An Ecological Health Assessment of the Karuah River

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Executive Summary

In 2011 the Great Lakes Council contracted the New South Wales Office of Environment and Heritage to undertake an ecological health assessment of the Karuah River estuary including The Branch River tributary. The objective was to assess the condition and inform the development of a catchment plan for the Karuah River.

A broad ranging approach incorporating different scales and trophic (food chain) levels was used, so as to best capture the current ecological condition of the Karuah River estuary and the environmental pressures threatening it. A variety of biological, chemical and physical measures were utilised to determine the condition of, and pressures on, the ecology of Karuah River estuary. These measures fell into the categories of system structure, biological structure, energy flow, biological stress and pressures. These are summarised in Table i. Sampling began in November 2011 and concluded in June 2012.

Overall, the Karuah River estuary and catchment was assessed to be in moderate ecological condition, but there are some significant threats to the ecology of the system from environmental pressures. Some degradation of system structure is evident and some areas of the estuary and catchment are in poor condition. Specifically, the major system-wide issues are:

- seagrass habitas have declined and are now almost non-existent
    - caused by chronic high turbidity
- saltmarsh habitats are declining
    - likely due to encroachment by mangroves
- riparian habitats are degraded
    - largely a result of stock access
- excessive algal recruitment on pneumatphores
    - indicative of elevated nutrient concentrations
- elevated water column turbidity
    - caused by sediment generating landuses and resuspension in the estuary
- elevated water column nutrient concentrations
    - caused by nutrient generating landuses
- elevated runoff nutrient concentrations and turbidities
    - related to landuses and riparian condition

In particular, The Branch River sub-catchment is an area of concern, as concentrations of total nitrogen and phosphorus in runoff were particularly high there. Nutrient concentrations in estuarine reaches of The Branch River were, correspondingly, the highest in the Karuah River estuary. Investment should be aimed at restoring riparian zones and investigating whether there are other significant sources of nutrients in The Branch River sub-catchment.

We recommend that ongoing monitoring of ecological condition and the environmental pressures are undertaken in the Karuah River estuary and catchment. Although the system is in moderate ecological condition, the risk of degradation given current pressures is substantial. Further research is also needed to better understand the sources of nutrients and sediment in the catchment so that these can be better managed into the future.

Table i. Summary of Results from Bioassays for Ecological Health.

Component	Measures	Status that would suggest Karuah River was impacted	Current Status
SYSTEM STRUCTURE	Presence of healthy mangroves, saltmarsh and seagrass.	Absence of, or reduction in, seagrass, mangrove or saltmarsh habitats.	Poor condition. Increased mangrove extent. Saltmarsh and seagrass have reduced in extent. Seagrass extent very limited.
	Condition of riparian zones.	Degraded condition when compared to reference sites.	Poor condition. Only 47% of sites passed the riparian assessment.
BIOLOGICAL STRUCTURE	Macroinvertebrates on intertidal flats.	Diversity lower than reference sites.	Good condition. Invertebrate assemblages similar at Karuah River and Twelve Mile Creek, but different at Wallingat.
	Estuarine fish assemblages.	Diversity lower than reference sites.	Good condition. Karuah River estuary fish diversity similar to Wallingat River, but less than Twelve Mile Creek.
	Shorebird assemblages.	Absence of common birds.	Good condition. Abundances of shorebirds and other waterbirds and temporal patterns of shorebird species richness in the vicinity of the Karuah River estuary did not differ from those in other parts of Port Stephens.
	Freshwater macroinvertebrates.	Fewer taxa observed than would be expected.	Good condition. Mean number of taxa similar to expected.

Table i. Summary of Results from Bioassays for Ecological Health (cont.).

Component	Measures	Status that would suggest Karuah River was impacted	Current Status
	Phytoplankton.	Chlorophyll concentrations greater than trigger values.	Good condition. Chlorophyll concentrations generally below trigger values.
	Benthic microalgae.	Little or no BMA.	Good condition. Concentrations of sediment chlorophyll *a* were not significantly less than in other estuaries in NSW.
	Algal recruitment on seagrass and mangroves.	Excessive amounts of algae growing on mangrove pneumatophores.	Poor condition. Algal growth on artificial pneumatophores was greater in the Karuah River than in control estuaries.
		Excessive amounts of algae growing on seagrass leaves.	Good condition. Algal growth on artificial seagrass was greater in the Karuah River than at Twelve Mile Creek, but less than at Wallingat River.
	Micro-carnivore scavengers.	Consumption of baits different from reference sites.	Good condition. Rate was similar to control estuaries.
ENERGY FLOW	Macro-carnivore scavengers.	Consumption of baits different from reference sites.	Good condition. Rate was similar to Twelve Mile Creek, but more than at Wallingat River.
	Frequency of ulcers in fish.	Frequency greater in Karuah River than reference sites.	Good condition. No ulcers observed on fish caught in the Karuah River.
BIOLOGICAL STRESS	Mangrove leaf damage.	Higher rates of leaf damage in Karuah River than reference sites.	Good condition. Rates of leaf damage similar at Karuah River and Wallingat River sites, but greater at Twelve Mile Creek sites.

Table i. Summary of Results from Bioassays for Ecological Health (cont.).

Component	Measures	Status that would suggest Karuah River was impacted	Current Status
	Estuarine turbidity.	Water clarity reduced by obvious turbidity (suspended matter in water).	Poor condition. River has very low clarity due to suspended matter. Turbidity typically exceeds trigger values.
	Estuarine nutrient concentrations.	Nutrient concentrations greater than trigger values.	Poor condition. Nutrient concentrations generally exceeded trigger values.
	Nutrients in surface runoff.	Nutrient concentrations greater than trigger values.	Poor condition. Total nitrogen and total phosphorus concentrations typically exceed trigger values.
	Total suspended solids in surface runoff.	Turbidity greater than trigger value.	Poor condition. Turbidity typically greater than trigger value.
PRESSURES	Catchment landuses.	Sediment and nutrient generating landuses dominate.	Good condition. Most of the catchment is dominated by tree and shrub cover and grazing land.

1. Introduction

1.1. Background

The Office of Environment and Heritage (OEH) Estuaries and Catchments Unit (ECU) was asked by the Great Lakes Council (GLC) to undertake an ecological health assessment of the Karuah River estuary inclusive of The Branch River tributary.

The Karuah River estuary is a priority oyster production area which has sufferred periodic water quality issues associated with catchment runoff. Currently there is no baseline ecological health information for this estuary and ecological processes have not been considered in any adequate detail in earlier studies. The Port Stephens Myall Lakes Estuary Management Plan called for a Karuah Catchment Plan as a way of addressing water quality issues associated with catchment runoff. It is considered essential and consistent with current best practice estuary management to have benchmark assessment of the ecological condition to guide the development of future catchment based water quality improvement strategies. The Karuah Catchment Plan would be undertaken as a second and future stage and would be heavily informed by the Great Lakes Water Quality Improvement Plan and community and industry engagement.

The objective of the current project was to undertake an ecological health assessment of the Karuah River, providing baseline information that will allow for well informed decisions for the development of a catchment plan.

The outcomes of the project are:

- an assessment of the ecological condition of the Karuah River estuary.
- determination of the health and extent of seagrass, mangrove and saltmarsh communities.
- an assessment of the riparian condition of streams in the Karuah River catchment.
- an assessment of the major pressures threatening the ecological health of the Karuah River.

1.2. Scope

The ecological health of the Karuah River is of economic significance to New South Wales. The Karuah River discharges into Port Stephens, one of the largest oyster growing areas in the state, an important comercial and recreational fishery and a popular tourist destination. This report describes a range of short-term studies of the ecological health of the Karuah River estuary and catchment. It provides an assessment of current ecological condition that will inform future decisions regarding management of the estuary.

The Karuah River is a wide riverine estuary on the Mid-North Coast of New South Wales and provides the only significant input of sediment to Port Stephens (MHL, 1999). The catchment is approximately 1,460 km^2, largely comprised of grazing land, forest and woodland and is sparsely populated, the largest settlements being Karuah (pop.~1000), located at the mouth of the river, and Stroud (pop.~700), located in the centre of the catchment.

Based on a range of indicators, the pressures on the Karuah River have previously been categorised as low, but nutrient (nitrogen and phosphorus) loads to the estuary and the proportion of cleared land are moderate (Roper *et al.*, 2011). Landuse in the Karuah River catchment has undergone continuous change since European settlement beginning with land clearing for forestry and dairying from the late 19th century (GLC, 2007). More recently deregulation of the dairy industry has led to a decline in the number of dairy farms in the catchment, while some former forestry areas have been transferred to reserves and, anaecdotally, there has been a general increase in the area of wooded land in the catchment. These recent changes, combined with improvements to sewage treatment plants at Stroud and Karuah, are likely to have reduced the nutrient and sediment loads to the estuary, but loads from grazing and rural residential areas, forestry and poultry operations remain an issue. If not carefully managed, spreading of manure from the large number of poultry operations in the catchment could generate substantial nutrient loads. Proper management is needed to prevent excess nutrient and sediment losses to the estuary. It is also important that these pressures and their impacts are monitored so that the effectiveness of management can be determined, allowing re-evaluation of management so as to avert environmental degradation.

Increasing concern regarding environmental degradation around the world has amplified the demand for the development of monitoring programs which measure changes related to the health of affected ecosystems (Vora, 1997, Scanes *et al.*, 1998). Estuary monitoring programs worldwide have tended to focus on physical and chemical water quality parameters, such as conductivity, salinity, temperature, dissolved oxygen concentrations, chlorophyll *a* concentrations, turbidity, total suspended solids and concentrations of species of nitrogen and phosphorus, as measures of estuary health (Couillard and Lefebvre, 1985, Stevenson *et al.*, 1993, Boynton *et al.*, 1996, Cloern, 2001, Walker *et al.*, 2006). However, chemical parameters have been demonstrated to be poor indicators of stressor levels for some estuaries in southeastern Australia (Scanes *et al.*, 2007).

Scanes *et al.* (2007) tested a range of parameters as indicators of estuary health in coastal lagoons across a gradient of catchment disturbance. They found that chlorophyll *a* and turbidity were the only parameters that showed correlations with catchment condition (Scanes *et al.*, 2007). Fairweather (1999) assessed the efficacy of measuring processes in mangrove habitats, such as “herbivory and decomposition of mangrove leaves, attack of fallen wood by shipworms, and colonisation of pneumatophores by algae, as well as with more traditional estimates of ‘standing stocks’”, as indicators of ecological health with varied results. Another study measured the rate of decomposition of seagrass (*Zostera capricornii*) leaf as an ecoassay of the activity of meiofauna (Dye, 2006), while Barton (2003) considered ecoassays as a means of monitoring the condition of Victorian estuaries.

To assess the ecological condition of the Karuah River estuary, we used a combination of physico-chemical monitoring, surveys of biota and quantification of rates of ecological processes. The ecosystem was examined at a range of trophic (food chain) levels to comprehensively represent system structure and function.

This study used a planned design to test hypotheses that the values of each of a range of indicators at the test site (the Karuah River), were not significantly different from expected conditions. The expected conditions were pre-defined management standards (e.g. Australian and New Zealand Environment and Conservation Council (ANZECC) trigger value), earlier time periods or condition of reference sites. This design was necessary as there were insufficient pre-existing data for the Karuah River estuary to make temporal comparisons for most indicators. The specific aim of the design was to determine whether ecosystem function in the Karuah River is impaired in comparison to other estuarine environments that do not have the stresses that are perceived to impact on the Karuah River or whether there are trends of improving or degrading ecological condition.

2. Methods

The Karuah River discharges into the northwestern part of Port Stephens, near the town of Karuah, on the Mid-North Coast of New South Wales (Figure 1). Two nearby riverine estuaries were selected as control sites for estuarine biological structure, energy flow and biological stress. These were Twelve Mile Creek, a nearby tidal creek located to the south of Karuah River and also flowing into Port Stephens, and the Wallingat River, a tidal river north of Myall Lakes and flowing into Wallis Lake (Figure 1). Both control estuaries are relatively undisturbed with very little catchment development. Some limited commercial and recreational fishing occurs in the Wallingat River, as in the Karuah River, but no fishing occurs in Twelve Mile Creek, as it is a sanctuary zone within the Port Stephens-Great Lakes Marine Park.

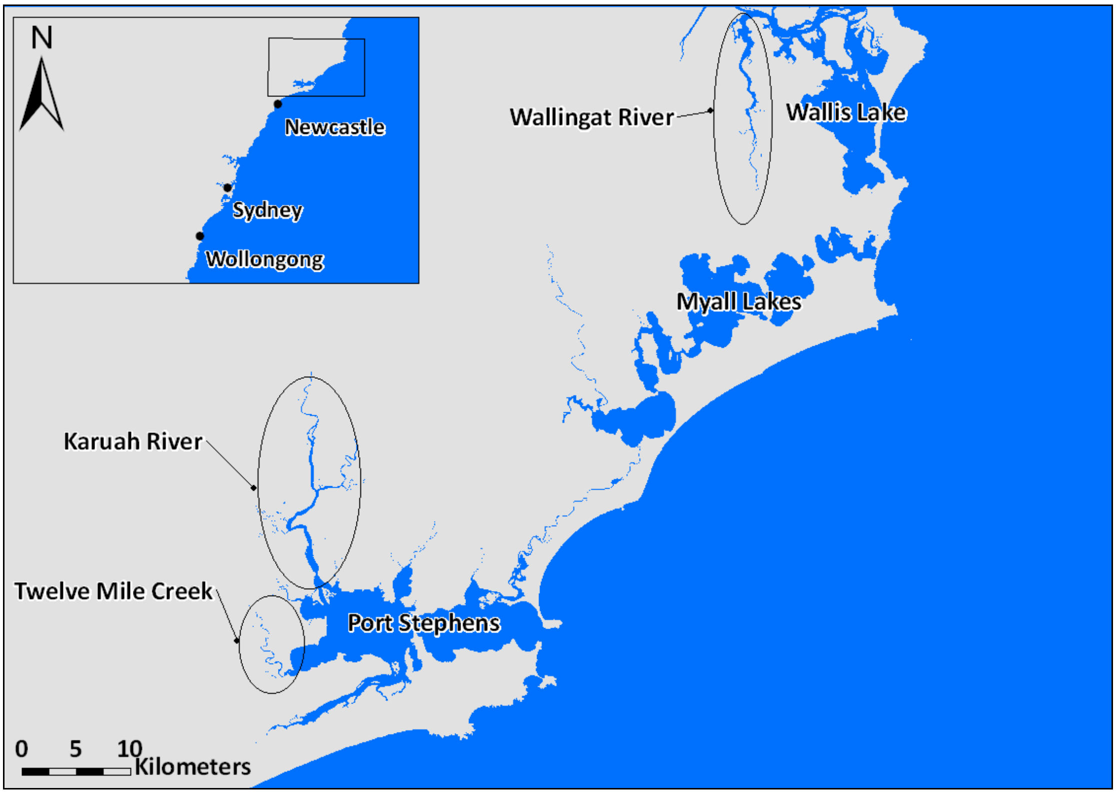

Figure 1. Locations of control estuaries in relation to the Karuah River.

Sampling methods, aimed at determining the pressures upon and condition of multiple levels of the ecosystem, are summarised in Table 1. Table 3 expands upon these, providing details of the specific indicators, hypotheses tested and methods used to determine the condition of the ecological health measures. Sampling was carried out between November 2011 and June 2012.

Table 1. Ecological health measures utilised.

Component	Measures	Comparison
System Structure	Estuarine macrophyte habitat availability.	Temporal
	Condition of riparian habitats.	Reference
Biological Structure	Composition of intertidal mudflat invertebrate assemblages.	Reference
	Composition of estuarine fish assemblages.	Reference
	Composition of bird assemblages.	Temporal
	Composition of freshwater invertebrate assemblages.	Reference
Energy Flow	Phytoplankton abundance.	Standards
	Abundance of benthic microalgae.	Reference
	Rates of algal recruitment on pneumatophores and seagrass.	Reference
	Rate of scavenging by carnivores.	Reference
Biological Stress	Prevalence of ulcers on fish.	Reference
	Prevalence of mangrove leaf damage.	Reference
Pressures	Estuarine turbidity.	Standards
	Estuarine nutrient concentrations.	Standards
	Surface runoff nutrient concentrations and turbidity.	Standards
	Areal coverage of nutrient and sediment generating landuses.	Benchmark

2.1. System Structure

2.1.1. Saltmarsh, Mangrove and Seagrass Habitats

The current areal extent and temporal trends in the areal extent of estuarine macrophytes, saltmarsh, mangroves and seagrass, were examined by comparing two habitat mapping studies, West *et al.* (1985) and Creese *et al.* (2009).

2.1.2. Condition of Riparian Zones in the Karuah River Catchment

Riparian assessments were conducted at 30 randomly selected sites in the Karuah River catchment (Figure 2). Estimates were made of a range of habitat characteristics, outlined in Table 2, within each of four 5m wide strip transects running 10m back from the stream edge as well as within the adjacent 5m section of stream. Data were compared to data from reference sites in the nearby Wallis Lake and Myall Lakes Catchments and a point was allocated when a value for a habitat variable was within the range of values at reference sites or, in the case of riparian width, exceeded to the minimum recommended value. Each strip transect was determined to have passed if it scored a point for at least 75% of habitat characteristics. Sites were determined to have passed the riparian assessment where at least 3 of the 4 strip transects passed.

In 2009, the New South Wales Office of Water (NOW) and the Department of Environment, Climate Change and Water (DECCW) produced a spatial dataset of types of riparian vegetation (e.g. woody or non-woody) throughout New South Wales by analysis of aerial photography (NOW and DECCW, 2009). We extracted data for the Karuah River catchment to determine the proportional extent of woody and non-woody riparian vegetation and to identify areas of the catchment where there riparian zones are predominantly non-woody.

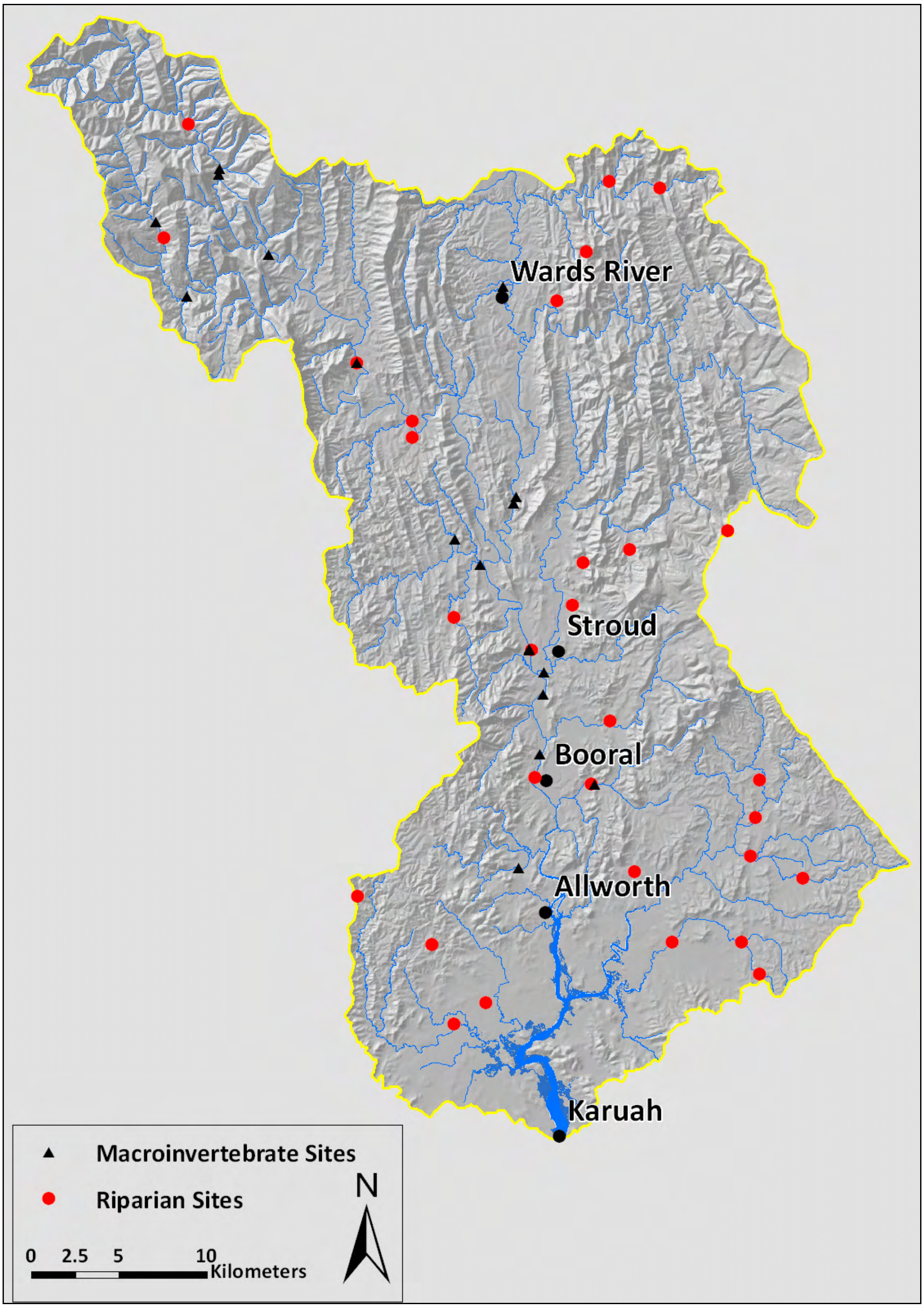

Figure 2. Locations of riparian assessment sites and aquatic macroinvertebrate sampling sites.

Table 2. Habitat characteristics and pass criteria used in riparian assessments.

Habitat Characteristic	Measure	Pass criterion
Riparian width (m)	Width of continuous woody riparian vegetation greater than 2 m in height.	Greater than or equal to 10m.
Shading (%)	Percentage of stream area shaded at midday.	Sliding scale based on log-linear regression of channel width and shading at reference sites. Shading greater than or equal to the 10th percentile of all data.
Macrophytes (%)	Percentage of stream area where macrophytes are visible.	Less than or equal to the 90th percentile of all data.
Vegetation >5m (%)	Percentage of riparian area covered by vegetation >5m tall.	Greater than or equal to the 10th percentile of all data.
Vegetation >5m Native (%)	Percentage of riparian area covered by native vegetation >5m tall.	Greater than or equal to the 10th percentile of all data.
Vegetation 1-5m Tall (%)	Percentage of riparian area covered by vegetation 1-5m tall.	Greater than or equal to the 10th percentile of all data.
Vegetation 1-5m Tall Native (%)	Percentage of riparian area covered by native vegetation 1-5m tall.	Greater than or equal to the 10th percentile of all data.
Vegetation <1m Tall (%)	Percentage of riparian area covered by vegetation <1m tall.	Less than or equal to the 90th percentile of all data.
Vegetation <1m Tall Native (%)	Percentage of riparian area covered by native vegetation <1m tall.	Greater than or equal to the 10th percentile of all data.
Leaves and Twigs (%)	Percentage of riparian area covered by leaves and twigs.	Less than or equal to the 90th percentile of all data.
Exposed Soil (%)	Percentage of riparian area covered where bare soil is exposed.	Greater than or equal to the 10th percentile of all data.

2.2. Biological Structure

2.2.1. Mudflat Invertebrate Assemblages

Between January and March 2012, estuarine intertidal mudflat assemblages were sampled in the lower reaches of the Karuah River and control estuaries, Twelve Mile Creek and Wallingat River, where typical salinities were comparable (Figures 3, 4 & 5). At each of four sites in each estuary, 15 random pump points were chosen. At each of these points eight “pumps” with a commercial yabby pump were ejected into a large diameter 1mm sieve. The sample was then washed to remove sediment and the remaining organisms were retained to be counted and identified to class. Data compared among estuaries.

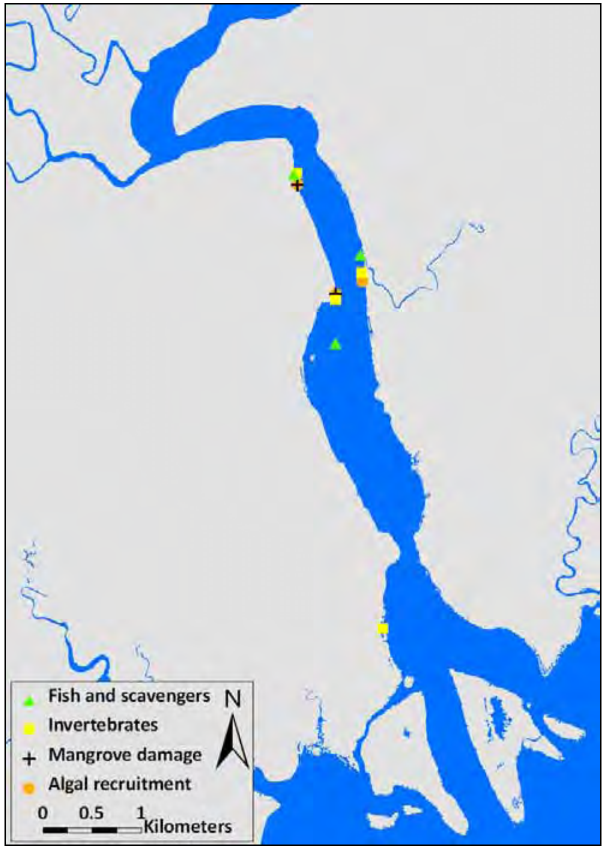

Figure 3. Locations of Karuah River invertebrate, fish, algal recruitment on artificial pneumatophores and seagrass, micro- and macro-carnivore scavengers and mangrove leaf damage sampling sites.

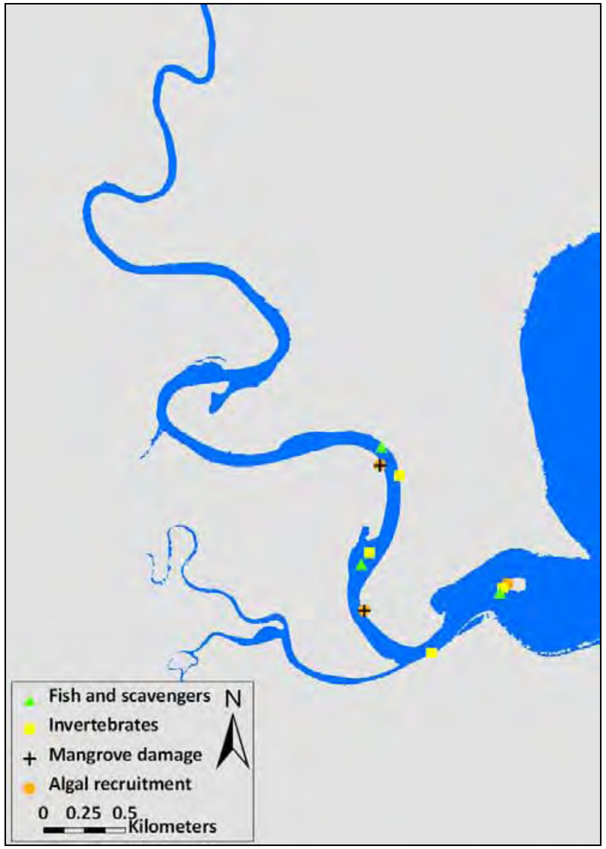

Figure 4. Locations of Twelve Mile Creek invertebrate, fish, algal recruitment on artificial pneumatophores and seagrass, micro- and macro-carnivore scavengers and mangrove leaf damage sampling sites.

Figure 5. Locations of Wallingat River invertebrate, fish, algal recruitment on artificial pneumatophores and seagrass micro- and macro-carnivore scavengers and mangrove leaf damage sampling sites.

2.2.2. Estuarine Fish Assemblages

Between January and March 2012, estuarine fish were also sampled at sites in the lower reaches of the Karuah River and control estuaries, Twelve Mile Creek and Wallingat River (Figures 3, 4 & 5). Samples were collected using a seine net with 20m headline x 2m drop x 12mm stretched mesh and cod-end. This was undertaken at three sites in each of the three estuaries. During each sampling event, five seine net shots and 3 x 25m multi panelled gill nets were deployed per site, with gill nets left out for a minimum of 1 hour. Fish were counted, measured and identified and released alive where possible. Fish abundance, species richness, diversity and assemblage composition data were compared among estuaries.

2.2.3. Shorebird Assemblages

The NSW National Parks and Wildlife Service (NPWS) have been surveying birds in the Port Stephens area every summer since 2004. Each summer, counts of all shorebird and other waterbird species along each of six transects were recorded (Figure 6). Two of these transects, Charlie and Delta Sectors, were located in the vicinity of the mouth of Karuah River (Figure 6). We examined shorebird assemblage data from the different sectors, so as to test whether there were spatial or temporal trends.

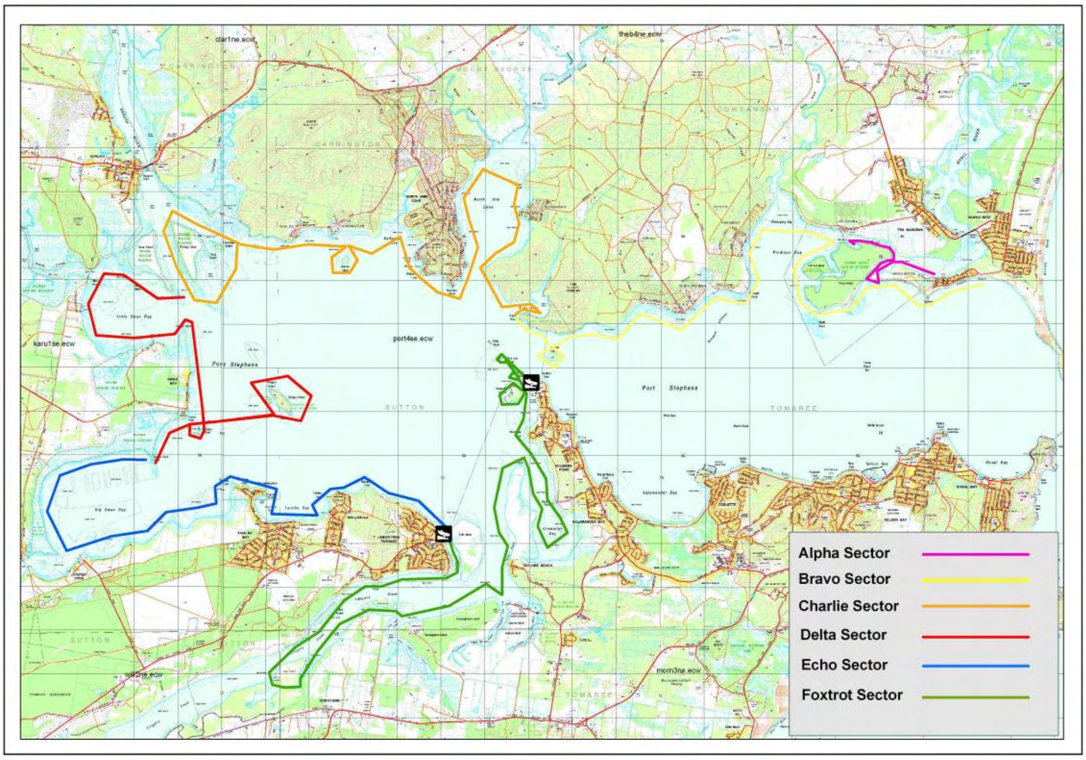

Figure 6. Map of shorebird survey sectors.

2.2.4. Freshwater Macroinvertebrates

Macroinvertebrate data collected from 17 sites in the Karuah River catchment by the Office of Environment and Heritage as part of the Coastal Macroinvertebrate Monitoring Programme were used to assess the ecological condition of streams in the Karuah River catchment. Sites were distributed along the Karuah River and tributaries (Figure 2) and were sampled between 1994 and 2010. Macroinvertebrate assemblage data were analysed using the Australian River Assessment System (AUSRIVAS) predictive modelling software (Ransom et al., 2011).

Three outputs of the software were used to assess the ecological condition of sites. The first of these was the OE50, which is the ratio of observed number of invertebrate families that had a greater than 50% probability of occurring to the number of families expected with a probability greater than 50% (Ransom *et al.*, 2011). This provides a measure of the taxonomic diversity of the macroinvertebrate assemblage in comparison to reference sites. The second output was the OE50 SIGNAL (Stream Invertebrate Grade Number Average Level) score, which is the ratio of the observed to expected SIGNAL score per site for families that have a probability of occurrence greater than 50% (Ransom *et al.*, 2011). The SIGNAL score incorporates a sensitivity weighting for each family and so is indicative of pollution at the site (Barmuta *et al.*, 2002). Both the OE50 and OE50 SIGNAL score have a minimum value of 0 (Barmuta *et al.*, 2002). An OE50 value of 1 indicates that the site has exactly the same number of families with a probability of occurring greater than 50% as would be expected based on reference site data (Barmuta *et al.*, 2002, Ransom *et al.*, 2011). Values less than or greater than 1 indicate that the site had a lesser or greater number of families respectively (Barmuta *et al.*, 2002). An OE50 SIGNAL score of 1 indicates that the suite of families collected are exactly as sensitive to pollution as expected, while values greater than or less than 1 indicate better or worse water quality respectively (Barmuta *et al.*, 2002). The third output was the band, which is a grading scheme that is used represent degrees of ecological impairment based on the OE50 and the OE50 SIGNAL score (Ransom *et al.*, 2011). The sites are categorised into bands X, A, B, C or D, band X indicating a richer, A similar, B poorer, C much poorer and D impoverished invertebrate assemblage and water quality compared with reference condition (Ransom *et al.*, 2011).

2.3. Energy Flow

2.3.1. Phytoplankton

Seven water quality sampling sites distributed along the Karuah River and The Branch River, a tributary of the Karuah River, were selected (Figure 7). These sites were selected so as to effectively reperesent the entire estuary upstream of Karuah. Sites were sampled approximately monthly between November 2011 and May 2012. Samples were analysed for concentrations of chlorophyll *a* concentrations.

OEH has been developing chlorophyll *a* trigger values for different types and parts of estuaries as part of the Coastal Zone Management programme. These triggers are based on those reported in Roper *et al.* (2011), but modified according to the protocols outlined in ANZECC and ARMCANZ (2000). Chlorophyll*a* concentrations in the Karuah River estuary were compared to these draft trigger values. Sites were determined to have passed where median chlorophyll *a* concentrations were below the trigger.

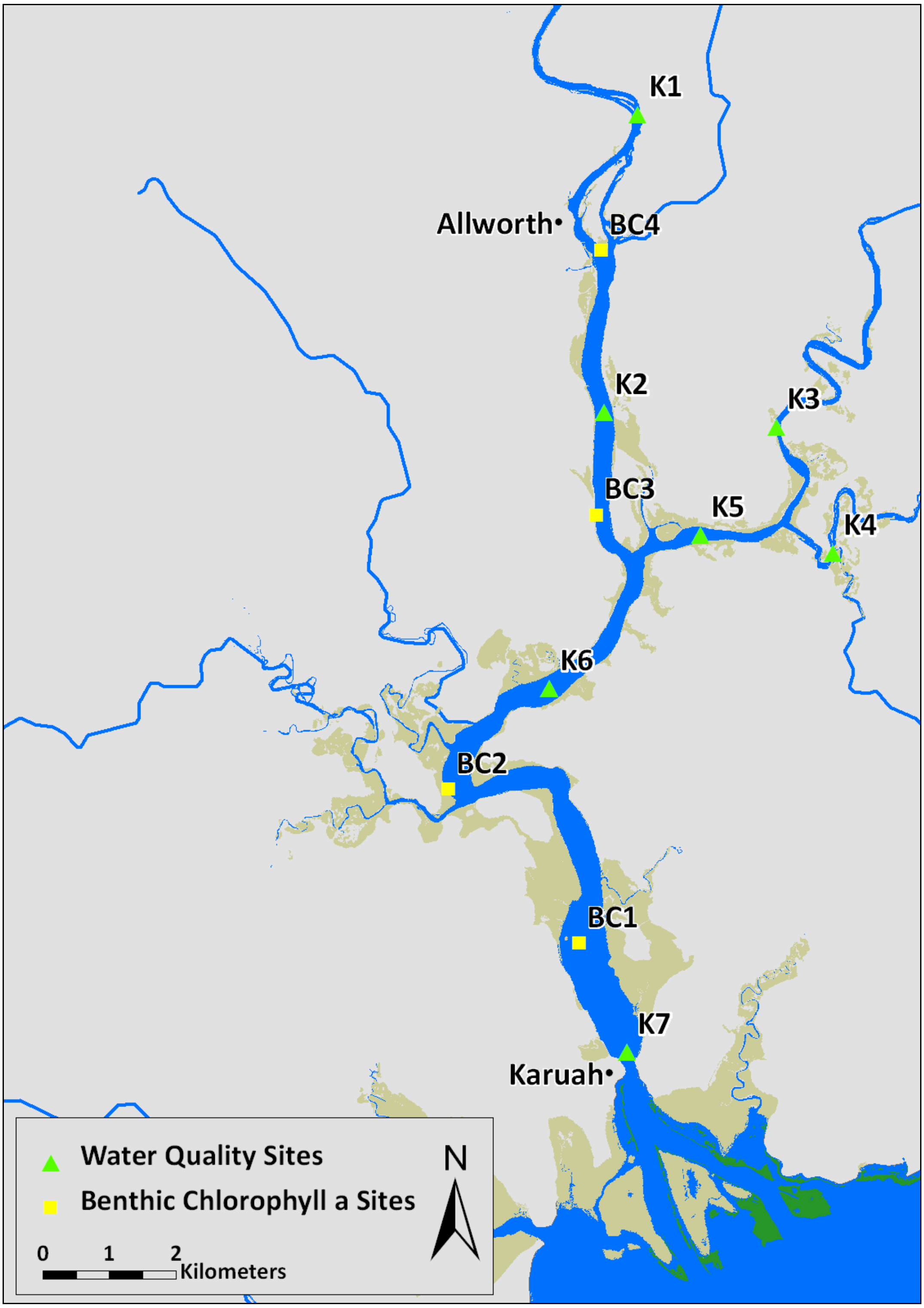

Figure 7. Locations of estuary water quality and benthic chlorophyll *a* sampling sites.

2.3.2. Benthic Microalgae

Benthic chlorophyll *a* sampling sites were distributed along a salinity gradient in the Karuah River estuary between Karuah and Allworth (Figure 7). Sampling was carried out in February 2012. At each site, four sediment core samples were collected from a depth equivalent to 1.5m at mid tide and analysed for chlorophyll *a* concentrations. Data from the Karuah River compared to data collected from similar depths in other estuaries.

2.3.3. Algal Recruitment on Pneumatophores and Seagrass

Algal recruitment rates on artificial pneumatophores and seagrass were measured at sites in the lower reaches of the Karuah River and control estuaries between February and March 2012 (Figures 3, 4 & 5). Bunches of artificial seagrass were made by fixing four 1.5 x 29.5 cm strips of waterproof paper to a 30cm piece of dowel. Five artificial seagrass bunches were deployed at each of three sites in each of the three estuaries,. After five weeks, stakes and straps were retrieved. Straps were removed and chlorophyll *a* was extracted and quantified to determine the concentration per unit area.

Artificial mangrove pneumatophores, made from 10mm diameter dowel, cut to lengths of 8cm and inserted into aluminium tubes to a depth of 20mm, were deployed at the same sites as the artificial seagrass. At each site, 5 rods were placed within the pneumatophore zone at 1m intervals 1m from the seaward limit of the pneumatophores. The rods were pushed into the sediment with the aluminium tube pointing downwards so that the top of the tube was above the surface of the sediment. After five weeks, they were retrieved and chlorophyll *a* was extracted and quantified to determine the concentration per unit area.

Concentrations were then divided by the deployment duration to calculate a rate of recruitment. These rates were then compared among estuaries.

2.3.4. Micro-Carnivore Scavenging

Between March and April 2012, micro-carnivore scavenging rates were measured at four sites in the lower reaches of the Karuah River and control estuaries, Twelve Mile Creek and Wallingat River (Figures 3, 4 & 5). At each site, eight separate pre-weighed baits were placed on the sediment surface in a 10 mm mesh container. Baits were deployed for four hours. After retrieval, baits were reweighed and tissue loss per hour calculated. Rates were compared among estuaries.

2.3.5. Macro-Carnivore Scavenging

Between March and April 2012, macro-carnivore scavenging rates were measured at four sites in the lower reaches of the Karuah River and control estuaries, Twelve Mile Creek and Wallingat River (Figures 3, 4 & 5). At each site, eight separate pre-weighed baits were placed unprotected on the sediment surface. Baits were deployed twice, each for a period of 30 minutes. After retrieval, baits were reweighed and tissue loss per hour calculated. Rates were compared among estuaries.

2.4. Biological Stress

2.4.1. Fish Ulcers

The presence of ulcers on estuarine fish was recorded during sampling of fish assemblages. The prevalence of fish ulcers was compared among estuaries.

2.4.2. Mangrove Leaf Damage

The prevalence of mangrove leaf damage was examined at two sites in each of the three estuaries, the Karuah River, Twelve Mile Creek and Wallingat River, in February 2012 (Figures 3, 4 & 5). At each site, five small branches removed from each of four trees. Leaves were examined for presence of various conditions including galls, pitts and whether they were chewed or whole. The prevalence of leaf damage was compared among estuaries.

2.5. Pressures

2.5.1. Water Column Turbidity

Between November 11 and May 12, turbidity of the uppermost 1m of the water column was measured approximately monthly over six months at the seven water quality sampling sites in the Karuah River estuary (Figure 7).

OEH has been developing turbidity trigger values for different types and parts of estuaries as part of the Coastal Zone Management programme. These triggers are based on those reported in Roper *et al.* (2011), but modified according to the protocols outlined in ANZECC and ARMCANZ (2000). Turbidities in the Karuah River estuary were compared to these draft trigger values. Sites were determined to have passed where median turbidities were below the trigger.

2.5.2. Water Column Nutrients

Between November 11 and May 12, water samples collected approximately monthly over six months at the seven water quality sampling sites in the Karuah River estuary (Figure 7). Samples were analysed for concentrations of total suspended solids (TSS), total nitrogen (TN), total dissolved nitrogen (TDN), ammonia (NH^{4+}), oxides of nitrogen (NO_x), total phosphorus (TP), total dissolved phosphorus (TDP) and phosphate (PO_4^{3-}), as well as for turbidity levels. Dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), particulate nitrogen (PN), dissolved organic phosphorus (DOP) and particulate phosphorus (PP) concentrations were derived from the concentrations of other nutrient fractions.

OEH has been developing nutrient trigger values for different types and parts of estuaries as part of the Coastal Zone Management programme. These triggers are based on those reported in Roper *et al.* (2011), but modified according to the protocols outlined in ANZECC and ARMCANZ (2000). Nutrient concentrations in the Karuah River estuary were compared to these draft trigger values. Sites were determined to have passed where median nutrient concentrations were below the trigger.

2.5.3. Nutrients and Turbidity in Surface Runoff

Surface water was sampled at five sites on streams draining selected sub-catchments of the Karuah River. Samples were collected approximately monthly between November 2011 and May 2012 . The sub-catchments sampled comprised Limeburners Creek, Ramstation Creek, upper Karuah River, Wards River and The Branch River (Figure 8). Samples were analysed for concentrations of total suspended solids (TSS), total nitrogen (TN), total dissolved nitrogen (TDN), ammonia (NH_4^+), oxides of nitrogen (NO_x), total phosphorus (TP), total dissolved phosphorus (TDP) and phosphate (PO_4^{3-}), as well as for turbidity levels. Dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), particulate nitrogen (PN), dissolved organic phosphorus (DOP) and particulate phosphorus (PP) concentrations were derived from the concentrations of other nutrient fractions.

OEH has been developing turbidity trigger values for different types and parts of estuaries as part of the Coastal Zone Management programme. These triggers are based on those reported in Roper *et al.* (2011), but modified according to the protocols outlined in ANZECC and ARMCANZ (2000). Turbidities in the Karuah River estuary were compared to these draft trigger values. Sites were determined to have passed where median turbidities were below the trigger.

Nutrient concentrations were compared to the existing ANZECC trigger values (ANZECC and ARMCANZ, 2000).

The Coastal Eutrophication Risk Assessment Tool (CERAT) is a modelling package developed by the Office of Environment and Heritage. The catchment model uses soil, terrain, climate and landuse data to calculate TN, TP and TSS generation rates for a giver location (OEH, 2012). These rates are then multiplied by the area to calculate annual diffuse source loads for that location (OEH, 2012). The model does not factor in historical landuses, current management practices or point sources. CERAT was used to estimate TN, TP and TSS loads to the Karuah River estuary from the catchment. The outputs of the tool were also used to produce maps identifying areas of the catchment with higher nutrient and sediment generation rates.

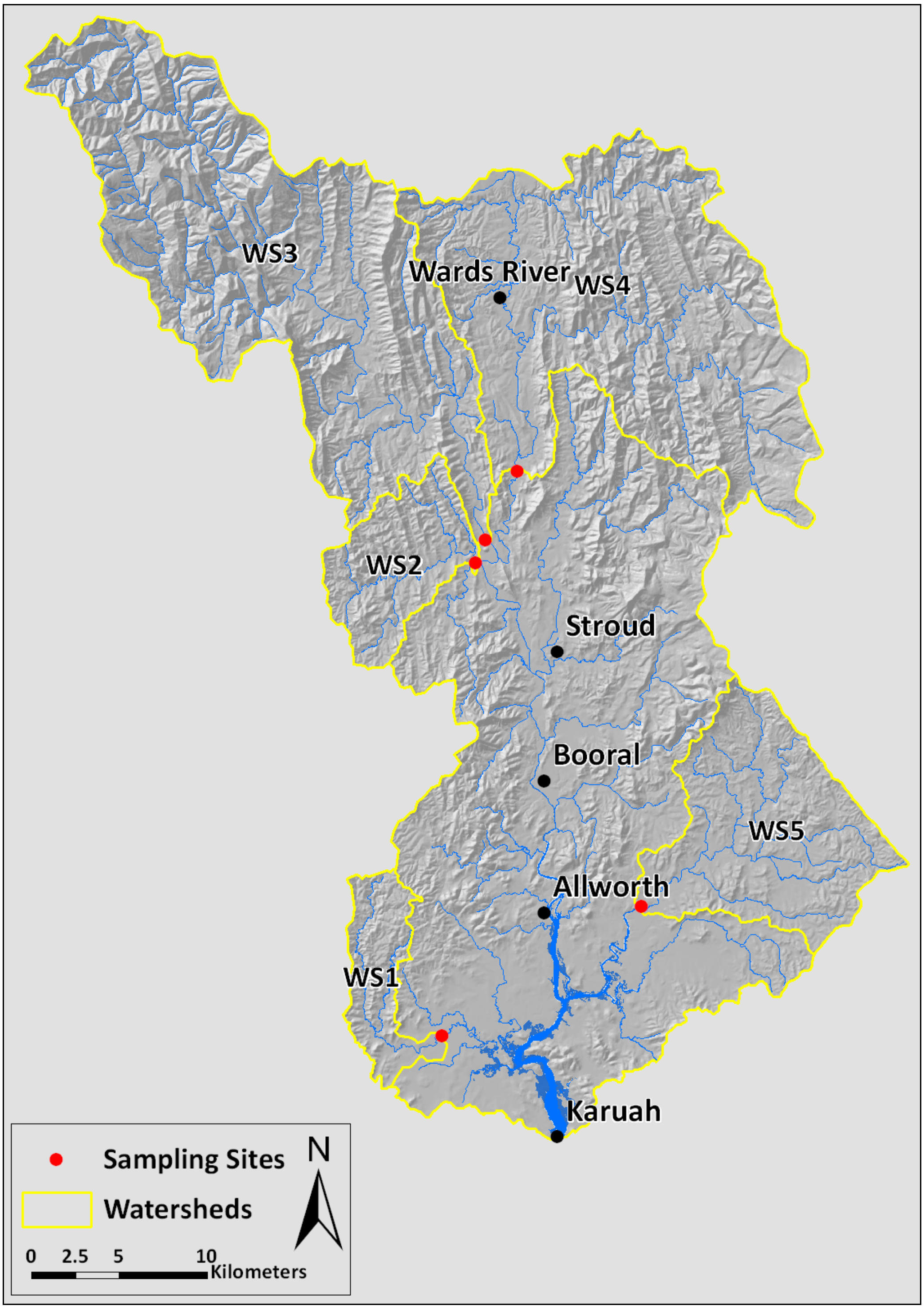

Figure 8. Locations of catchment water quality sampling sites.

2.5.4. Catchment Landuses

The relative areal coverage of landuses in the Karuah River catchment were determined through analysis of a spatial landuse dataset created in 2007 by the Department of Environment and Climate Change (DECC, 2007). Data for the Karuah River catchment were extracted using ArcGIS software (ESRI, 2008), Landuse categories were then grouped into the following simplified landuse categories, tree and shrub cover, grazing, rural residential, urban, cropping, intensive agriculture, wetlands, river and drainage or other. The total areal coverage of each of these landuses was then calculated for the Karuah River catchment. For the purposes of the assessment, the pressure from landuses in the Karuah River catchment were considered to be low if the proportion of the catchment with tree and shrub cover was greater than 50% and the sum of rural residential, urban, cropping, intensive agriculture and other was less than 10%.

2.6. Data Analysis

All single variable estuary data were analysed using analysis of variance (ANOVA) to determine whether the variation between estuaries was greater than that within estuaries (i.e. Whether the condition at Karuah River sites differed from control sites). Where ANOVA showed a significant difference among estuaries ($P < 0.05$), differences between pairs of estuaries were tested using Bonferroni adjusted orthogonal contrasts. This determined whether there was a significant difference between the Karuah River and each of the control estuaries. This type of analysis was used to test hypotheses, such as "the rate of mangrove leaf damage in the Karuah River does not differ from control estuaries". If the mean of data from the Karuah River were either greater than or less than both the control estuaries and the ANOVA and Bonferroni tests were significant ($P < 0.05$), then the hypothesis was rejected. So, "the rate of mangrove leaf damage in the Karuah River does differ from control estuaries."

Non-metric multi dimensional scaling (nMDS) was used to examine the similarities among assemblages of fish or invertebrates from different estuaries using the Primer v6 software package (Warwick and Clarke, 1991, Clarke, 1993, Clarke and Gorley, 2006). The result of the nMDS represents the relative similarity of assemblages simplified on a two dimensional plot. The closer two points (e.g. sites) are on the plot, the more similar their assemblages are, so similar assemblages can be grouped visually.

Principal components analysis (PCA) was also used to examine the similarities among intertidal mudflat invertebrate assemblages from the different estuaries. PCA is similar to nMDS, but can be used to analyse species and environmental data together or even environmental data alone. This was useful because sediment organic matter content varied among estuaries making it necessary for the effects of these to be determined prior to examining differences among estuaries. Using the Canoco for Windows 4.5 statistical package, PCA was performed on intertidal mudflat invertebrate data, but with the effect of sediment organic matter content excluded prior to analysing differences between invertebrate assemblages (ter Braak and Smilauer, 2002). Riparian habitat characteristic data were also analysed using PCA to determine whether stock access to riparian zones impacted on condition. Mangrove leaf damage data was also analysed using PCA to determine whether leaf damage differed among estuaries.

Table 3. Summary of sampling methods.

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
SYSTEM STRUCTURE				
Presence of healthy estuarine macrophyte habitats.	What habitats are available in the river and what is their relative abundance?	There are substantial areas of mangrove, saltmarsh and seagrass habitats present in the estuary.	Photogrammic analysis of aerial imagery	The current areal extent and temporal trends in the areal extent of estuarine macrophytes, saltmarsh, mangroves and seagrass, were examined by comparing two existing inventory of estuarine habitats.
	Have the areal extents of macrophyte habitats changed?	There has been no change in the areal extent of mangrove, saltmarsh and seagrass habitats in the estuary	Photogrammic analysis of aerial imagery	Temporal trends determined by comparison of 2009 data with 1985 data.
Riparian condition	What is the condition of riparian habitats in the Karuah River catchment?	The condition of the majority of riparian habitat in the Karuah River catchment is not different from reference sites.	Assessment of riparian condition at selected sites.	30 randomly selected sites throughout the Karuah River catchment sampled between May and June 12. Percentage cover of different vegetation strata and habitat characteristics recorded. Compared to reference sites.

Table 3. Summary of sampling methods (cont.).

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
BIOLOGICAL STRUCTURE				
Invertebrates on intertidal flats.	Do the intertidal invertebrate assemblages differ in the Karuah River compared with control estuaries?	There are no differences between the composition of invertebrates on intertidal flats in the Karuah River and control estuaries.	Sampling of invertebrates on intertidal flats using a yabby pump.	Four sites in each of four estuary locations (Karuah River, Twelve Mile Creek and Wallingat River). At each site, 15 random pump points were chosen. At each of these points eight “pumps” with a commercial yabby pump were ejected into a large diameter 1mm sieve. The sample was then washed to remove sediment and the remaining organisms were retained to be counted and identified to class. Sampled in Jan and March 12. Data compared among estuaries.
Fish assemblages.	Do the near-shore fish assemblages differ in the Karuah River compared with control estuaries?	There are no differences between the composition of near shore fish assemblages in the Karuah River and control estuaries.	Sampling of fish using gill and seine nets.	Samples were collected using a seine net with 20m headline x 2m drop x 12mm stretched mesh and cod-end. This was undertaken at three sites in each of three estuaries (Karuah River, Twelve Mile Creek and Wallingat River). During each sampling event, five seine net shots and 3 x 25m multi panelled gill nets were deployed per site, with gill nets left out for a minimum of 1 hour. Fish were counted, measured, identified and released alive where possible. Sampled in Jan and Mar 12. Data compared among estuaries.
Bird surveys	Have there been changes in bird utilisation of the river over the last six years?	There has been no change in the utilisation of the estuary by birds over the last 6 years.	Existing NPWS bird survey data, 2004 – 2010.	Temporal trends in abundance and diversity of bird assemblages were examined.
Freshwater invertebrates	Do the invertebrate assemblages differ from what would be expected?	Invertebrate assemblages do not differ from assemblages at reference sites.	Existing OEH invertebrate data, 1994-2010	Observed taxa compared with expected taxa using AUSRIVAS model.

Table 3. Summary of sampling methods (cont.).

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
ENERGY FLOW				
Pelagic algae	What is the abundance of pelagic microalgae?	Chlorophyll *a* concentrations are typically below the trigger value.	Monitoring of chlorophyll *a* concentrations in the estuary.	Chlorophyll a concentration was measured monthly over six months, between Nov 11 and May 12, at seven sites in the estuary. Chlorophyll a concentration was compared to trigger value.
Benthic micro-algae	Is the abundance of benthic micro-algae within the range that would be expected?	The abundance of benthic micro-algae does not differ from similar estuaries.	Quantifying benthic chlorophyll a concentrations.	Four cores were collected from a depth equivalent to 1.5m at mid tide at each of four sites in the Karuah River in Feb 12 and analysed for photosynthetic pigments. Data compared to results from other studies.
Algal recruitment on seagrass.	Does the rate of recruitment of algae on seagrass in the Karuah River differ from control estuaries?	There is no difference between the rate of recruitment of algae in the Karuah River and that of control estuaries.	Quantifying the amount of algae settling on "artificial seagrass" during a set time interval.	Three sites in each of three estuary locations (Karuah River, Twelve Mile Creek and Wallingat River). Sampled between Feb and March 12. Bunches of artificial seagrass were made by fixing four 1.5 x 29.5 cm strips of waterproof paper to a 30cm piece of dowel. Five bunches were deployed at each site. After five weeks, stakes and straps were retrieved. Straps were removed and chlorophyll *a* was extracted and quantified to determine the concentration per unit area. Compared among estuaries.

Table 3. Summary of sampling methods (cont.).

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
ENERGY FLOW (cont.)				
Algal recruitment on mangrove pneumatophores.	Does the rate of recruitment of algae on mangrove pneumatophores differ in the Karuah River compared with control estuaries?	There is no difference between the rate of recruitment of algae in the Karuah River and that of control estuaries.	Quantifying the amount of algae settling on "artificial pneumatophores" during a set time interval.	Three sites in each of three estuary locations (Karuah River, Twelve Mile Creek and Wallingat River). Sampled between Feb and March 12. Artificial mangrove pneumatophores were made from 10mm diameter dowel cut to lengths of 8cm. The bases of the rods were then inserted into aluminium tubes to a depth of 20mm. At each site, five rods were placed at 1m intervals about 1m from the seaward limit of the pneumatophores. The rods were pushed into the sediment with the aluminium tube pointing downwards so that the top of the tube was above the surface of the sediment. After five weeks, they were retrieved and chlorophyll *a* was extracted and quantified to determine the concentration per unit area. Compared among estuaries.
Micro-carnivore scavengers	Does the rate of consumption of fish flesh by small (<10 mm) organisms differ in the Karuah River compared with control estuaries?	There is no difference between the rate of consumption in the Karuah River and that of control estuaries.	Fish baits (pilchard) were placed on the sediment surface in a 10 mm mesh container.	Four sites in each of three estuary locations (Karuah River, Twelve Mile Creek and Wallingat River). Sampled Between March and April 2012, Eight separate pre-weighed baits were deployed once for four hours. After retrieval, baits were reweighed and tissue loss per hour calculated.
Macro-carnivore Scavengers	Does the rate of consumption of fish flesh by all organisms differ in the Karuah River compared with control estuaries?	There is no difference between the rate of consumption in the Karuah River and that of control estuaries.	Unprotected fish baits (pilchard) were placed on the sediment surface.	Four sites in each of three estuary locations (Karuah River, Twelve Mile Creek and Wallingat River). Sampled Between March and April 2012, Ten separate pre-weighed baits were deployed for 30 minutes. After retrieval, baits were reweighed and tissue loss per hour calculated. Two deployments.

Table 3. Summary of sampling methods (cont.).

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
BIOLOGICAL STRESS				
Fish ulcers	Is the rate of fish ulceration greater in the Karuah River compared with control estuaries?	There is no difference between the frequency of ulcers in fish in the Karuah River and that of control estuaries.	Record number of ulcerated fish during fish sampling.	The presence of ulcers or any external damage to fish was recorded during fish sampling.
Mangrove leaf damage	Is the prevalence of mangrove leaf damage greater in Karuah River compared to control estuaries?	There are no differences between the frequency of leaf damage in the Karuah River and that of control estuaries.	Visual assessment of the extent of mangrove leaf damage.	Sampled in February 12. Three estuaries, two sites per estuary, four trees per site with five small branches removed from the tree. Leaves were examined for presence of various conditions including galls, pitts and whether they were chewed or whole.

Table 3. Summary of sampling methods (cont.).

Indicators	Question/s to be answered	Hypothesis	Method of Data Collection	Protocol
PRESSURES				
Estuarine turbidity	Is water clarity in the estuary within the range that would be expected?	Turbidity is typically below the trigger value.	Monitoring of turbidity in the estuary.	Turbidity measured approximately monthly over six months, between Nov 11 and May 12, at seven sites in the estuary. Turbidity compared to trigger value.
Estuarine nutrient concentrations	Are nutrient concentrations in the estuary within the range that would be expected?	Nutrient concentrations are typically below trigger values.	Monitoring of nutrient concentrations in the estuary.	Water samples collected approximately monthly over six months, between Nov 11 and May 12, at seven sites in the estuary and analysed for concentrations of various nitrogen and phosphorus fractions. Nutrient concentrations compared to trigger values.
Turbidity of surface runoff	Is turbidity of surface runoff within the range that would be expected?	Turbidity is typically below the trigger value.	Runoff sampling.	Turbidity measured approximately monthly over six months, between Nov 11 and May 12, at five catchment sites. Turbidity compared to trigger value.
Nutrient concentrations of surface runoff	Are surface runoff nutrient concentrations within the range that would be expected?	Nutrient concentrations are typically below the trigger value.	Runoff sampling.	Runoff water samples were collected approximately monthly over six months, between Nov 11 and May 12, at five catchment sites and analysed for concentrations of various nitrogen and phosphorus fractions. Nutrient concentrations compared to trigger values.
Catchment landuses	Is the catchment dominated by nutrient generating landuses?	Majority of the catchment has tree cover.	Analysis of spatial dataset.	Relative areal coverage of landuses in the Karuah River catchment were determined using ArcGIS software,

3. Results and Discussion

3.1. System Structure

3.1.1. Saltmarsh, Mangrove and Seagrass Habitats

Hypothesis 1: Substantial areas of saltmarsh, mangrove and seagrass habitats exist in the Karuah River estuary.

Was the hypothesis accepted or rejected? Rejected.

Hypothesis 2: There have been no changes in the areal extent of mangrove, saltmarsh and seagrass habitats in the Karuah River estuary between 1985 and 2009.

Was the hypothesis accepted or rejected? Rejected.

Macrophyte communities (i.e. saltmarsh, mangrove and seagrass habitats) are important components of estuarine ecosystems, having the greatest rates of productivity (photosynthesis) of all estuarine habitats (Morrisey, 1995). Mangrove and seagrass habitats provide protection to juvenile fish and substantially contribute to the abundance and diversity of fish and other organisms in estuaries (Keough and Jenkins, 1995). Saltmarsh provides habitat for crabs and is an important food source for fish (Mazumder *et al.*, 2006, Mazumder *et al.*, 2011) and foraging shorebirds (Creese *et al.*, 2009).

Loss of seagrass decreases productivity, the amount of sheltered habitat for juvenile fish and the stability of sediment (Walker and McComb, 1992, Creese *et al.*, 2009), increasing resuspension of sediment. This in turn causes reduced light availability inhibiting re-establishment of seagrass. There have been substantial losses and degradation of seagrass habitats in New South Wales (Walker and McComb, 1992), which have been largely attributed to reduced light availability (Walker and McComb, 1992). This in turn is most likely due to increased turbidity caused by elevated concentrations of suspended solids and/or increased phytoplankton abundance. In contrast, mangrove habitats have increased in extent in estuaries in New South Wales since European colonisation (Saintilan and Williams, 1999, McLoughlin, 2000, Harty, 2004), but this expansion has largely taken place in a landward direction and at the expense of saltmarsh habitats (Saintilan and Williams, 1999).

Large areas of saltmarsh and mangrove, but only very small areas of seagrass present in the Karuah River estuary according to both West *et al.* (1985) and Creese *et al.* (2009). However, there were substantial differences between the areal extents indicated in the two reports (Table 4; Figures 9, 10, 11 & 12). Mangrove extent increased by almost half, while the saltmarsh reduced by more than 20% and seagrass by a massive 80% between 1985 and 2009 (Table 4). There was less than 400 m^2 of seagrass habitat according to West *et al.* (1985) and this was reduced to only 70 m^2 according to Creese *et al.* (2009) with many seagrass beds disappearing completely (Table 4; Figures 11 & 12). Several locations, indicated as being seagrass beds by Creese *et al.* (2009), were visited as part of the current study, but seagrass was not present at these sites. Substantial areas of saltmarsh habitats were lost due to encroachment by mangroves between 1985 and 2009.

Table 4. Extent of macrophyte habitats in the Karuah River.
Comparison of data from West *et al.* (1985) and Creese *et al.* (2009).

	Extent (km^2)		
	West *et al.* (1985)	Creese *et al.* (2009)	Change (%)
Mangrove	3.48	5.07	46%
Saltmarsh	4.83	3.76	-22%
Seagrass	0.38	0.07	-83%

The increase in mangrove habitat extent and decrease in saltmarsh extent suggests that, as has been the case in other New South Wales estuaries (Saintilan and Williams, 1999), mangroves have encroached into saltmarsh habitats in the Karuah River estuary. This is most likely due to increased water levels, propagule delivery and/or increased nutrient availability (Saintilan and Williams, 1999). Low light availability, due to high turbidity, is the most likely reason for the lack of seagrass in the Karuah River estuary. Seagrass habitats are unlikely to reestablish under the current high turbidity conditions. Hypothesis 1 was rejected due to the lack of seagrass habitats in the estuary. Hypothesis 2 was rejected as it appears that mangrove habitats have expanded leading to a decrease in saltmarsh extent, while the limited seagrass habitats observed by West *et al.* (1985) have all but disappeared.

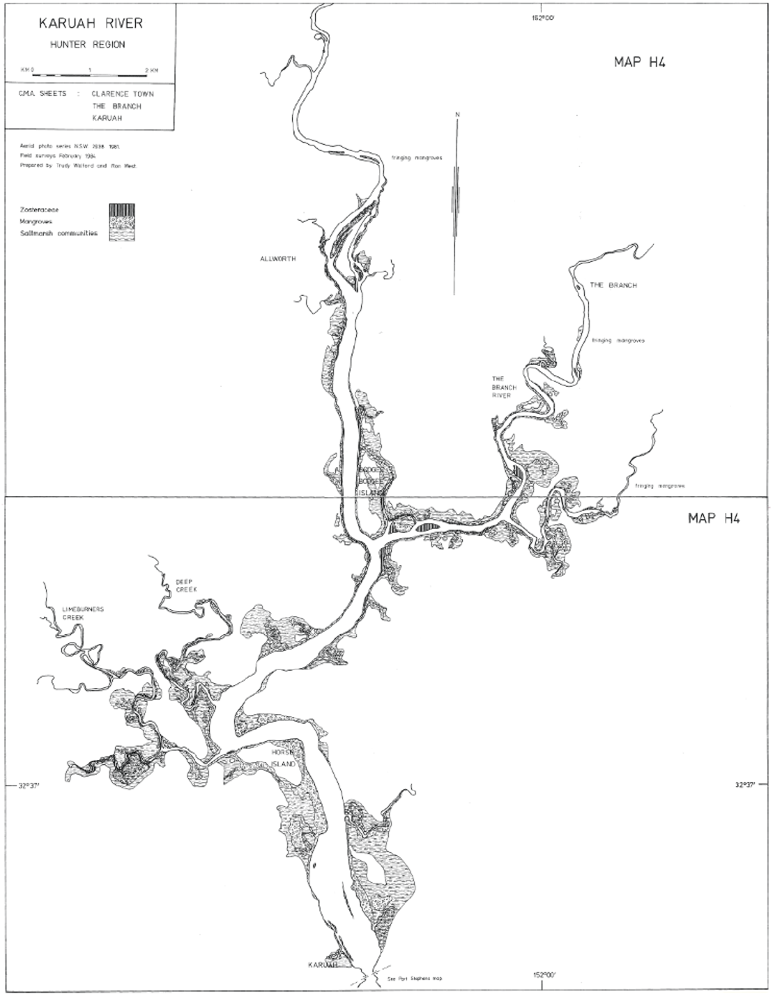

Figure 9. Extent of macrophyte habitats in the Karuah River in 1985.
(West *et al.*, 1985)

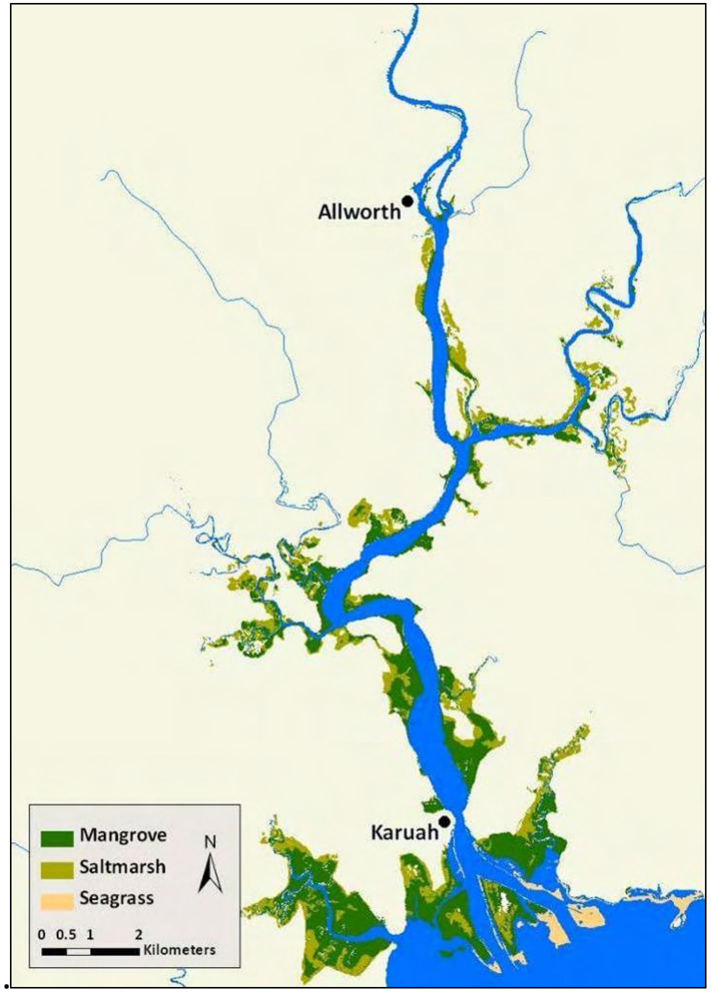

Figure 10. Extent of macrophyte habitats in the Karuah River in 2006.
(Adapted from Creese *et al.*, 2009)

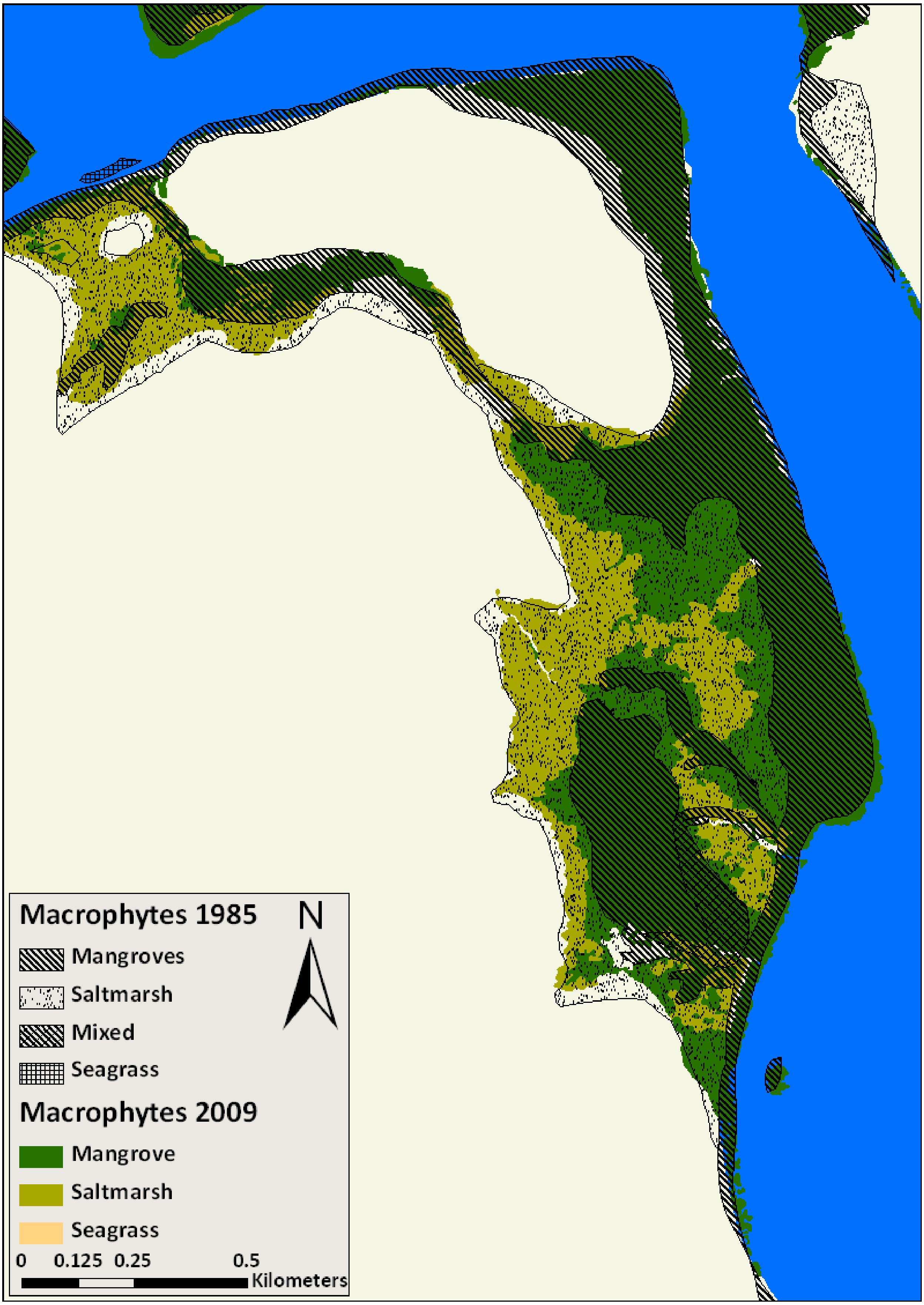

Figure 11. Comparison of the extent of macrophyte habitats in a large wetland in the vicinity of Horse Island in 1985 and 2009.
Adapted from West (1985) and Creese (2009).

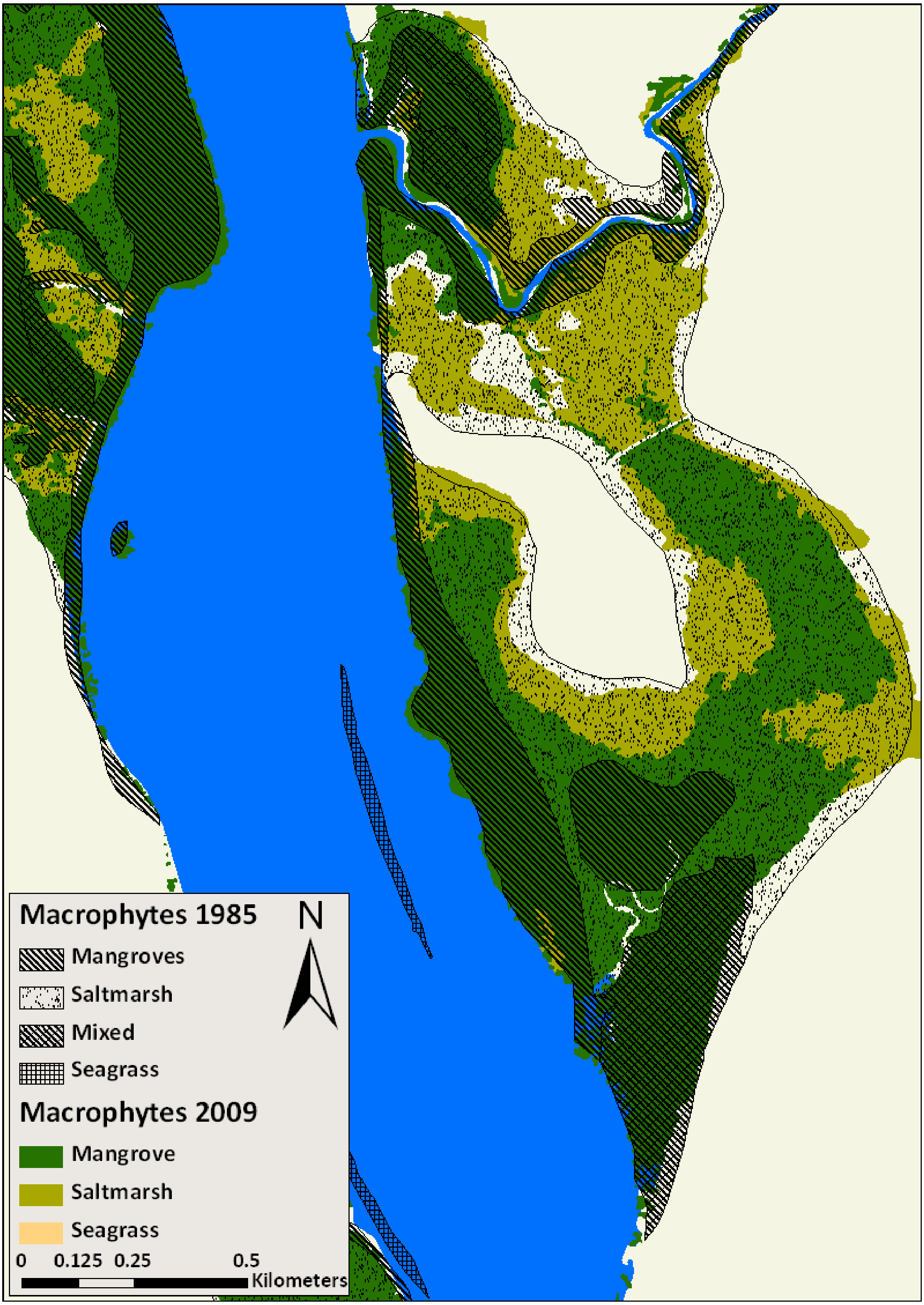

Figure 12. Comparison of the extent of macrophyte habitats in a large wetland north east of Karuah in 1985 and 2009.
Adapted from West (1985) and Creese (2009).

Condition of Riparian Zones in the Karuah River Catchment

Hypothesis: The condition of the majority of riparian habitat in the Karuah River catchment is not different from reference sites.

Was the hypothesis accepted or rejected? Rejected.

The importance of riparian zones in maintaining stream health is well established (Lucas *et al.*, 2004). Riparian zones are ecotones, mediating interactions between terrestrial and aquatic systems (Kauffman and Krueger, 1984, Naiman and Decamps, 1997). They buffer streams against sediment and nutrient pollution (Naiman and Decamps, 1997, Tubman and Price, 1999, Robertson and Rowling, 2000), provide shade, habitat and bank stability (Tubman and Price, 1999) and have been suggested to reduce bacterial contamination of streams (Collins and Rutherford, 2004). Management of riparian zones is also important because riparian vegetation characteristics significantly affect macroinvertebrate assemblages (Sponseller *et al.*, 2001, Parkyn *et al.*, 2003) and the ecology of streams in general (Cummins *et al.*, 1975).

Slightly less than half the sites passed the riparian assessment. A pass would indicate that the condition was similar to that which would be expected in relatively undisturbed riparian habitats (Table 5). Not surprisingly, the pass rate of those sites on private land was much lower (30%) compared with those located within national park, reserve or state forest land (80%, Table 5). In particular, habitat component pass rates for sites on private land were particularly low for the proportional area of exposed soil (15%), proportional cover of native vegetation 1 to 5m tall (20%), leaf litter (30%), all vegetation 1 to 5m tall (35%), native vegetation greater than 5m tall (35%) and all vegetation greater than 5m tall (35%) (Figure 13). Two of the riparian assessment sites that were located in reserves actually failed the assessment. These sites were unusual as they were in areas of low relief and, being somewhat swampy, were atypical. Sites located in reserves had a relatively low pass rate for proportional areal coverage of leaf litter and exposed soil. This suggests that relatively undisturbed sites in the Karuah River catchment had less leaf litter and more exposed soil in riparian zones compared with reference sites in the neighbouring Myall River and Wallis Lake catchments.

Table 5. Proportion of sites that passed the riparian assessment.
Comparison of sites located within national parks (NP), reserves or state forests (SF) with those located on private property.

	NP, Reserve or SF	Private Land	All Sites
Total no. of sites sampled	10	20	30
No. of sites that passed	8	6	14
Proportion of sites that passed	**80%**	**30%**	**47%**

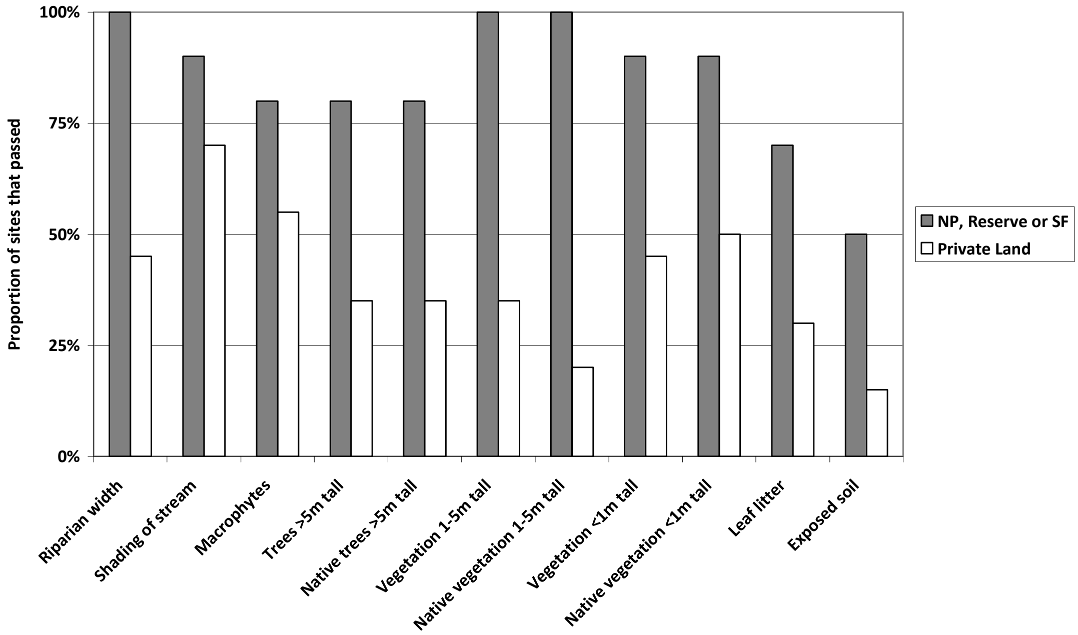

Figure 13. Proportion of sites that passed condition tests for various riparian habitat characteristics.
Sites within national parks (NP), reserves or state forests (SF) are compared with those on private land.

The vast majority of sites on private land had excessive areas of exposed soil in the riparian zone. This was simply down to stock accessing streams via the riparian zone for water and shade. This was reinforced by the fact that sites on private land where stock had access to the riparian zone had more exposed soil, less leaf litter, native groundcover than those without stock access (Figure 14). The lack of shrubs and saplings was also particularly evident for these sites. So, although some sites may have relatively wide vegetated riparian zones, the quality and structure of riparian vegetation has been diminished and very little recruitment of native vegetation is occurring. Sites on private land without stock access had slightly less tree cover than those with stock access (Figure 14). Although the presence of trees is important to the riparian and stream health, tree cover is a function of historical land management and is unlikely to be immediately related to current stock access. There could be the perception that riparian zones are in good condition due to the presence of large trees, but without continued recruitment their condition will deteriorate as older trees die off and are not replaced. This transition to low diversity even-aged riparian plant communities as a result of grazing has been observed elsewhere (Belsky *et al.*, 1999) and has significant implications for water quality, biodiversity and ecological health of streams and their estuarine receiving waters.

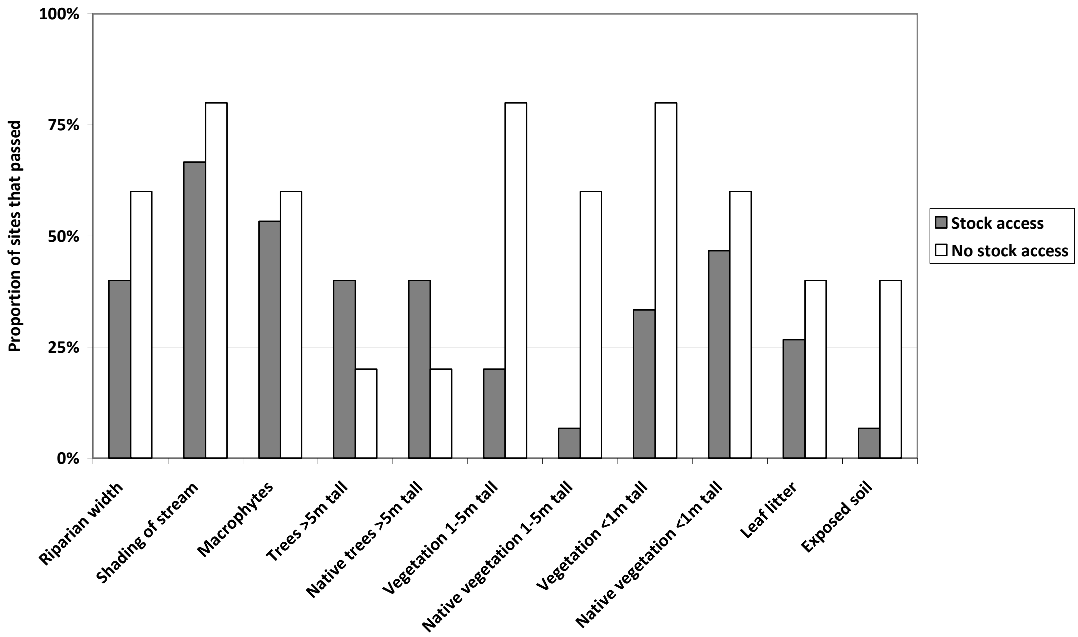

Figure 14. Proportion of sites on private land that passed condition tests for various riparian habitat characteristics.
Comparison of sites with and without stock access.

While upper vegetation strata are declining, the cover of grasses and low non-native vegetation is increasing. This could be seen as a positive in terms of buffering of sediment and nutrients in runoff, but it is accompanied by a decrease in the cover of leaf litter and, as mentioned, an increase in exposed soil. Leaf litter is important in riparian zones as it helps to protect the soil from the direct impact of rain, reducing erosion (Xiong and Nilsson, 1997), and also contributes carbon to the soil, increasing infiltration (Reyes-Goomez *et al.*, 2007). Litter suppresses germination of plant species with small seeds (Xiong and Nilsson, 1997), such as many herbaceous weeds, so is an important determinant of the composition of vegetation communities. Leaf litter input is also an important influence on in-stream ecology and reductions in litter inputs leads to decreased stream biodiversity (Cummins *et al.*, 1989, Wallace *et al.*, 1997).

Principal components analysis of riparian habitat data indicated that sites in national parks, reserves or state forests were similar to those on private land with no stock access, while they differed from sites on private land with stock access differed (Figure 15). Stock access, therefore, appears to be an important factor impacting on the condition of riparian zones in the Karuah River catchment.

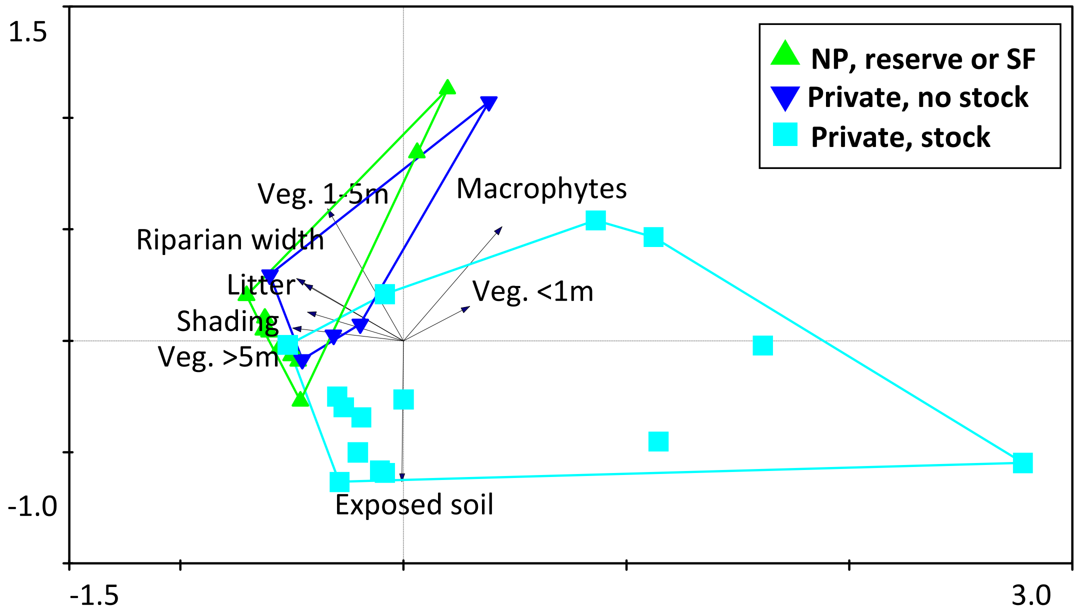

Figure 15. Principal components analysis plot representing the relative similarity of riparian habitats.

Arrows indicate increasing value of the labelled habitat characteristic. Macrophytes = proportion of stream where macrophytes are visible; Veg. <1m = percentage cover of vegetation less than 1m tall in the riparian zone; Exposed soil = percentage of riparian zone by area where exposed soil is visible; Veg. >5m = percentage cover of vegetation greater than 5m tall in the riparian zone; Shading = proportion of stream that is shaded; Litter = percentage cover of leaf litter in the riparian zone; Riparian width = width of continuous riparian vegetation greater than 2m in height; Veg. 1-5m = percentage cover of vegetation 1-5m tall in the riparian zone.

There appeared to be some clustering of sites with poor riparian condition in the central northern and south eastern parts of the catchment (Figure 16). These corresponded with areas where large sections of riparian zones were dominated by non-woody vegetation (Figure 17). Some sites with fair or poor condition riparian habitats were located in areas dominated by woody vegetation (Figures 16 & 17), suggesting that, although there was substantial tree cover, the understoreys and groundcover were in poor condition.

The hypothesis was rejected because the condition of riparian zones at the majority of sites in the Karuah River catchment was poorer than reference sites. Future catchment management and monitoring programmes should include a strong focus on riparian condition. Ideally, targeted funding should be directed towards stock exclusion fencing, particularly in the central-northern and southeastern parts of the catchment. However, many landholders may be reluctant to fence off riparian zones, so perhaps in lieu of this targeted plantings or recruitment zones could be protected to facilitate renewal of riparian vegetation and off-stream watering and of alternative shade could be provided for stock.

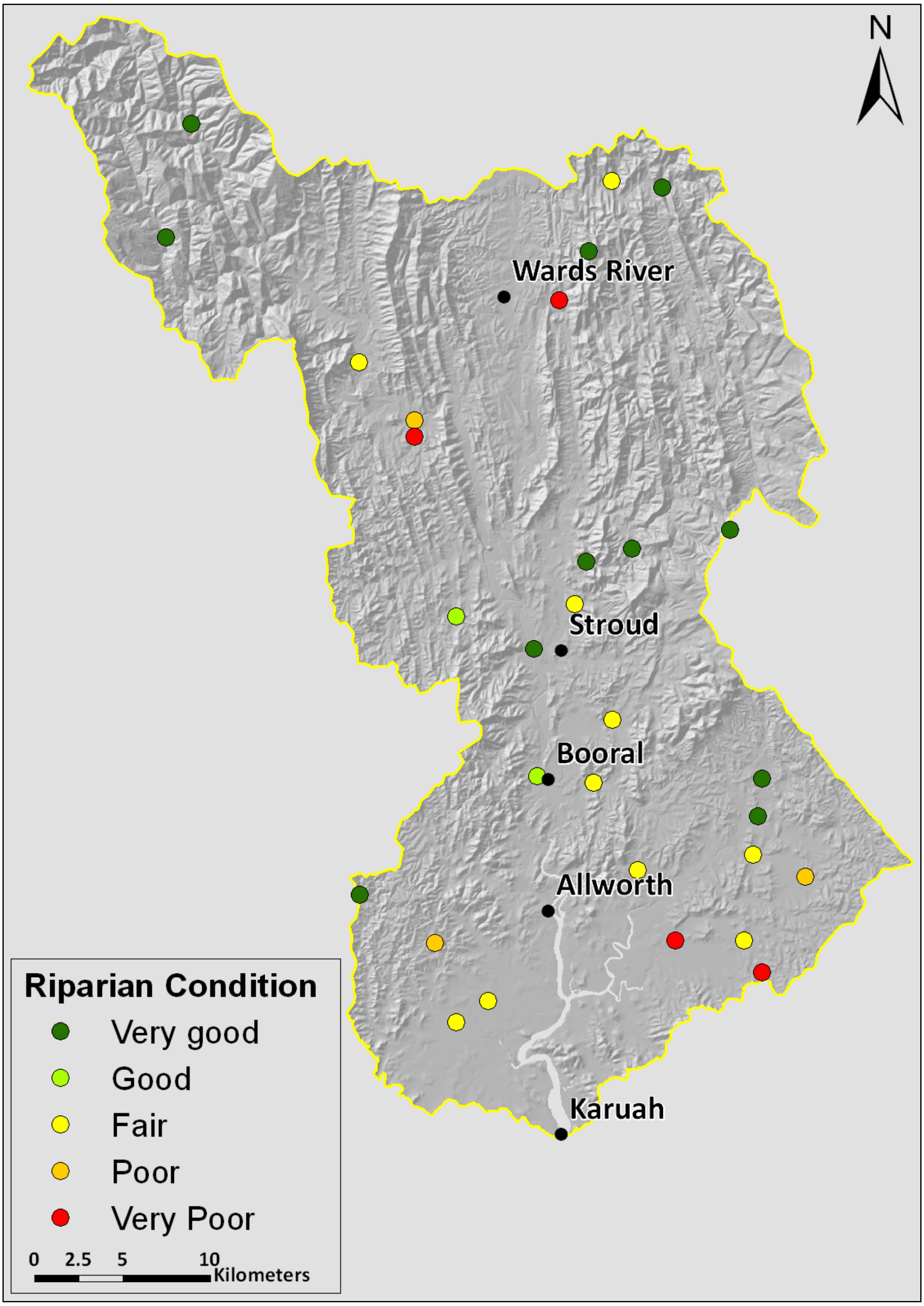

Figure 16. Riparian condition in the Karuah River catchment.
Riparian condition is derived from riparian assessments.

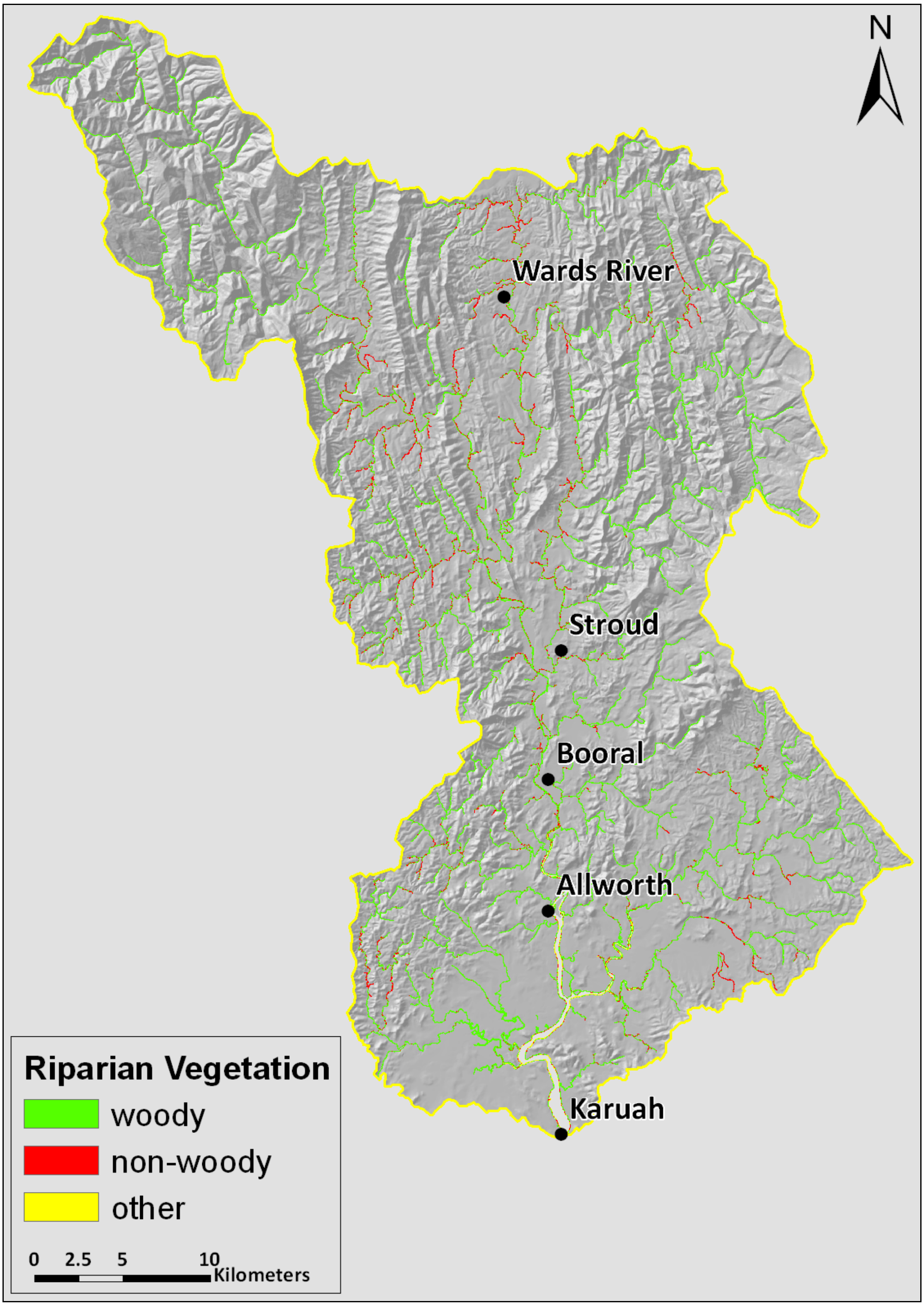

Figure 17. . Riparian vegetation type in the Karuah River catchment.
Vegetation type (woody or non-woody) was derived from analysis of aerial photography carried out by NOW and DECCW (2009).

Biological Structure

3.1.2. Mudflat Invertebrate Assemblages

Hypothesis: The composition of invertebrate assemblages on intertidal mudflats in the Karuah River does not differ from control estuaries.

Was the hypothesis accepted or rejected? Accepted.

Mudflats are often perceived as less important than other estuarine habitats, but they are an important source of food for many fishes and birds (Inglis, 1995) and, in the Karuah River estuary, mudflats constitute a substantial proportion of the intertidal area.

Invertebrate diversity was generally low at all estuaries (Figure 18). There was no significant difference in the mean number of invertebrate taxa per sample found at the Karuah River sites compared with other sites (Figure 18), but there were significant differences in the abundance of some taxa (Figure 19). Crustaceans were more abundant at Karuah River and Twelve Mile Creek sites than at Wallingat River sites, while bivalves were more abundant at Wallingat River sites than at either Karuah River or Twelve Mile Creek sites (Figure 19). Oligochaetes were more common at Karuah River sites than at other sites (Figure 19). The abundances of all other taxa were not significantly different among estuaries (Figure 19).

Analysis of similarities (ANOSIM) indicated that invertebrate assemblages were not significantly different at Karuah River and Twelve Mile Creek sites, but differed at Wallingat River sites ($P<0.05$). Non-metric multidimensional scaling grouped Karuah River and Twelve Mile Creek sites together, indicating that the assemblages in these estuaries were similar, while Wallingat River sites were separated, indicating that they differed (Figure 20). Principal components analysis (PCA), adjusted for the effect of organic matter content of sediments, produced similar results (Figure 21).

The hypothesis was accepted because intertidal mudflat invertebrate assemblages in the Karuah River did not differ from those in Twelve Mile Creek. Although mudflat invertebrates could be good indicators of condition, this work was very labour intensive. In particular, sieving samples was very time consuming because of the substantial amounts of organic matter and clay in sediments. We recommend that alternative methods of sampling and processing mudflat invertebrate assemblages, such as counts of burrows, should be used for future monitoring programmes.

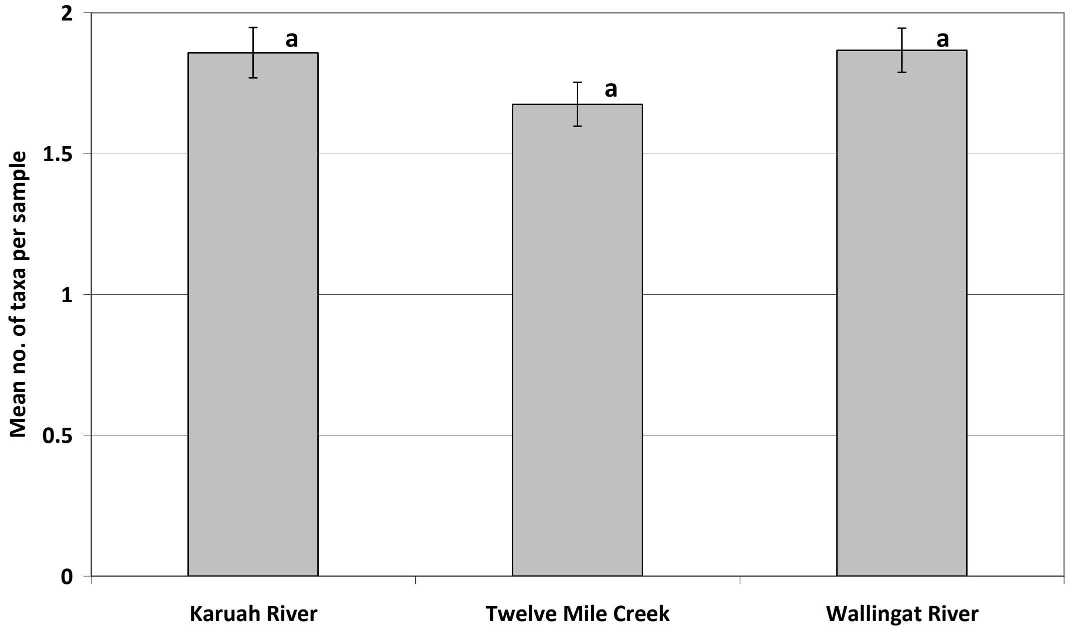

Figure 18. Mean number of invertebrate taxa per sample.
Different letters indicate means were statistically different (P<0.05).

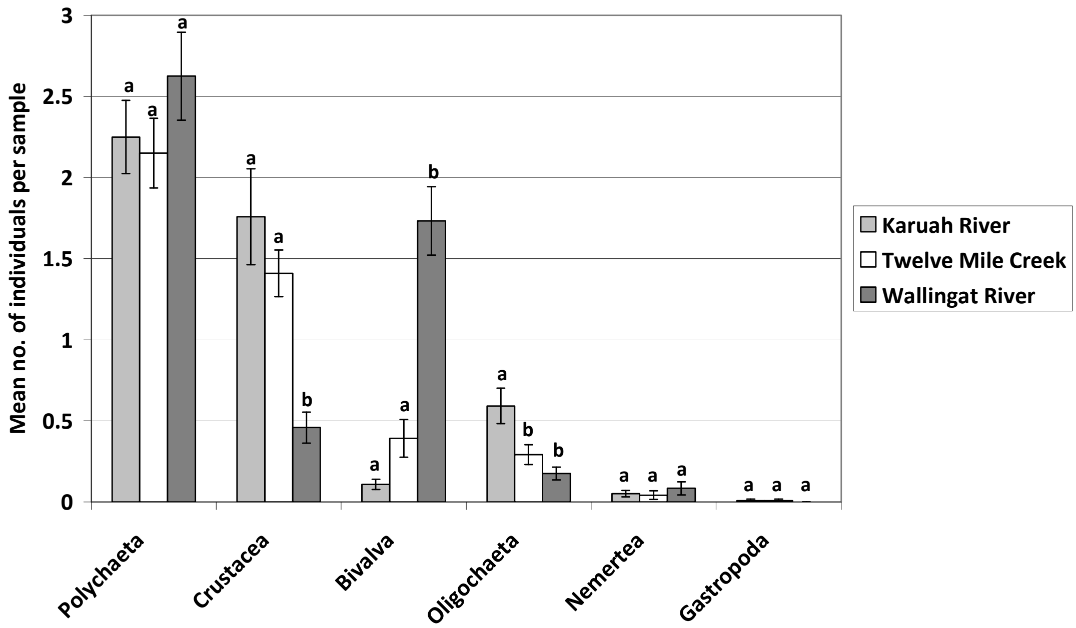

Figure 19. Mean abundance of invertebrates per sample.
Different letters indicate means were statistically different among estuaries (P<0.05).

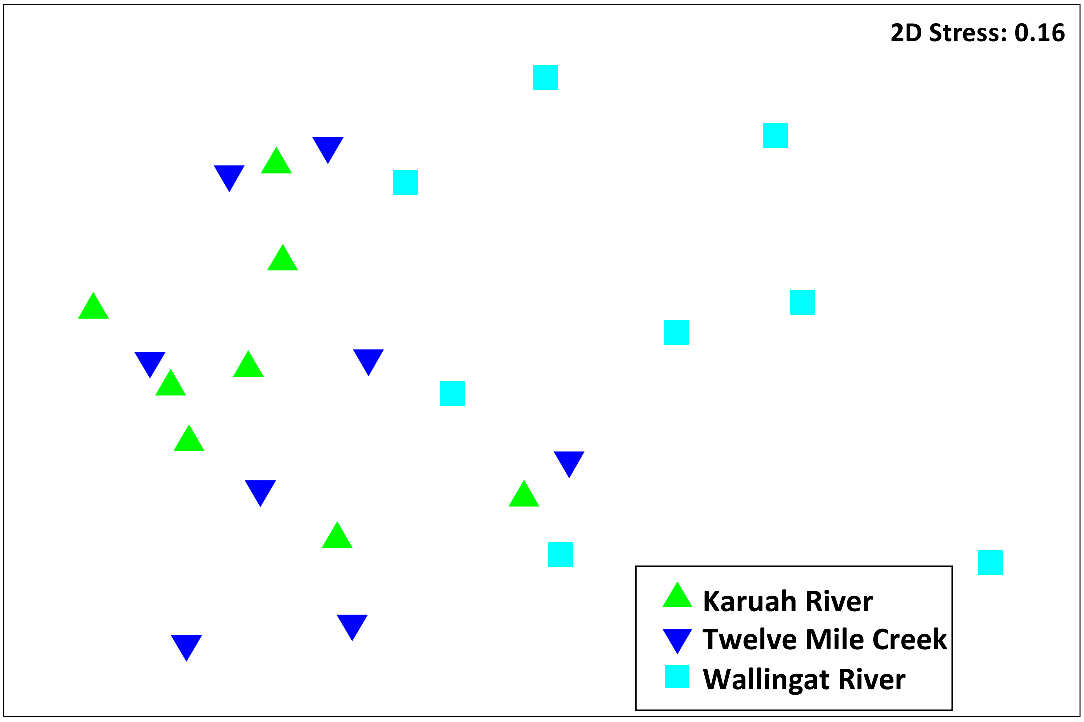

Figure 20. Non-metric multidimensional scaling plot of macroinvertebrate assemblages.

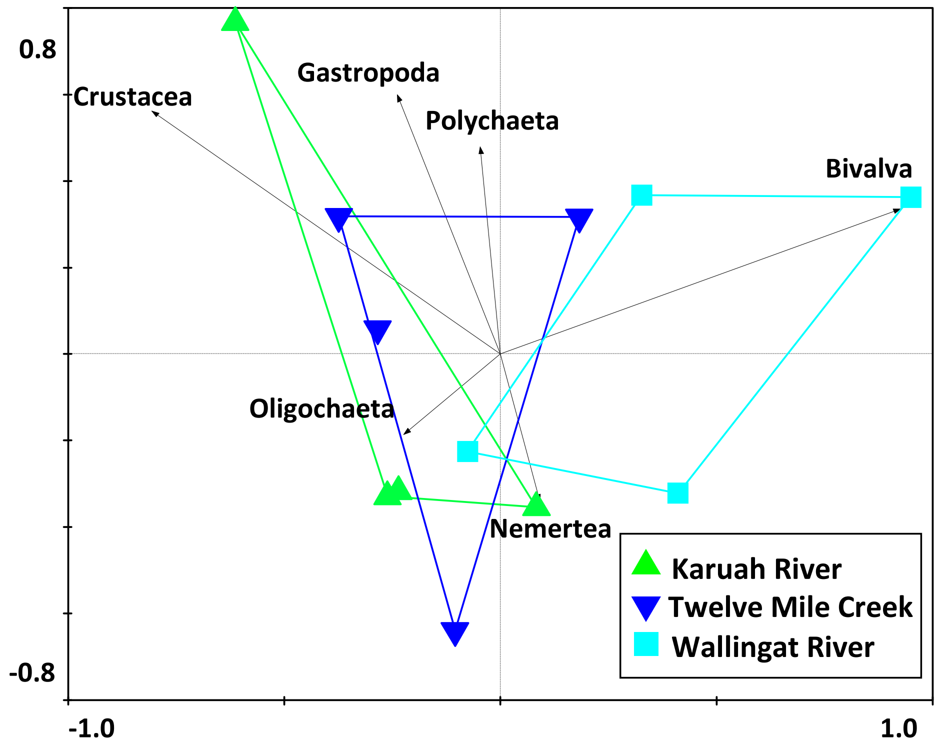

Figure 21. Principal components analysis plot representing the relative similarity of macroinvertebrate assemblages.
Arrows indicate increasing abundance of taxa.

3.1.3. Estuarine Fish Assemblages

Hypothesis: The composition of fish assemblages in the Karuah River does not differ from control estuaries.

Was the hypothesis accepted or rejected? Accepted.

Estuarine fish are an important resource, providing economic, recreational and environmental benefits. The Karuah River estuary is an important recreational and commercial fishery and is part of the larger Port Stephens system. The composition of fish assemblages provides a direct measure of the available resource but, having relatively long life cycles and being sensitive to environmental pressures, fish can also be good indicators of overall ecological condition (Camargo and Alonso, 2006, Hallett *et al.*, 2012).

A total of 22 species of fish were observed in the Karuah River estuary compared with 26 in Twelve Mile Creek and 23 in Wallingat River estuaries. There were no significant differences in the mean number of taxa per sample among estuaries (Figure 22), but there were differences in the abundances of some taxa. Small-toothed flounder (*Pseudorhombus jenynsii*, Bleeker, 1855) were significantly more abundant at Twelve Mile Creek sites than at Karuah or Wallingat River sites (Figure 23). Yellowfin bream (*Acanthopagrus australis*, Owen, 1853) were significantly more abundant at Twelve Mile Creek sites than at Karuah River sites, but abundances at Wallingat River sites were not significantly different from Twelve Mile Creek sites or Karuah River sites (Figure 24). Exquisite sand gobies (*Favonigobius exquisitus*, Whitley, 1950) were significantly more abundant at Wallingat River sites than at other sites (Figure 25).

Analysis of Similarities (ANOSIM) indicated that fish assemblages were not significantly different at Karuah River and Twelve Mile Creek sites, but differed at Wallingat River sites ($P<0.05$). Non-metric multidimensional scaling weakly grouped Karuah River and Twelve Mile Creek sites together, while Wallingat River sites appeared separated (Figure 26). Simpson's D', a measure of diversity, did not differ among estuaries (Figure 27).

The hypothesis was rejected because, overall, fish assemblages did not differ among estuaries. Fish assemblage measures should be a component of future monitoring programmes as these are sensitive to environmental degradation and fish constitute an important resource.

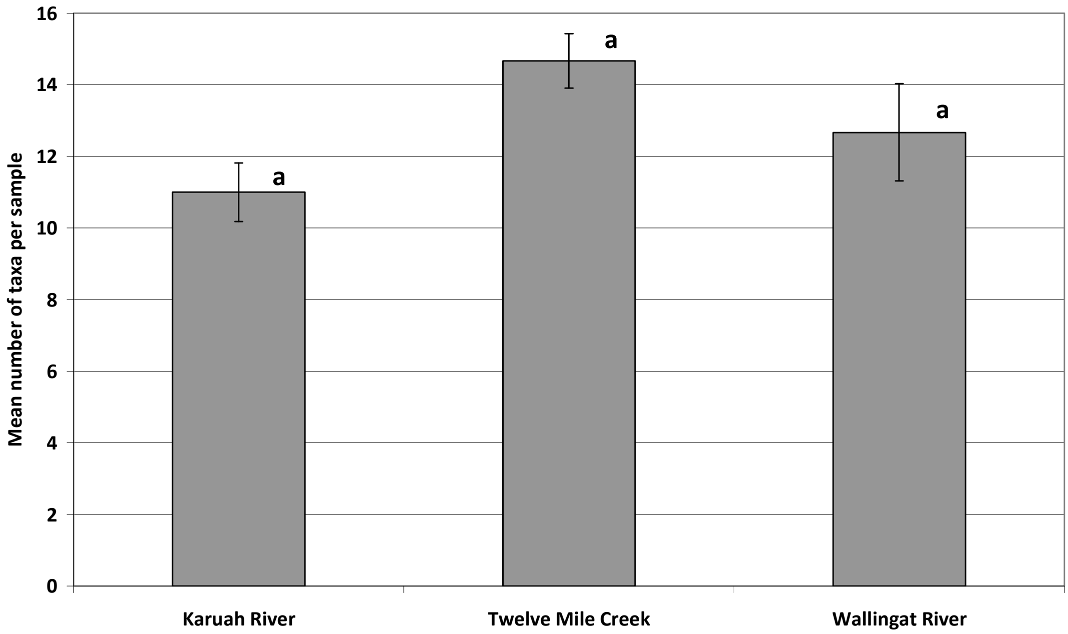

Figure 22. Mean number of fish taxa per sample.
Different letters indicate means were statistically different (P<0.05).

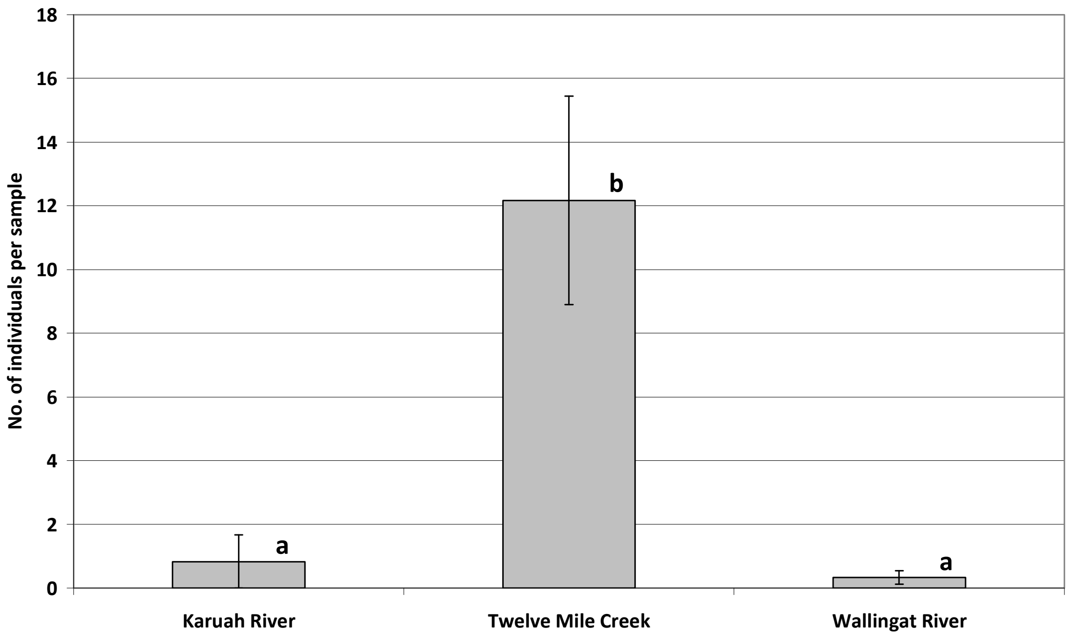

Figure 23. Mean number of small-toothed flounder (Pseudorhombus jenynsii) per sample.
Different letters indicate means were statistically different (P<0.05).

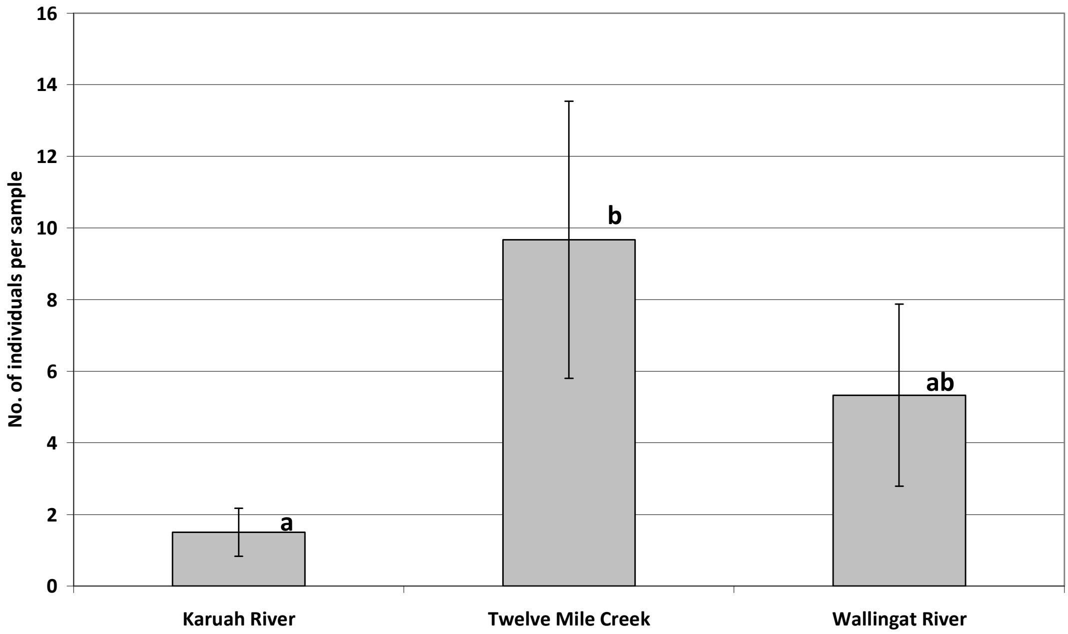

Figure 24. Mean number of yellowfin bream (Acanthopagrus australis) per sample.
Different letters indicate means were statistically different (P<0.05).

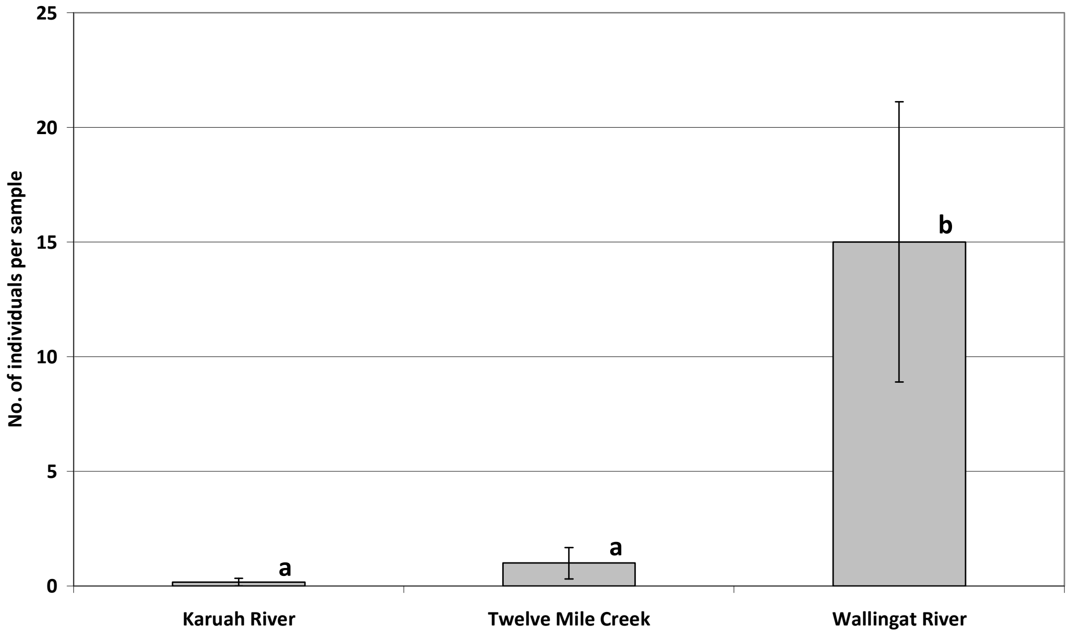

Figure 25. Mean number of exquisite sand gobies (Favonigobius exquisitus) per sample.
Different letters indicate means were statistically different (P<0.05).

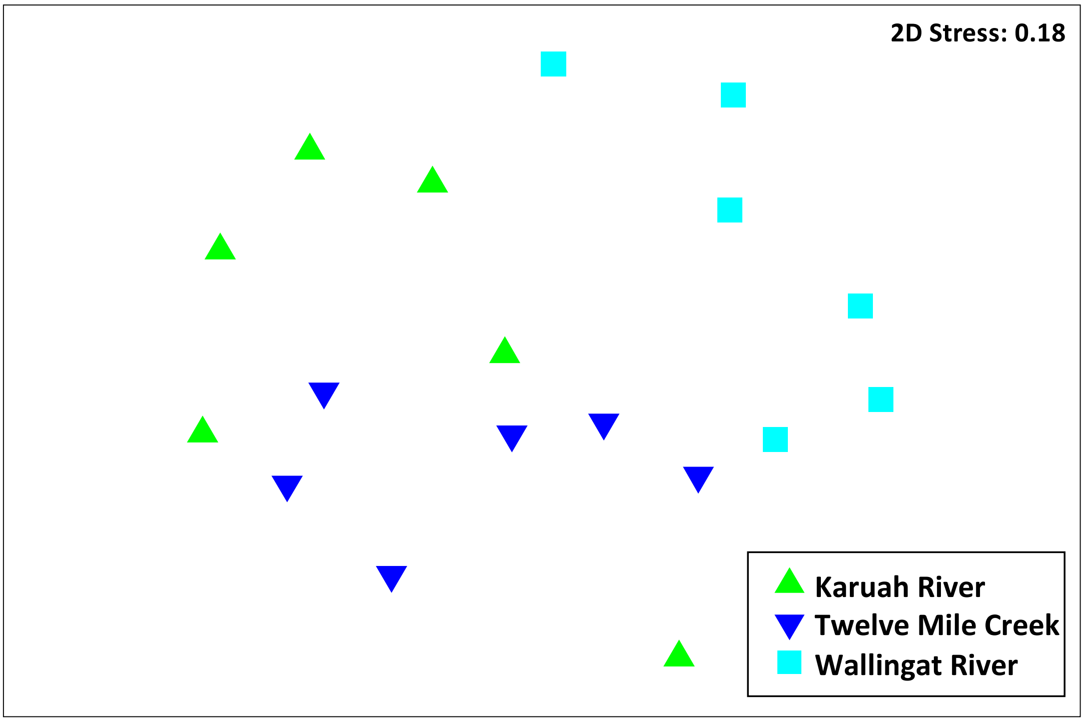

Figure 26. Non-metric multidimensional scaling plot of fish assemblages.

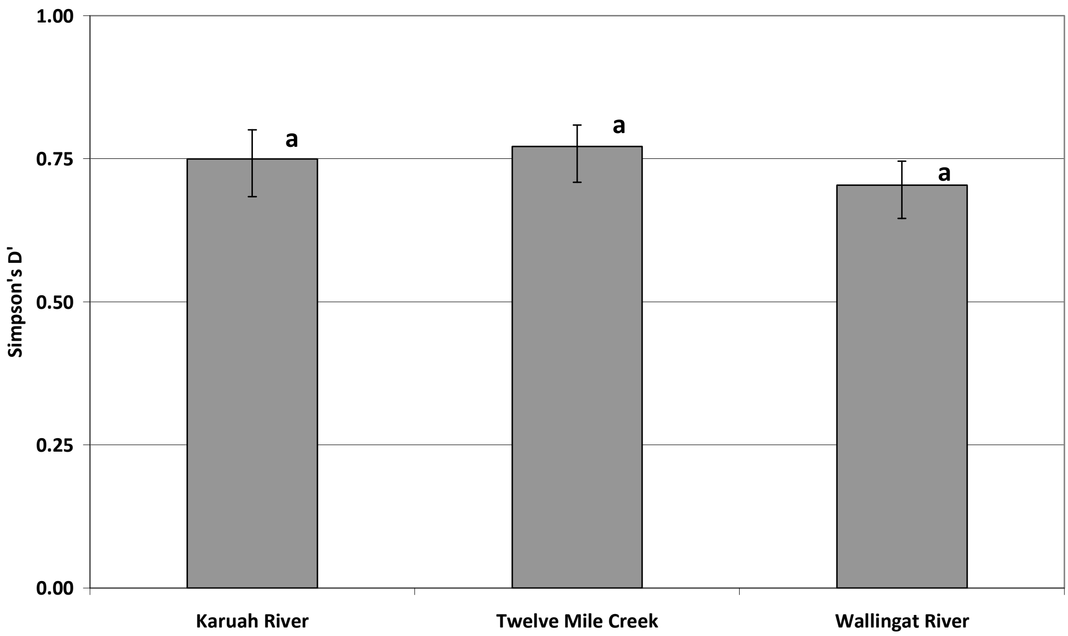

Figure 27. Mean Simpson's D' value for fish assemblages.
Different letters indicate means were statistically different (P<0.05).

3.1.4. Shorebird Assemblages

Hypothesis: The composition of shorebird assemblages in the vicinity of the Karuah River estuary do not differ from other parts of Port Stephens.

Was the hypothesis accepted or rejected? Accepted.

Shorebirds feed mainly on invertebrates in intertidal zones (Dann, 1987, Finn, 2007). Different species of shorebirds target different prey and environmental pressures affect the abundance and composition of prey assemblages as well as affecting the ability of shorebirds to harvest these prey (Lane, 1987, Finn, 2007). So, the composition of shorebird assemblages and the abundances of particular shorebird species are indicative of environmental pressures on an estuary. Shorebird assemblage composition is also influenced by the availability of different intertidal habitats (Finn, 2007). Thus, shorebirds are good indicators of the biodiversity and ecological condition of an estuary.

The mean numbers of shorebird species, mean numbers of other waterbird species and mean abundances of black swans (*Cygnus atratus*) in Charlie and Delta sectors (the sectors closest to the Karuah River) were within the range observed in other sectors (Figures 28 & 29). There were no downward trends in the number of bird species and temporal patterns at Charlie and Delta sectors roughly followed those of other sectors (Figures 30 & 31). So, as bird assemblages in sectors in the vicinity of Karuah River did not differ from those of other sectors, the hypothesis was accepted.

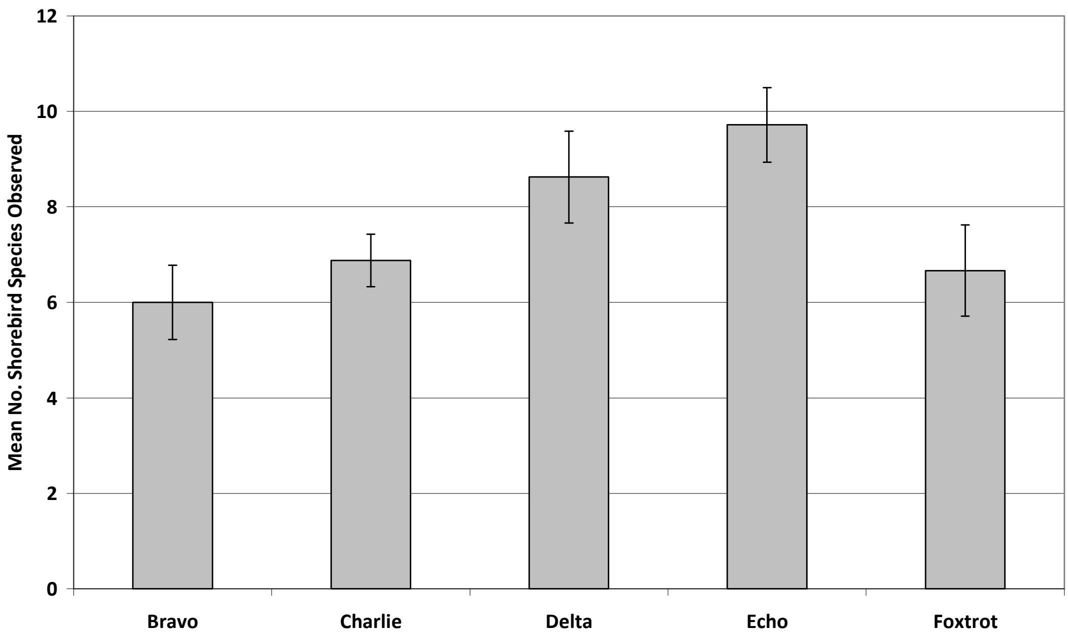

Figure 28. Mean number of shorebird species observed in different sectors.

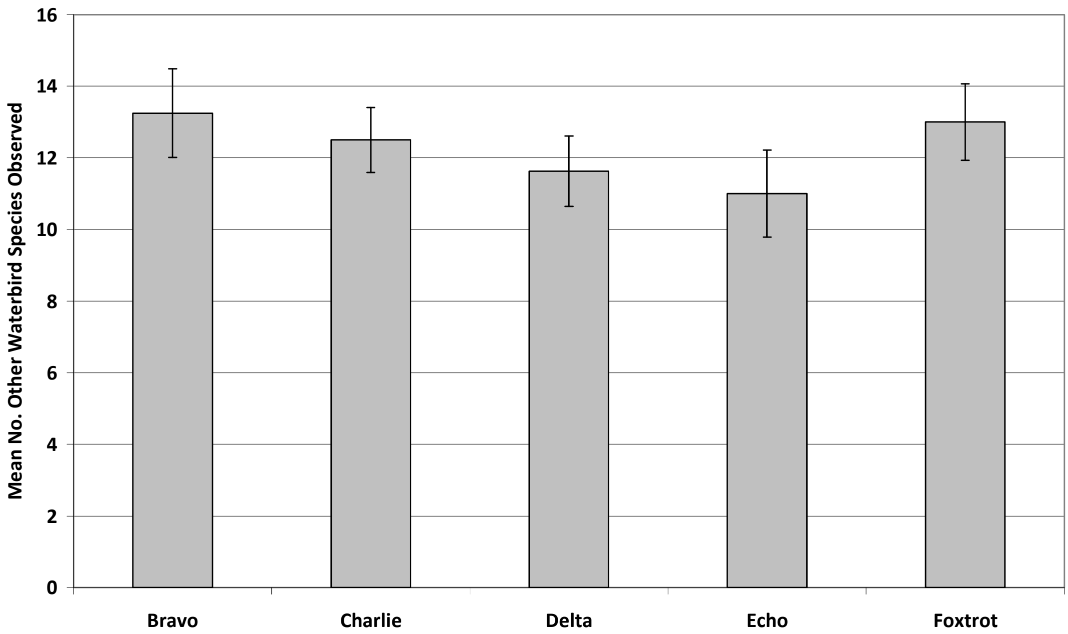

Figure 29. Mean number of other waterbird species observed in different sectors.

Figure 30. Mean number of shorebird species observed, 2004 -2012.
Comparison of Charlie and Delta sectors with other sectors.

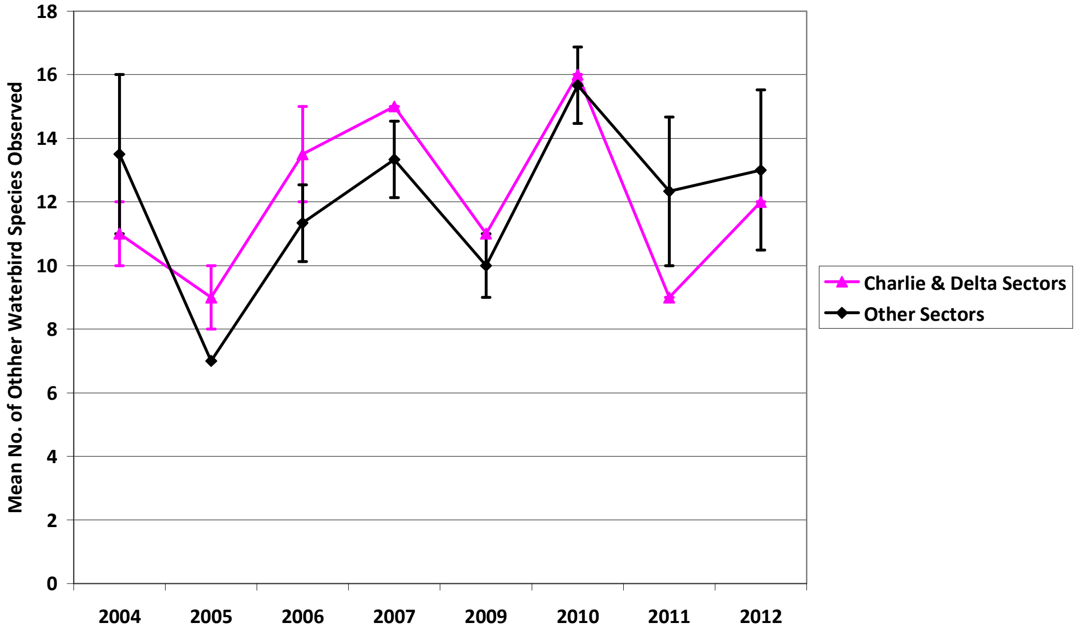

Figure 31. Mean number of other waterbird species observed, 2004 -2012.
Comparison of Charlie and Delta sectors with other sectors.

3.1.5. Freshwater Macroinvertebrates

Hypothesis: The composition of aquatic macroinvertebrate assemblages in the Karuah River system does not differ from reference sites.

Was the hypothesis accepted or rejected? Accepted.

Aquatic macroinvertebrates are commonly used as indicators of the ecological condition of streams in relation to landscape scale stressors (Bailey *et al.*, 2007) and to a lesser extent have been utilised as indicators of stream or river condition in agricultural landscapes in relation to farm scale stressors (Sponseller *et al.*, 2001, Parkyn *et al.*, 2003). Macroinvertebrates have relatively long life cycles and, as a consequence, the composition of an assemblage is indicative of water quality over longer time frames (Rosenberg and Resh, 1993, Chapman, 1996) while physical and chemical measures only provide an indication of water quality at the time of sampling (Chapman, 1996).

The mean OE50 ratio for all sites in the Karuah River catchment was 0.96, indicating that the number of invertebrate families collected at sites was similar to reference sites (Table 6). The mean OE50 SIGNAL score for all sites was very close to 1, indicating that water quality at Karuah River catchment sites was also similar to reference sites (Table 6). Not surprisingly, macroinvertebrate assemblages at Karuah River catchment sites generally typically fell into band A, indicating that both taxonomic diversity and water quality were equivalent to reference sites. Two sites, 51086 and 52063, fell into band B due to lower OE50 scores indicating fewer families were collected than expected (Table 6). Site 51086 is located on the Mill Creek near Stroud and site 52063 is located on Ramstation Creek near Stroud Road.

The hypothesis was accepted because, in general, freshwater macroinvertebrate assemblages did not differ from those at reference sites.

Aquatic macroinvertebrate sampling is rapid and inexpensive, providing an effective measure of stream ecological condition. We recommend that, if aquatic macroinvertebrate assemblages are included as indicators, some sites in The Branch River and Mammy-Johnsons River sub-catchments be included in future monitoring programmes.

Table 6. Mean OE50 ratios, mean OE50 SIGNAL scores and typical AUSRIVAS band of macroinvertebrate samples from sites in the Karuah River catchment.

Site	Mean OE50	Mean OE50 Signal	Typical Band
51069	1.15	0.93	A
51086	0.79	1.01	B
51226	0.91	1.01	A
51228	1.00	1.04	A
52063	0.76	1.02	B
52069	0.84	1.04	A
52275	1.05	1.02	A
52281	1.05	1.00	A
52430	1.03	1.06	A
52434	1.13	1.03	A
53066	0.91	1.02	A
KARU02	0.88	1.00	A
KARU502	1.04	1.01	A
KARU504	0.85	1.03	A
KARU540	0.99	0.94	A
KARU601	0.98	0.96	A
KARU858	1.06	1.01	A
All Sites	**0.96**	**1.01**	A

3.2. Energy Flow

3.2.1. Phytoplankton

Hypothesis: Chlorophyll a concentrations in the Karuah River estuary are typically below the trigger value.

Was the hypothesis accepted or rejected? Accepted.

The concentration of chlorophyll *a* in the water column is a surrogate for phytoplankton abundance (Ward *et al.*, 1998). Phytoplankton populations can increase in response to elevated nutrient concentrations, leading to shading of benthic habitats, causing changes to the structure and composition of ecological communities and in some cases depleting oxygen concentrations (ANZECC and ARMCANZ, 2000, Camargo and Alonso, 2006). Thus, chlorophyll *a* can be indicative of ecological condition of an estuary.

Both median and mean chlorophyll *a* concentrations were below respective trigger values at all Karuah River estuary sites (Table 7; Figure 32). Median chlorophyll a concentrations ranged from 1.7 to 2.0 mg L^{-1} for the upper estuary sites, K1 to K4, and from 1.4 to 1.8 mg L^{-1} in lower estuary sites, K5 to K7 (Table 7). There was very little difference in chlorophyll *a* concentrations among sites, but upper estuary sites, K1 to K3, tended to have higher concentrations than lower estuary sites (Table 7; Figure 32). Pass rates for sites (i.e. the proportion of samples that were below the trigger value) ranged from 67 to 100% and the overall pass rate was 79% (Table 7).

Table 7. Median water column chlorophyll *a* concentrations in the Karuah River estuary. Comparison with trigger values.

Site	Median chlorophyll *a* concentration (µg L^{-1})	Trigger value	Pass rate
K1	1.8	3.5	100%
K2	2.0	3.5	67%
K3	2.0	3.5	67%
K4	1.7	3.5	100%
K5	1.6	2.2	67%
K6	1.8	2.2	67%
K7	1.4	2.1	83%
All			79%

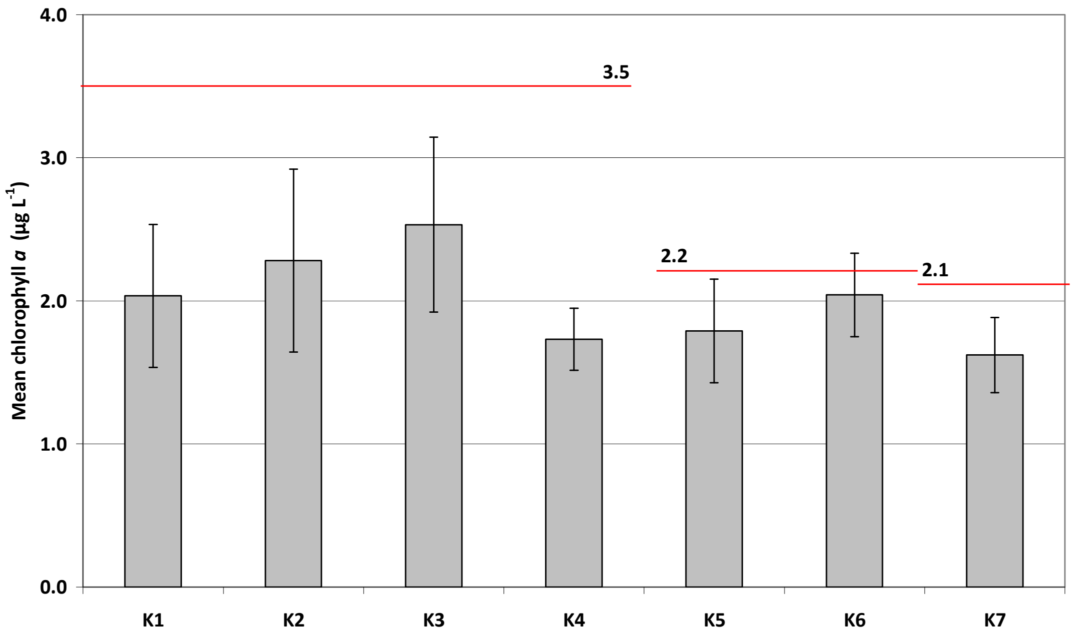

Figure 32. Mean water column chlorophyll *a* concentrations at sites in the Karuah River estuary.
Red lines indicate trigger values. Specific trigger values are labelled above lines. Sites K1 to K4 were upper estuary sites, sites K5 and K6 were middle estuary sites and site K7 was located in the lower estuary.

The hypothesis was accepted because median chlorophyll *a* concentrations were below the trigger at all sites. However, the growth response of phytoplankton may have been inhibited due to low light availability caused by high turbidity in the Karuah River estuary (see Water Column Turbidity section). Chlorophyll *a* concentrations should be included in future monitoring, but must be interpreted in the context of other environmental factors, such as light availability.

3.2.2. Benthic microalgae

Hypothesis: Densities of benthic microalgae in the Karuah River estuary do not differ from control estuaries.

Was the hypothesis accepted or rejected? Accepted.

Benthic microalgae are important primary produces in estuaries, providing a food source for other organisms. Benthic microalgae also bind sediments, stabilising them and preventing resuspension (Madsen *et al.*, 1993). We measured sediment chlorophyll *a* concentration as an analogue for benthic microalgae abundance.

Mean sediment chlorophyll *a* concentrations were significantly greater in samples from the Richmond River and Tweed River estuaries compared with those from the Karuah River, Tuggerah Lakes and Wallis Lake estuaries (Figure 33). There were no significant differences among the mean concentrations of chlorophyll *a* in sediments from the Karuah River, Tuggerah Lakes and Wallis Lake estuaries (Figure 33).

The hypothesis was accepted because benthic chlorophyll *a* concentrations were within the range of those observed in other New South Wales estuaries. This measure could be a useful component of future monitoring programmes, but could be improved if more data were available for nearby relatively undisturbed riverine estuaries.

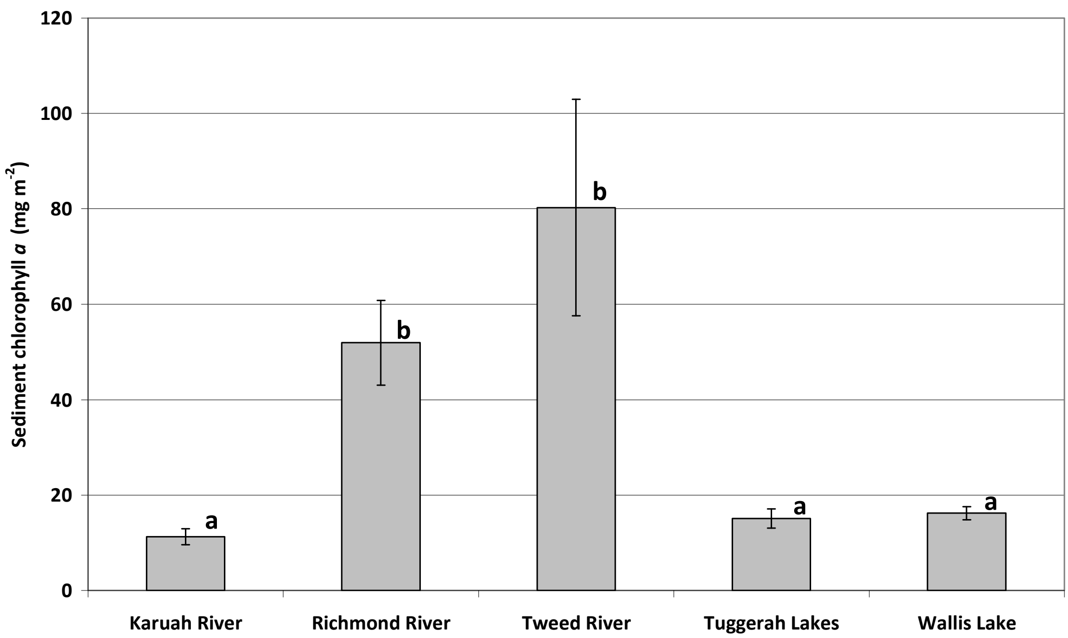

Figure 33. Sediment chlorophyll *a* concentrations in the Karuah River estuary compared with two other riverine estuaries in NSW.
Cores were collected from a depth equivalent to 1.5m at mid tide. Different letters indicate means were statistically different ($P<0.05$).

3.2.3. Algal Recruitment on Pneumatophores and Seagrass

Hypothesis 1: The rate of algal recruitment on artificial pneumatophores in the Karuah River estuary does not differ from control estuaries.

Was the hypothesis accepted or rejected? Rejected.

Hypothesis 2: The rate of algal recruitment on artificial seagrass in the Karuah River estuary does not differ from control estuaries.

Was the hypothesis accepted or rejected? Accepted.

Pneumatophores, the aerial roots of some mangrove species, provide a surface which epiphytic organisms can colonise. The biomass of epiphytic macroalgae on pneumatophores has been shown to be affected by levels of pollutants (Melville and Pulkownik, 2006). Biomass is, for example, negatively correlated with metal concentrations and positively correlated with nutrient concentrations in the estuary (Melville and Pulkownik, 2006). Chlorophyll *a* concentration on artificial pneumatophores, following deployment for a period of time, provides a measure of the rate of recruitment of epiphytic macroalgae. This can be used as an indicator of the levels of pollutants in an estuary.

Mean chlorophyll *a* concentrations were greater on artificial pneumatophores left in the intertidal zone at Karuah River sites compared with those at Twelve Mile Creek or Wallingat River sites (Figure 34). There was no significant difference between mean concentrations at Twelve Mile Creek sites compared with Wallingat River sites (Figure 34). The significantly greater rate of recruitment of algae on artificial pneumatophores in the Karuah River compared with the two control estuaries could be due to the high concentrations of nitrogen and phosphorus in the water column. Hypothesis 1 was rejected because algal recruitment on artificial pneumatophores was significantly greater than in control estuaries.

Elevated water column nutrient concentrations can lead to increased epiphyte biomass on seagrass leaves, shading seagrass, inhibiting growth and preventing carbon uptake (Sand-Jensen, 1977, Bulthuis and Woelkerling, 1983, Borum, 1985, Silberstein *et al.*, 1986, Coleman and Burkholder, 1994, Wear *et al.*, 1999, Fong *et al.*, 2000, Drake *et al.*, 2003, Peterson *et al.*, 2007, Bryars *et al.*, 2011). Previous studies have shown that rates of epiphyte recruitment on artificial seagrass are similar to those on real seagrass (Horner, 1987). The concentration of chlorophyll *a* on artificial seagrass after a period of immersion is a measure of algal recruitment and can be used as an indicator of the effect of nutrient loads. The rate of recruitment can also be indicative of the potential for epiphytic algae to inhibit seagrass growth in the estuary.

In contrast to the artificial pneumatophores, algal recruitment on artificial seagrass was in the range of that observed at control estuaries (Figure 35). A possible explanation for this is that the algal growth responses to elevated nutrient concentrations are inhibited by the low light availability, due to high turbidity, in the Karuah River. Hypothesis 2 was accepted because the rate of algal recruitment on artificial seagrass in the Karuah River was within the range observed at control estuaries.

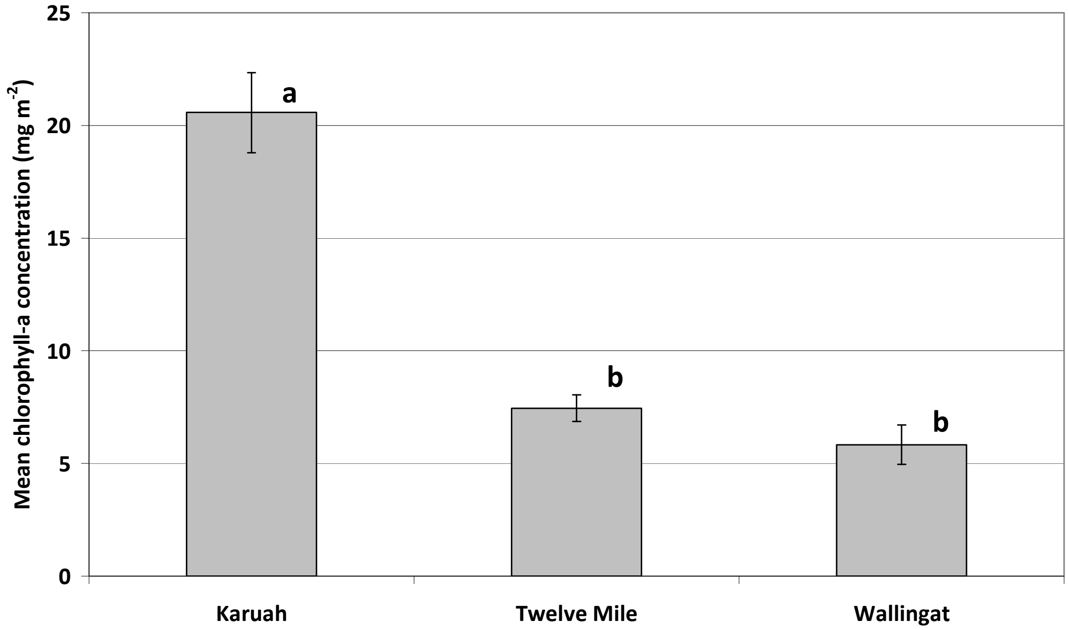

Figure 34. Mean chlorophyll *a* concentrations on artificial pneumatophores.
Different letters indicate means were statistically different (ANOVA, P<0.05).

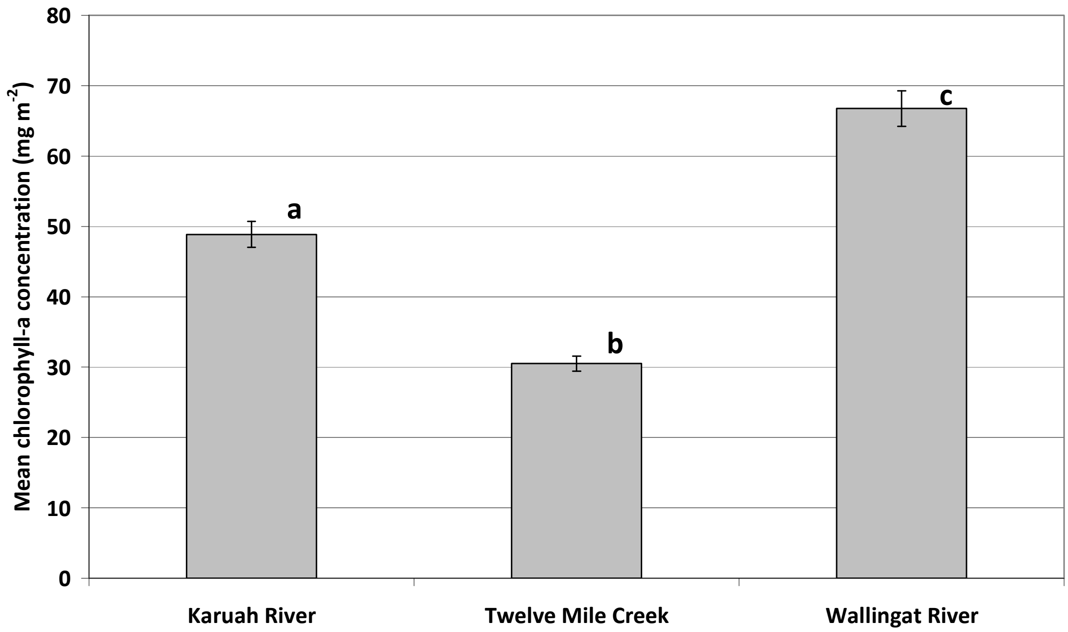

Figure 35. Mean chlorophyll *a* concentrations on artificial seagrass.
Different letters indicate means were statistically different (ANOVA, P<0.05).

3.2.4. Micro-Carnivore Scavenging

Hypothesis: The rate of micro-carnivore scavenging in the Karuah River does not differ from other control estuaries.

Was the hypothesis accepted or rejected? Accepted.

The term micro-carnivores refers to carnivorous invertebrates, such as crustaceans, molluscs and worms, and small fish. The rate of scavenging by micro-carnivores scavengers is a measure of activity in lower trophic levels. There were no significant differences in mean rates of micro-carnivore scavenging among estuaries (Figure 36), so the hypothesis was accepted.

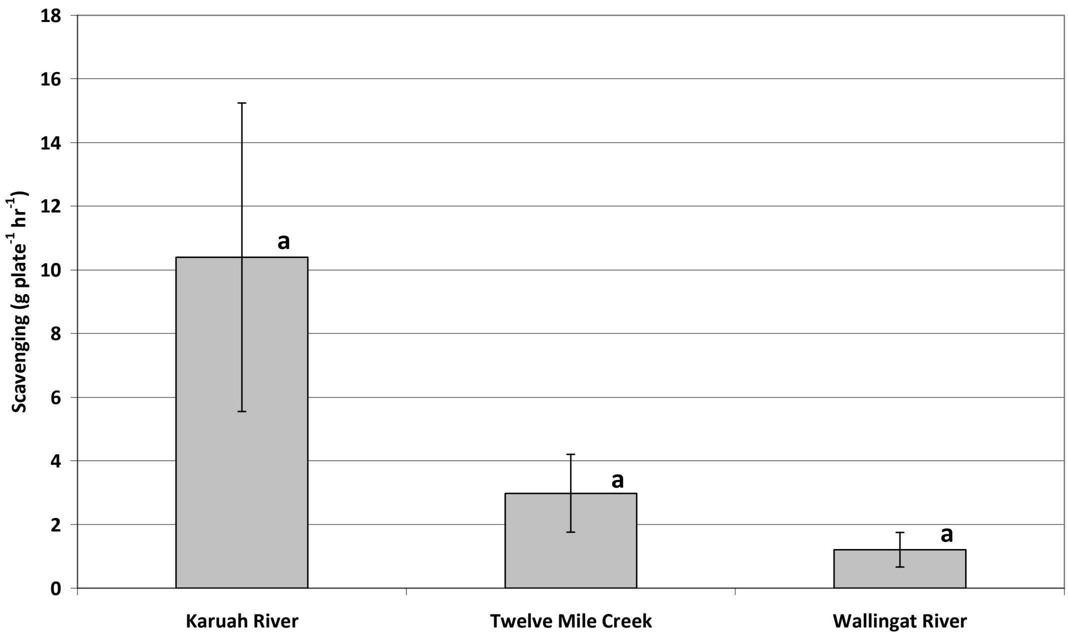

Figure 36. Mean rates of scavenging by micro-carnivores.
Different letters indicate means were statistically different (ANOVA, P<0.05).

3.2.5. Macro-Carnivore Scavenging

Hypothesis: The rate of macro-carnivore scavenging in the Karuah River does not differ from other control estuaries.

Was the hypothesis accepted or rejected? Accepted.

Macro-carnivore scavengers include fish, crustaceans, molluscs and worms. The rate of macro-carnivore scavenging is a measure of the levels of activity of upper trophic level organisms. There were no differences in the mean rate of macro-carnivore scavenging among estuaries (Figure 37), so the hypothesis was accepted.

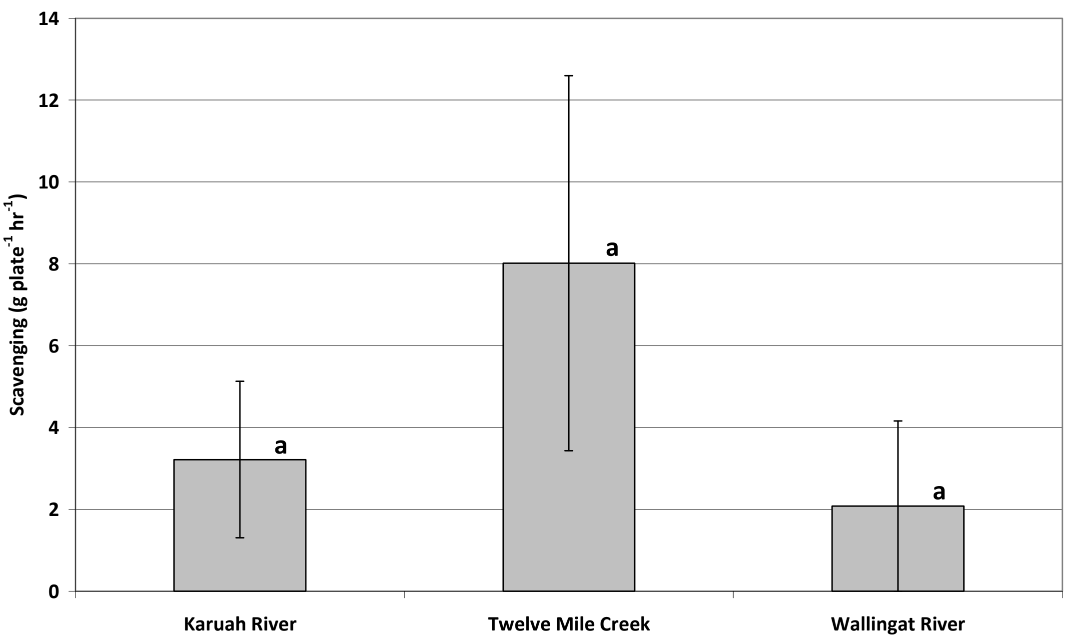

Figure 37. Mean rates of scavenging by macro-carnivores.
Different letters indicate means were statistically different (ANOVA, P<0.05).

3.3. Biological Stress

3.3.1. Fish Ulcers

Hypothesis: There is no difference between the frequency of ulcers in fish in the Karuah River and that of ***control estuaries.***

Was the hypothesis accepted or rejected? Accepted.

The occurrence of skin diseases and other conditions in fish has been linked to exposure to pollution or other stressors (Burkholder *et al.*, 1997, Noga, 2000, Tango *et al.*, 2006, Vethaak *et al.*, 2009). Therefore, the prevalence of ulcerations on fish can be an indicator of poor water quality in an estuary.

No ulcers or other significant damage were observed on fish sampled in the Karuah River estuary. The hypothesis was accepted because the prevalence of ulcers on fish was within the range observed in the control estuaries.

3.3.2. Mangrove Leaf Damage

Hypothesis: There is no difference in the frequency of leaf damage in the Karuah River compared with control estuaries.

Was the hypothesis accepted or rejected? Accepted.

The frequency of leaf herbivory in mangroves has been suggested as a possible indicator of environmental stress (Fairweather, 1999).

The occurrence of leaf damage in the Karuah River was not significantly different from that in either of the control estuaries, although it was significantly greater at Wallingat River than Twelve Mile Creek (Figure 38). PCA separated the three estuaries, indicating that the prevalence of different types of mangrove leaf damage in the Karuah River was not unusual when compared to control estuaries (Figure 39). The hypothesis was accepted because the prevalence of mangrove leaf damage was within the range of that found at the control estuaries.

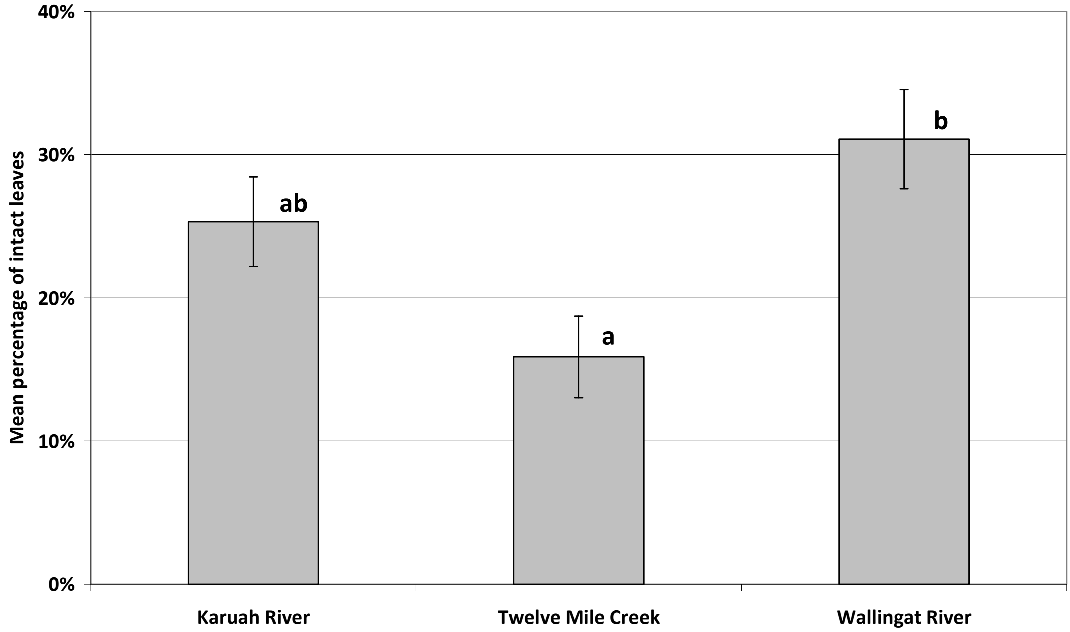

Figure 38. Mean percentage of intact leaves on branches collected from mangroves in the Karuah River and control estuaries.
Different letters indicate means were statistically different (ANOVA, P<0.05).

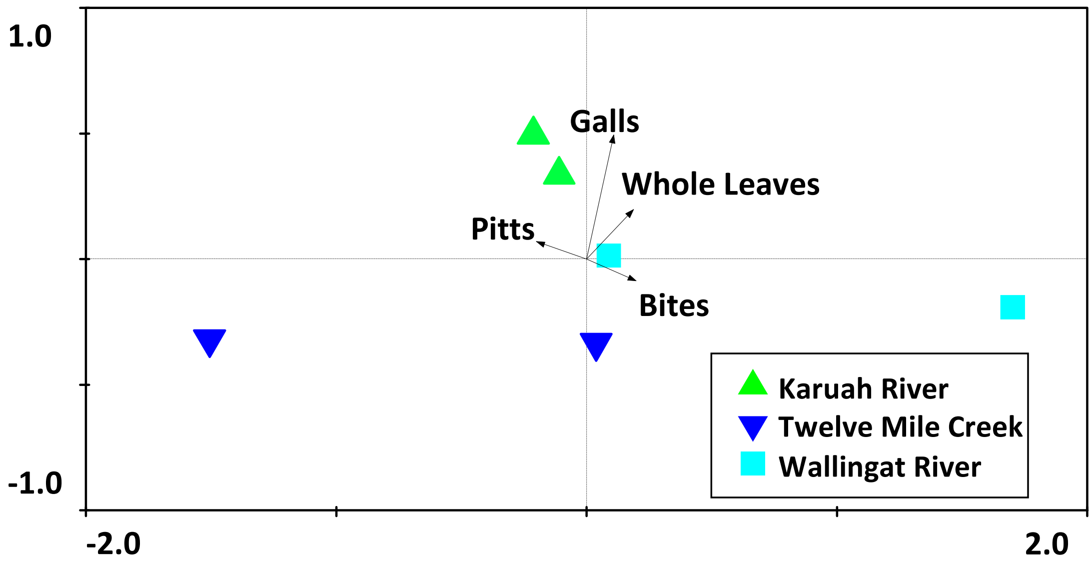

Figure 39. Principal components analysis plot representing the relative similarity of mangrove condition.

3.4. Pressures

3.4.1. Water Column Turbidity

Hypothesis: Turbidity levels in the Karuah River estuary are typically below the trigger values.

Was the hypothesis accepted or rejected? Rejected.

Turbidity, the 'cloudiness' of water, in estuaries has been shown to be positively correlated with catchment disturbance and nutrient loads (Scanes *et al.*, 2007) and is an indicator of light attenuation or the amount of light reaching deeper depths (ANZECC and ARMCANZ, 2000). Where waters have chronic high turbidity, very little light reaches the bed, so seagrass and benthic algae cannot survive (ANZECC and ARMCANZ, 2000). High turbidity is often caused by high concentrations of suspended sediment in the water column (Scanes *et al.*, 2007), which can adversely affect fish and macroinvertebrates and smother seagrasses and benthic algae (ANZECC and ARMCANZ, 2000). So, turbidity is a good measure of the pressures of low light and suspended sediment in an estuary.

Median turbidities exceeded the trigger at all sites except K1 (Table 8), Pass rates for sites (i.e. the proportion of samples that were below the trigger value) ranged from 0 to 60% and the overall pass rate was only 30% (Table 8). Although there was substantial temporal variability, mean turbidity levels were far greater than the trigger values at all sites (Figure 40). Mean turbidity levels ranged from 24 to 31 at upper estuary sites, K1 to K4, well in excess of the trigger value of 6.5 for the upper reaches of riverine estuaries (Figure 40). Similarly, mean turbidity levels of middle and lower estuary sites, K5 to K7, ranged from 16 to 33, many times greater than the trigger value of 1.9 (Figure 40). Mean turbidities were much greater than medians because turbidities were much higher during two of the sampling events.

Table 8. Median water column turbidities in the Karuah River estuary.
Comparison with trigger values.

Site	Median turbidity	Trigger value	Pass rate
K1	2.5	6.5	60%
K2	19.1 x	6.5	50%
K3	19.3 x	6.5	50%
K4	20.7 x	6.5	50%
K5	13.7 x	1.9	0%
K6	11.1 x	1.9	0%
K7	7.9 x	1.9	0%
All			30%

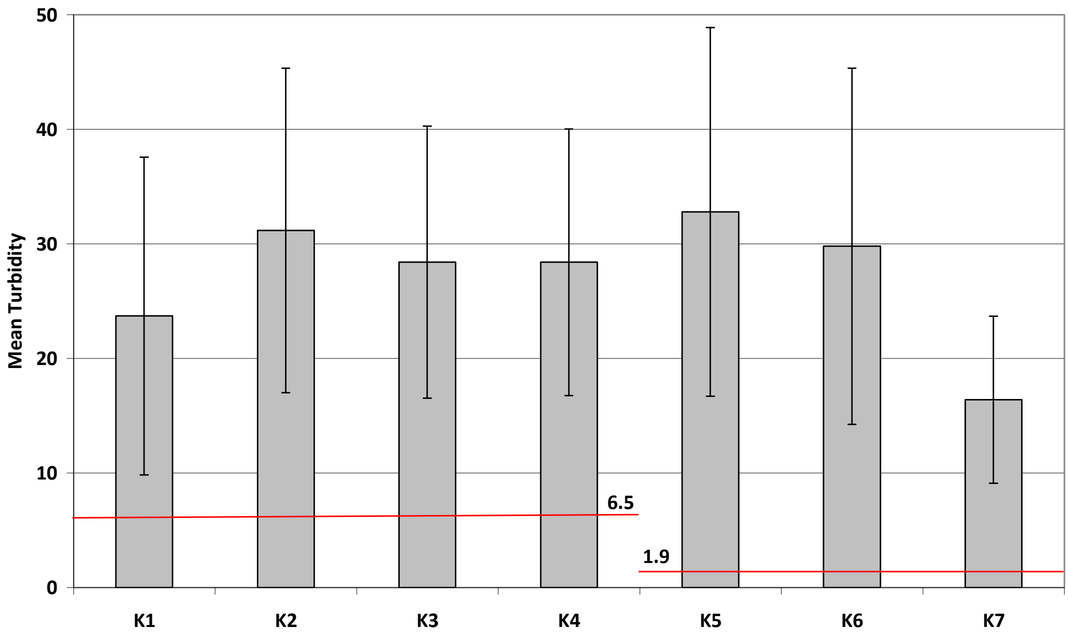

Figure 40. Mean turbidity at Karuah River estuary sites.
Red lines indicate trigger values. Specific trigger values are labelled above lines. Sites K1 to K4 were upper estuary sites, sites K5 and K6 were middle estuary sites and site K7 was located in the lower estuary.

The hypothesis was rejected because the median turbidities exeeded the trigger at the majority of sites. These very high turbdities are of great concern and should be a major focus any future management plan or monitoring programme. The causes of high turbidity in the Karuah River need to be identified so resources can be directed towards better management.

3.4.2. Water Column Nutrient Concentrations

Hypothesis: Nutrient concentrations in the Karuah River estuary are typically below the trigger values.

Was the hypothesis accepted or rejected? Rejected

High concentrations of nitrogen and phosphorus in estuaries can profoundly influence estuarine ecology by stimulating excess growth of phytoplankton and macroalgae, causing shifts in food web structure and, in the worst cases, even depleting dissolved oxygen concentrations, releasing toxins from sediments and causing fish kills (ANZECC and ARMCANZ, 2000, Camargo and Alonso, 2006). Therefore, water column concentrations of nutrients can be good indicators of environmental pressures affecting the ecological condition of an estuary.

The variability of nutrient concentrations at each site was quite high, but there were some patterns evident (Figures 41, 42, 43, 44 & 45). Nutrient concentrations in the Karuah River estuary were generally greater than the trigger values. In particular, median concentrations of both total phosphorus and phosphate (DIP) were greater than the triggers at all sites (Table 9). In fact, concentrations of TP and DIP were in excess of the trigger in all samples from all of the sites (Table 10). Median concentrations of all nutrient fractions except oxides of nitrogen were greatest at site K3, in The Branch River reach of the estuary (Table 9). Median concentrations of all nutrient fractions exceeded the trigger values at sites K3 and K4 (Table 9). Contrastingly, median oxides of nitrogen concentrations were amongst the lowest at site K3, but were greatest at site K2, located on the main branch of the Karuah River upstream of the confluence with The Branch River (Table 9). Median concentrations of all nutrient fractions were lowest at site K7, the most downstream site, located near Karuah (Table 9).

The median molar ratios of dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) were less than the lower limit trigger value at all sites (Table 9). Median DIN to DIP ratios were greatest (9.4) at the most upstream site, K1, decreased rapidly to 5.6 at site K2, upstream of the confluence with The Branch River, and ranged from 4.0 and 4.7 at sites in The Branch River reach and the lower Karuah River Estuary, sites K3 to K7 (Table 7; Figure 46). No samples from any of the sites were greater than the lower limit pass rate for DIN to DIP ratios (Table 10). This indicated that ratios were outside the 'safe' range and were at risk of stimulating algal growth. This was largely due to the very high phosphate concentrations, as demonstrated by the 0% pass rate for phosphate (Table 10).

Table 9. Median nutrient concentrations in the Karuah River estuary.
Comparison with OEH draft nutrient trigger values for riverine estuaries. Values in bold italics were the lowest and those underlined were the greatest among sites. An "x" indicates that the median was greater than the upper limit or less than the lower limit trigger value.

	TN	**Ammonium**	**NO_x**	**TP**	**Phosphate**	**DIN:DIP**
	(µg L^{-1})	(µg L^{-1})	(µg L^{-1})	(µg L^{-1})	(µg L^{-1})	(molar)
Trigger value	>516	>34	>24	>13	>3.5	<50 or >200
K1	442	25	53 x	33 x	16 x	9.4 x
K2	571 x	24	54 x	54 x	22 x	5.6 x
K3	678 x	39 x	25 x	62 x	26 x	4.4 x
K4	605 x	38 x	27 x	55 x	25 x	***4.0*** x
K5	543 x	30	39 x	50 x	24 x	4.4 x
K6	463	29	31 x	44 x	21 x	4.7 x
K7	***326***	***17***	***22***	***32*** x	***16*** x	4.3 x

Table 10. Proportion of samples from sites in the Karuah River estuary that were below upper limit and above lower limit triggers.

	TN	Ammonium	NO_x	TP	Phosphate	DIN:DIP
K1	60%	80%	40%	0%	0%	0%
K2	50%	83%	33%	0%	0%	0%
K3	50%	33%	50%	0%	0%	0%
K4	50%	33%	50%	0%	0%	0%
K5	50%	50%	33%	0%	0%	0%
K6	50%	67%	33%	0%	0%	0%
K7	67%	67%	67%	0%	0%	0%
All	54%	59%	44%	0%	0%	0%

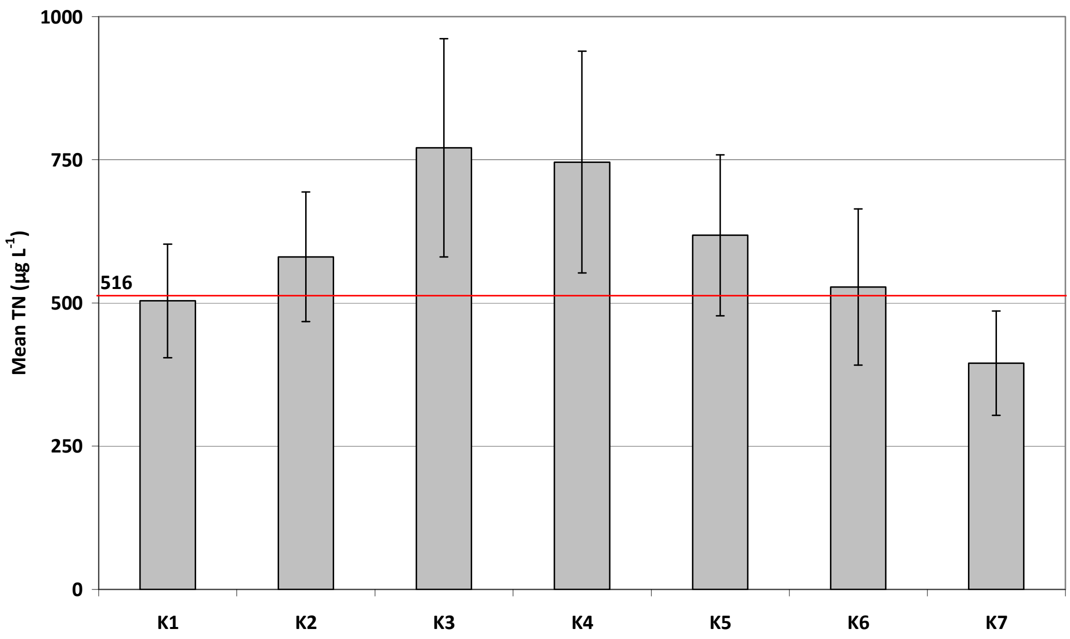

Figure 41. Mean total nitrogen concentrations at Karuah River estuary sites.
The red line indicates the trigger value and the specific value is labelled above the line.

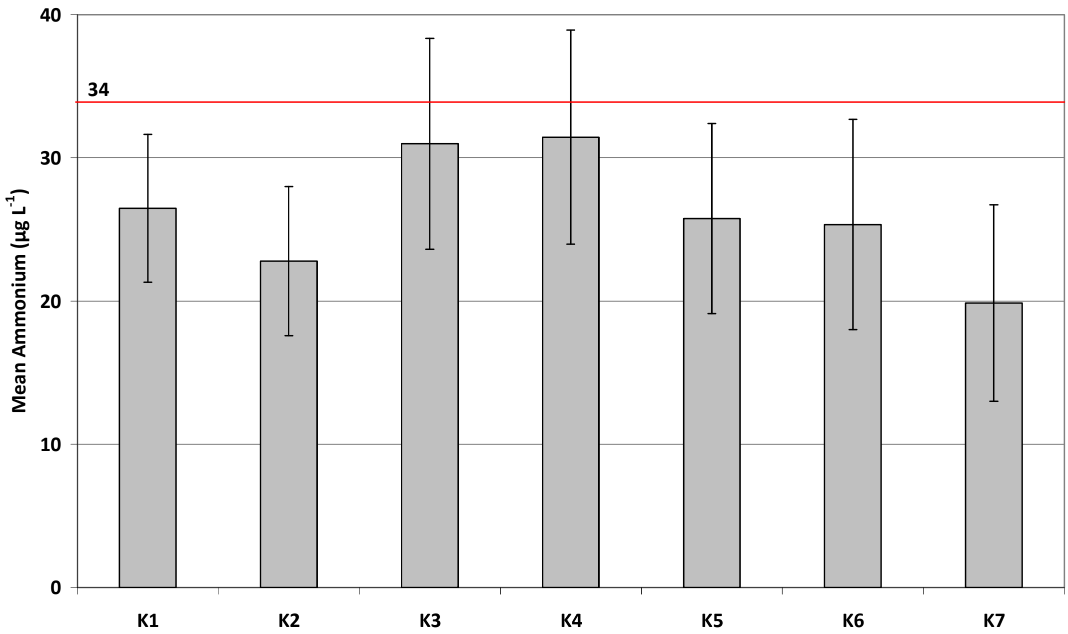

Figure 42. Mean ammonium concentrations at Karuah River estuary sites.
The red line indicates the trigger value and the specific value is labelled above the line.

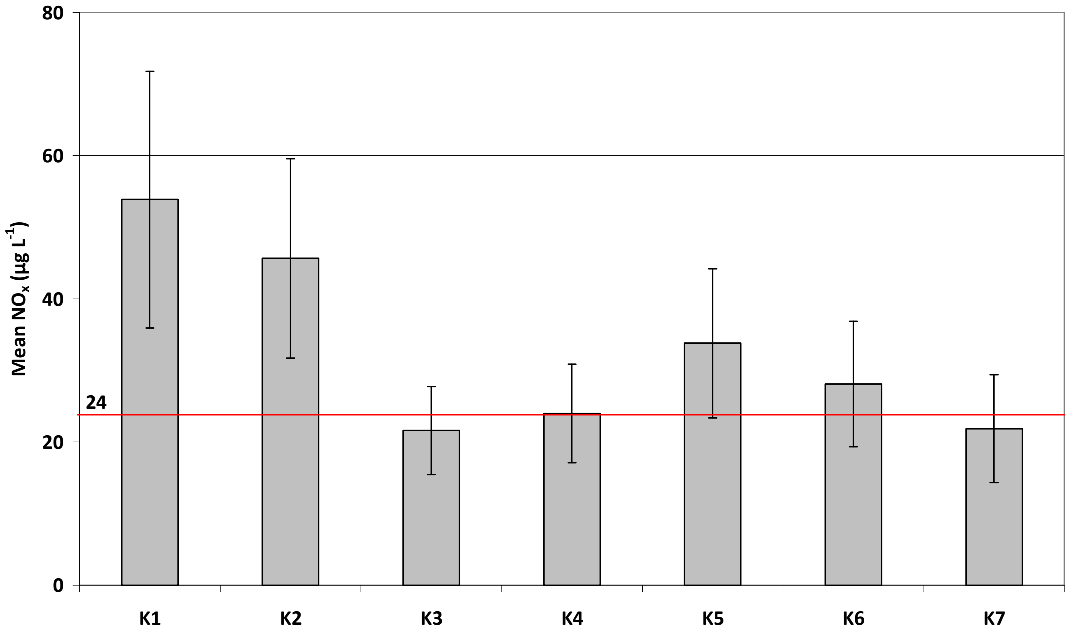

Figure 43. Mean concentrations of oxides of nitrogen at Karuah River estuary sites.
The red line indicates the trigger value and the specific value is labelled above the line.

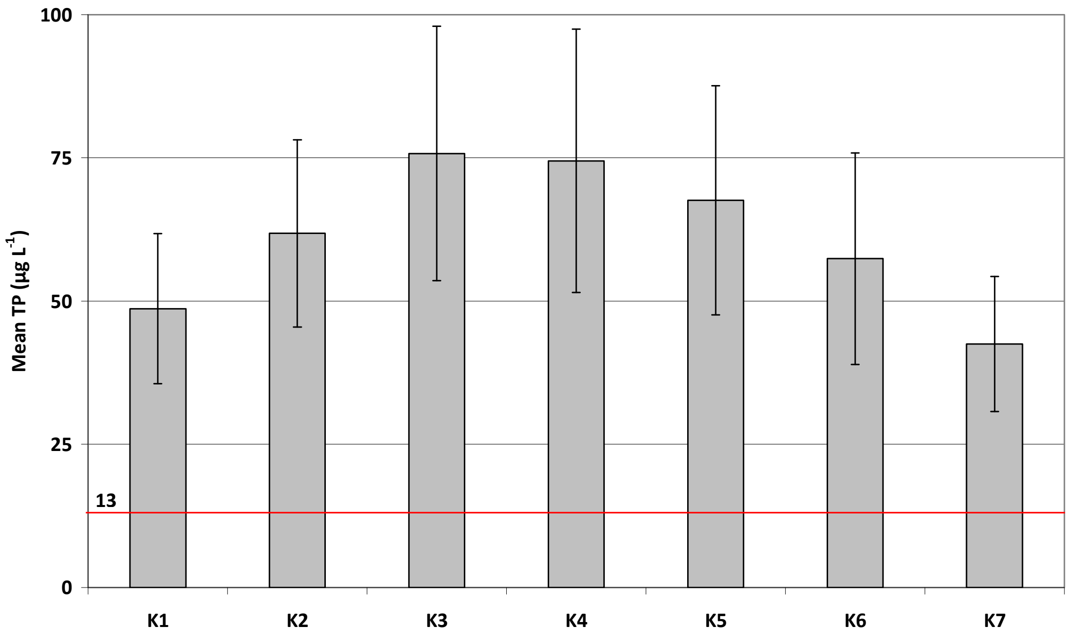

Figure 44. Mean total phosphorus concentrations at Karuah River estuary sites.
The red line indicates the trigger value and the specific value is labelled above the line.

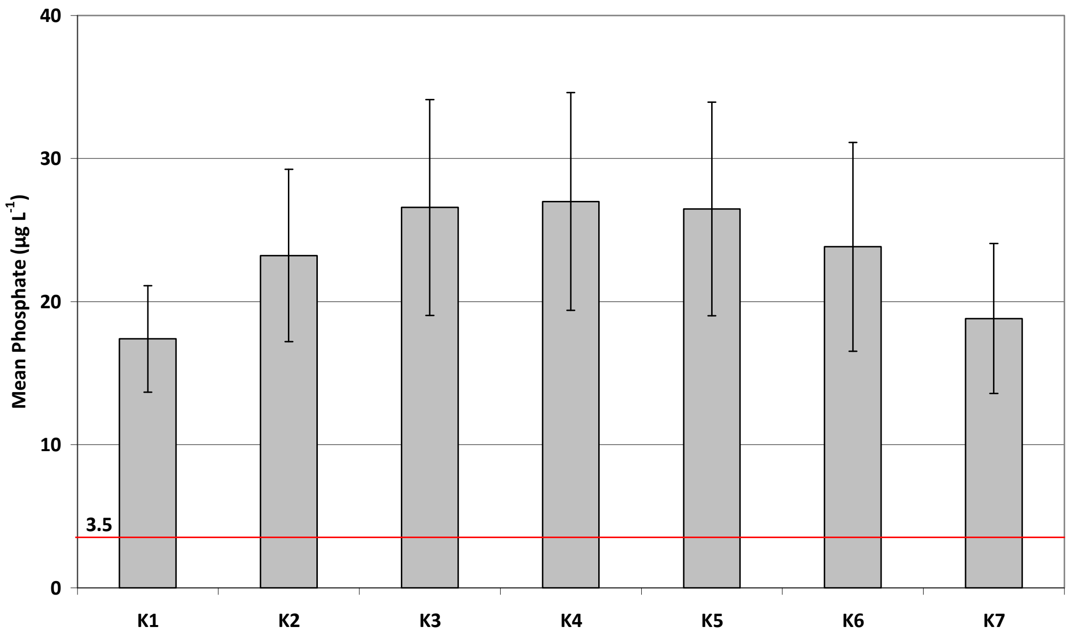

Figure 45. Mean phosphate concentrations at Karuah River estuary sites.
The red line indicates the trigger value and the specific value is labelled above the line.

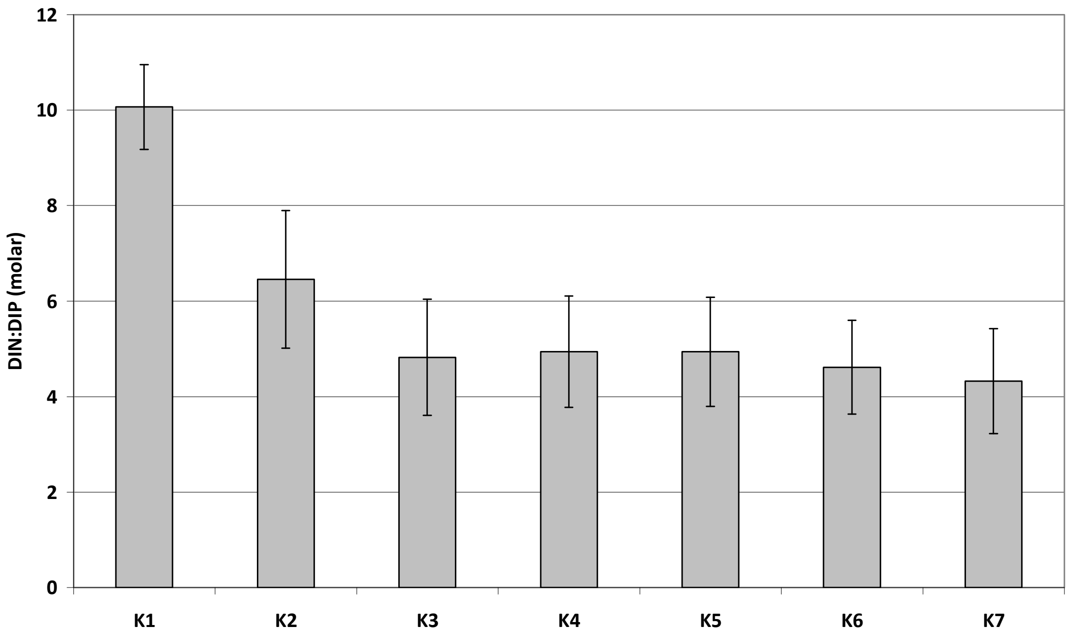

Figure 46. Mean molar DIN to DIP ratio at Karuah River estuary sites.
The lower limit trigger value is not indicated on the plot as it is far greater (lower limit trigger = 50) than the ratios observed.

The high nutrient concentrations observed, particularly in The Branch River reach at sites K3 and K4, are grounds for concern. The vast majority of nutrients were in non-labile forms, such as particulates and organics, and are generally not bioavailable (Figures 47 & 48). Even so, median concentrations of labile nutrients, such as phosphate, ammonium and oxides of nitrogen, exceeded the trigger values. Concentrations of ammonia exceeded the trigger in two thirds of samples from sites K3 and K4. Ammonia is readily oxidised to nitrate and nitrite. So the high concentrations of ammonia are indicative of a local source of nitrogen.

The ratios of DIN to DIP were very low, meaning that bioavailable phosphorus (i.e. phosphate) is in high concentrations relative to bioavailable nitrogen. These low DIN to DIP ratios, mainly due to high phosphate concentrations, indicate that the Karuah River estuary is strongly at risk of excess algal growth. Given suitable light and temperature conditions, there is a risk of eutrophication in the estuary.

The hypothesis was rejected due to the very high concentrations of nutrients and low DIN to DIP ratios in the estuary.

The pattern of higher nitrogen and phosphorus concentrations and the higher concentrations of ammonia in The Branch River reach indicate that there is a substantial nutrient input to the estuary in this reach. Future monitoring and management should include a strong focus on this section of the estuary and catchment.

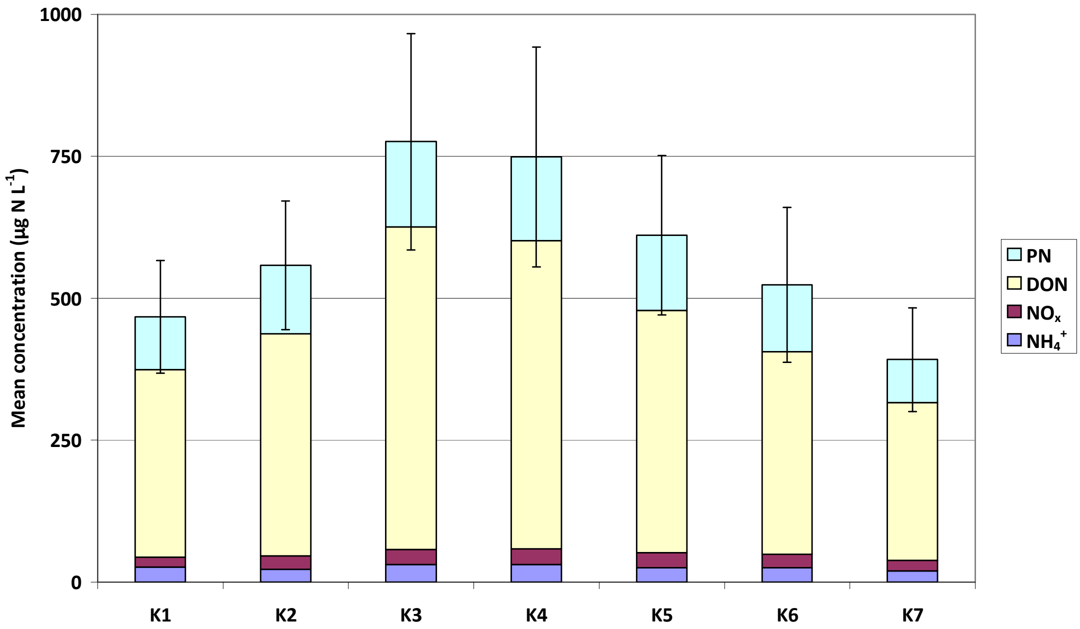

Figure 47. Mean concentrations of nitrogen fractions in the Karuah River estuary.
Error bars indicate standard errors around the mean for total phosphorus concentrations. Particulate Nitrogen (PN), Dissolved Organic Nitrogen (DON), Oxides of Nitrogen (NO_x) and Ammonia/Ammonium (NH_4^+).

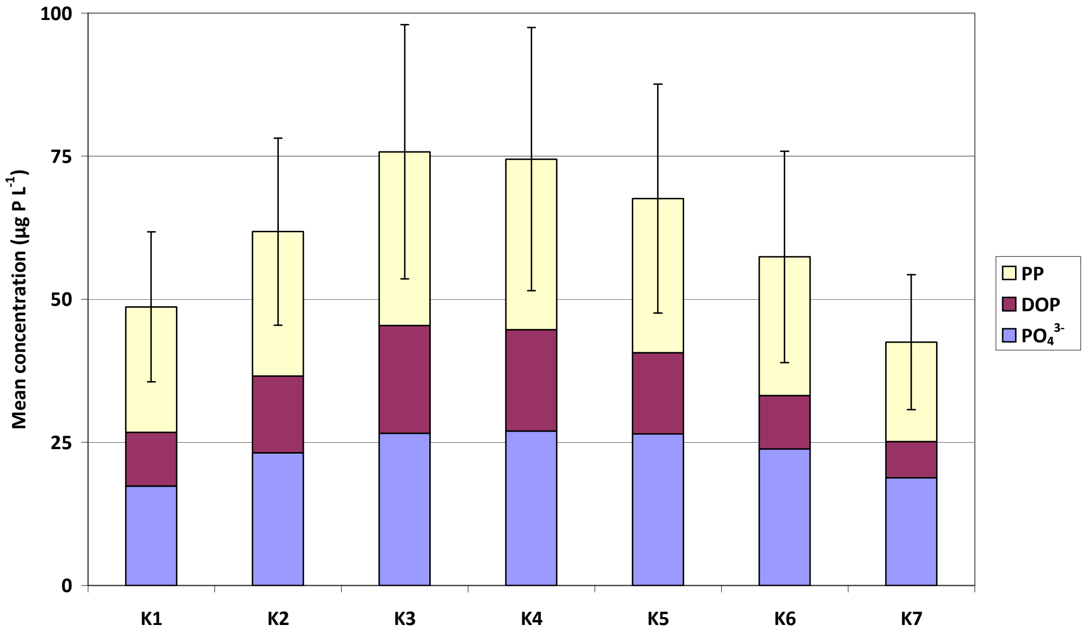

Figure 48. Mean concentrations of phosphorus fractions in the Karuah River estuary.
Error bars indicate standard errors around the mean for total nitrogen concentrations. Particulate Phosphorus (PP), Dissolved Organic Phosphorus (DOP) and Phosphate (PO_4^{-3}).

3.4.3. Nutrients and Turbidity in Surface Runoff

Hypothesis 1: Nutrient concentrations in runoff in the Karuah River catchment are typically below the trigger values at all sites.

Was the hypothesis accepted or rejected? Rejected.

Hypothesis 2: Turbidity levels in runoff in the Karuah River catchment are typically below the trigger values at all sites.

Was the hypothesis accepted or rejected? Rejected.

High nutrient concentrations and turbidity can be detrimental to the ecological 'health' of streams and rivers (ANZECC and ARMCANZ, 2000). For example, elevated nutrient concentrations can trigger algal blooms, which in some cases can lead to depletion of oxygen resulting in mortality of fish and other aquatic organisms (ANZECC and ARMCANZ, 2000), while the high concentrations of suspended particles associated with high turbidity can directly impact upon fish and other aquatic organisms by smothering their gills, preventing oxygen uptake (Boulton and Brock, 1999). Nutrients and suspended particles in coastal streams and rivers are also, of course, largely destined for estuaries, so are indicative of pressures on the ecology of both streams and their estuarine receiving waters.

Of the five sub-catchments sampled, sub-catchment 3 (Upper Karuah River) had the lowest median total nitrogen (TN) concentration and was the only one where more than 40 percent of samples had concentrations below the ANZECC trigger value, having a pass rate of 75 percent (Tables 11 & 12; Figure 49a). Samples from sub-catchment 1 (Limeburners Creek) and sub-catchment 4 (Wards River and Mammy Johnsons River), passed in 17 and 25 percent of cases respectively, while no samples from sub-catchment 2 (Ramstation Creek) or sub-catchment 5 (The Branch River) were below the trigger for TN (Figure 49a). Noteably, the median TN concentration for sub-catchment 5 was at least 3 to 4 times greater than any other sub-catchment (Table 11). Sub-catchments 4 and 5 were the only sub-catchments where median ammonium concentrations exceeded the ANZECC trigger value, with pass rates of 50% and 25% respectively (Tables 11 & 12; Figure 49b). The general pattern for concentrations of oxides of nitrogen (NO_x) was quite different to that for TN or ammonium, sub-catchment 3 being the only sub-catchment where the median concentration exceeded the ANZECC trigger value with a pass rate of only 25% (Tables 11 & 12; Figure 49c).

Sub-catchments 4 and 5 were the only sub-catchments where the median total phosphorus (TP) concentrations exceeded the ANZECC trigger value, but all sub-catchments other than sub-catchment 3 had pass rates of less than 60% (Tables 11 & 12; Figure 49d). Median TP concentrations were particularly high for sub-catchment 5, being more than 3 times greater than any other sub-catchment and having a pass rate of 0% (Tables 11 & 12; Figure 49d). Phosphate concentrations were generally low, except for sub-catchment 5 where the median concentration exceeded the ANZECC trigger value and where the pass rate was 50% (Tables 11 & 12; Figure 49e).

Median turbidity levels were greater than the OEH trigger value and pass rates were generally low for all sub-catchments (Tables 11 & 12; Figure 49f). Sub-catchment 1 had lowest pass rate, 0%, but sub-catchment 5 had the greatest median turbidity, 45, more than double the trigger value (Tables 11 & 12; Figure 49f).

Table 11. Median nutrient concentrations and turbidity levels for runoff in the Karuah River catchment.

Comparison with trigger values. Values in bold italics were the lowest and those underlined were the greatest among sites. An “x” indicates that the median was greater than the upper limit or less than the lower limit trigger value. [a] ANZECC trigger value [b] OEH trigger value

Sub-catchment	TN (µg L^{-1})	Ammonium (µg L^{-1})	NO_x (µg L^{-1})	TP (µg L^{-1})	Phosphate (µg L^{-1})	Turbidity
Trigger	500 [a]	20 [a]	40 [a]	50 [a]	20 [a]	6.6 [b]
SC1	635 x	***8***	***10***	47	***7***	18 x
SC2	621 x	15	27	49	12	8 x
SC3	***337***	12	56 x	***30***	10	***6***
SC4	543 x	21 x	34	53 x	14	12 x
SC 5	2070 x	33 x	19	179 x	22 x	45 x

Table 12. Proportion of samples from sites in the Karuah River catchment that were below triggers.

Sub-catchment	TN	Ammonium	NO_x	TP	Phosphate	Turbidity
SC1	17%	100%	100%	50%	100%	0%
SC2	0%	75%	75%	50%	100%	50%
SC3	75%	75%	25%	75%	100%	50%
SC4	25%	50%	75%	50%	75%	25%
SC5	0%	25%	75%	0%	50%	17%
All	23%	65%	70%	45%	85%	28%

Overall sub-catchment 5, essentially The Branch River sub-catchment, had a very poor pass rate for all variables except NO_x. Ammonium is readily oxidised to nitrate and nitrite, so the high concentrations of ammonium in sub-catchments 4 and 5 indicate that there were ammonium sources close to the sampling sites. Sub-catchments 1 and 3, Limeburners Creek and the Upper Karuah River, had generally the lowest nutrient concentrations with the exception of TN in the case of sub-catchment 1 and NO_x in the case of Sub-catchment 3.

Previous studies have investigated turbidity and/or nutrient concentrations in streams of the Karuah River catchment. For example, in 1995 a review of existing data, for the Karuah River catchment upstream of Booral, found that TP concentrations exceeded the ANZECC trigger in 90 to 100% of samples collected from sites on the Karuah River between Stroud Road (Sampled at the same site as sub-catchment 3 in the current study) and Booral (Not sampled in the current study, Bishop, 1995). TP exceedences were 50% in the upper reaches of the Karuah River (In the upper part of sub-catchment 3 in the current study) and were “moderate” in Mammy Johnsons River (Similar area to sub-catchment 4 in the current study, Bishop, 1995). Bishop (1995) stated that high TP concentrations in the Karuah River near Stroud Road corresponded to the location of heavy application of chicken litter in the 1980s and extensive aerial application of super phosphate in the 1970s. Similarly, the high TP concentrations in the river near Booral corresponded to substantial chicken litter applications on paddocks adjacent to the river, but also the presence of a large number of poultry sheds and inputs from the Stroud sewage treatment plant upstream of this reach (Bishop, 1995). According to Bishop (1995), exceedences for total suspended solids concentrations were very high at most sites.

Bishop (1995) also described a major cyanobacterial (blue-green algal) bloom in the freshwater reaches of the Karuah River, in November-December 1994 (Bishop, 1995). This indicates that there might be a history of excess nutrient concentrations in the river. In fact, Bishop (1995) suggests that releases from the Stroud sewage treatment plant would have brought the TN and TP concentrations up to 2.3 and 2.5 mg L^{-1} respectively in the month preceding the bloom. These concentrations are more than four times the ANZECC trigger value for TN and, astoundingly, 50 times the trigger for TP.

The 2010 State of the Catchments Report found that total phosphorus and turbidity exceedences in the Karuah River at Booral were 44% and 58% respectively (DECCW, 2010). This suggests a reduction in TP concentrations between 1995 and 2010, perhaps at least in part due to the upgrade to the Stroud sewage treatment plant in 2009.

These earlier studies focused on the catchment upstream of Booral and did not include either Limburners Creek (sub-catchment 1) or The Branch River (sub-catchment 5). Both these sub-catchments and that of Ramstation Creek had very high concentrations of TN in the current study, while The Branch River in particular had very high TP concentrations. Any future monitoring should include these sub-catchments so as to track future trends in nutrient concentrations and further investigation should be undertaken to identify major sources of nutrients.

Limited turbidity data were also collected from stream sites in coastal catchments between 1994 and 2010 as part of the OEH Coastal Macroinvertebrate Monitoring Programme. At sites in the Karuah River catchment, mean turbidity levels were well below the OEH trigger value of 6.6 coastal rivers and significantly less than at sites in the nearby Myall River/Boolambayte Creek and Wallamba/Wang Wauk River catchments (Figure 50). These data contrast somewhat with those reported by Bishop (1995) and DECCW (2010). This is probably because the macroinvertebrate sampling was only carried out during low flow conditions, when turbidity was lowest. The data is, however, useful in allowing a comparison of low flow turbidity levels in the Karuah River catchment and other nearby catchments.

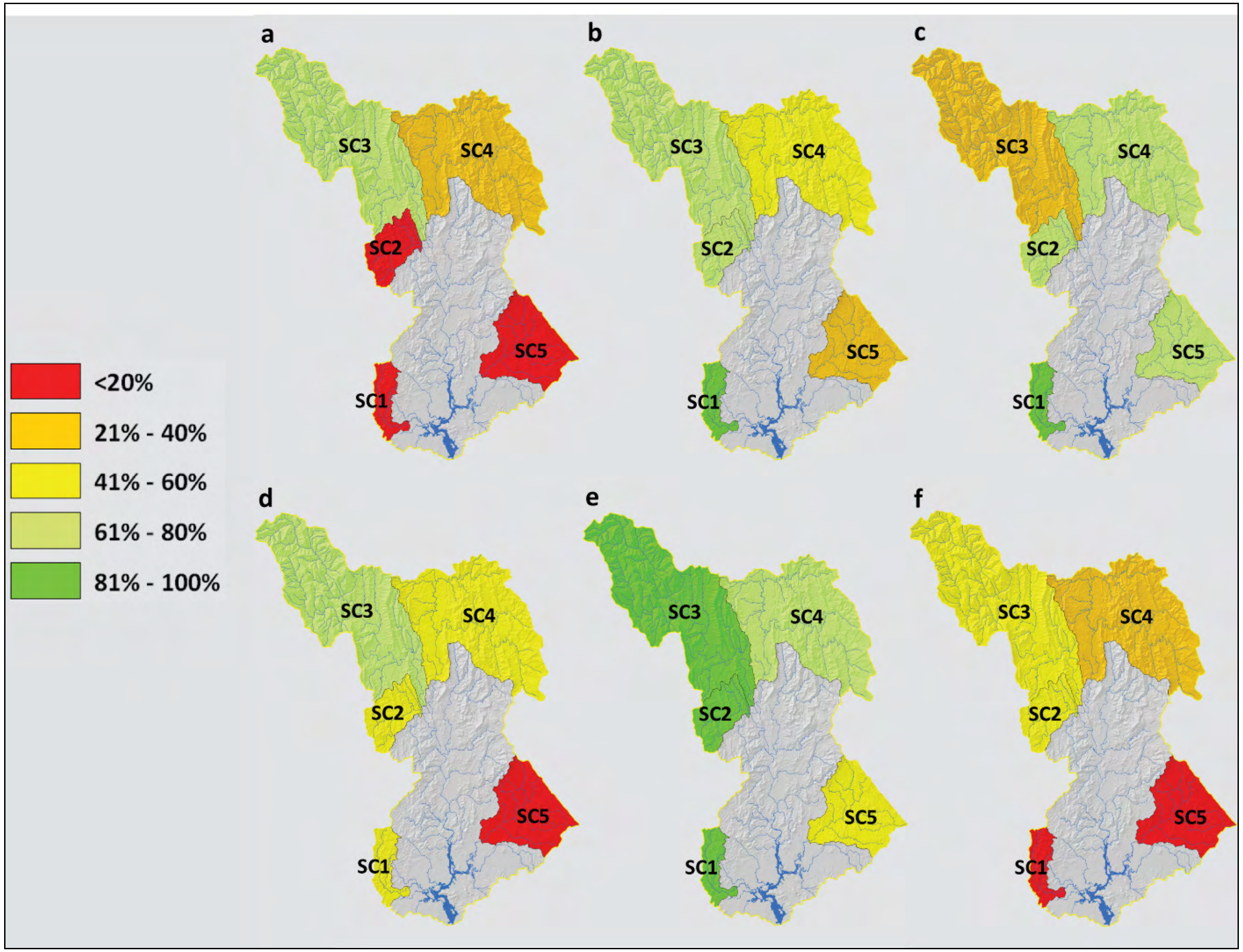

Figure 49. Proportion of runoff samples from selected sub-catchments with nutrient concentrations and turbidity levels below the trigger value.
a) Total nitrogen; b) Ammonium; c) Oxides of nitrogen; d) Total phosphorus; e) Phosphate; f) Turbidity; Sub-catchments are labelled SC1 to SC5.

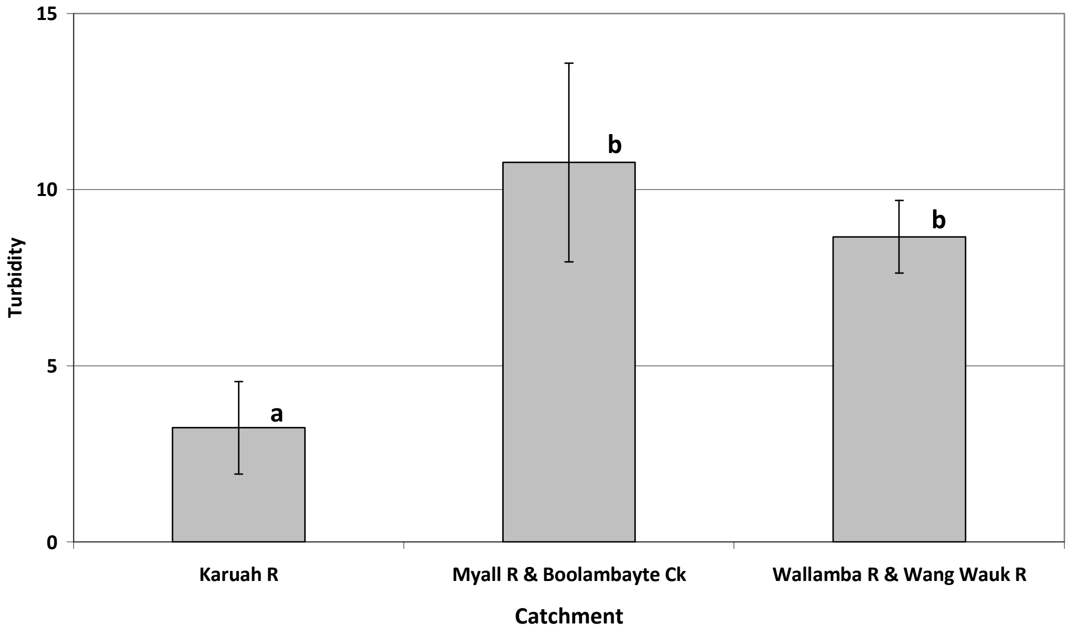

Figure 50. Mean turbidity at macroinvertebrate sampling sites, 1994 to 2010.
Different letters indicate means were statistically different ($P<0.05$). Data collected by OEH as part of the Coastal Macroinvertebrate Monitoring Programme.

The total diffuse source loads of TN, TP and TSS in the Karuah River catchment, calculated using CERAT, were 216, 22 and 3,548 t yr^{-1} respectively (Table 13). There were similarities between the patterns of TN, TP and TSS generation rates (Figures 51, 52 & 53). Generally, rates were highest in the southeast, in The Branch River sub-catchment, and in the northwest, in the Upper Karuah River sub-catchment (Figures 51, 52 & 53). There were also some areas in the centre of the catchment, near Booral, and in the northeast, near Terreel, with high generation rates (Figures 51, 52 & 53).

Table 13. Total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) loads for the Karuah River catchment.

	TN	TP	TSS
Load (t yr^{-1})	216	22	3,548

In the current study, runoff was not sampled in the central part of the catchment so comparisons cannot be made with the CERAT generation rates in this area. In other parts of the catchment, there were some parallels between patterns in the CERAT generation rates and those observed in nutrient concentrations and turbidity in surface runoff. Specifically, the nutrient and sediment generation 'hotspot' observed in The Branch River sub-catchment, in the CERAT data, was located within watershed 5, where the highest nutrient concentrations and turbidity were observed in runoff (Figures 49, 51, 52 & 53). The relatively high concentrations of nutrients observed in runoff from watershed 2, Ramstation Creek, correspond with part of the 'hotspot' in the north-western part of the catchment in the CERAT data (Figures 49, 51, 52 & 53). In contrast, low concentrations of nutrients were observed in runoff from watershed 3, the Upper-Karuah River, which also includes part of the northwest 'hotspot' in the CERAT data (Figures 49, 51, 52 & 53).

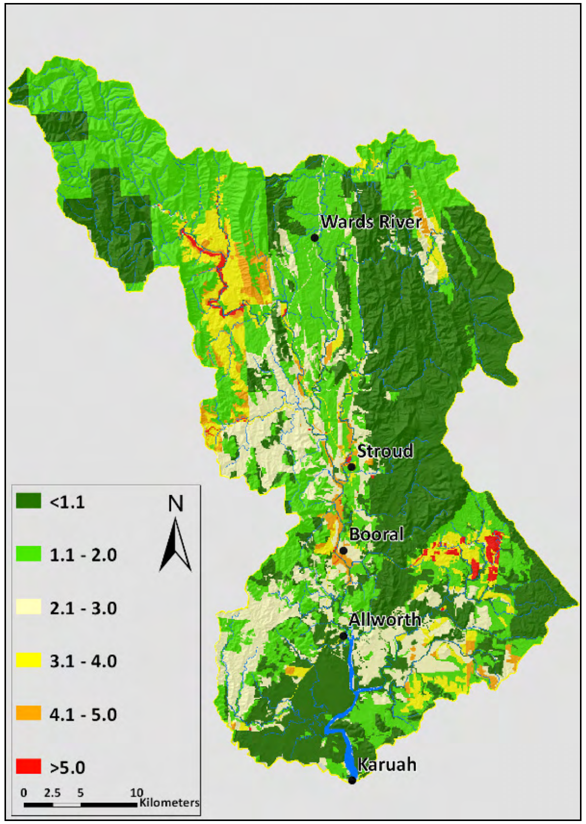

Figure 51. Total nitrogen generation rates in the Karuah River catchment (kg ha yr^{-1}).
(OEH, 2012)

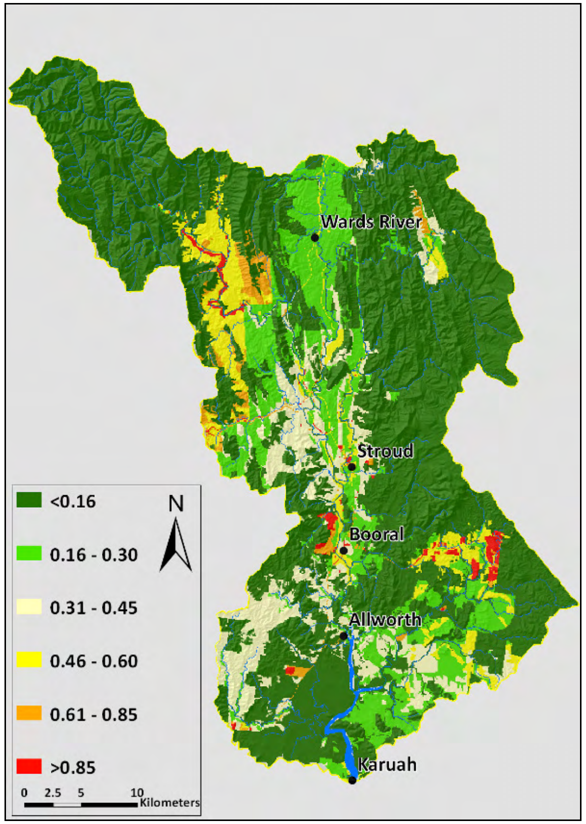

Figure 52. Total phosphorus generation rates in the Karuah River catchment (kg ha yr^{-1}).
(OEH, 2012)

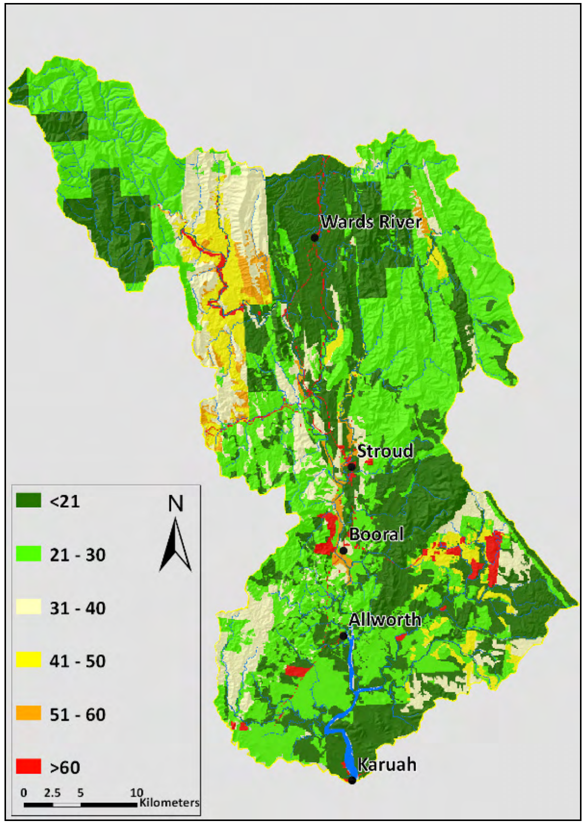

Figure 53. Total suspended solids generation rates in the Karuah River catchment (kg ha yr^{-1}).
(OEH, 2012)

Hypothesis 1 was rejected because the median TN concentrations exceeded the triggers at most sites and median concentrations of all other nutrient fractions exceeded the triggers in at least one sub-catchment. Hypothesis 2 was rejected because the median turbidity levels exceeded the trigger for four of the five sub-catchments.

The generally elevated total nitrogen concentrations and turbidities are concerning and water quality was very poor in The Branch River in particular. The Branch River was also identified as a nutrient and sediment generation ‘hotspot’ in the CERAT model outputs, but other areas, particularly in the northwestern and central parts of the catchment were also identified as hotspots. Targetted monitoring of turbidity and nutrient concentrations, with particular focus on these areas, is recommended. The information generated will help to inform catchment management decisions and prioritise resource allocation.

3.4.4. Catchment Landuses

Hypothesis: Most of the Karuah River catchment is composed of landuses that do not typically have high rates of nutrient and sediment generation.

Was the hypothesis accepted or rejected? Accepted.

The degree of catchment disturbance (e.g. clearing of forest) is negatively correlated with estuary condition (Scanes *et al.*, 2007). Some agricultural and urban landuses have very high nutrient and sediment generation rates, constituting a significant pressure on estuaries and the rivers and streams that flow into them and contributing to the risk of eutrophication. Therefore the proportional area of these nutrient and sediment generating landuses is a measure of pressure on waterways.

Lands with tree and shrub cover comprise 64% of the Karuah River catchment. The remainder is overwhelmingly grazing land (33%) with small areas of rural residential (1%), some wetlands (0.6%) and very small areas of other landuses (1.4%) (Figures 54 & 55). There are a number of intensive poultry farms and several aquaculture farms in the Karuah River catchment, which could potentially constitute significant point sources for nutrients. Sewage from Karuah and Stroud constitute potential significant sources of nutrients in the catchment, but an effluent reuse scheme was implemented in Karuah in 2003 and a new and improved sewage treatment plant and reuse scheme was opened in Stroud in 2009. Hence, releases from STPs are unlikely to contribute significant nutrient loads.

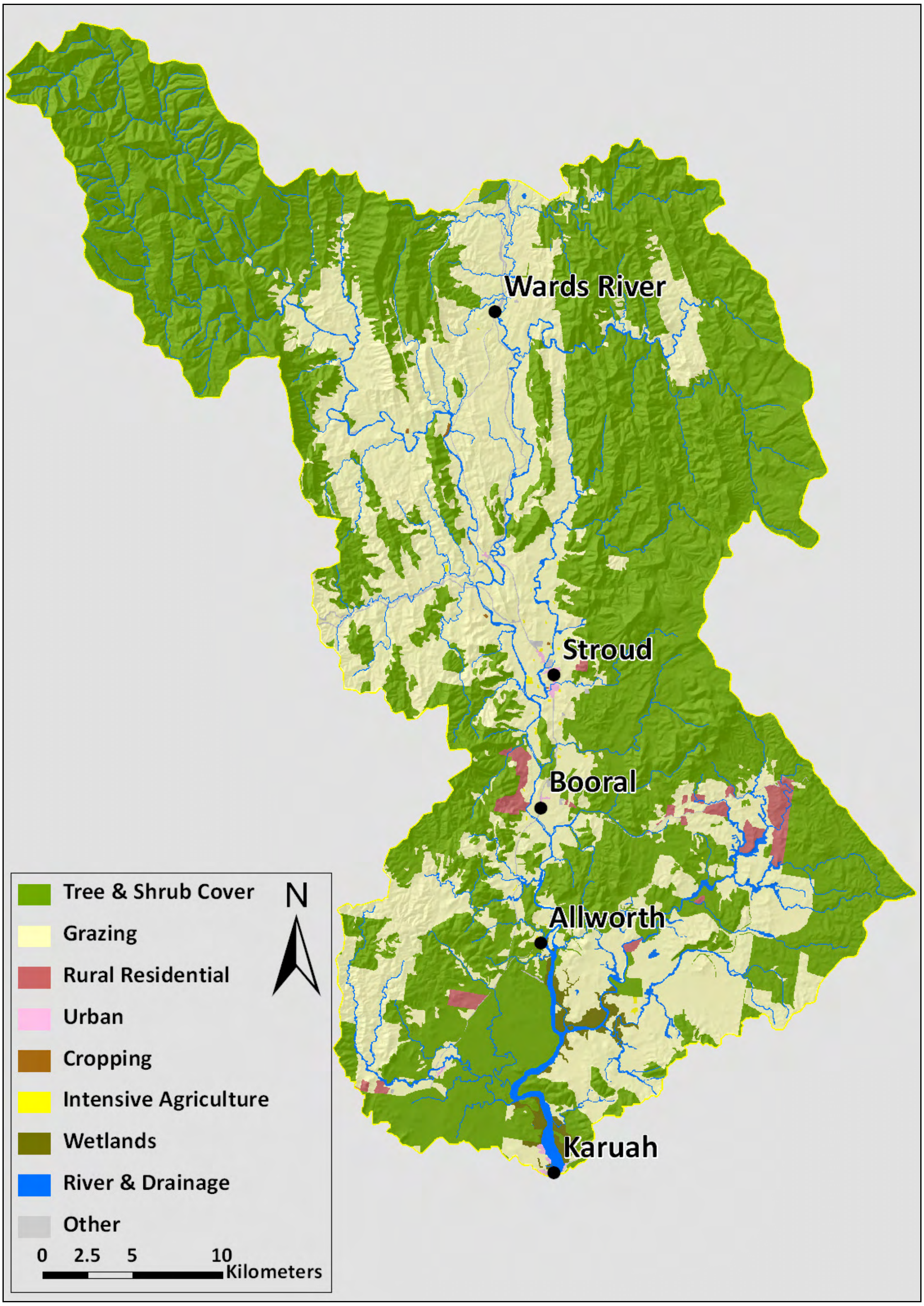

Figure 54. Landuses in the Karuah River catchment.
After DECC (2007).

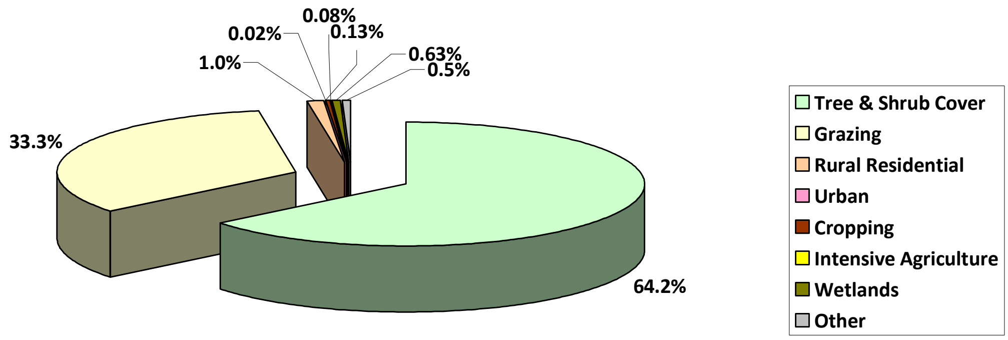

Figure 55. Proportional coverage of landuses in the Karuah River catchment.
After DECC (2007).

3.5. Estuarine Site Grades

The ecological condition of Karuah River estuary sites were also scored using a combination of the proportion of, and extent to which, turbidity and chlorophyll *a* concentrations exceeded triggers. These scores were then converted to grades based on how they compared to scores for similar estuaries in New South Wales (Table 14).

Table 14. Explanation of site grading system.

Grade	Result	Description
A	Excellent	The highest 20% of scores in the state
B	Good	Next 20 % of high scores
C	Fair	Middle 40% of scores
D	Poor	Lower 15 % of scores
F	Fail	Lowest 5 % of scores

All sites were graded F for turbidity and ranged from A to B for chlorophyll *a* (Table 15). The combined grade for all sites and, in fact, the entire estuary was C (Table 15) indicating moderate condition. This somewhat belies the true condition of the estuary as algal growth is likely to be inhibited by the low light availability as a result of the very high turbidity. It might even be possible that a reduction in turbidity leading to an increase in algal growth (chlorophyll *a* concentrations) could result in a worse grade. This would not properly represent the ecological condition of the estuary. So, it is important to consider both the overall site grade and the component turbidity and chlorophyll *a* grades.

Table 15. Site sample pass rates, scores and grades in relation to turbidity and chlorophyll *a* trigger values.

	Sample pass rate		Score			Grade		
Sites	Turbidity	Chlorophyll *a*	Turbidity	Chlorophyll *a*	Site	Turbidity	Chlorophyll *a*	Site
K1	60%	100%	0.63	0.00	0.32	F	A	C
K2	50%	67%	0.71	0.08	0.39	F	B	C
K3	50%	67%	0.71	0.10	0.40	F	B	C
K4	50%	100%	0.71	0.00	0.35	F	A	C
K5	0%	67%	0.73	0.08	0.41	F	B	C
K6	0%	67%	0.71	0.09	0.40	F	B	C
K7	0%	83%	0.67	0.06	0.36	F	A	C
All	30%	79%	0.70	0.07	0.38	F	B	C

4. Conclusion

This study was carried out to determine the current ecological condition of the Karuah River estuary to provide a baseline for the Great Lakes Council to make informed decisions for the development of a catchment plan for the Karuah River. A variety of measures were utilised to determine the condition of, and pressures on, the Karuah River estuary.

These measures fell into several categories, system structure, biological structure, energy flow, biological stress, pressures. The overall system structure was in poor condition (Table 16). This was evident in the lack of seagrass habitats, an apparent trend of mangroves encroachment on saltmarsh habitats combined with degraded riparian habitats in the catchment. Biological structure, in contrast, was in good condition, the composition of intertidal mudflat invertebrate, fish, bird and freshwater invertebrate assemblages being similar to those at reference sites (Table 16). Energy flow in the Karuah River was generally indicative of good ecological condition (Table 16). Chlorophyll *a* concentrations, indicative of phytoplankton abundance, were below trigger values. Rates of algal recruitment on pneumatophores were significantly greater in the Karuah River than at control estuaries, but those on seagrass were within the range of control estuaries. Amounts of benthic microalgae and rates of scavenging by micro- and macro-carnivore were not significantly different from control estuaries. Biological stress was very low and indicative of good ecological condition, with no ulcers observed on fish in the Karuah River and no difference in the prevalence of mangrove leaf damage in the Karuah River and control estuaries. There were, however, substantial pressures on the ecology of the Karuah River, constituting a threat to ecological condition (Table 16). This was evident in the very high median turbidities and nutrient concentrations in the estuary, generally exceeding the trigger values. Median total nitrogen concentrations and turbidity in surface runoff also exceeded the trigger value at four of the five sites, while median total phosphorus was in exceedence at three sites. Contrastingly, the Karuah River catchment is dominated by tree and shrub cover and grazing, landuses that do not usually generate substantial nutrients and/or sediments. There are, however, large numbers of poultry enterprises, which can cause high rates of nutrient generation if manure is inappropriately applied to paddocks in the catchment.

Overall, the Karuah River is in moderate ecological condition. However, there are substantial pressures on the ecology and signs of degradation of system structure are evident, with some areas of the estuary and catchment in poor condition.

Table 16. Summary of the ecological condition of the Karuah River estuary and catchment.

Component	Measures	Current Status
SYSTEM STRUCTURE	Presence of healthy mangroves, saltmarsh and seagrass.	Poor condition. Increased mangrove extent. Saltmarsh and seagrass have reduced in extent. Seagrass extent very limited.
	Condition of riparian zones.	Fair condition. 47% of riparian zones in good condition.
BIOLOGICAL STRUCTURE	Macroinvertebrates on intertidal flats.	Good condition. Invertebrate assemblages similar at Karuah River and Twelve Mile Creek, but different at Wallingat.
	Estuarine fish assemblages.	Good condition. Karuah River estuary fish diversity similar to Wallingat River, but less than Twelve Mile Creek.
	Shorebird assemblages.	Good condition. Abundances of shorebirds and other waterbirds and temporal patterns of shorebird species richness in the vicinity of the Karuah River estuary did not differ from those in other parts of Port Stephens.
	Freshwater macroinvertebrates.	Good condition. Mean number of taxa similar to expected.
ENERGY FLOW	Phytoplankton.	Good condition. Chlorophyll concentrations generally below trigger values.
	Benthic microalgae.	Good condition. Concentrations of sediment chlorophyll *a* were not significantly less than in other estuaries in NSW.
	Algal recruitment on seagrass and mangroves.	Poor condition. Algal growth on artificial pneumatophores was greater in the Karuah River than in control estuaries.
		Good condition. Algal growth on artificial seagrass was greater in the Karuah River than at Twelve Mile Creek, but less than at Wallingat River.
	Micro-carnivore scavengers.	Good condition. Rate was similar to control estuaries.
	Macro-carnivore scavengers.	Good condition. Rate was similar to Twelve Mile Creek, but more than at Wallingat River.
BIOLOGICAL STRESS	Frequency of ulcers in fish.	Good condition. No ulcers observed on fish caught in the Karuah River.
	Mangrove leaf damage.	Good condition. Rates of leaf damage similar at Karuah River and Wallingat River sites, but greater at Twelve Mile Creek sites.
PRESSURES	Estuarine turbidity.	Poor condition. River has very low clarity due to suspended matter. Turbidity typically exceeds trigger values.
	Estuarine nutrient concentrations.	Poor condition. Nutrient concentrations generally exceeded trigger values.
	Nutrients in surface runoff.	Poor condition. Total nitrogen and total phosporus concentrations typically exceed trigger values.
	Turbidity of surface runoff.	Poor condition. Turbidity typically exceeded trigger value.
	Catchment landuses.	Good condition. Most of the catchment is covered by tree and shrub cover and grazing land.

Table 17 outlines the main issues of concern for the whole system, possible causes and management recommendations.

During this study, The Branch River was identified as an area of particular concern. Turbidity and concentrations of total nitrogen and total phosphorus in runoff were very high in this sub-catchment. Not surprisingly, nutrient concentrations in estuarine reaches of The Branch River were the highest of any in the Karuah River estuary. Future investment should be directed towards improving freshwater and estuarine water quality and investigating the sources of nutrients in The Branch River area.

Finally, we suggest there is a need for ongoing monitoring of ecological condition and the environmental pressures in the Karuah River estuary and catchment. The system is in moderate ecological condition, but there is a serious risk of degradation given current pressures. Further research is also needed to better understand the sources of nutrients and sediment in the catchment so that these can be better managed into the future.

Table 17. Major system-wide issues, their possible causes and recommendations.

Issue	Possible cause/s	Recommendations
Loss of seagrass habitats.	High turbidity.	Restore and protect riparian habitats and manage and prevent erosion in the catchment.
Loss of saltmarsh habitats.	Mangrove encroachment (due to sedimentation or sea level rise?). Damage by vehicles, people or stock access.	Further research to determine cause/s. The drivers of mangrove encroachment are not well understood. Control access to saltmarsh habitats, where this is an issue.
Degraded riparian condition.	Stock access.	Riparian restoration. Implement stock exclusion fencing, install off-stream watering and/or provide alternative shade trees. Targeted protected riparian plantings so as to prevent continued loss of riparian structure.
Excessive algal recruitment on pneumatophores.	Elevated nutrient concentrations.	Restore and protect riparian habitats and manage and prevent erosion in the catchment. Further investigation is needed to identify possible sources of nutrients in the catchment.
Elevated water column turbidity.	Sediment generation from catchment landuses. Point sources of highly turbid effluent. Resuspension due to strong tidal currents and loss of seagrass.	Restore and protect riparian habitats and manage and prevent erosion in the catchment.
Elevated water column nutrient concentrations.	Nutrient generation from catchment landuses and point sources.	Restore and protect riparian habitats and manage and prevent erosion in the catchment. Further investigation is needed to identify possible sources of nutrients in the catchment.
Elevated runoff nutrient and sediment concentrations.	Generation from catchment landuses and point sources.	Restore and protect riparian habitats and manage and prevent erosion in the catchment. Further investigation is needed to identify possible sources of nutrients in the catchment.

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6. Appendix

6.1. Fish Species Lists

Table 18. List of fish taxa caught at Karuah River sites.

Species	Common name	No. caught
Acanthopagrus australis	Yellowfin Bream	9
Acentrogobius frenatus	Half Bridled Goby	94
Ambassis jacksoniensis	Port Jackson Glassfish	173
Arenigobius bifrenatus	Bridled Goby	12
Brachirus nigra	Black Sole	1
Dasyatis fluviorum	Estuary Stingray	2
Favonigobius exquisitus	Exquisite Sand Goby	1
Gerres subfasciatus	Silver Biddy	39
Girella tricuspidata	Luderick	2
Herklotsichthys castelnaui	Southern Herring	25
Hyperlophus vittatus	Sandy Sprat	52
Hyporhamphus regularis ardelio	Eastern River Garfish	1
Mugil cephalus	Sea Mullet	73
Platycephalus fuscus	Dusky Flathead	7
Pomatomus saltatrix	Tailor	63
Pseudorhombus jenynsii	Smalltoothed Flounder	5
Rhabdosargus sarba	Tarwhine	2
Sardinops sagax	Australian Sardine	1
Sillago ciliata	Sand Whiting	17
Sillago maculata	Trumpeter Whiting	25
Tetractenos hamiltoni	Common Toadfish	5
Tylosurus gavialoides	Stout Long Tom	1
	No. of individuals	**610**
	No. of taxa	**22**

Table 19. List of fish taxa caught at Twelve Mile Creek sites.

Species	Common name	No. caught
Acanthopagrus australis	Yellowfin Bream	58
Acentrogobius frenatus	Half Bridled Goby	51
Ambassis jacksoniensis	Port Jackson Glassfish	455
Arenigobius bifrenatus	Bridled Goby	1
Brachirus nigra	Black Sole	1
Centropogon australis	Fortescue	5
Cnidoglanis macrocephalus	Estuary Catfish	1
Dicotylichthys punctulatus	Threebar Porcupinefish	1
Favonigobius exquisitus	Exquisite Sand Goby	6
Gerres subfasciatus	Silver Biddy	277
Girella tricuspidata	Luderick	3
Herklotsichthys castelnaui	Southern Herring	20
Hyperlophus vittatus	Sandy Sprat	10
Hyporhamphus regularis ardelio	Eastern River Garfish	5
Liza argentea	Goldspot Mullet	2
Mugil cephalus	Sea Mullet	98
Philypnodon grandiceps	Flathead Gudgeon	16
Platycephalus fuscus	Dusky Flathead	10
Pomatomus saltatrix	Tailor	55
Pseudogobius olorum	Blue Spot Goby	1
Pseudorhombus jenynsii	Smalltoothed Flounder	73
Rhabdosargus sarba	Tarwhine	3
Sillago ciliata	Sand Whiting	7
Sillago maculata	Trumpeter Whiting	67
Tetractenos glaber	Smooth Toadfish	1
Tetractenos hamiltoni	Common Toadfish	8
	No. of individuals	**1235**
	No. of taxa	**26**

Table 20. List of fish taxa caught at Wallingat River sites.

Species	Common name	No. caught
Acanthopagrus australis	Yellowfin Bream	32
Afurcagobius tamarensis	Tamar River Goby	2
Ambassis jacksoniensis	Port Jackson Glassfish	1023
Arenigobius bifrenatus	Bridled Goby	20
Brachirus nigra	Black Sole	6
Dasyatis fluviorum	Estuary Stingray	1
Engraulis australis	Australian Anchovy	1
Favonigobius exquisitus	Exquisite Sand Goby	90
Gerres subfasciatus	Silver Biddy	885
Herklotsichthys castelnaui	Southern Herring	14
Hyperlophus vittatus	Sandy Sprat	30
Hyporhamphus regularis ardelio	Eastern River Garfish	53
Mugil cephalus	Sea Mullet	92
Philypnodon grandiceps	Flathead Gudgeon	1
Platycephalus fuscus	Dusky Flathead	4
Pomatomus saltatrix	Tailor	17
Pseudorhombus jenynsii	Smalltoothed Flounder	2
Rhabdosargus sarba	Tarwhine	6
Sillago ciliata	Sand Whiting	19
Sillago maculata	Trumpeter Whiting	31
Taenioides sp.	Eel Goby	1
Tetractenos glaber	Smooth Toadfish	1
Tylosurus gavialoides	Stout Long Tom	4
	No. of individuals	**2335**
	No. of taxa	**23**

6.2. Estuarine Fish Assemblages: A Comparison with the lower Myall River Ecological Condition Assessment

An assessment the ecological condition of the lower Myall River was carried out in 2009/2010 (Scanes *et al.*, 2010). The Myall River study employed the same fish sampling methods as were used in the current study, but both vegetated (seagrass) and unvegetated (bare sediment) sites were sampled (Scanes *et al.*, 2010), In the current study, only bare sites were sampled due to a lack of seagrass habitat in the Karuah River estuary. The Myall River study compared fish assemblages at Myall River sites to those at control estuaries (Scanes *et al.*, 2010). Here we compare the fish assemblages observed in the Myall River study with those observed in the current study.

Fish species richness was greater at all estuaries in the current study compared with bare (unvegetated) sites in other nearby estuaries sampled Myall River study (Table 21, Scanes *et al.*, 2010). Overall species richness was lower in the current study, but Scanes *et al.* (2010) sampled both bare and seagrass sites (Table 21). Overall, many more fish species were present at seagrass sites than at bare sites in Scanes *et al.* (2010), highlighting the importance of seagrass as fish habitat (Table 21). The In the Karuah River estuary, the mean number of species per bare site was in the middle of the range observed at other estuaries (Table 21). Thus, as stated in section 3.1.4,

Table 21. A comparison of fish diversity in different estuaries on the New South Wales mid-north coast.

		Mean No. of species per site		
		Bare	Seagrass	Species Richness
Karuah River Ecological Health Assessment	Karuah River	11.0	n/a	22
	Twelve Mile Creek	14.7	n/a	26
	Wallingat River	12.7	n/a	23
Ecological Condition of the lower Myall River Estuary (Scanes *et al.*, 2010)	Myall River	6.5	19	40
	Pindimar Bay	8.0	16	43
	Wallis Lake	8.0	19.5	42

6.3. Existing Water Quality Data for the Karuah River Estuary

Water sampling was carried out in the Karuah River estuary as part of the NSW MER programme's Estuaries Theme. There were two sampling periods, 2007/2008 and 2010/2011. During the 2007/2008 sampling period, the MER sites were located in the upper estuary, upstream of site K1 from the current study. Sampling during 2010/2011 was carried out in the vicinity of site K6 from the current study. Data collected as part of the MER programme during the 2007/2008 and 2010/2011 sampling seasons were compared with data collected at sites K1 and K6 respectively.

At both sites K1 and K6, salinity was similar between years, but variability was much greater in the current study than in earlier years (Figures 56 & 57). Turbidity was also similar between years at both sites, but at site K1 variability was much greater in 2011/2012 compared with 2007/2008 (Figures 56 & 57). In contrast, at site K6, the variability of turbidity was much greater in 2010/2011 than in 2011/2012 (Figures 58 & 59). Chlorophyll *a* concentrations at sites K1 and K6 were less in 2011/2012 than in earlier years (Figures 58 & 59).

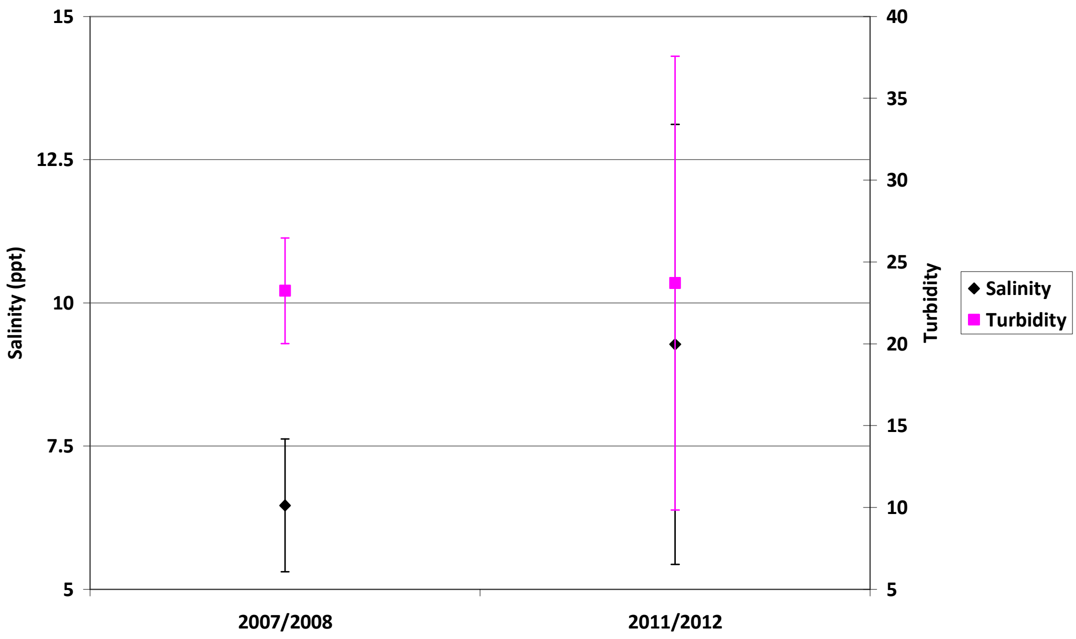

Figure 56. Mean salinity and turbidity at site K1 during the present study (2001/2012) compared with an earlier study (2010/2011).

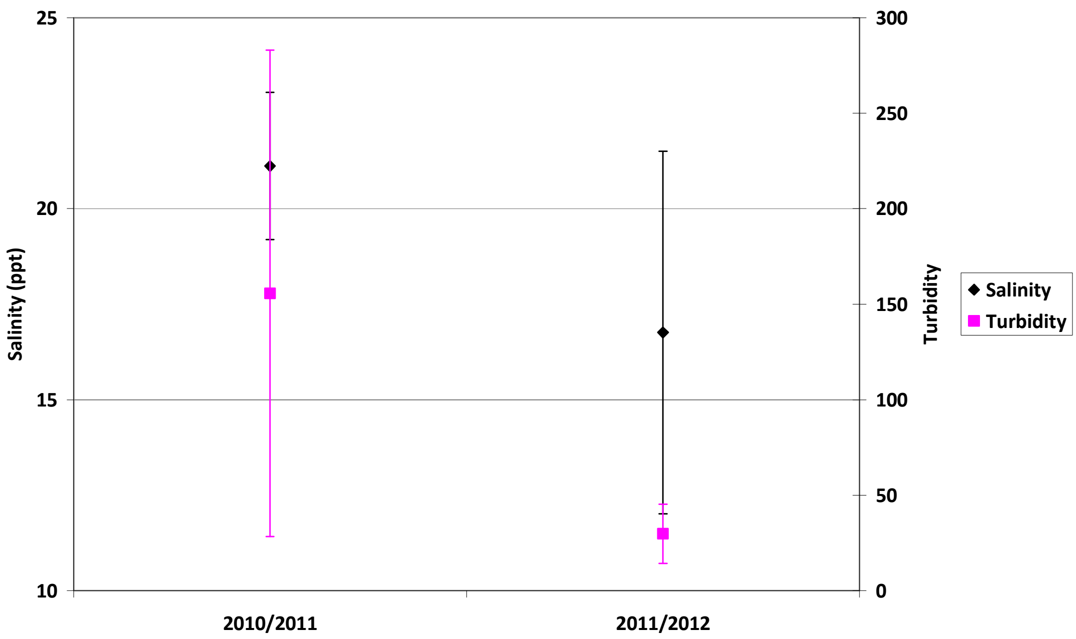

Figure 57. Mean salinity and turbidity at site K6 during the present study (2011/2012) compared with an earlier study (2010/2011).

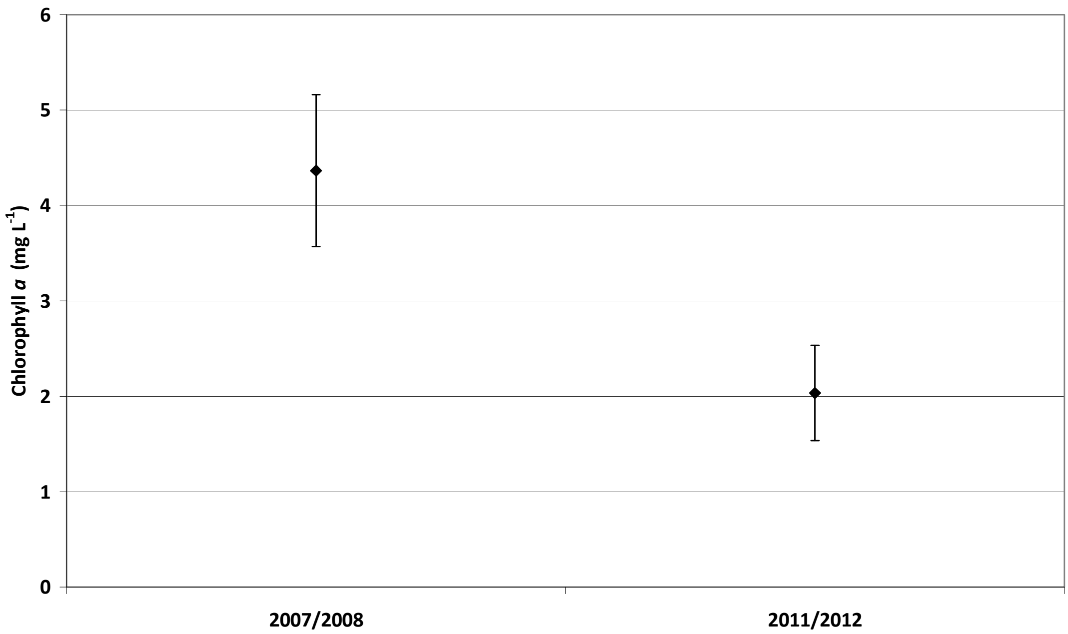

Figure 58. Mean chlorophyll a concentration at site K1 during the present study (2011/2012) compared with an earlier study (2010/2011).

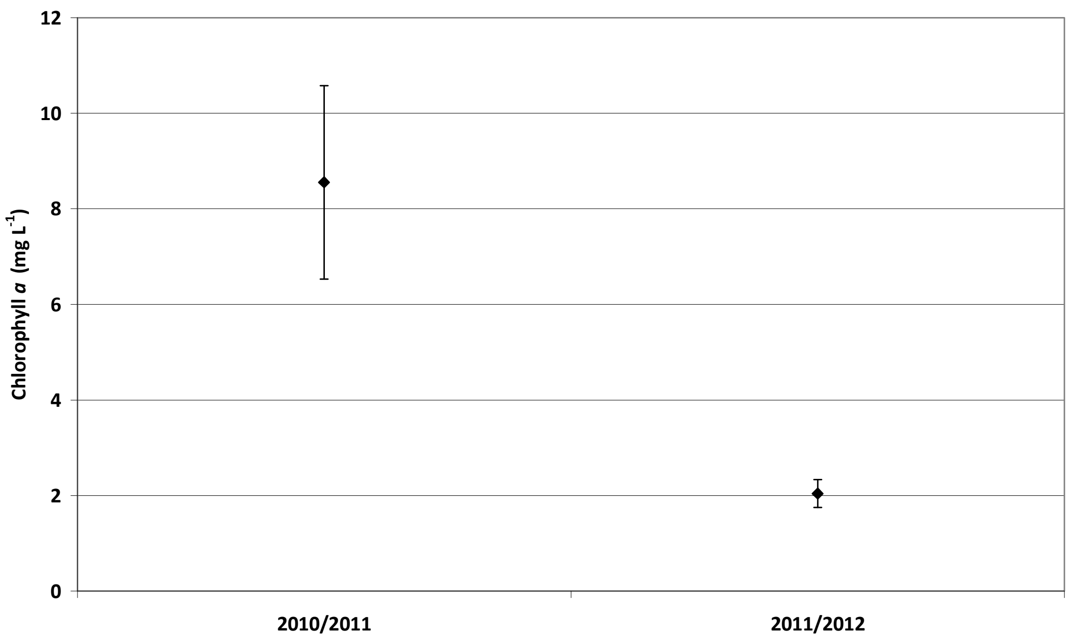

Figure 59. Mean chlorophyll *a* concentration at site K6 during the present study (2011/2012) compared with an earlier study (2010/2011).

Mean concentrations of nitrogen fractions were similar between years at site K1, but at site K6 PN was greater and both DON and DIN less in 2011/2012 than in 2010/2011 (Figures 60 & 61). Mean PP and DOP concentrations were similar between years at site K1, but phosphate (DIP) concentrations were less in 2011/2012 than in 2007/2008 (Figure 62). At site K6, mean total phosphorus concentrations were greater in 2011/2012 than in 2010/2011 (Figure 63). This was largely due to increased PP and DOP concentrations (Figure 63).

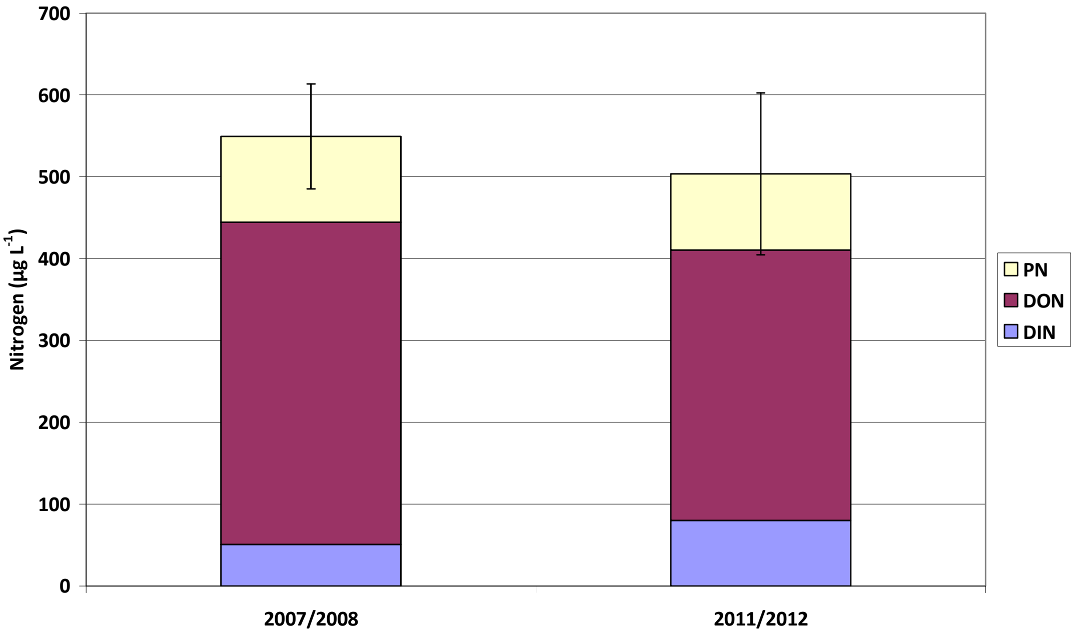

Figure 60. Mean concentrations of nitrogen fractions at site K1 during the present study (2011/2012) compared with an earlier study (2007/2008).
Error bars represent standard error for total nitrogen.

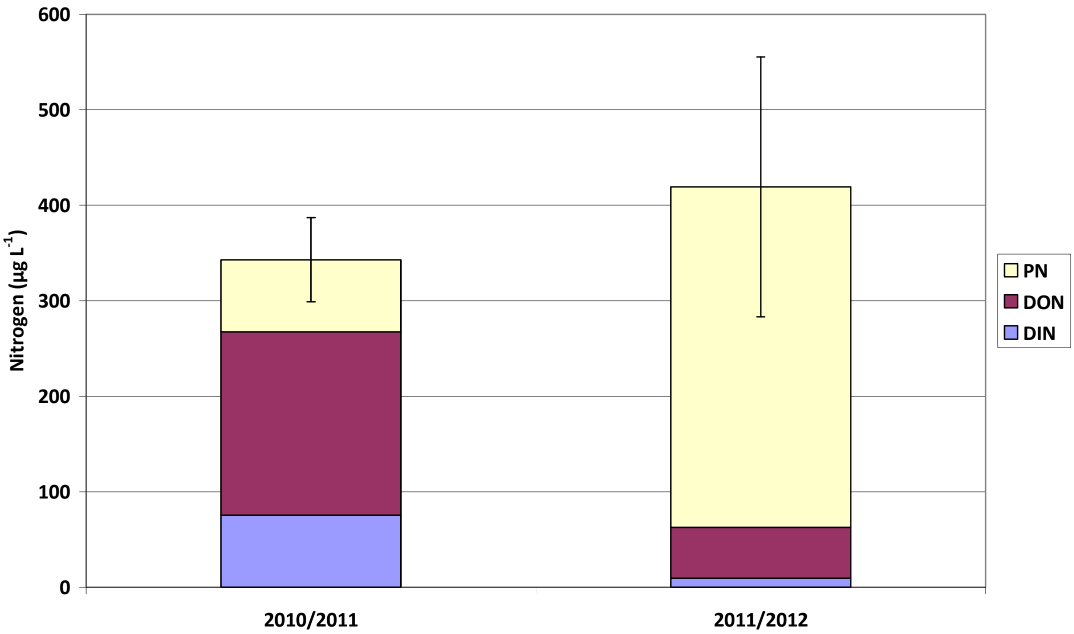

Figure 61. Mean concentrations of nitrogen fractions at site K6 during the present study (2011/2012) compared with an earlier study (2010/2011).
Error bars represent standard error for total nitrogen.

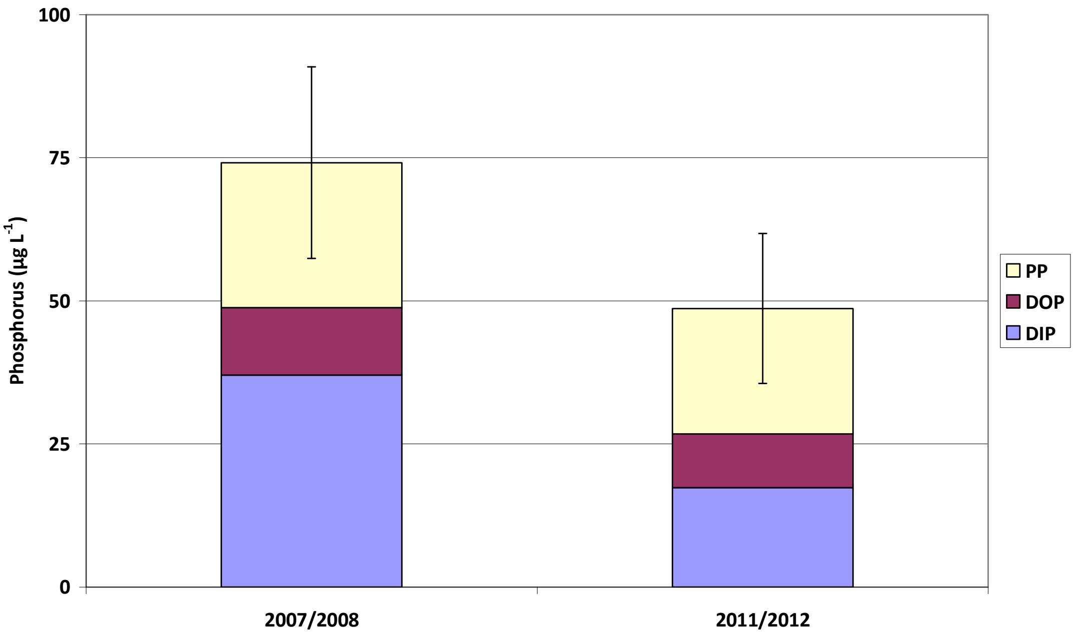

Figure 62. Mean concentrations of phosphorus fractions at site K1 during the present study (2011/2012) compared with an earlier study (2007/2008).
Error bars represent standard error for total phosphorus.

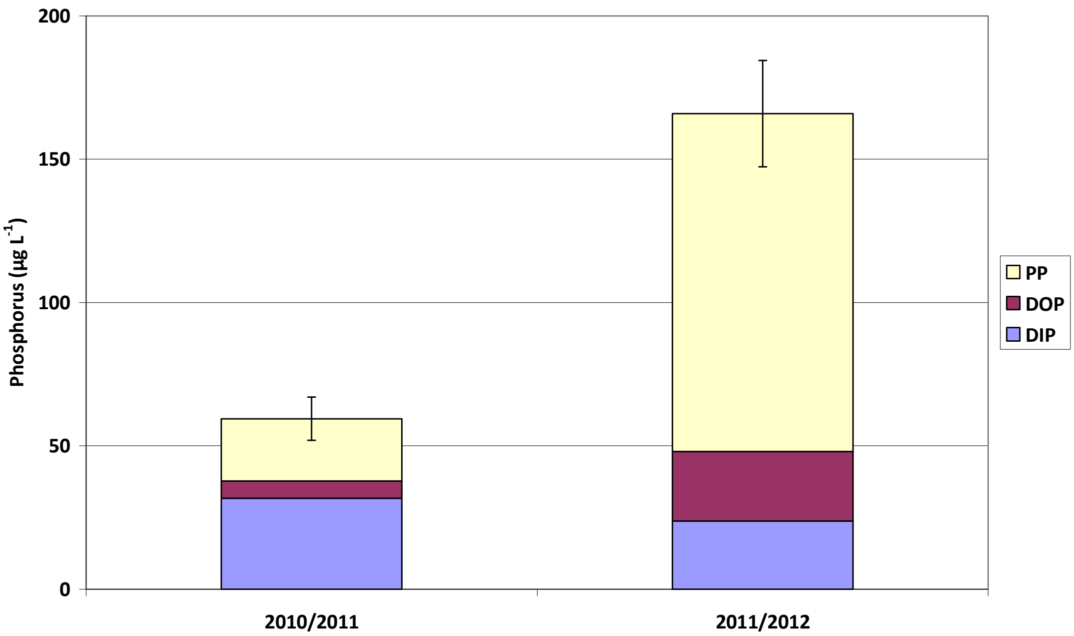

Figure 63. Mean concentrations of phosphorus fractions at site K6 during the present study (2011/2012) compared with an earlier study (2010/2011).
Error bars represent standard error for total phosphorus.

6.4. Relationships among Water Quality Variables in the Karuah River Estuary

Data collected from the seven water quality monitoring sites in the Karuah River estuary were examined to identify relations ships among variables.

There were some strong relationships among water quality variables in the Karuah River estuary. Concentrations of nutrients were negatively correlated with salinity indicating the strong influence of catchment runoff (Figure 64). There appeared to be a trend of decreasing chlorophyll *a* concentrations with increasing turbidity supporting (Figure 65). This is either due to light limitation inhibiting algal growth or algae being flushed downstream by highly turbid freshwater inflows. As was the case for nutrients, turbidity was also negatively correlated with salinity, suggesting that freshwater inflows, rather than resuspension, are the main cause of high turbidity in the Karuah River estuary (Figure 66). Chlorophyll *a* concentrations were positively correlated with salinity at low salinities and negatively correlated at high salinities (Figure 66). The chlorophyll *a* maximum was at salinities of around 15 to 20 ppt (Figure 66). There was a very strong correlation between TN and TP concentrations in the Karuah River estuary (Figure 67) and these in turn were correlated with turbidity indicating that turbidity could be a good surrogate for nutrient concentrations in the Karuah River estuary (Figure 68).

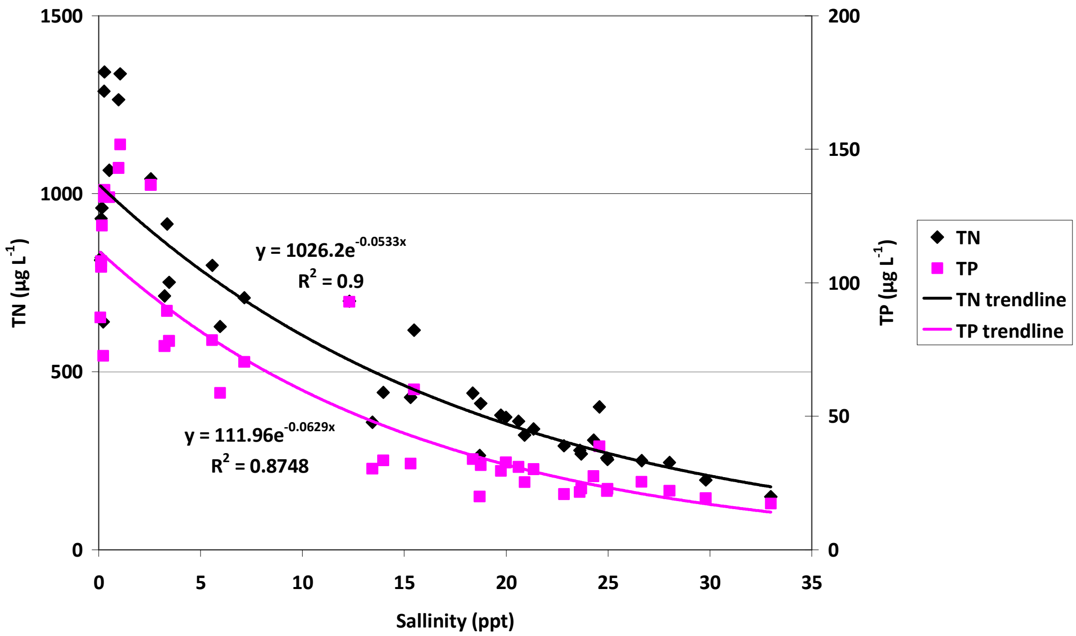

Figure 64. Relationship between salinity and both Total Nitrogen (TN) and Total Phosphorus (TP) concentration in the Karuah River estuary.

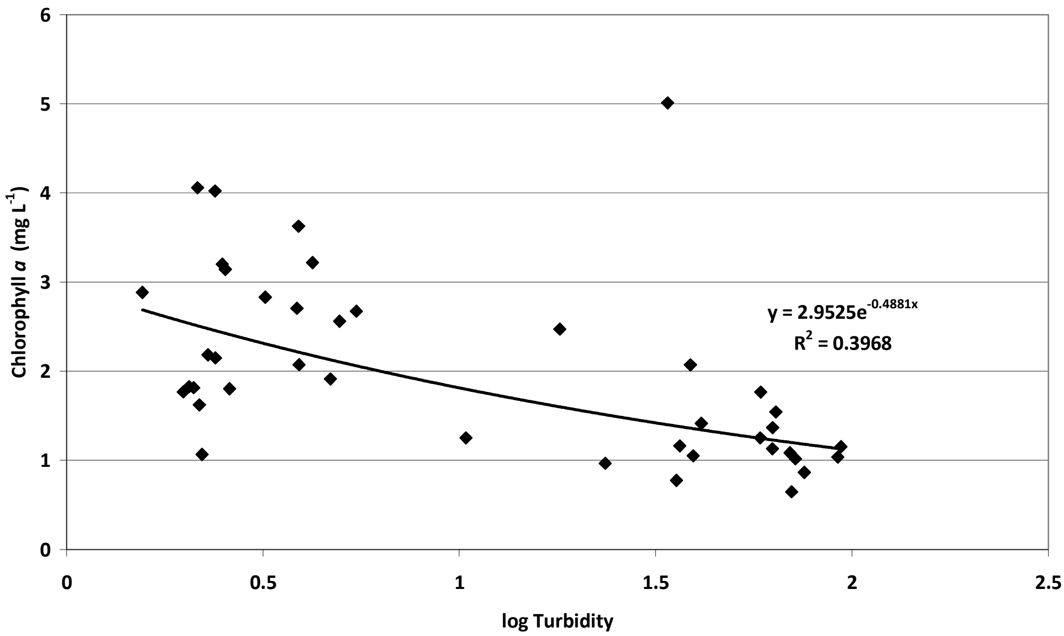

Figure 65. Relationship between turbidity and chlorophyll a concentration in the Karuah River estuary.

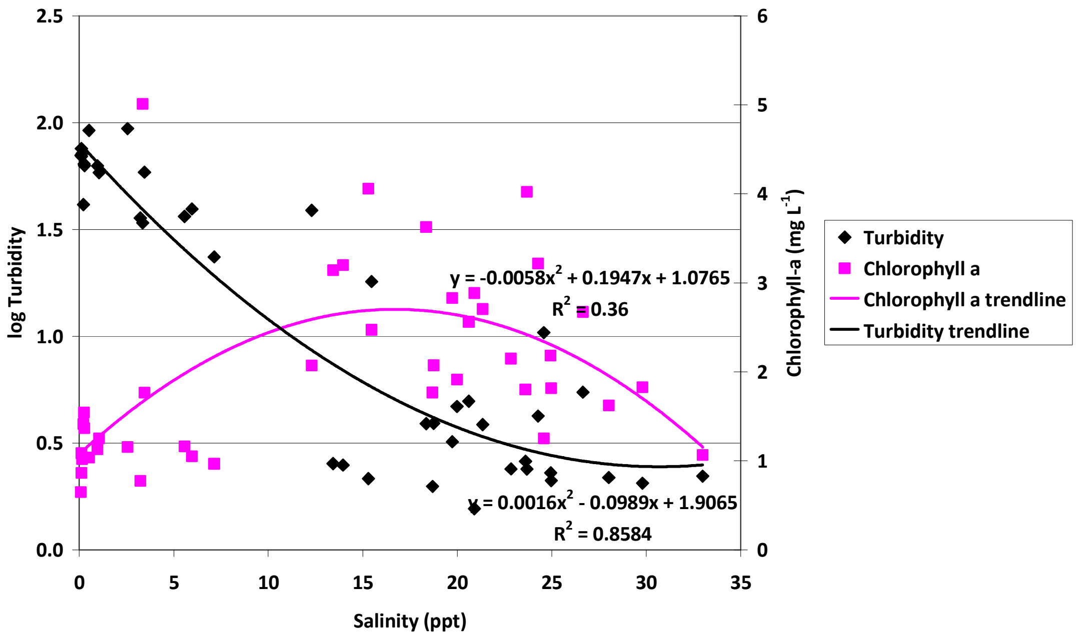

Figure 66. Relationship between salinity and both turbidity and chlorophyll a concentrations in the Karuah River estuary.
Turbidity data have been log transformed.

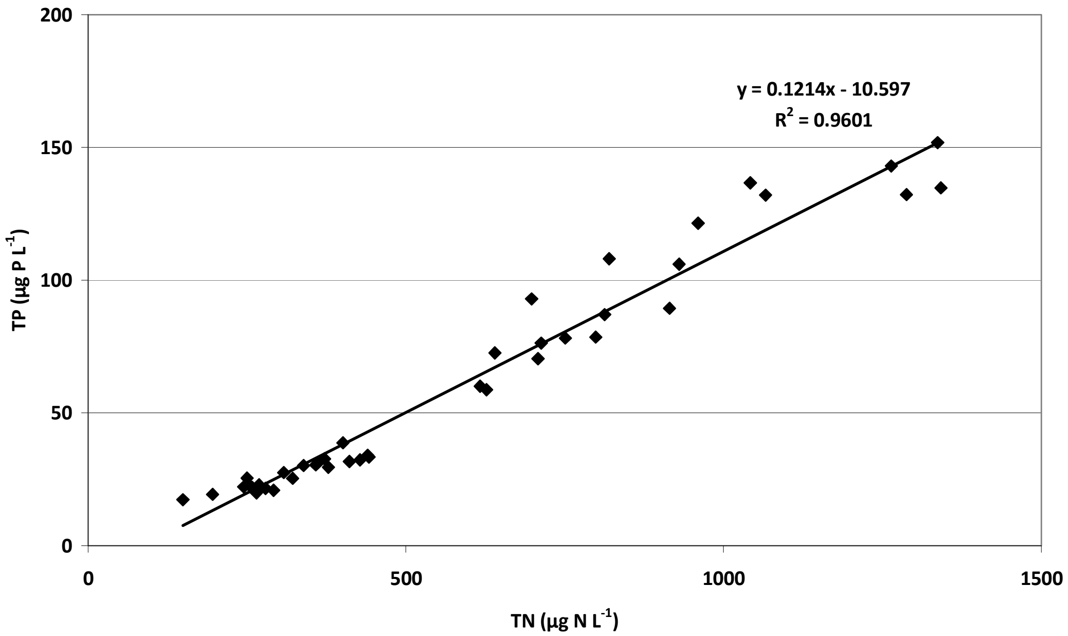

Figure 67. Relationship between Total Nitrogen (TN) and Total Phosphorus (TP) concentrations in the Karuah River estuary.

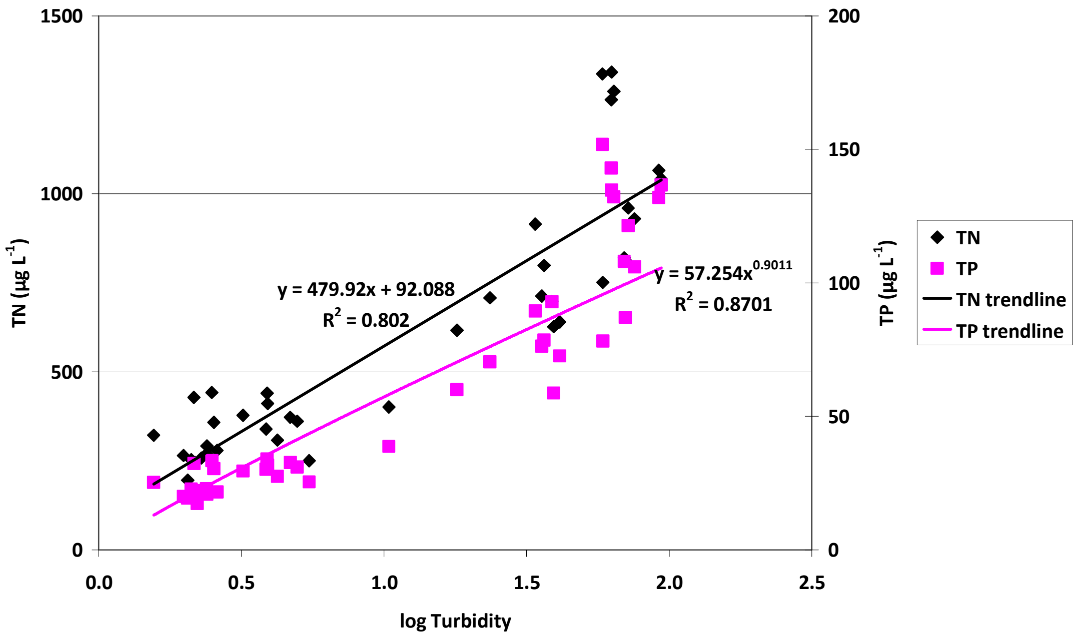

Figure 68. Relationships between turbidity and both Total Nitrogen (TN) and Total Phosphorus (TP) concentrations in the Karuah River estuary.
Turbidity data have been log transformed.

6.5. Relationships among Water Quality Variables in Surface Runoff in the Karuah River Catchment

Data collected from the five runoff sampling sites in the Karuah River catchment were examined to identify relations ships among variables.

Unsurprisingly, turbidity and total suspended solids concentrations were strongly correlated in surface runoff from the Karuah River catchment, so turbidity was a good indicator of TSS concentrations (Figure 69). TN and TP were also highly correlated (Figure 70) and both of these were weakly correlated with turbidity (Figure 71).

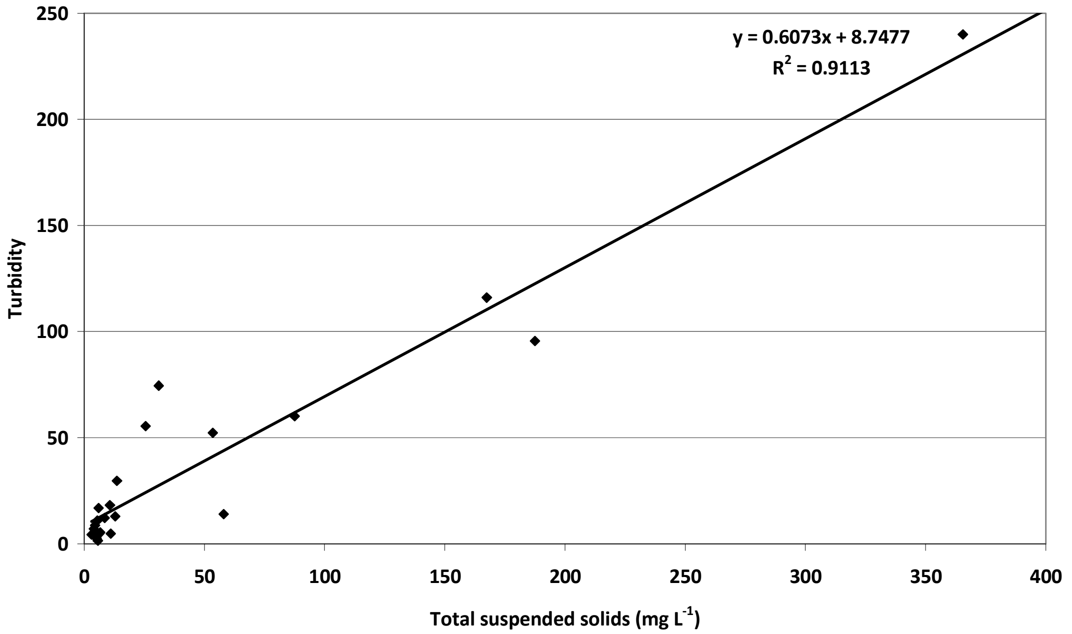

Figure 69. Relationship between total suspended solids and turbidity in runoff in the Karuah River catchment.

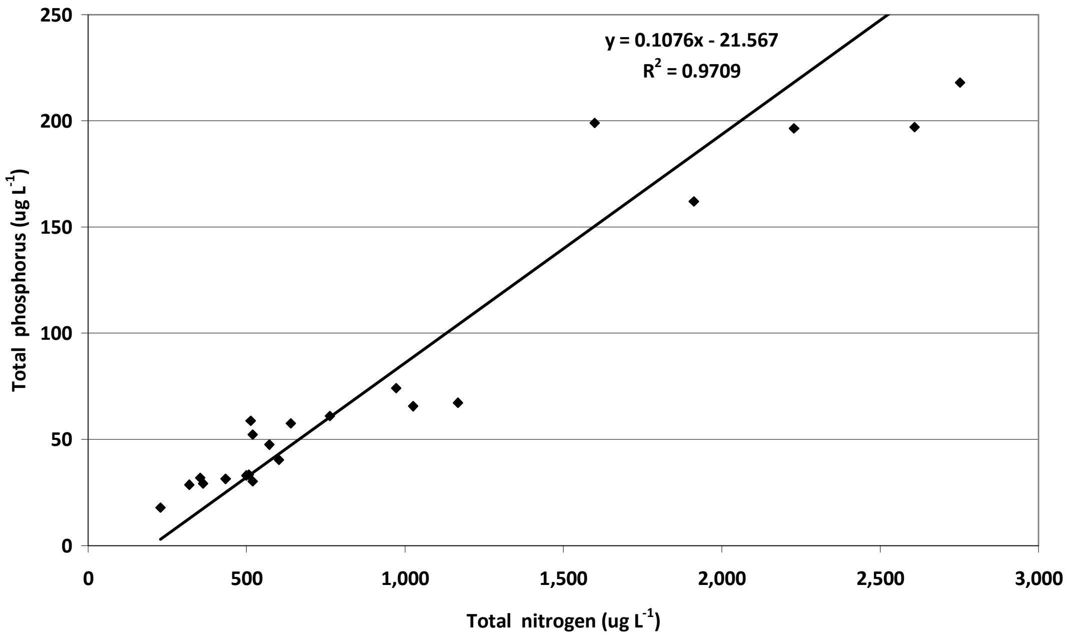

Figure 70. Relationship between total nitrogen and total phosphorus concentrations in runoff in the Karuah River catchment.

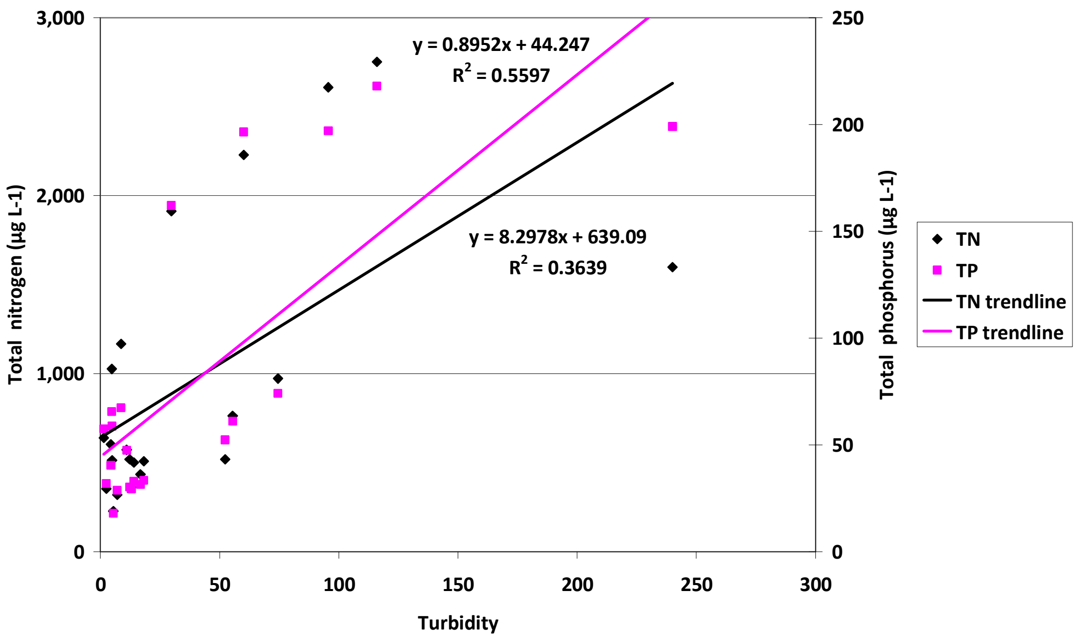

Figure 71. Relationships between turbidity and both Total Nitrogen (TN) and Total Phosphorus (TP) concentrations in runoff in the Karuah River catchment.

6.6. Prawns and Shrimp

Prawns and shrimp were sometimes inadvertently captured in the seine net during the fish sampling, so estimates of numbers caught per sample were made. The different taxa were not differentiated. Prawns and shrimp were significantly more abundant at Wallingat River sites than at Karuah River or Twelve Mile Creek sites (Figure 72).

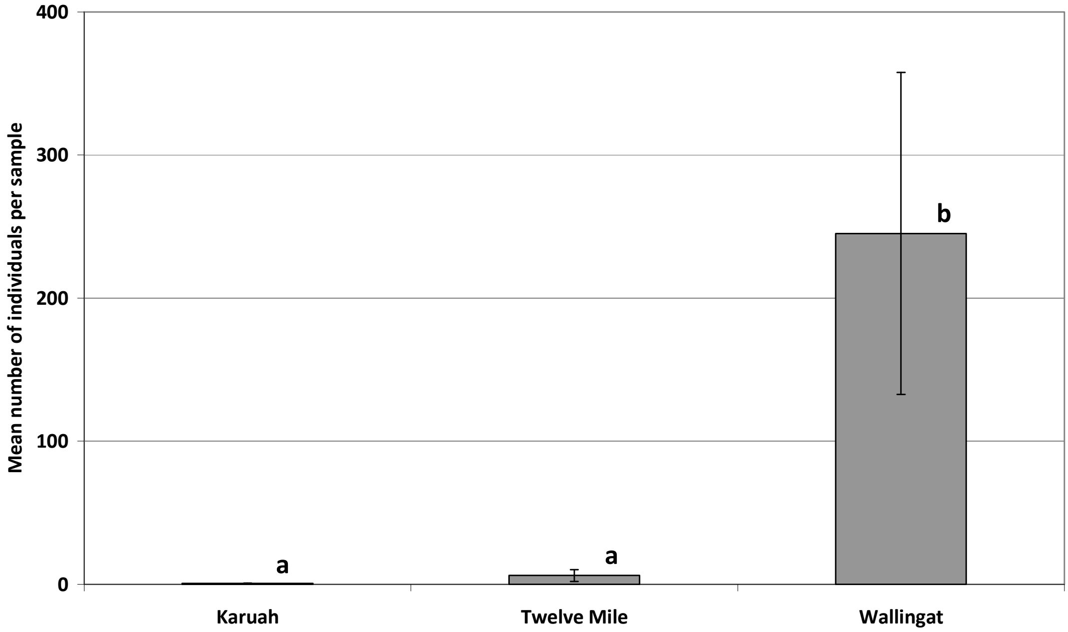

Figure 72. Mean number of prawns (Penaidaea) and shrimp (Caridea) per sample.
Different letters indicate means were statistically different (ANOVA, P<0.05).