and it would come in like sago. It comes from the ocean but you don't see it coming in any more. They might only see 2 or 3 head of blubber this year.* (Pat Clifford)

Disappearance of jellyfish in the early 1970s
The jellyfish Catostylus mosaicus, which was once so abundant as to block cooling water screens (Pulley 1971) has virtually disappeared from the lakes since 1974 (J Bell, Environmental Officer Wyong Shire Council, pers. comm.). (Extract from page 6 of Batley et al 1993, Report by CSIRO entitled "The ecology of the Tuggerah Lakes System – Stage one.")

5.6.2 Crabs

A number of people, particularly professional fishermen, commented on the very large numbers of blue swimmer crabs that have been in the lakes in the last 3-5 years. Such large numbers were considered unusual and had not occurred for about 40-50 years. Mud crabs had also been quite common in the last few years. A few people commented that the number of crabs in the lakes depended on the size of the opening at The Entrance. If there was a large opening, more crabs would move into the lakes.

Blue swimmer crabs plentiful again
Years ago, in the 30s or 40s I think, they (crabs) *were thick, the Blue Swimmer Crabs. And then there weren't as many until just the last 3 or 4 years when they were very thick again. Martin* (Bill's son) *was coming in every day with anything up to 10-12 boxes, and one day 23 boxes. A few weeks ago (May 1998) they were disappearing again and they were getting just a couple of boxes a day.* (Bill Byles)

5.6.3 Shellfish

Quite a few of the professional fishermen reported a decline in shell life in the lakes (Scott 1998). Thirty to forty years ago shell life was abundant but then slowly started to die off. A few commented that shell life had started to increase again in the last couple of years.

These changes in abundance might be part of a natural cycle, possibly associated with the periodic opening and closing of the entrance channel or to changes in salinity. Thomson (1959) suggested that the loss of some shellfish species in Lake Macquarie during the late 1940s occurred when very heavy rainfall caused a marked stratification of the lake water, and that the lower saline layer became deoxygenated.

In addition to natural fluctuations, the shellfish might also have been affected by pollution entering the lakes, either from industrial and urban runoff. In Lakes Munmorah and Budgewoi it is possible that the spawn of some species of molluscs were harmed by the dosing of chlorine or by the increase in temperature when passing through the cooling system of the Munmorah Power Station.

Unfortunately however, there are no detailed scientific studies of the shell life in the Tuggerah Lakes, and so it is not possible to draw any firm conclusions.

Shell life in the lake
As a kid we used to see heaps of cockle shells and mussel shells along the east side of the lake near North Entrance, and then they disappeared. They only started to slowly reappear recently and this year on 'big flat' there were as many cockles as I've ever seen since I was a young fella. (John Brown)

Cockles in Top Lake
It (Top Lake) *had a lot of those little cockles, and that is why I think it was such a good bream dig, because they lived on these. Always chomp, chomp. That is why Top Lake consisted of such beautiful bream.* (Elizabeth Denniss)

5.6.4 Other species

Anecdotes about stingrays, eels and octopus were provided by many of those interviewed during this study (Scott 1998). However it is difficult to determine whether there has been any long term changes in abundance of these species. A few fishermen believed that the size of eels caught had declined over the years, possibly because eels are a very slow growing species.

There were also reports about sharks waiting off The Entrance for fish and eels to enter the sea. Other species described were sandworms, and a type of cungevoi that has only been sighted recently.

Eels taken by sharks at The Entrance
Eels; I can remember on one particular occasion sitting in the boat in the channel with Dad and we had the net out, and every now and then you would hear a terrible crunch, and that was a shark taking an eel. The eels used to flow out of the lake in great quantities and the sharks would wait for them. There used to be a lot of eels. I don't know how many eels are in the lake now. (Doug Duffy)

6 Nutrients in the Tuggerah Lakes

6.1 Sources of nutrients

There is strong evidence to suggest that the increased growth of macroalgae in the Tuggerah Lakes is a result of the increased input of plant nutrients to the lake system, and especially compounds of nitrogen and phosphorus.

In the Tuggerah Lakes, plant nutrients enter the lakes from both natural and anthropogenic sources. These include (currently or in the past):

a) Natural sources

- seawater
- rainfall
- windblown dust
- aquatic bird droppings (counter-balanced by extraction of nutrients when feeding)
- organic matter (such as leaf litter) and soil particles in surface runoff from undisturbed lands
- lakebed sediments

b) Agricultural and forestry sources

- fertilizers
- animal wastes
- sediment derived from sheet and gully erosion in disturbed land.

c) Urban and industrial sources

- Domestic sewage, (seepage from septic tanks, sewer overflows and effluent from treatment plants)
- Industrial wastes
- Urban runoff (fertilisers, organic matter, greywater washed into gutters and drains from parks, gardens and streets)
- Flyash from Munmorah Power Station (from stack emissions and from ash dam)
- Particulate and gaseous emissions (particularly nitrogen oxides) from the burning of fossil fuels by power stations, factories and motor cars. These can reach the lake via wet or dry deposition directly into the lake or onto the surrounding catchment.

6.2 Chemical availability

The principal nutrients involved in eutrophication in coastal waters, nitrogen and phosphorus, may exist in a range of chemical forms.

The forms of nitrogen include the dissolved inorganic compounds such as nitrate, nitrite and ammonium/ammonia; dissolved organic compounds such as amino acids and urea; and also organic nitrogen in particulate form (Figure 27).

Organic forms of nitrogen are broken down by bacteria into ammonium, which under aerobic conditions, is oxidised to nitrate. The nitrate can then be reduced through microbial action to molecular N_2 which can be lost to the atmosphere. Other microbial organisms, such as cyanobacteria, are able to convert gaseous nitrogen from the atmosphere back into organic nitrogen for cell growth. Hence, in aquatic systems, nitrogen is not considered to be a conservative element since it can be lost to, and gained from, the atmosphere.

In general, nitrate and ammonium are the forms of nitrogen that are most readily available (or bioavailable) to aquatic plants and algae for growth. Average concentrations for nitrate in Budgewoi Lake are presented in Table 9.

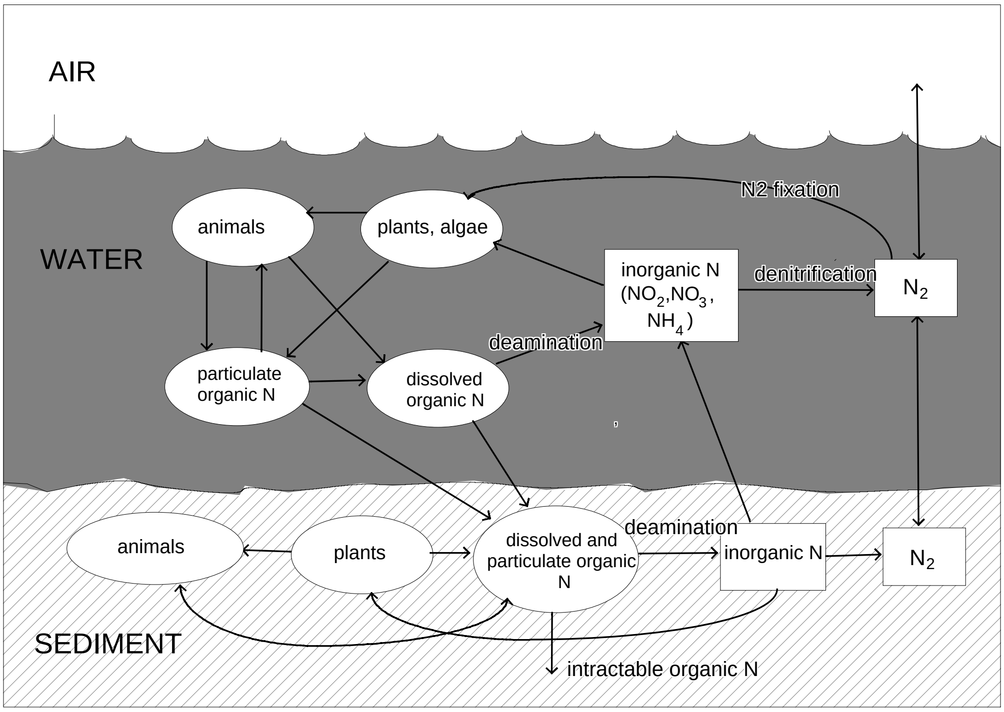


Figure 27. The Nitrogen Cycle

Phosphorus may occur as dissolved inorganic compounds such as orthophosphate; dissolved organic compounds; particulate organic matter; or particulate inorganic matter.

Unlike nitrogen, phosphorus is considered to be a conservative element in aquatic systems since it is not gained or lost to the atmosphere. After it enters a river or lake system, it will remain there, recycling through components of that system (biological and inorganic) until it either reaches the sea, is permanently lost to the sediment or leaves as part of a food chain (eg fish-eating bird).

Orthophosphate (or phosphate) is the most bioavailable form of phosphorus and is commonly derived from fertiliser application, animal wastes and sewage effluent. The particulate inorganic phosphorus includes mineral substances in which the phosphorus is not readily available for uptake by marine organisms and often settles out at the bottom of a river or lake.

Table 9. Nitrate and phosphate concentrations for Budgewoi Lake (at water surface)

	1963-66	*1973-79*	*1980-84*	*1985-91*
Salinity (ppt)	32.7	19.0	26.9	18.6
phosphate (ug/L)	6	2	4	2.6
nitrate (ug/L)	15	23	12	9.1

Source; King and Hodgson (1986)

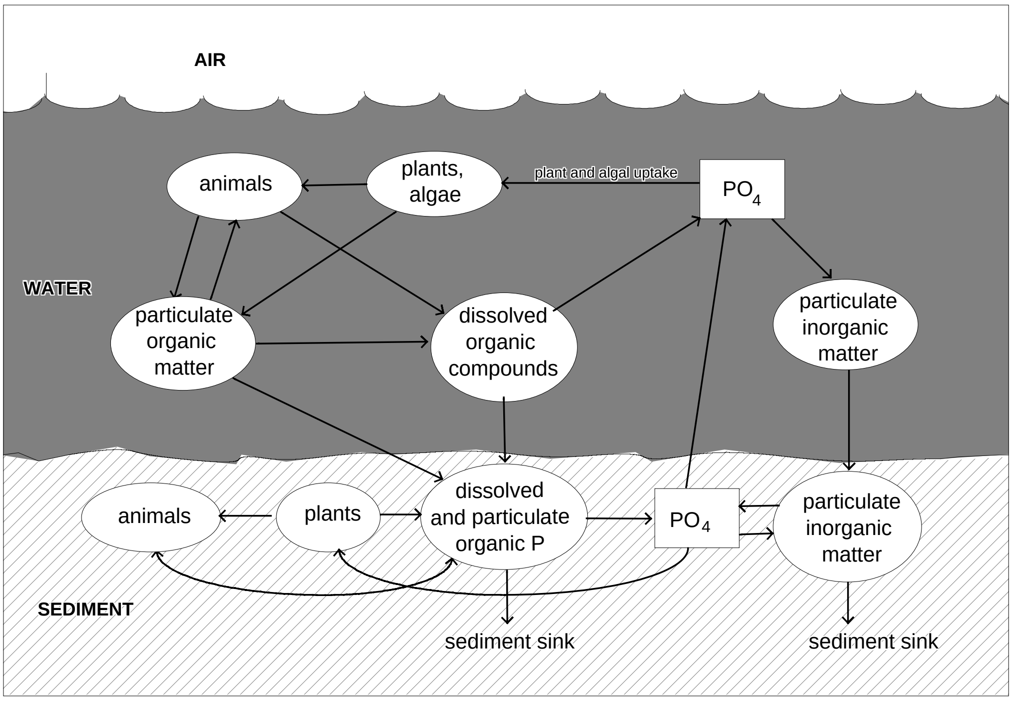


Figure 28. The Phosphorus Cycle

6.3 Nutrient limitation

In very general terms, the growth of aquatic plants and algae in fresh water systems tends to be limited by the availability of phosphorus. Nitrogen, however, is generally the limiting nutrient in marine ecosystems (Howarth 1988) including estuaries and shallow coastal lagoons (Boynton *et al* 1982, Fong *et al* 1993, Harlin 1995). Doering *et al* (1995) found that P was limiting at low salinities of 0, 5 and 10 ppt, but N was limiting at salinities of 25 ppt. The salinity of the Tuggerah Lakes is usually in the range 15 to 30 ppt and the growth of aquatic plants and algae is probably limited by the availability of nitrogen under most (but not all) circumstances.

The limiting nutrient also depends on the plant or algal species being examined, as they each require nitrogen and phosphorus in different ratios. The fit between the available nutrients (the N to P ratio in the water column) and the needs of particular species is one of the determinants of their relative abundance. Walkerden and Gilmore (1996) suggested that for Tuggerah Lakes;

- Phytoplankton are phosphorus limited
- Seagrasses are nitrogen limited
- Macroalgae lie somewhere in between, possibly leaning towards nitrogen limitation.

In summary, it is advisable for lake management to control both nitrogen and phosphorus, since varying the N to P ratio might simply alter the aquatic vegetation which flourishes. If the lakes are fertilised, one form of aquatic plant or algae will make use of the available nutrients.

6.4 Nutrient budget for the Tuggerah Lakes

There have been many studies of nutrients in the waters and sediments of the Tuggerah Lakes System (see table 17 of Batley *et al* 1990), including a large amount of water quality data collected by the Electricity Commission since the early 1960s. Batley *et al* (1990) attempted to use this data to construct a nutrient balance but had difficulty due to missing data, and also due to the very large fluctuations in some nutrient sources from year to year. For example, the nutrient loads from the upper catchment can be orders of magnitude greater during flood events compared with dry periods. The nutrient balance is also complicated by the complex hydrodynamics of the system in which the inflow and outflow of large volumes of water containing nutrients of various concentrations occurs at irregular intervals.

Despite these problems, constructing a nutrient balance (Table 10 and Figures 29 and 30) can be a very useful way of determining the major nutrient sources, and this can be used to develop practical guidelines for nutrient management within the lake system.

Table 10. Nutrient sources for the Tuggerah Lakes

Source	*Total Phosphorus load (tonnes/yr)*	*Total Nitrogen load (tonnes/yr)*	*Comments*
Runoff from upper catchment (Wyong River and Ourimbah Creek)	25-30	150-170	Based on typical nutrient export data for each land-use. (see Appendix 1). Data from Boake (1991) indicated a P load of 10-20 tonnes/yr and an N load of 50-100 tonnes/yr.
Runoff from lower catchment including urban areas)	10-15	60-80	Based on typical nutrient export data for each land use (see Appendix 1).
Ocean	-13	-260	3 tonnes/yr of P and 190 tonnes/yr of N enters via tidal flows (Garofalow 1998). However on average about 16 tonnes/yr of P and 450 tonnes/yr of N flows out of the lakes, particularly during wet weather.
Wet and dry deposition of nutrients from atmosphere, directly onto the lakes	2	10	Nitrogen oxides originate from natural sources, burning of fossil fuels at nearby Power Stations, factories and motor cars (see Appendix 1). Phosphorus is deposited in the form of wind blown dust.
Waterbird droppings	-	-	This is just one of many natural pathways that simply recycle nutrients. The nutrients in the droppings originate from food taken in the lakes.
Nitrogen fixation from atmosphere	-	Unknown	Blue-green algae can obtain nitrogen from the atmosphere.

Some key points about the nutrient balance for the Tuggerah Lakes are summarised below;

- Garofalow (1998) estimated that the total nitrogen inputs from the catchment has increased at least three fold and the total phosphorus inputs over 6 fold since pre-European times.

- Hodgson (1979) measured chlorophyll-a values in the lakes over the period 1973/74 and noted a coincidence between high chlorophyll values and the influx of nutrients from the catchment with rain. Higginson (1968) also observed an increases in phosphate and nitrate concentrations in lake water caused by entry of freshwater from the catchment after heavy rainfall. These nutrients enter the lake via the main river and creek systems as well as stormwater drains in residential areas. These observations indicate that a major input of nutrients occurs during rainfall events.

- The upper catchment provides the largest input of nutrients to the lake system, and would have done so since large scale clearing and logging commenced over 100 years ago. A large percentage of the nutrient load from the upper catchment occurs during flood events and is attached to particulate matter. Much of this material is deposited at the mouths of Wyong River and Ourimbah Creek, and also in the middle of Tuggerah Lake. Some also passes through to the ocean via the entrance channel. Only a small fraction would settle in the shallow nearshore zones where macroalgal blooms tend to occur.

- Pollution from sewage would have been an important source of pollution in the shallow nearshore zones during the 1950s to the late 1980s prior to the completion of a reticulated sewerage scheme. Sewage effluent contains high levels of both dissolved orthophosphate, and dissolved nitrogen compounds (such as ammonium and nitrate), which are readily available for algal growth. Nutrients derived from sewage have been virtually eliminated from the lakes since the completion of the sewerage system and the disposal of all treated effluent to the ocean.

- Nutrients from urban runoff have become an increasingly important source of nutrients in the last 20-30 years, particularly for the shallow nearshore zone, as more land around the lakes is transformed into residential and industrial areas.

- A significant proportion of the phosphorus that enters the lakes, either in dissolved or particulate form, eventually becomes attached to the sediments on the lakebed where it slowly accumulates. This process has buffered the system against increasing loads from external sources. However, from time to time, some of this phosphorus can be released back into the water column and made available for algal growth. The rate of release depends on many variables, such as the water temperature and the oxygen concentration at the sediment-water interface. The store of phosphorus in the lakebed sediments could mean that there will be a significant lag (of years, if not decades) between a reduction in nutrients entering the lakes and a reduction in algal problems.

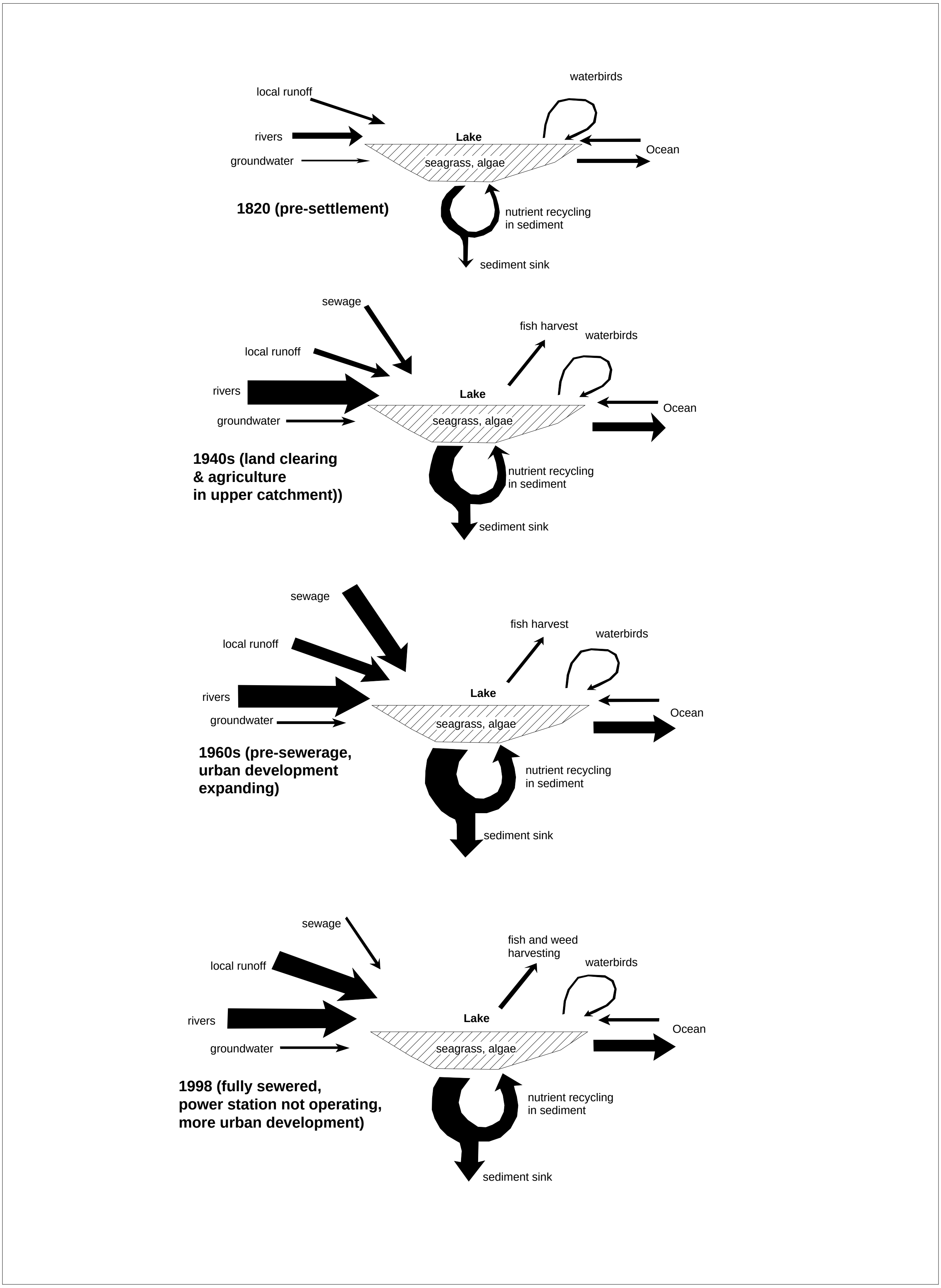


Figure 29. Phosphorus loads

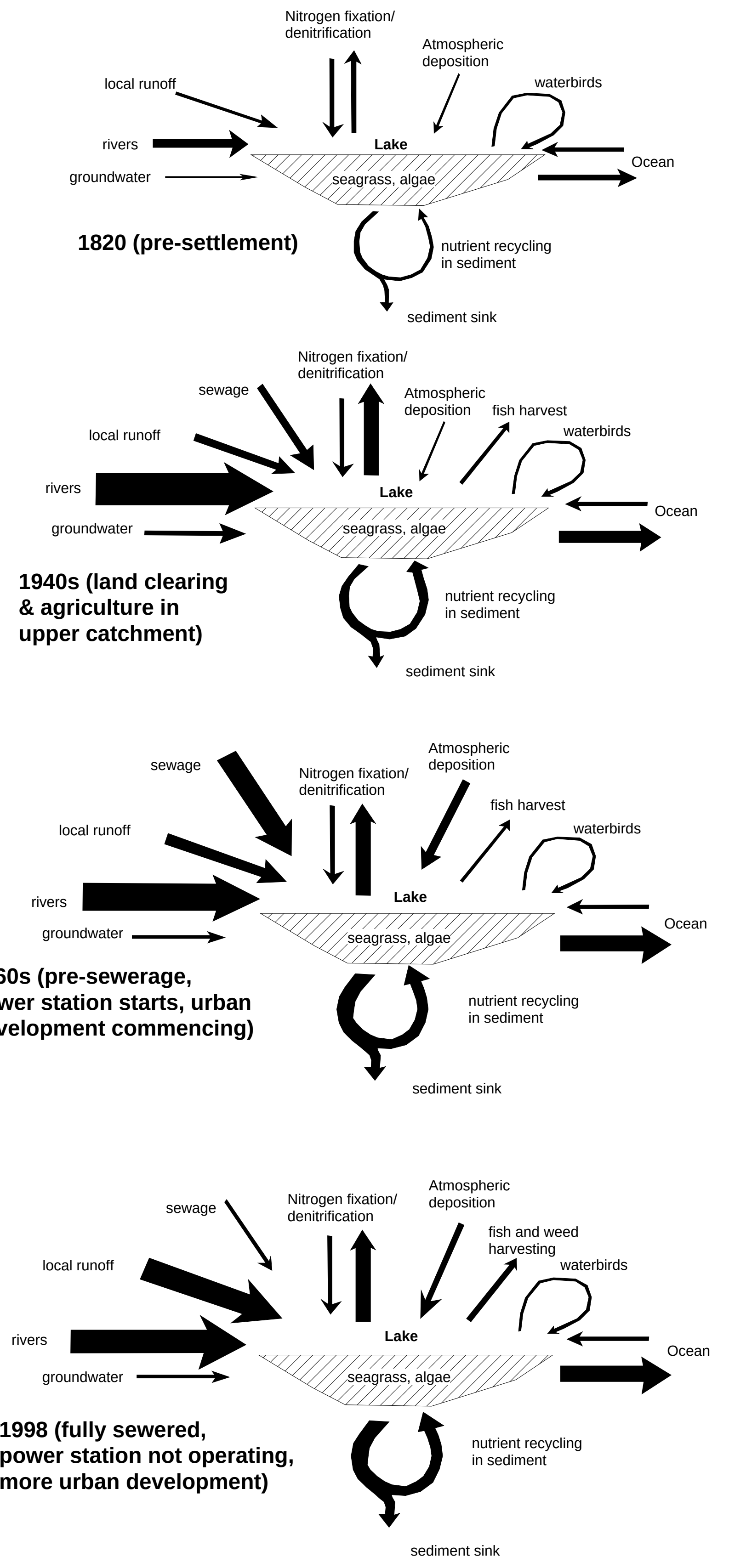


Figure 30. Nitrogen loads

6.5 Sediment and nutrients from the upper catchment

Before European settlement the catchments of the Wyong River, Ourimbah Creek and Wallarah Creek were forested and the quality of water reaching the lakes would have been high. However, the disturbance to the land caused by forestry and agriculture would have resulted in a steady increase in erosion (and hence sediment yield) throughout the 19th century. The highest rates of erosion probably occurred in the early 1900s when large areas of land were being cleared for the rapidly expanding agricultural industries, and the logging industry was at its peak. This is supported by erosion studies in the other regions of NSW , such as the southern tablelands, where land clearing, followed by grazing, occurred on a large scale in the mid to late 19th century, and the peak erosion rates occurred in the following fifty years (Starr 1989). After that, the erosion rate (and hence the sediment yield) slowly declined to a new and stable value (Wasson *et al* 1992, Starr 1989). The new value was well below the peak, but up to two orders of magnitude above the pre-settlement values. A similar trend could be expected for the Tuggerah Lakes catchment although the peak erosion rates were probably considerably lower than those experienced in the southern tablelands where land clearing was far more rapid and extensive. Garofalow (1998) estimated that the increase in total nitrogen from the catchment has increased at least three fold and the total phosphorus over 6 fold.

In recent years the implementation of erosion control practices and the increased awareness of catchment management principles would have also helped to reduce the sediment yields in the upper catchment.

Nutrients can also enter the lakes from the upper catchment in the form of plant fertilisers, and organic matter (such as animal manure or leaf litter). Fertiliser use in Australia increased sharply from the early 1950s onwards (Brodie 1995, McLaughlin *et al* 1992).

In recent decades, two major users of fertiliser, the dairy and citrus industries have declined, although this has been partially offset by the expansion of the turf industry. Overall, the use of fertiliser in the catchment of the Tuggerah Lakes probably follows the national trend and has declined from a peak in the 1960s and 1970s.

Despite the recent decline in both sediment yields and fertiliser use, there are still some areas of the catchment where relatively high concentrations of nutrients are found in local streams (Boake 1991).

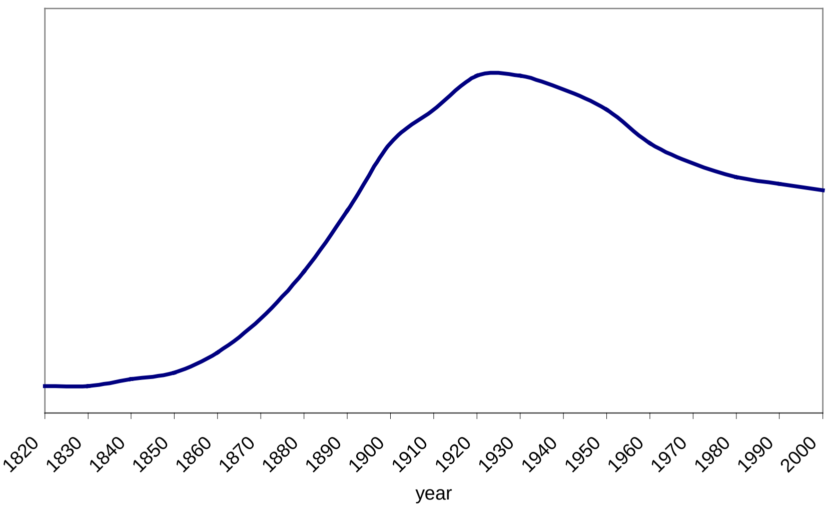


Figure 31. Long term trends in sediment yield from the upper catchment

Erosion of streambanks
Major issues with water quality have been the degradation and erosion of streambanks and the loss of riparian vegetation. It is particularly associated with grazing of the riparian zone. In earlier years there was little regard for erosion control or riparian vegetation, but in the last 10 years or so the awareness of this issue has greatly increased and effort is being put into controlling erosion of stream banks by protecting riparian vegetation. (John McPherson, catchment officer at Wyong Shire Council)

Erosion Survey of Wyong and Ourimbah Creeks

In 1974, the Soil Conservation Service completed an erosion survey of the Wyong and Ourimbah Creeks, which constitute 90% of the total catchment of the Tuggerah Lakes (IDC 1979). It was estimated that 19% of the catchment was affected by sheet erosion and a further 1% by gully erosion.

Sheet erosion was most severe where landuse included citrus orchards, pastures for grazing, partially cleared timber, or forested areas that had previously been logged. Gully erosion was associated entirely with grazing areas.

The remaining 80% of the catchment area was recorded as having no appreciable erosion.

(source; IDC 1979)

6.6 Sewage pollution

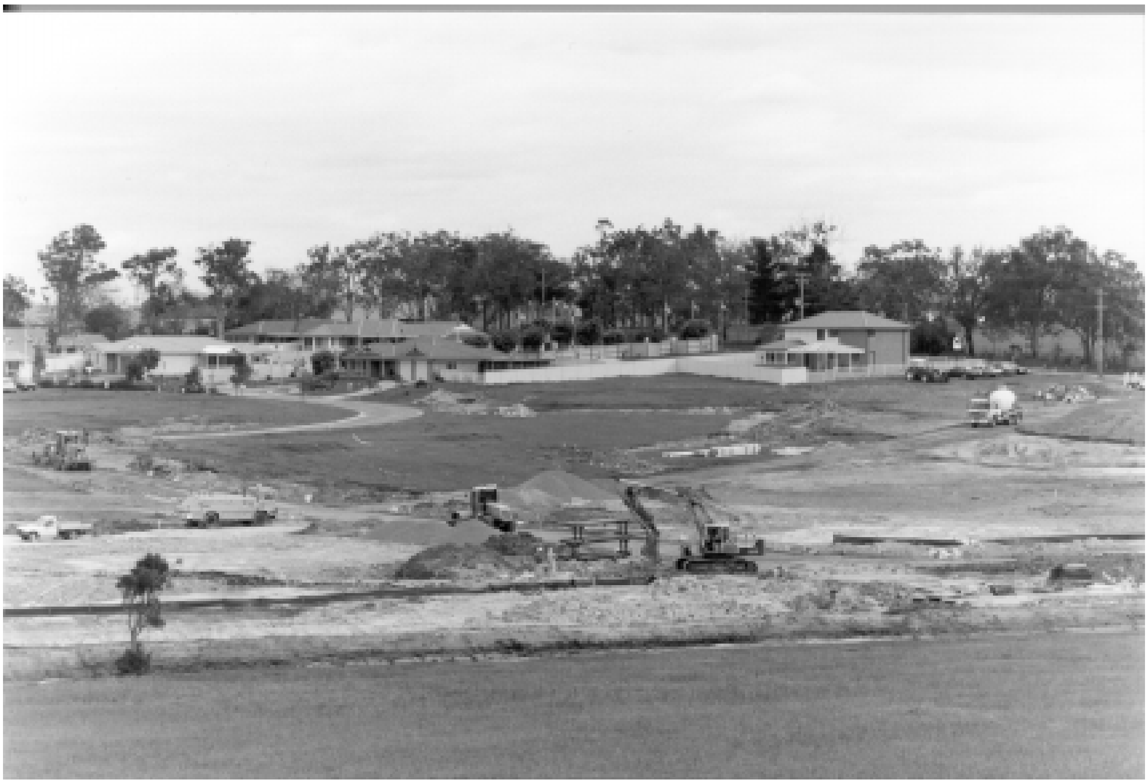
Early this century there was no reticulated sewage disposal system and each house had a pit toilet to dispose of human waste. Wastewater, from bathing or the washing of clothes was discharged into drains which eventually flowed into the lake. However there was probably only a small impact on the lakes since there were very few houses in the district at that time and water was used sparingly since most residents relied on tank water.

In the 1940s and 50s, as small towns started to develop in the district, a sanitary pan service commenced. Each week the pans were collected and emptied at waste dumps. These were located at Noraville, Bateau Bay and Mardi.

In the late 1950s and 1960s, after town water was connected, the volumes of greywater being discharged to local drains increased significantly and as the population increased this became a significant source of pollution (Ken Grantham, Wyong Shire Council, pers. comm.). Also, after town water was connected, flushing toilets were installed in some houses and the waste was treated on-site using septic tanks. These tended to perform very poorly and there are numerous reports of them overflowing or seeping into the lakes. Seepage from septic tanks in the 1960s and 70s was regarded by many residents (and the Wyong Council) as a major cause of pollution (both faecal contamination and nutrients). The problem was exacerbated by the rapidly increasing population.

Problems with the septic systems eventually led to the construction of a reticulated sewerage system, commencing in the mid 1960s and completed in the early 1990s. This greatly reduced sewage pollution entering the lake system.

Initially, however, treated effluent from some of the sewage treatment plants ended up in the lakes, particularly during wet weather. From 1969 until 1988 there was a secondary sewage treatment plant at Wyong. It used to discharge effluent into an oxidation pond and would be re-used by Wyong Golf Course. Overflows would enter the nearby wetlands, which ultimately could have reached Wyong Creek. After 1988 all sewage got pumped across to the Toukley Sewage treatment plant and then ocean outfall at Norah Head.



Residential Development along the Wallarah Road, near Kanwal, May 1998. Increased sediment loads in nearby creeks are often observed during the construction phase, due to removal of vegetation and disturbance of soil.

Wyong River, May 1998. The brown colour of the water is due to fine silt being carried downstream after heavy rainfall.

The Toukley (or Noraville) sewage treatment plant was initially built in the early 1970s, and augmented in the early to mid 1980s. It used to discharge treated effluent into settling ponds in the nearby sandhills. The ponds were designed so that effluent would then seep through the sandhills towards the ocean but a small portion would seep back towards the lakes (Manly Hydraulics Lab 1983). In 1988 the ponds were taken off line and effluent was discharged directly into the ocean. The ponds are now only used in emergency when the outfall is out of operation.

Today, there would be very little sewage pollution entering the lake system, apart from the very occasional sewage overflow (see WSC 1997).

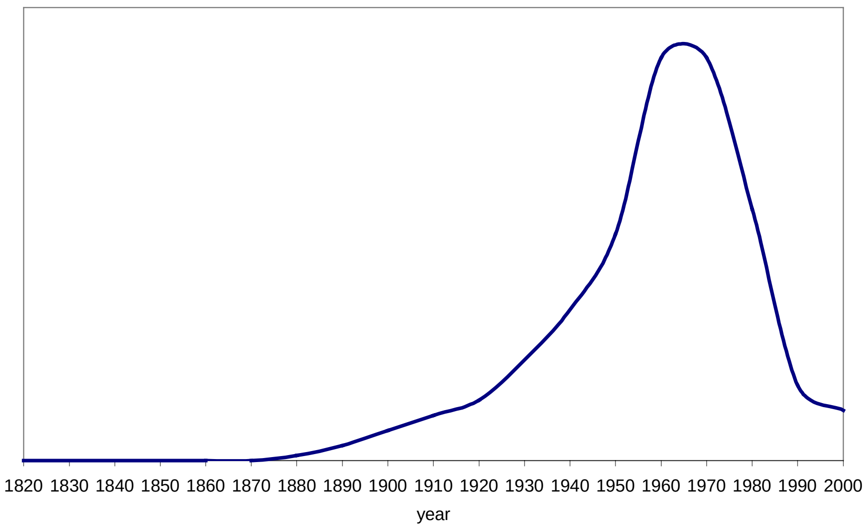


Figure 32. Trends in nutrient inputs from sewage pollution

<u>*Sanitary pans and septics at Chittaway Point.*</u>
At Chittaway Point in the 40s everyone had sanitary pans which would be collected. All other washing water or dirty water used to go straight into the creek via a drain pipe. In the 60s people started to use septic systems and this was part of the problem. Sewerage came later.. (Arthur Sterrit)

<u>*Seepage from septic systems*</u>
Growth of weed absolutely flourished due to nutrients seeping into the lake from septic systems. The septic systems must have been having an impact, there was nowhere else for the effluent to go. There were very few controls on where septic systems were built or on how well they operated, so systems were installed on sandy areas right next to the lake. The effluent must have been seeping down into the lake. In heavy rain they would be flooded and overflow into the lake. Septic systems in sandy areas next to the lake never worked. We had one at our house in Tuggerawong Rd and it didn't work properly and neither did our neighbour's. In rain it used to overflow and run down the street into the lake. This was common. (John McPherson)

<u>*Seepage from sanitary depot at Noraville*</u>
The sanitary depot at Noraville was commissioned in 1959. It was used for treating night soil and septic effluent. Trench and lagoon disposal methods were used. Effluent leaked through to Eel Haul Bay causing an increase in nutrient inputs. (IDC 1979, Appendices)

<u>*Council claims septic water flows into lake*</u>
Wyong Shire Council has decided to take legal action against Astor Hotel Motels Ltd., owners of the Beachcomber Hotel at Toukley. Reason for the action is council's claim that the company is allowing septic tank effluent to flow into Budgewoi Lake…… (The Advocate, 4/5/1966)

<u>*Less weed growth when the district was sewered*</u>
There is a definite improvement in the state of the lakes since the whole of the shire was sewered, in terms of too much weed growth. (John Brown)

6.7 Urban stormwater

Fifty years ago the towns around the Tuggerah Lakes were very small and most of the area consisted of bushland and farmland. Much of the runoff from these areas would have soaked into the ground and not reached the lake. Since then, there has been a ten fold increase in residential, commercial and industrial areas around the lakes and this has caused a very large increase in runoff, particularly during heavy rainfall. The stormwater is usually directed to existing drains and watercourses, where large volumes of high velocity water can cause severe erosion. The sediment passes down the stormwater system and settles out along the lake edge, causing localised siltation problems. The highest sediment loads are generated from new urban developments where vegetation has been recently removed and the soil disturbed. Urban stormwater also contains litter and pollutants washed from roads, footpaths, roofs and gardens.

Urban runoff is also considered to be one of the main contributors of nutrients to the shallow nearshore zones of the Tuggerah Lakes, and this is where excessive macroalgal growth has caused the most problems.

As a result of these problems, in the last 5-10 years, there has been an increasing effort by Council to reduce the amount of sediment, nutrients and gross pollutants contained in urban runoff. This has included the construction of sediment traps, trash racks and filter strips on stormwater drains, and increasing public awareness through education campaigns. Council has also been active in sealing all exposed road shoulders and table drains to reduce the quantities of eroded sediment (Terry Gibbs, Wyong Shire Council, pers. comm.).

After the construction of new urban areas around the lakes is completed, a slow reduction in sediment yield should follow as the area is progressively stabilised by the establishment of drainage facilities, paved roads and lawns. A new steady state in sediment yield will eventually be reached which will be below the peak values during the construction of new urban areas, but well above the yield prior to urbanisation

Stormwater drain at Charmhaven during heavy rain in May 1998

Stormwater drain at Canton Beach.

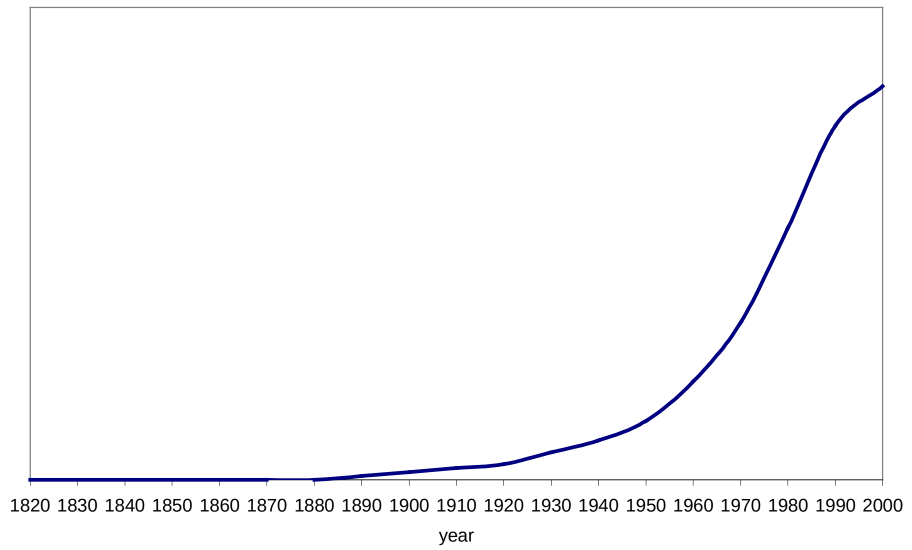


Figure 33. Trend in nutrient inputs from urban stormwater pollution. (This trend closely reflects the growth in residential areas around the lakes. Over the last 5-10 years initiatives by Council to treat urban runoff are helping to address this problem)

Urban stormwater and lake pollution

There is still some pollution coming into the lake from all the houses but you can't really do anything about that. But at last Council is putting in some plants (rushes and oak trees) to filter the water that comes down all the drains. We used to just have open drains and everything used to just wash out into the lake. (John Brown)

Stormwater runoff has increased

Stormwater pollution has been steadily increasing in the last few decades due to the very large increase in urban areas near the lake. Monitoring data for stormwater drains is available. Nutrient input from stormwater runoff has increased over the years. Before urban development, most rain would soak into the ground where now it runs off the road surfaces, and house roofs into drains and then the lake. Land clearing and the draining and reclamation of wetlands has also increased runoff from some parts of the lower catchment. Sediment loads entering the lake from these areas has greatly increased. (John McPherson, catchment officer, Wyong Council)

Increased population causes more pollution

Every foot of curbing and guttering that is built, the runoff and rubbish goes straight into the creek or lake. The more people living around the lake the more pollution running into it. (Trevor Spiers)

Stormwater easement and siltation of the lake edge.

We have an easement along our boundary and we have had large amounts of gravel washed down that easement over the years. And this gravel has formed little islands where the easement enters the lake. The easement has a big flow in storms. The runoff has been caused by all the housing and roads that have been built over the years. It used to be an open drain and there was virtually no water in it. When we first came here it was all bush and the water soaked into the ground. But now we are getting all the runoff, and we also get coke bottles, Macdonald's, oil, anything that people throw into the drain. (Margaret Gedling)

7 Opening of the Entrance channel

The only connection between the lakes and the ocean is a small channel at The Entrance. This results in a restricted interchange of water between the lakes and the ocean, and very little tidal effect. Under natural conditions the channel would slowly block up with sand and could remain closed for a year or more. Eventually a large flood would burst over the sandbar and scour out the channel. This was often expedited by local residents who lived in low lying areas around the lake shores (eg Tacoma) and whose houses were being flooded. The sudden release of water during these floods would wash all of the sand out of the channel and for a while the entrance channel would be much wider and deeper than usual.

The channel is now kept permanently open by continuous dredging of the sand bar that slowly builds up across it. Keeping the entrance channel permanently open reduces the risk of floods around the edges of the lakes and hence the potential damage to residential areas. However, it would also have affected the lake ecology in the following ways;

- The floods will not reach such great heights as previously since the water will not bank up behind a closed entrance channel. This reduces the frequency of inundation of surrounding wetlands.

- The deep scouring effect of large floods is less likely to occur, and hence the entrance channel will rarely open up to the depths or widths that it has obtained previously (even if only for a short period).

- The variation in lake level is now a lot less since any runoff after rain events can quickly flow out into the sea rather than bank up. For the same reason the average level of the lake is likely to remain closer to sea level, (in other words slightly lower than it used to be). The more stable (and slightly lower) water level has allowed land plants (eg casuarinas and grasses) to establish in low lying areas along the shore line which used to be bare.

- The salinity of the lake will tend to be more constant. There is now a continuous exchange of salt and fresh water with each tide. In previous years, when the channel would block up, the lake would become quite fresh after heavy rains and very salty during extended dry spells. These fluctuations in salinity affect the type of weeds that grow in the lake and could have been one of the causes for the large cycles of growth and dieback of stackweed.

- In previous years, when the channel blocked up, the fish and prawns that spawn at sea could not leave the lake and would continue to grow within the lake. During these periods catches of larger fish were obtained, including good sized snapper which would have normally left the lake at an earlier stage. The lake closure also tended to favour the greasyback prawns which spawn within the lakes. If the lakes remained closed, the fish population would eventually decline as new stocks of fish could not replace those that were caught.

- After a large flood the channel would be deep and wide, allowing easy access to a variety of fish. An abundance of king and school prawns also depends on a deep entrance channel.

In summary, maintaining a constantly open entrance channel reduces the fluctuations in salinity, sea water exchange and lake level, which in turn will reduce some of the large natural fluctuations in lake ecology that previously occurred.

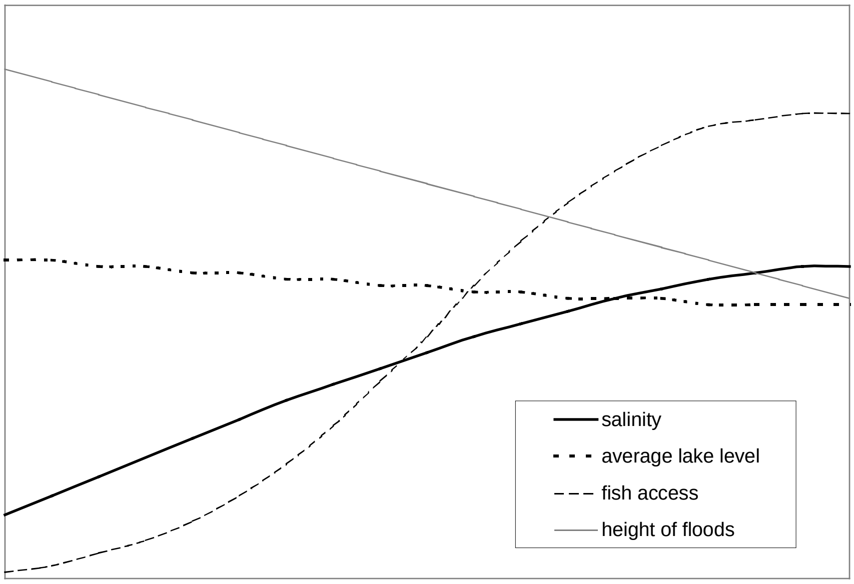


Figure 34. Effect of increasing channel size on salinity, average lake level, fish access and flood levels (Prior to the continuous dredging of the channel, the channel size would fluctuate widely, which in turn caused fluctuations in lake ecology.)

Lagoon entrances along the east coast of Australia (extracts from Bird 1984)

The shape and size of lagoon entrances is the outcome of a contest between the currents that flow through them and the effects of onshore and longshore drifting of sand which tend to seal them off. Currents are generated through entrances in several ways. There are tidal currents produced by tides entering and leaving the lagoon; there are currents due to outflow from rivers, particularly after heavy rain when floods build up the level of the lagoon so that water pours out through the entrance; and there are currents generated by wind action, onshore winds driving sea water into the lagoon and offshore winds driving lagoon water out to sea.

The entrance has a cross-sectional area which varies in relation to the volume of water passing through, being widened or deepened during episodes of floodwater discharge. When the outflow is weak the entrance may be filled in by the longshore movement of sand caused by waves and ocean currents.

The position and dimensions of lagoon entrances change frequently in response to variations in the processes at work and might vary from being completely closed off to being wide deep channels. Some lagoon entrances have been stabilised by the construction of bordering breakwaters. Examples include the entrances to Lake Macquarie, Lake Illawarra and the Gippsland Lakes.

The dimensions of lagoon entrances influence the extent to which tides invade a lagoon, the tide range diminishing rapidly inside the entrance. The more remote parts of large lagoon systems are unaffected by marine tides, but are subject to irregular changes of level from heavy rain, river flooding, or the action of strong winds. Winds blowing over a lagoon lower the level at the windward end and build it up to leeward.

Entrance dimensions also influence the pattern of salinity in a coastal lagoon. Salinity is determined by the meeting and mixing of freshwater from rain and rivers, and salt water from the sea; it generally diminishes from the lagoon entrance towards the mouths of rivers. During extended periods of hot, dry weather, the lagoons may become hypersaline when evaporation is high and the inflow of freshwater is low.

Salinity is of ecological importance, affecting the development and distribution of aquatic plants and algae growing in the lagoon, which in turn affects the types of aquatic fauna, (such as fish and crustaceans) that will be present.

Channel opened up in 1914

The entrance from Tuggerah Lake to the ocean was closed up in the beginning of January by the formation of a sand bar; and after a few months' closure, a large body of water, the result of heavy rain, accumulated and caused great inconvenience to the farming population settled on the banks of Wyong Creek. In view of the damage to property bordering on the lake and creeks by inundation from the backed up waters, the Public Works Department was authorised in July to open a channel to allow the accumulated waters to escape to the ocean. (1914 Fisheries Annual Report)

Channel opened to reduce water level - 1915

The entrance was closed for about eight months during 1915, and the lake rose so high that the Shire Council was compelled to open it, since when it has remained open, though it is now rapidly closing again. (Letter from C Gordon, the Fisheries Inspector, in the 1915 Fisheries Annual Report)

Large channel allows jewfish into the lake

When they have a good entrance the jewfish would come into the lakes in big quantities but they haven't been there for years because the entrance is too small. (Arthur Clouten)

Bigger fish when channel closed

There have been big cycles in the numbers of prawns caught, a lot of it is controlled by what sort of entrance channel there is. If it is closed for awhile, I can remember Dad saying it was closed for three years at one stage. When it is closed for a while, little fish such as the red bream that are in the lake they can't leave and will keep growing until they are quite large. The greasyback prawns do well when it is closed too. But if it was to stay closed, then you might fish the lakes out. When it closed people tend to catch bigger fish because the fish can't leave, but the problem is that it might be fished out because there are no others coming in. (Trevor Spiers)

Prawns need an open entrance channel

Over the years when the entrance to Tuggerah closed, then the prawns cut out, and the old fishermen wondered why, then they discovered that prawns have to go to sea to breed. The 'schoolies' and the 'kings' go to sea, if they didn't go to sea, the spawn never came back in and the prawns gradually died out until we got a flood and opened the channel again. That happened several times before the war, 1935-1940. (Clarrie Wynn)

The Entrance in the late 1940s (photo; Wyong Historical Society)

Looking east at The Entrance in the 1940s. (photo; Wyong Historical Society)

The Entrance, May 1998

8 Munmorah Power Station

The Munmorah Power Station commenced operation in 1967 and was fully commissioned with a maximum power output of 1400 MW at the end of 1969. During the mid 1980s the generating load was reduced as other power stations came on line. In 1990, two of the four generating units were shut down, and since July 1998, has operated as a one unit station. Current operational arrangements are for intermittent service as a standby plant.

Figure 35. Munmorah Power Station – power output (data from Delta Electricity, May 1999)

8.1 Impacts of the Power Station

There are a number of impacts that the Power Station had on the Tuggerah Lakes, most of which have been assessed in detail by Ruello (1978), Henry and Virgona (1980), Batley *et al* (1990) and Thresher *et al* (1993). A summary of the main impacts, along with observations from local residents and fishermen, are presented below.

8.1.1 Alteration to the natural water circulation patterns

The power station drew cooling water from Lake Munmorah and discharged it to Budgewoi Lake. At full capacity the power station circulated cooling water at 54 m^3/s (4,600 ML per day). This is equivalent to 25% of the total volume of water in Lake Munmorah (which is 18,500 ML) passing through the power station each day. Batley *et al* (1990) concluded that the power station had a measurable impact on the hydrology and limnology of Lake Munmorah and Budgewoi Lake. The cooling water circulation meant that the two lakes effectively had a common water body and the flow between the two lakes was changed completely.

8.1.2 Increased lake water temperature.

At maximum power generation the temperature of the water passing through the condenser system was raised 10 ºC while at average operating conditions it was raised 7.5 ºC (Batley *et al* 1990). The heated water was discharged into Budgewoi Lake, and data for the period 1973-79 show that within 500 metres of the power station outfall the surface temperature was elevated about 7 ºC on average. The plume of heated water slowly dispersed and raised the average surface temperature in Lake Budgewoi by 2 to 5 ºC (Batley *et al* 1990, King and Hodgson 1995). The extent of the temperature plume depended on power station output and wind direction, but was generally confined to the surface layers. As water recirculated back into Lake Munmorah, most of the heat had already dissipated and the average water temperature in this lake was only elevated by about 0.8 ºC (Batley *et al* 1990).

The power station's heated effluent affected the beds of ribbonweed (*Zostera capricorni*) close to the outfall, especially in a zone of about 2km extending along the northern shore of Budgewoi Lake towards Buff Point (IDC 1979, Barclay 1983, Hodgson, in ECNSW 1987, Batley *et al* 1990). The most probable explanation for the loss of *Zostera* from this area is that they were thermally stressed, since the growth of *Zostera* is inhibited at temperatures above 30 ºC (Batley *et al* 1990). Robinson (1987) observed similar declines in seagrass beds immediately adjacent to the outlet of the Vales Point Power Station in Lake Macquarie.

There has been no documented evidence of seagrass beds in other parts of Budgewoi or Munmorah Lakes being affected by the heated water, although Batley *et al* (1990) concluded that well designed manipulative experiments would be required to obtain the relevant data.

Although the outflow of heated water from the power station could possibly have led to increased growth of macroalgae in some parts of Budgewoi Lake, the increased levels of nutrients from urban runoff is almost certainly a much greater factor. It is also worth noting that the problem of excessive algal growth is by no means limited to those areas which lie within the cooling field of the power station. Biomass data collected from Chittaway Point in Tuggerah Lake, and well outside the direct influence of the thermal plume from the power station, show similar values to those from San Remo, near the station outfall (King 1988). Also, the most troublesome growths of algae have occurred in shallow waters around the edges of the lake where heating is dominated by solar radiation rather than the influences of the power station.

<u>*Warmer water in Budgewoi Lake*</u>
The fishermen who used aluminium boats, they used to say that they could feel the change in water temperature as soon as they went under the Toukley bridge and entered Budgewoi Lake. (John Brown)

8.1.3 Increased salinity.

Although there was an increase in salinity from power station driven evaporation (caused by increased lake water temperature), it was estimated to be less than 3 ppt (Batley *et al* 1990). Local rainfall and catchment runoff are the dominant factors in salinity variation and under most conditions any effect from the power station would have been negligible compared with these. The only exception might have been in times of severe drought when salinity levels were already high (levels over 40ppt have been recorded) and organisms near their upper lethal limits for salinity could be affected (Thresher *et al* 1993).

8.1.4 Entrainment and impingement.

When the power station was operating at full capacity, 25% of the total volume of water in Lake Munmorah would pass through the power station each day. Screens placed in the inlet channel would filter this water and prevent any fish or debris from entering the cooling system.

Ruello (1978) suggested that some species of fish collected on the inlet screens and then bypassed into the warmer water of the outlet canal (which was up to 10ºC warmer) would be stressed by the sudden increase in temperature and perhaps injured or killed. At other power stations around the world, fish kills have also been blamed on the excess heat of the outlet water, particularly in summer (Gallaway and Strawn 1974).

Some fish species, such as anchovies, also suffered physical damage, such as losing their scales, when caught on the inlet screens, and would be vulnerable to attack from predation while passing through the outlet channel. Other species, such as eels were more resilient and probably suffered a very low mortality. However, Henry and Virgona (1980) concluded that the number of commercially important fish species impinging on the screens was low and hence would not affect total abundance.

Small organisms which passed through the inlet screens and entered the cooling system could have been killed or injured either by physical damage (Waritswat 1975), or by the increased water temperature (up to 10 ºC increase). Up to 1983, a temperature of 35 ºC at the end of the outlet channel had been exceeded 2.5% of the time. (Thresher *et al* 1993). These incidents would occur in December, January and February when inlet water temperatures were high (SPCC 1983). There have been a number of studies which investigated the impact of entrainment on zooplankton populations, some of which found a reduction in abundance at the outfall whereas others found no impact (see Thresher *et al* 1993 for a brief summary of these studies). Entrainment effects may also be secondary or tertiary (Thresher *et al* 1993). Zooplankton form a major component of the diet of the anchovy, which are themselves eaten by some of the commercially important species within the lakes (Ruello 1978, Henry and Virgona 1980). Thus a decrease in the abundance of zooplankton could potentially result in a decrease in fish catches, though these linkages are not yet fully understood (Thresher *et al* 1993).

Fish larvae and eggs are also susceptible to mechanical or thermal damage when passing through the cooling system (Miskiewicz 1987, Edmunds and Jensen 1974). Although the larvae of marine-spawned fish were unlikely to be affected, the larvae of species that spawn in the lakes, such as anchovies and garfish could have been. The eggs of anchovy are pelagic and hence were also susceptible (Friedlander 1976). However, given the fecundity of female anchovies, Thresher *et al* (1993) concluded that the overall impact on the anchovy population of the Tuggerah Lakes was probably small. The eggs of the garfish are attached to seagrass leaves and hence were less likely to be entrained.

Prawns in general and in particular the larvae of the greasyback prawn were also susceptible to the effects of high temperature and mechanical damage during entrainment. Even if not killed, incapacitated individuals would quickly be eaten when they exited the power station (Ruello 1978).

Despite the effects of entrainment and impingement, most commercial catches in the Tuggerah lakes did not show a noticeable decline during the operation of the Power Station. The only exceptions are possibly the greasyback prawn and the garfish (see section 5), although there are many other factors that are equally as likely to have caused their decline.

<u>*Fish kill at outlet channel – hot water the most likely cause*</u>

In mid December 1975 the outlet water temperature frequently exceeded 34 ºC and rose to a high of 36 ºC, according to the station's temperature records, and on the 15th December dead and dying bream were seen on the water's surface in the outlet canal. At that time "cool water" was being pumped from the inlet canal to the outlet canal to try to lower the water temperature in the outlet canal and thereby reduce fish mortality. In view of the observations cited above and Clark's experimental studies (referred to earlier in the report) it seems likely that this fish kill was a result of the high water temperature in the outlet canal. …..

It should be noted that dead prawns sink (and presumably are quickly consumed by fishes and other predators) and consequently any mass mortality of prawns in the outlet canal, should it occur, would normally go unnoticed. (From Ruello, 1978, 'Report on studies on the impact of the Munmorah Power Station on the Tuggerah Lakes prawns and fishes'.)

Effects on greasyback prawns

We used to get a lot of greasyback prawns in the lakes. The school and king prawns breed at sea and the spawn comes back in, but the greasybacks breed in the lakes. Before the power station we used to get cycles of them. You got plenty of prawns. Then they put the power station in. The spawn goes through and is cooked there and we got no greasybacks. The power station is off now and the greasybacks are coming back. This year we had the most in years and years. (Arthur Clouten, May 1998)

8.1.5 Emissions of gaseous nitrogen oxides

Nitrogen oxides (NOx) can be deposited either as wet deposition (dissolved in rain) or as dry deposition (attached to dust). This includes both natural and anthropogenic sources. The main anthropogenic sources are power stations that burn fossil fuels, factories and motor cars.

Bridgman *et al* (1988) provided data on the major anthropogenic sources of NOx gases in the Hunter region for 1984-85;

Wangi Power Station	130 tonnes/yr
Munmorah Power Station	12,200 tonnes/yr
Vales Point	24,500 tonnes/yr
Eraring	35,200 tonnes/yr
Liddell and Bayswater P.S.	38,700 tonnes/yr
Automobiles in whole Hunter region	9,840 tonnes/yr
Factories	10,890 tonnes/yr
Total NOx emissions in Hunter region in 1984/85	131,000 tonnes per year.

The NSW EPA (1993) reported a similar total of 128,000 tonnes/yr of NOx emissions for the Newcastle and Hunter region, most of which originated from power stations (NSW EPA 1993).

Despite these anthropogenic emissions, Bridgman *et al* (1988) reported for the Hunter Valley and Newcastle region that NOx in rainfall was only slightly above background levels. This indicates that for the Tuggerah Lakes, the bulk of NOx deposited from the atmosphere is from natural sources rather than anthropogenic emissions.

8.1.6 Sawdust and ash

Sawdust was used in the cooling water to minimise leaks due to corrosion in the condenser tubes. The average amount used in the first 16 years of operation was 250 tonnes per year. There was some concern that the sawdust contributed to the nutrient loading in the lakes, but compared with other sources of nutrients it was insignificant. However, there could have been some localised effects in Budgewoi Lake near the outlet channel (Batley *et al* 1990). In the early 1980s the quantity of sawdust was reduced when doses of ferrous sulphate and ferric chloride were introduced to retard corrosion of the tubes.

Ash was produced by the burning of coal at the power station and was collected in the Colongra Creek Dam (bottom ash) and Lake Mannering (fly ash). Excess water from the Colongra Creek Dam (including the water used to transport the ash to the dam) passed back through the cooling water system and into Budgewoi Lake. In the early years of operation there were some problems with the ash disposal system and modifications were made to reduce the amount of ash reaching the lakes (Batley *et al* 1990). Also, ash in stack emissions (flyash) was dispersed over the lakes by prevailing winds or washed in from the catchment during storm events. The result of these emissions was that the top layers of sediment in Lakes Munmorah and Budgewoi contain a small proportion of ash, although the exact quantity has been difficult to assess (Batley and Brockbank 1992).

Sawdust and ash
There was ash coming out in the early stages. And they also used to put sawdust into the cooling water to block the leaks up in the pipes, and all this sawdust would then come out into the lake. (Mick Asquith)

Sawdust – Latest Threat to the Lakes
Immense quantities of sawdust and tiny wood chips are being pumped into Budgewoi Lake from Munmorah Power Station, and responsible local residents fear that the resultant pollution could seriously affect the whole Tuggerah Lakes system.

The sawdust has apparently been going into the lake in increasing quantities all summer, and reliable information is that the present rate of discharge into the lake is a massive 1000 bags a week.

It is believed that the sawdust is poured through a condenser at the power station in attempt to plug leaks in the cooling system. It goes through in the stream of salt water drawn from Lake Munmorah, and is then discharged through the outlet channel into Budgewoi Lake. (Wyong and Lakes District Advocate, 28/4/1971)

Weekend work to clear ash off lake
Gangs of Electricity Commission men worked overtime at the weekend to clear masses of drifting flyash from the surface of Budgewoi Lake. The ash, which at one time lightly covered as much as one-third of the lake's surface, was one of the unusual results of last week's drought-breaking rains. …

By midday on Friday an ash scum had built up thickly against fishing boats moored near the narrows between Budgewoi and Tuggerah Lakes. Currents brought the ash across Budgewoi Lake from the power station, then swept it through into Tuggerah Lake.

When first notified of the ash covering on Friday, Electricity Commission officers at Lake Munmorah power station could not imagine how there could have been any escape. A spokesman told "The Advocate" that the stacks were monitored day and night, and no unusual emission could pass unnoticed.

Immediately it was realized that the ash was waterborne, not airborne, the Electricity Commission sent inspection teams to the southern shore of Budgewoi Lake, where the scum was beginning to pile up. They identified it positively as flyash, and immediately made plans to counteract the effect by tracing the cause.

A spokesman stressed that there was no danger whatsoever to fish from the ash. It was unsightly but harmless. …(Wyong and Lakes District Advocate, 9/9/1970)

8.1.7 Chemical Pollution.

Chemical analyses of sediment cores indicate that there has been enrichment of zinc, copper and lead by factors of 60 to 100% in the top 20-30 cm of both Munmorah and Budgewoi Lakes (Batley *et al* 1990, Batley and Brockbank 1992). The sources of such metals include ash from the power station, corrosion of power station condenser tubes, and also runoff from surrounding urban areas (particularly for the lead).

Despite the enrichment of these metals in the sediments, none exceeded the concentrations which are considered to be of concern for either aquatic biota or human health (Batley *et al* 1990). There was also no evidence of accumulation of heavy metals by seagrasses or other aquatic biota (Batley *et al* 1990).

Continuous dosing of chlorine to water passing through the cooling system occurred until 1973 to control build-up of slime, barnacles and other fouling organisms. After 1973 it was only used in one of the four units at a time for 2 hours per day, from October to June. In 1990 chlorine use ceased altogether.

Although fish kills at the outlet were occasionally blamed on abnormally high chlorine levels, such incidents did not occur under normal operating conditions as care was taken to ensure that chlorine levels were close to zero when cooling water finally entered the lake.

The organisms which would have experienced the greatest exposure to chlorine would have been those that passed through the cooling system where the chlorine was added. Estimates of mortality caused by chlorine vary widely in the literature (eg Heinle 1976, Gentile *et al* 1976, Coughlan and Davis 1983), although it appears to be particularly damaging to phytoplankton and zooplankton. Even if the chlorine didn't kill immediately, it could have caused incapacitation, and combined with mechanical damage and heat stress, might have led to increased levels of predation at the outlet. This problem was eliminated in 1990 when chlorine dosing ceased.

The dosing of ferric chloride and ferrous sulphate started in 1982 to retard corrosion of the cooling tubes and allow a reduction in sawdust usage. This resulted in 4-5 tonnes of iron being added to the upper two lakes every year. Thresher *et al* (1993) concluded however, that the addition of iron would have had little effect on the ecology of the lakes.

A few fish kills were also reported after cleaning and maintenance of the canal, possibly due to the decomposition of the fouling organisms which had been removed and the resulting deoxygenation of the water (Thresher pers. comm.).

<u>*Fish kill caused by chlorine? – 1972*</u>
A number of fish kills in Budgewoi and Munmorah Lake in the 1970s have been attributed to the operation of the Munmorah Power Station. The NSW State Fisheries departmental files (73/3881) record that dead bream and silver biddy were found around the outlet canal area of Budgewoi Lake in mid November 1972 and that there was a strong smell of chlorine in the neighbourhood at that time. The Sydney Daily Mirror newspaper of the 13th November 1972 reported that "two truckloads of dead fish have been taken from Budgewoi Lake in the past few days." The cause of the fish kill was not ascertained but it seems likely that the kill was a result of an excessive amount of chlorine in the discharge waters.

In more recent years the Munmorah Power Station has only been using chlorine on an intermittent basis and there has been no evidence that this chlorination programme has been harmful to prawns or fishes… (from Ruello, 1978, 'Report on studies on the impact of the Munmorah Power Station on the Tuggerah Lakes Prawns and Fishes')

<u>*Fish kill caused by Power Station*</u>
The first big kill they had, just after the power station started, I rang up the fishing inspector, Jack Trifford, and told him that there was dead fish floating all over the lake. So he came over to have a look. I took him out in the boat on Budgewoi Lake, there was dead bream, mullet, blackfish, everything, and they were all over the lake, and I said they are coming from the power house. He said how do I know so I took him right up to the outlet and you could see them coming down in the current. That was in the early days. (Mick Asquith)

8.1.8 Decline in jellyfish abundance.

The jellyfish *Catostylus mosaicus* has declined in abundance in the Tuggerah Lakes since the early 1970s. The decline was observed by local residents and professional fishermen and many blame the power station (Scott 1998). Pulley (1971) suggested that the high temperatures generated by the power station caused the disappearance of the larvae from the upper two lakes in the winter of 1971, although others suggested that they were eliminated from the lakes by flooding (Hodgson 1979). Thresher *et al* (1993) proposed an alternative reason for their slow decline, and this was a secondary effect from the Power Station; the depletion of their food supplies. *Catostylus mosaicus* are planktivores and the thermal effects of the Power Station caused a depletion of some species of plankton during winter when the jellyfish larvae are growing. It is also possible that a combination of mortality during floods, a lack of stock to provide recruitment and/or starvation of larvae has prevented this species from reappearing.

Other possible impacts of the Power Station on the jellyfish population might have been;
- the effect of chlorine dosing on both the adults and the larvae;
- mechanical and thermal damage to larvae as they pass through the cooling system, and
- the entrainment of adult jellyfish on the inlet screens (note that at full capacity the Power Station was circulating a volume of water equivalent to 25% of the total volume of Lake Munmorah, each day). There are reports (for example Pulley 1971, Ruello 1978) that jellyfish would collect on the Power Station screens in such large quantities that it would cause operational problems.

Alternatively, the observed decline might not be isolated to the Tuggerah Lakes. The decline could be part of a long term natural fluctuation (possibly caused by climatic factors), or it could have been caused by some coast-wide anthropogenic impact such as chemical pollution or destruction of habitat.

Loss of blubber caused by Power Station?
This place used to be full of blubber too, the blubber was blocking the screens at the power house, so they got a 'blubber expert' in and they wiped them out. This expert was up there for three years working out how to kill the blubber and we've never had them since. We used to catch prawns in the inlet canal, and the 'blubber man' used to come down and talk to us, he took us up to the power house, and showed us what he was doing, he showed us how he was killing them, and we'd end up getting the dead blubber in our nets, they'd have no legs we'd just get the head of them. The blubber would be dead and would go hard, and you'd only get the head of it. (Mick Asquith)

8.1.9 Effects on fish and prawn catches

A positive impact of the Munmorah Power Station was that recreational fishing opportunities were enhanced, particularly during winter, when the outlet canal would account for 80% of the total number of anglers around the lakes and 90% of the catch (Henry and Virgona 1980). The increased water temperature, along with a good food supply made it a most productive area. Bream were attracted to the mussels on the canal walls, and mullet liked the algae that would grow there (Ruello 1978). There was also a plentiful supply of larvae, small fish, prawns and zooplankton which had been injured or killed while passing through the power station and these made easy prey.

At the power station inlet, the professional fishermen were allowed to place their nets across the channel and they would catch the prawns that were being drawn into the power station. These would often be large sized prawns that had been trapped in Lake Munmorah by the strong current passing up through the Budgewoi Creek channel.

Despite the opportunities to catch prawns at the inlet channel, most professional fishermen felt that the power station had a detrimental effect on prawning (Scott 1998). As mentioned earlier, the greasyback prawn spawns in the lakes, and the fishermen believed that the spawn was killed when it passed through the power station, causing a major reduction in numbers. Unfortunately, the NSW Fisheries records prior to 1978/79 only report the total prawn catch and do not specify the catch by species, and so the anecdotal evidence of a decline in greasyback prawns cannot be confirmed.

With regard to finfish, professional fishermen had mixed feelings about the impacts of the power station. Some felt that the abundance of fish had declined in Lake Munmorah, while others felt it had not been affected. Others believed that the only change had been in the distribution of fish, particularly in winter, with many of the fish moving from Tuggerah Lake into the warmer water near the outlet in Budgewoi Lake (Scott 1998).

After a biological investigation and a review of the historical fishing data, Henry and Virgona (1980) concluded that there was no apparent detrimental effect by the Munmorah Power Station on the commercial catch of finfish and that it had enhanced the recreational catch.

Less fish in Lake Munmorah
From 1936 large quantities of greasyback prawns bred in Lake Munmorah, and from 1953 good quantity of bream and luderick and mullet caught with meshing nets. This lake was closed to hauling nets about 1952. After the start of operation of the Power Station in 1967, there were big falls in fish and prawns in this area, so most fishermen never got there as catches would be small compared with the catches before 1967. (Arthur Clouten)

Large prawns caught at the inlet canal
Munmorah inlet channel became a prawning bonanza with large king prawns the main catch. Draws took place to determine who could set nets on each night. (Peter Clifford)

Power House killed the greasybacks
...the power house took the greasybacks. Greasybacks are a prawn that doesn't go to sea, and the power house killed the spawn when the water passed through. Well the power house hasn't been working for a few years now and the greasybacks are starting to come back. There were a lot of greasybacks last year and the year before. (Mick Asquith, 1998)

Outlet channel made good fishing spot
They closed the outlet channel to amateurs because they were catching all the small fish. The fish seemed to love the hot water. (Bill Byles)

8.1.10 Dredging of channels.

In order to provide sufficient circulation of cooling water, Budgewoi Creek (the channel between the two lakes) was deepened. Dredging was also undertaken in the channel around the northern edge of Budgewoi Lake between Buff Point and Budgewoi, and also in Lake Munmorah near the inlet channel. In earlier years, when the channel was quite shallow, some fish would become trapped in Lake Munmorah and would grow to a large size. The deepening of the channel probably resulted in less of these large sized fish being caught.

Effect of deepening the Budgewoi channel on the fish
Interviewer: When they deepened the channel through to Munmorah, did that change the type of fish you caught there?
Mick; Yes, it was that shallow that when fish went in there, they'd stay in there and keep growing and they were always the biggest fish you would catch. They couldn't easily get out so they'd stay there and keep growing. Everything was always bigger in Top Lake. That changed when they deepened it. You see now, if mullet go into Top Lake, they might only stay there for a day and then come back out again, where previously when they went in, they would stop there. (Mick Asquith)

8.1.11 Improvements since Power Station reduced operation?

The Power Station has greatly reduced its operations over the last 10 years and is now on standby duty only. Some fishermen believe there has been an improvement in the condition of both Budgewoi and Munmorah Lakes (Scott 1998). In particular they have observed increasing numbers of greasyback prawns and shellfish, and changes in the types of weed (seagrass and algae) present. Whether these changes are connected to the Power Station reducing its operations or are the result of other factors (anthropogenic or natural) is difficult to determine. For instance, the observed changes might be associated with long term fluctuations in salinity or rainfall, which are part of a natural cycle, or they might be associated with other anthropogenic factors such as the reduction in sewage effluent entering the lakes.

It can however be concluded that the closing down of the Power Station reduces the number of potential impacts on the lakes' ecology and returns the system closer to its original condition.

Types of weed are changing due to colder water now
The weeds that the power house created, that is going, because the water is not as warm any more (after the Power Station stopped operating). *That's just my opinion.* (Mick Asquith)

Shell life is now returning
The lake is slowly getting better now that the power house is off, you now can find a live shell in the lake, they're only small but when the power house was going you couldn't find them. You see they had to kill the barnacles; well by killing the barnacles they killed everything else. (Mick Asquith)

9 Waterbirds

The Tuggerah Lakes and surrounding wetlands support an abundant and diverse population of waterbirds. Some of the highlights described by Miller and Ruello (1978), Morris (1992, 1997, pers. comm.) and Wettin (1981) are;

- Miller and Ruello (1978) recorded 69 species of waterbirds in the Tuggerah Lakes and surrounding freshwater wetlands during four surveys between March and December 1977. This included a large population of waterfowl possibly due to a drought in inland NSW which drove many nomadic species to the coast. The mudflats on the eastern side of Budgewoi Lake were considered the single most important area for waterbird feeding in the Tuggerah Lakes system. Other important areas identified were Terilbah Island and surrounding mudflats, Chittaway Bay and Chittaway Point, and the freshwater rivers and wetlands around the lakes.

- About 2500 black swan come to the lakes each summer for post breeding moult and to feed on the seagrass beds when the smaller coastal and larger inland wetlands have dried out, particularly in dry years. Maximum number recorded is 3234 in December 1996. Favourite sites for the black swan are the sand flat on the east side of Budgewoi Lake, Tuggerah Bay and Chittaway Bay.

- The lakes are a nationally important site for waders with about 2000 spending each summer there. In the drought summer of 1991/92 between 7,000 and 8,000 waders were present. The usual wader population consists of 300 bar-tailed godwit, 500 sharp-tailed sandpiper, 300 red-necked stint, 300 curlew sandpiper, 100 knot, 50 greenshank, 20 marsh sandpiper, 250 black-winged stilt, 50 Pacific golden plover, 120 masked lapwing, 40 red-capped plover, and 30 double-banded plover. The sand flat on the east side of Budgewoi Lake is a favourite site for waders since it is shallow (generally between 0-30cm depth) and has a good supply of benthic organisms in the sand/mud sediment. Another favourite site is the tidal sandflats at Picnic Point and around Terilbah Island. Many of the waders are migratory, and in autumn they leave the lakes to start their trip to the northern hemisphere.

- Less common waders that are seen around the lakes include terek sandpiper, black-tailed godwit, grey plover and great knot.

- About 2500 chestnut teal gather on the lake each year in late summer and autumn for moulting and pair formation. The sandflat on the east side of Budgewoi Lake is a popular site for them.

- About 300 Australian pelican are resident on the lakes and nest to the south in a colony located in Blackall Bay, Brisbane Water.

- Cormorants are abundant near The Entrance where they can be seen diving under the water in their search for fish and crustaceans. Three species are common, the black, little black and little pied cormorant, while the pied cormorant is less common. In September 1996, 544 black cormorants were observed on the lakes. Cormorants and small numbers of darters breed in the Colongra wetland

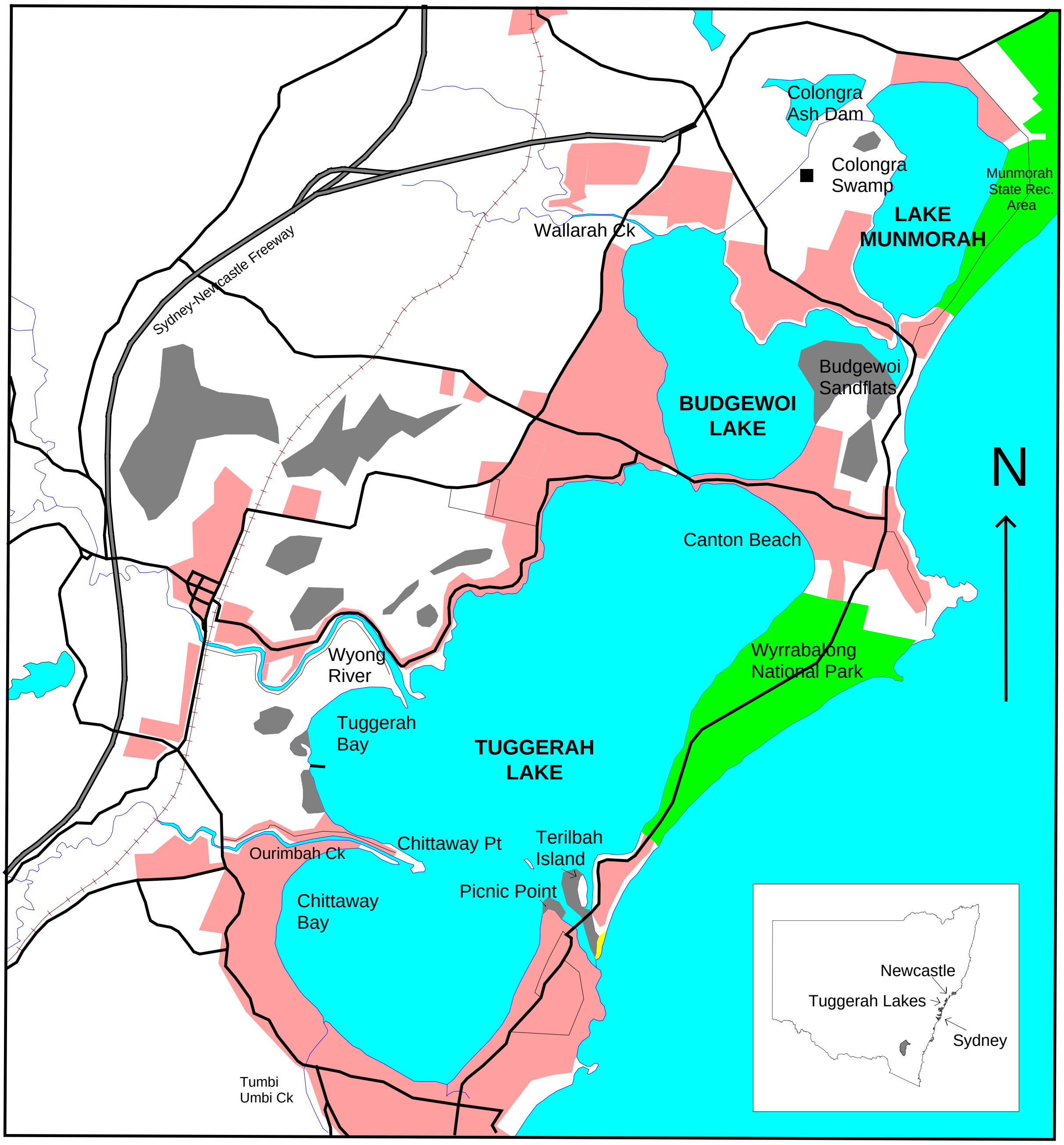
- Black bittern are a rare breeding resident along the streams that feed the lakes, and striated heron are moderately common and can be observed in the casuarina groves that border the lake.

- About 25 pairs of little egret have nested annually at Chittaway Point since 1982.

- Hoary-headed grebe are an uncommon visitor and small numbers have been seen at Colongra Lake, Tuggerah Bay and off Canton Beach.

- White-breasted sea-eagle and whistling kite are common and nest around the lakes.

Figure 36. Waterbird sites



0   5 km

Towns and suburbs

wetlands

It is clear from historical records that the Tuggerah Lakes have always supported an abundance of waterbirds and this was an attraction for hunters. Fishermen on the other hand, saw the fish-eating waterbirds as pests and in the early 1900s the local fishing inspector was attempting to reduce the cormorant population by shooting them.

There is however, anecdotal evidence that some changes in species composition have occurred over the last 60-70 years. These changes include;

- A decline in the abundance of the musk duck. A number of the older residents who were interviewed could recall seeing musk duck on all three lakes, particularly Lake Munmorah (Scott 1998). Musk duck are now only seen in very small numbers on Colongra Lake. Morris (pers. comm.) suggested that the presence of musk duck was possibly linked to the closing of the lakes to the sea, which is no longer allowed to happen. When the entrance were closed off, the salinity of the lakes could remain low for many months, or even years, and this allowed the abundance of bivalve molluscs to increase, which are a favourite food of the musk duck.

- An increase in abundance of wood duck (or maned duck), probably associated with the increase in lawns and parks in suburban areas, where these duck can graze. A newspaper report in 1867 said "*The wood duck is a very rare bird with us, as I expected it to be. I can only find one person who has seen any specimens at Tuggarah.*"

- In 1842, John Mann attended a corroboree at the mouth of Wyong Creek and described "*the black swans; their nests built in the water of sticks were dotted over the whole of the shallow beaches of the lake. Every nest contained several eggs, and we each colleted as many as we could conveniently carry.*" A number of other historical references and anecdotal accounts mention black swans nesting in wetlands around the Tuggerah Lakes (Scott 1999, Scott 1998). Although black swan do still breed in wetlands surrounding the Tuggerah Lakes, it is now only in small numbers.

- Little terns formerly nested at Budgewoi and The Entrance (Morris 1992, Scott 1998), but while about 10 breeding pairs seem to be present each summer, no breeding takes place. By late summer up to 120 little terns gather at The Entrance, before departing in late April.

- A possible decline in the abundance of the jabiru (black-necked stork). In 1867 it was reported that "*jabirus are not uncommon at Tuggarah. I am informed that it is seldom a sportsman goes out for a days shooting without seeing some.*" New South Wales is at the southern extent of this species distribution, however the draining of wetlands, flood mitigation and urban development along the coast have probably reduced the population to its present low level (Dodkin 1983). A pair of black-necked stork are still occasionally sighted on the western side of Tuggerah Lakes and in the freshwater wetlands along Wyong Creek. They were last recorded in 1995.

- Disappearance of the brolga. In 1867 it was reported that "*In the swamps an occasional native companion is seen, but, they are a rare bird with us. It is a very shy bird. It is more like the English crane than most birds which we call cranes here, but larger than the European bird. The general colour is light slate blue, with a red cere and a bare head; they are nearly as tall as the jabiru*". Populations of brolgas have declined markedly throughout southern Australia since European settlement although the species is still common in its northern range (Blackman 1983).

For many other species, it is difficult to determine whether there has been a decrease or increase, particularly when there are large natural fluctuations associated with flood and drought conditions. It is clear however, that the Tuggerah Lakes continue to support a large and diverse community of waterbirds and are an important site along the NSW coast.

Shallow coastal estuaries such as the Tuggerah Lakes not only provide an important refuge for waterbirds escaping inland droughts, but are also an important resting and feeding site for migratory waders. In addition, the lakes and surrounding wetlands provide a feeding and breeding site for a variety of resident waterbirds.

The most important issue for the conservation of waterbirds around the Tuggerah Lakes is the preservation of habitat. This includes the mudflats and shallow sandbars around the edges of the lakes, such as the large sand bar on the east side of Budgewoi Lake, Tuggerah Bay on the west side of Tuggerah Lake and the shallow waters around Terilbah Island at The Entrance. Dredging of these shallow areas should be avoided. Other important waterbird habitat includes the wetlands surrounding the lakes, and riparian vegetation along the edges of lake.

Lake covered with swans and other fowls - 1884

On the Great Northern Line- Gosford to Newcastle; Tuggerah Beach Lake is an estuary or inlet of the sea, and at the time of our artist's visit the entrance to it on the sea coast was blocked with sand, and the road from Ourimbah Creek to Tumbi Umbi was completely under water. The lake is literally covered with black swans and other fowls. (Town and Country Journal 2nd February, 1884)

The ravages of waterbirds on small fish - 1890

I am, however, much impressed with the importance of Lake Budgewoi as a breeding ground and nursery; it contains extensive flats, on which food exists in abundance. These flats are so mercilessly hauled by fishermen that future fish supply will assuredly suffer, as also it will suffer from the ravages of water birds, which collect on them in immense flocks.

Some part at least of these flats ought to be closed against the use of fishing nets, and an effort should be made to destroy or drive away the birds. It would be scarcely consistent to close the flats against netters, and yet allow these voracious pests to remain unmolested. …. (1890 Fisheries Annual Report)

"In my young days there were millions of birds" – early 20th century

To the west of "the big plain" is a low-lying area which includes the new Killarney Vale shopping centre. My father told me once that back in the last century, perhaps a hundred years ago, and certainly before my time, the entrance to the ocean was blocked (and this has happened many times) and big floods in the Yarramalong and Dooralong and Ourimbah Creek valleys had raised the waters of the lakes to unheard-of heights. The waters poured into the lake and there was nowhere for them to go but to spill over into the low-lying grounds along the foreshores. All that land where the shopping centre is now and right out to the hills to the south was submerged in big swamps which were there for many months and swans made their nests there.

In my young days there were millions of birds - swans, pelicans, cormorants and ducks - on the lake which in places was black with them. I have seen swans massed there for as far as the eye could see. I have heard that on the middle lake there was once great numbers of redbills. I can remember when there was four pence a head bounty on cormorants, or shags as some people call them. They were eating so many fish, they were treated as pests. People went in with guns and shot great numbers of the birds or frightened them away. Very few remain now. (Memoirs of Raymond Taylor of The Entrance, born 1892. From Stinson, vol 1, 1979)

A visit to the Tuggerah Lakes (NSW) - 1904

Waterfowl were plentiful, especially the Black Swan (Chenopis atrata), which were congregated in thousands on the weedy shallows, where an abundance of food is procurable. Several species of Cormorants were seen, including the Black (Phalacrocorax carbo), Pied (P. hypoleucus), and the Little Cormorant (P. melanoleucus). The Silver Gull (Larus novae-hollandiae) graced the scene with its silvery plumage, while Black Duck (Anas superciliosa) and the Grey Teal (Nettion gibberifrons) were fairly plentiful. Up a sluggish and brackish river that empties itself into the lake the Darter (Plotus novae-hollandiae) was seen; while here and there along the banks Blue Kingfishers (Alycone azurea) would dart along like flashes of light in the rays of the sun, or the more stately Sacred Kingfisher (Halycon sanctus) could be seen perched on a dry tree near the water. …. Far aloft the wedge-tailed eagle (Aquila audax) soared in circles out of harms way, and further on a pair of White-bellied Sea-eagles (Haliaetus leucogaster) was seen.

A morning spent near the lake's edge gave opportunity of seeing a few shore birds, and several Sharp-tailed Stints (Heteropygia acuminata) were secured. The Curlew (Numenius cyanopus) could be seen wading in the shallows, while a White-fronted Heron (Notophoyx novae-hollandiae) was perched on a neighbouring dry tree. A few Spur-winged Plovers (Lobivanellus lobatus) gave their warning cry, which every sportsman well knows, often to his cost. Some Silver Gulls (Larus novae-hollandiae) were floating on the wing just above the salt water. Over the open flats between the lake and timbered country a Spotted Harrier (Circus assimilis) soared in search of prey, and the innocent little Nankeen Kestrel (Tinnunculus cenchroides) hovered in the air over a mouse or other titbit ere it descended to carry it off. Here too the Swallow (Hirundo neoxena) swept the surface of the pools and chased the gnats, that were plentiful. …(The Emu, Official Journal of the Australian Ornithologists Union, Vol 5, pages 1-6, July 1905.)

McPherson's Brush – breeding in the swamps

The heavily timbered area to the west of Tuggerah Straight was known as McPherson's Brush. This brush was largely swampy and a breeding ground for a great number of waterbirds - wild ducks, redbills, swans, egrets and the like. (Stinson, vol 5, 1984)

Less swans but still a good number

Interviewer; Do you remember in the 1920s and 1930s lots of swans in these lakes?

Peter; Yes, there always were, and there still are, but not as many now. We lived directly opposite the big flat at Terilbah Island, that has been dredged away now. You used to hear them calling all night. The swans used to nest in Wyong Bay.

Interviewer; So you feel that there are less swans about now?

Peter; There are less swans but there is still a good number. (Peter Clifford)

Snipe on Terilbah mud flats

Interviewer; What about waders or snipe?

Peter; They are coming back. They used to be on the mud flats at Terilbah. I have eaten lots of snipe. There are three or four different types of snipe. We called the little one the Jack Snipe.

Interviewer; So there were lots there in the 20s and 30s?

Peter; Heaps, then they disappeared for a while because they were shot, and now they are coming back. (Peter Clifford)

Hunting waterbirds

We'd have swan for Xmas dinner because it was all we could afford. We'd clean him, pluck him and then boil him. When he was nice and soft we'd shove him in with the 'taties' and bake him. That's all we lived on, birds; pigeons, whatever we could shoot, legal or ill'. (Elizabeth Denniss)

Musk ducks

We'd see them (musk ducks) *often, they were mainly in Top Lake but you'd see them in the other lakes too. You might see half a dozen or so. They mainly bred up in Colongra swamp, but that's another thing, when the power house was built they filled most of the swamp in.* (Mick Asquith)

Waterbirds on Budgewoi Lake

Behind where the (Toukley) *golf club is now, was a wonderful swamp, and you could always get wild duck, such as black duck and teal, and flock pigeons also. When there was a dry season in the west, they used to come here in the summer, thousands of ducks, swans and coot would turn up on the 'Big Sand'. It was nothing to see thousands of ducks up there. The main ones were the black duck and teal, there weren't many wood ducks around in the early years. And in February, when we were kids, it used to be great because the jack snipe used to come in, the ones that migrate from Japan and Siberia, they used to come here in great numbers, up on the big sand. In the last couple of years I saw a few outside here* (at Peel St). (Bill Hansen)

10 Other impacts

There are a number of other ecological impacts and issues that have not been fully addressed in this report, but nonetheless should be carefully assessed when developing a management plan for the lakes. These include;

- Water extraction from Wyong and Ourimbah Creeks for drinking water. In dry years (such as in 1993 and 1994) almost all water flowing down the Ourimbah Creek and Wyong River are extracted for drinking water purposes (WSC 1997). This reduces the flushing and dilution effects of the freshwater flow entering the lakes during drought times. However, water extraction has little effect in wet years when annual flows are an order of magnitude higher (see Table 11).
- Industrial and agricultural pollution other than nutrients. This includes heavy metals and pesticides and faecal coliforms. One source of heavy metals was the Munmorah Power Station, but other sources such as urban and industrial runoff should also be considered. Pesticides can also be a concern, although water quality monitoring in the rivers and streams has so far indicated that pesticide contamination is minor.
- Acid sulphate. Problems were encountered during the Lakes Restoration Project in the early 1990s when large quantities of sediment were removed from the shallow nearshore sections of the lake and exposed to the air when piled up along the shore line (Sutas 1996, Leonard 1995).
- Mine subsidence along the lake shores and in the middle of lakes. These problems are associated with Lake Munmorah and Budgewoi Lake, in particular near Buff Point and along the shore line near Colongra Swamp.
- Loss of native riparian vegetation around the foreshores due to clearing for housing developments and parkland, and also due to the spread of weeds.
- Dredging associated with the Lakes Restoration Project. Dredging of shallow sand and mudflats improves the recreational amenity of the lakes but can destroy weed beds that are nursery areas for young fish and can also eliminate habitat for waterbirds, in particular the waders.
- Disturbance of lake bed by hauling and trawling (or snigging) of fishing nets. This could lead to damage to seagrass beds and re-suspension of muds.

Table 11 River flows and water extraction in Wyong Shire

Year	*Ourimbah Ck (ML)*	*Water extraction Ourimbah Ck (ML)*	*% of total water available*	*Wyong R and Jilliby Ck (ML)*	*Transfers, Mangrove Dam into Wyong R.*	*Water extraction from Wyong R.*	*% of total water available*
1989	46,276	n.a.	-	192167	n.a.	n.a.	-
1990	93,195	n.a.	-	360,182	n.a.	n.a.	-
1991	6,338	3,520	55	19,979	n.a.	7,318	37
1992	34,584	6,316	18	77,125	n.a.	12,912	17
1993	4,374	3,573	82	13,327	1,119	12,376	93
1994	2,307	1,350	58	14,265	5,903	15,571	109
1995	10,853	3,475	32	29,242	1,317	19,105	65

Note; The transfers from Mangrove Dam are included in the flow data for Wyong River
(All data from WSC 1997)

11 Conclusions

Collecting historical information
One of the problems facing the managers of the Tuggerah Lakes was the lack of scientific data that could provide an indication of what the lakes were like in pre-development times. To overcome this problem, historical information was collected which provided qualitative descriptions of the lakes over the last 50 to 150 years. This information was collected from historical documents, old newspapers and by interviewing residents who have lived in the area for up to 90 years. By combining this information with more recent scientific studies, a better understanding of long term ecological changes has been obtained.

The historical information that was collected consists mostly of passing comments and observations from a variety of people, including professional fishermen, fishing inspectors, local residents, Council employees and occasionally from professional scientists or naturalists. One cannot expect all these observations to be completely consistent due to different perceptions and observational skills, and also due to the large natural variability of the lakes both over time and at different locations. However, despite this, there were many topics for which most of the information collected was similar, and overall, a great deal of consistency was obtained. This has provided some valuable information about the past ecology of the Tuggerah Lakes and has enabled a picture to be constructed of what the lakes were like when the impact of European settlement was still minimal.

Pressures and impacts
The evidence collected suggests that European settlement has placed a number of pressures on the ecology of the lakes, including;

- Rapid urban development around the lakes, with associated problems with sewage and stormwater disposal.
- Operation of a coal-fired power station which used lake water for cooling purposes
- Land clearing and logging of the upper catchment, and resulting erosion problems
- Dredging of the entrance channel to reduce flooding and maintain a permanent opening
- Commercial and recreational fishing and prawning

These pressures have impacted on the lake ecology in many ways, some more obvious than others. The most noticeable long term impacts are:

- Increased nutrient concentrations in water and sediment, particularly in the nearshore zone,
- Increase in abundance of macroalgae in the nearshore zone,
- Loss of seagrass in the centre of the lakes, particularly *Ruppia megacarpa,*
- Increased levels of organic ooze (and associated smells) in nearshore zone,
- Possible decrease in abundance of some species of fish and prawns,
- Loss of riparian vegetation and reclamation of surrounding wetlands,
- Decrease in abundance of jellyfish in the lakes,
- A reduction in the natural variation of lake parameters (such as salinity and water level) due to the policy of maintaining a permanently open entrance channel;
- Increased sedimentation, particularly near stormwater drains.

The pressures and impacts for the Tuggerah Lakes are very similar to those being experienced by other estuarine lakes along the NSW coast, in particular Lake Macquarie near Newcastle and Lake Illawarra near Wollongong.

Recent changes in pressures and impacts
In recent years two of the pressures on the ecology of the lakes have been greatly reduced. In the late 1980s and early 1990s the sewerage scheme for the Shire was completed, and this has virtually eliminated one of the major sources of nutrients to the lakes. Secondly, the Munmorah Power Station

greatly reduced its operation in the mid 1990s and this returns the circulation patterns and water temperature of two northern lakes to their natural condition.

It has also become apparent that the 'health' of the lakes might have been slowly improving over the last four to five years. The growth of macroalgae in the nearshore zone, for instance, seems to have declined, and professional fishermen are starting to report increases in the abundance of the greasyback prawn. However, these anecdotal reports need to be tested by scientific monitoring of the lakes' ecology over a number of years to confirm that they are in fact a long term change rather than just part of a natural fluctuation in the system.

On a less positive note, is the ever expanding urban development around the lakes and the increasing quantities of sediment, nutrients and other pollutants associated with the runoff from these areas. Urban development is also accelerating the loss of riparian vegetation and reclamation of wetlands around the lakes. Controlling the impacts of urban development is probably the greatest challenge for those managing the Tuggerah Lakes.

<u>Linking pressures with impacts</u>

When attempting to link the major pressures on the system with observed changes in lake ecology, great care needs to be taken. Unless there is a very strong direct link between a particular pressure and how a part of the ecosystem operates, it can be a difficult task due to the extreme complexity of the ecological processes operating in the lake and the possibility of indirect secondary impacts going unnoticed. For the Tuggerah Lakes (and many other estuarine lakes along the NSW coast) this is further complicated by the high number of different pressures acting on the ecosystem at the same time. In addition, the natural variability of the system, over time periods of years and sometimes even decades, can make it difficult to determine what are natural fluctuations in the lake ecology and what are anthropogenic impacts.

However, by improving our understanding of the ecology, both in present times and in pre-European times, it should be possible to make more informed assessments of how the system has changed. This in turn should provide a better framework for the environmental management of the lakes, and assist with efforts to restore the lakes to a state closer to its original condition.

<u>The value of collecting historical information</u>

This study also demonstrates the value of using historical information to develop a better understanding of ecological systems such as the Tuggerah Lakes. Without this historical information, a <u>long term</u> perspective would be difficult to obtain. For many ecosystems, the natural fluctuations associated with long term weather patterns (such as the El Nino effect) can be in the order of 5 to 20 years and yet many scientific studies only cover one or two years. Also, for the Tuggerah Lakes, virtually all scientific studies have occurred since the early 1960s and there are few scientific records prior to this time. To develop a better understanding of the ecology before that date, the historical records were found to be a very useful source of information. It is hoped that further ecological studies will utilise this valuable source of information.

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Appendix 1 Some notes on calculating nutrient loads

Nutrients from the upper catchment
This was estimated using typical nutrient export data for each land use and was based on information from Garofalow (1998) and Wyong Shire State Of Environment Report 1996/97.

Land use	Area (ha)	P (kg/ha.yr)	Total P (kg/yr)	N (kg/ha.yr)	Total N (kg/yr)
Forestry	30,000	0.4	12	1.5	45
Extensive agriculture	36,000	0.3	11	3	108
Intensive agriculture	950	5	5	10	10
Total			28,000		163,000

Using flow rates and water quality data collected from Wyong River and Ourimbah Creek in 1989/90 Boake (1991) calculated a total P load of 10-20 tonnes/yr and an N load of 50-100 tonnes/yr.

Estimating runoff from lower catchment including urban areas
This was estimated using typical nutrient export data for each land use and was based on information from Garofalow (1998).

Land use	Area (ha)	P (kg/ha.yr)	Total P (kg/yr)	N (kg/ha.yr)	Total N (kg/yr)
Residential	3,450	1.5	5,100	7.5	25,900
Industrial/ commercial	1,100	3	3,300	8	8,800
National Park	2,400	0.1	240	1	2,400
Other (parks, golf courses, rural residential, bushland	8,300	0.6	5,000	4	33,200
total			13,600		70,300

Estimating wet and dry deposition of nutrients from atmosphere.
Nitrogen oxides (NOx) can be deposited either as wet deposition (dissolved in rain) or as dry deposition (attached to dust). This includes both natural and anthropogenic sources. The main anthropogenic sources are power stations that burn fossil fuels, factories and motor cars.

It has been estimated that 25% of the total nitrogen entering Chesapeake Bay, USA is derived from atmospheric nitrogen oxides. In New York-New Jersey Harbour it was estimated to be 38% and in Tampa Bay 28% (USEPA Office of Water web site 1999). In Port Phillip Bay, Victoria, atmospheric sources contributed between 10 and 20% of total nitrogen input (Harris *et al* 1996).

Bridgman *et al* (1988) found that rainfall acidity levels (caused by sulphide and NOx emissions) in the Hunter Valley were only slightly above background levels and significantly lower than those for north-eastern USA. This indicates that for the Tuggerah Lakes, the bulk of NOx deposited from the atmosphere is from natural sources rather than anthropogenic emissions.

They measured NOx in precipitation; and the average near the coast was 0.08 mg/L Nox-N

The direct input to the Tuggerah Lakes is therefore = (1.2m rainfall) * 0.08 mg/L * 77 sq km lake area
$=9.24*10^{10}$ L * 0.08 mg/L = 7.3 tonnes per year.

Jaworski *et al* (1995) increased their wet deposition figures by 40% to account for dry deposition. Therefore the total NOx deposition directly onto the Tuggerah Lakes is estimated to be 10 tonnes/yr.

This figure is lower than that calculated by Garofalow (1998) of 40.5 tonnes total nitrogen.

There is also indirect input via rain falling on the catchment. Assuming 15% of rainfall ends up as runoff, and average rainfall in catchment is 1200 mm, the indirect input from wet deposition is 9 tonnes/yr, and the total (both wet and dry deposition) is 13 tonnes/yr.

Hence the total NOx-N entering the Tuggerah Lakes either directly from the atmosphere or via deposition followed by runoff from the catchment, is estimated to be 23 tonnes/yr.

The deposition of phosphorus is less significant and is primarily in the form of dust particles. Garofalow (1998) estimated that 1.9 tonnes/yr of total phosphorus were deposited directly onto the Tuggerah Lakes from the atmosphere.