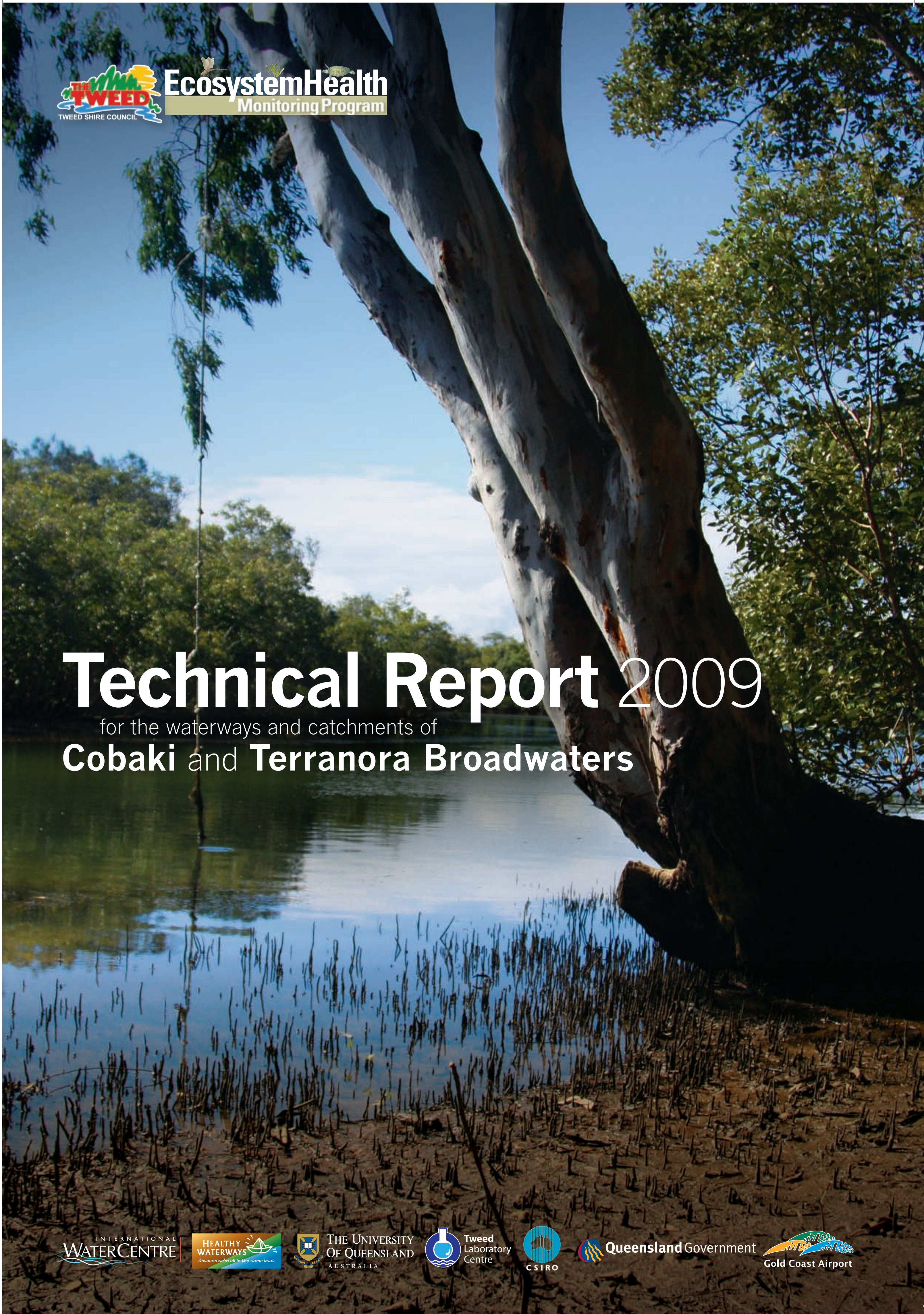

THE TWEED
TWEED SHIRE COUNCIL

Ecosystem Health Monitoring Program

Technical Report 2009

for the waterways and catchments of

Cobaki and Terranora Broadwaters

International WaterCentre | Healthy Waterways Because we're all in the same boat | The University of Queensland Australia | Tweed Laboratory Centre | CSIRO | Queensland Government | Gold Coast Airport

EHMP Team 2009

Queensland Government

The Tweed Shire Council was responsible for the overall guidance and funding of the program.

- Tom Alleton

The International Water Centre was responsible for the overall coordination, management and delivery of the EHMP.

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- Fiona Chandler

The Department of Environment and Resource Management (DERM) undertook all freshwater components of the EHMP including sampling and reporting.

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The Coastal Resource Management group (CRM) at the Centre for Marine Studies coordinated the estuarine component of the program, conducted the processed nitrogen tracking task ($\delta^{15}N$ mapping), the seagrass depth surveys and the estuarine riparian vegetation assessment. The CRM also provided expert advice and interpretation of scientific results, and the production of this report and the Ecosystem Health Report Card.

- Peter Hanington
- Dr Tony Chiffings
- Kim Hunnam
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The CSIRO Division of Mathematical and Information Sciences undertook the statistical analysis of all estuarine water quality data and derived the Environmental Health Index (EHI).

- Min Zhu
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The South East Queensland Healthy Waterways Partnership facilitated the scientific expert panel review process, and supported the use of the EHMP methodology and technical content.

- Jo Burton
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The Tweed Laboratory Centre undertook all estuarine water quality sampling and analysis.

- Edward Dickson

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Content also provided by the South East Queensland Healthy Waterways Partnership: 2006-07 EHMP Technical Report.

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Photo references

Cover: Ukerebagh Nature Reserve – University of Queensland, CRM
Executive Summary: Courtesy of Tweed Tourism
Contents: Seagrass, mangroves and salt marsh at Ukerebagh Island, Terranora Creek – University of Queensland, Vision and Remote Sensing
Inside Back Cover: Bilambil Creek – University of Queensland, CRM

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Executive Summary

Introduction

This report presents the results of an Ecosystem Health Monitoring Program (EHMP) commissioned by Tweed Shire Council of the Cobaki and Terranora Broadwaters and their catchments. Council have released an assessment of ecological health in the form of a Report Card in which four freshwater creek sub-catchments, as well as the Cobaki and Terranora estuary, are graded from "A" (excellent) to "F" (fail). This report complements the 2008 Ecosystem Health Report Card, providing scientific background and justification of the Report Card Grades.

This report provides a detailed assessment of the ecosystem health of the Cobaki and Terranora Broadwaters and their catchments during the period November 2007 to November 2008, based on monitoring at 15 freshwater sites and 28 estuarine sites.

In 2000-01, an initial EHMP was undertaken to assess the health of the Tweed River estuary, including the Cobaki-Terranora estuary. The results of the 2000-01 EHMP graded the Cobaki–Terranora estuary as being in 'fair' to 'good' ecological health. In 2007-08, the EHMP was expanded to cover both freshwater and estuarine waterways. The estuarine component of the EHMP has also been significantly improved by increasing the number of water quality sampling sites from 6 to 28, and from 3 events to monthly sampling over 12 months.

The EHMP process

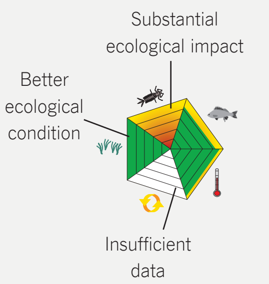
The process of conducting an EHMP is based on an objective assessment of ecosystem health using a range of ecological indicators. The health of an aquatic ecosystem is influenced by the current and past human activities within the catchment and its waterways. The current state of the Cobaki and Terranora catchment streams and estuary are therefore a reflection of the cumulative effects of catchment development and land use.

The EHMP methodology employed in the Tweed is based on those developed by the South East Queensland (SEQ) Healthy Waterways Partnership, which have been undertaking annual EHMPs within SEQ since 1999. These methods were used under agreement from the SEQ Healthy Waterways Partnership, with the program coordinated and delivered by the International WaterCentre, Brisbane.

Results and **Report Card Grades**

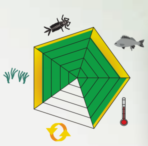
Freshwater

Summary of freshwater EHMP results for each indicator set using Ecosystem Health (EcoH) plots.



Piggabeen Creek
Piggabeen Creek is in fair condition, but its ecological health is compromised by high levels of nutrients and the loss of streamside vegetation.

Cobaki Creek
Cobaki Creek is in fair condition, but it suffers from elevated nutrients, and the degradation and loss of streamside vegetation.



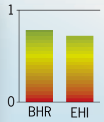
Bilambil Creek
Bilambil Creek is in fair condition, but it also suffers from elevated nutrients, and the degradation and loss of streamside vegetation.

Duroby Creek
Duroby Creek is in poor condition, as a result of elevated levels of nutrients, and low biological indicator scores. Duroby Creek showed the poorest health condition of all four creeks.

Cobaki Broadwater

The water quality in the broadwater deteriorates during the wetter months due to sediment and nutrient inputs from the catchment. The riparian vegetation is in good to very good condition.

2001 RATING: **C**

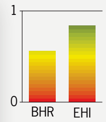


Terranora Creek

Water quality within Terranora Creek is influenced by the two broadwaters and tends to improve with distance towards the Tweed River mouth.

Wastewater discharges into the creek don't appear to have influenced the results of monthly water quality monitoring. However, the presence of sewage related nitrogen has been mapped and occurs along the entire length of the creek. The riparian vegetation has been assessed as fair to good condition.

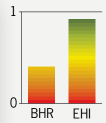
2001 RATING: **C to B-**



Tweed River Mouth

Water quality within the estuary mouth is good to excellent due to the high level of ocean exchange. The riparian condition is poor due to development along much of the river banks.

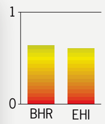
2001 RATING: **B+**



Terranora Broadwater

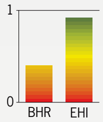
The water quality in the broadwater deteriorates during the wetter months due to sediment and nutrient inputs from the catchment. Water quality improves with distance away from the two creeks. The riparian vegetation is in good to very good condition.

2001 RATING: **C**

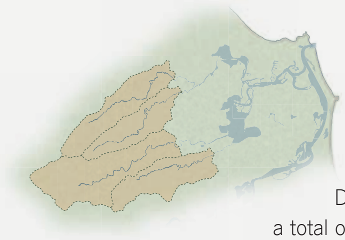


Estuarine

Summary of estuarine EHMP results showing water quality based Ecosystem Health Index (EHI) and Biological Health Rating (BHR)



Freshwater ecosystem health



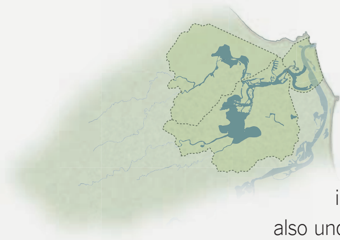
The 2007-08 Freshwater Ecosystem Health Monitoring Program marks the first ever ecological assessment of the four primary streams draining into the Cobaki and Terranora Broadwaters; being Piggabeen, Cobaki, Bilambil and Duroby creeks. For the Freshwater EHMP a total of 15 sites along freshwater (non-tidal) reaches of Piggabeen, Cobaki, Bilambil and Duroby creeks were assessed during spring (October–November) 2007. Assessments were made using five different indicator sets that respond to disturbances, directly or indirectly, caused by human activities: (1) Physical and chemical, (2) Nutrient cycling, (3) Ecosystem processes, (4) Aquatic macroinvertebrates, and (5) Fish. These indicators were chosen as representing the key elements of healthy freshwater ecosystems as defined by the SEQ EHMP. All assessments were conducted by staff of the Queensland Department of Environment and Resource Management, who conduct the SEQ Freshwater EHMP.

The results of the Freshwater EHMP for the spring 2007 sampling event for Piggabeen, Cobaki, Bilambil and Duroby creeks show an overall report card grade of D+, which equates to an ecological condition of "poor". Individually, Piggabeen, Cobaki and Bilambil creeks yielded a similar pattern of scores across indicators, with each creek scoring a report card grade of C-. Duroby Creek yielded the lowest scores of any of the four creeks with a report card grade of D.

The poor condition of the freshwater creeks is a result of impacted water quality, the loss of essential streamside vegetation and the alteration of in-stream ecological processes. More specifically:

- All creeks displayed elevated levels of the nutrients nitrogen and phosphorous. Nitrogen inputs were linked to sources such as septic tanks or on-site wastewater treatment systems, and/or livestock.
- Clearing of catchment and streamside native vegetation is widespread, and in many areas this has allowed extensive proliferation of weeds. The loss of streamside vegetation alters natural ecological processes such as stream shading, the supply of in-stream habitat and food, and the retention of sediments and nutrients by riparian vegetation.
- Creek bank erosion occurs due to changed hydrology, the clearing of streamside vegetation and trampling by livestock.
- High in-stream silt loads were observed, which causes smothering of critical habitats for fish and aquatic macroinvertebrates.
- A large number of stream road crossings featuring enclosed concrete culverts were also observed, and those culverts were likely to have a negative effect on the movement of native fish species within and between streams.

Estuarine ecosystem health



The estuarine component of the EHMP has monitored the health of the Cobaki and Terranora estuary. A total of 28 sites were monitored monthly (between November 2007 to October 2008) using a range of water quality indicators. Biological assessments were also undertaken and included an assessment of the riparian condition across the whole estuary, a survey of seagrass depth range and sewage plume mapping using mangrove $\delta^{15}N$. The overall status in ecosystem health is represented as a Report Card Grade. The estuarine Report Card Grade is calculated by combining the results of monthly water quality monitoring and the findings of the biological assessment.

The estuarine EHMP was conducted by staff from the Tweed Laboratory Centre and researchers from the Centre for Marine Studies, The University of Queensland.

The results of the estuarine EHMP for 2007-08 shows an overall report card grade of C, which equates to an ecological condition of 'fair'. Individually, Cobaki Broadwater obtained a grade of C (fair), Terranora Broadwater a grade of D+ (poor), Terranora Creek a C+ (fair) and the Tweed River mouth a B- (good).

In 2001, the Cobaki and Terranora Broadwaters were reported as being in fair health, with a report card rating of C. Terranora Creek was rated as fair to good (C to B-), and the Tweed River mouth rated as good (B+). Although the 2001 and 2008 EHMPs were similar in approach, the two programs differed considerably in terms of their spatial and temporal scales. Direct comparisons between the two monitoring events are therefore difficult. However, the similar report card results do suggest that the health of the estuary has remained relatively unchanged with no significant improvements apparent.

The estuarine component of the 2007-08 EHMP shows the following results and trends:

- Water quality within the estuary tends to improve with distance towards the Tweed River mouth.
- Water quality also tends to improve during the drier winter months compared with the wetter summer months, suggesting a close relationship with season and climate.
- Both broadwaters were assessed as having good riparian condition due to extensive areas of well-vegetated natural bank conditions. However, riparian condition tends to decline in other sections of the estuary, both upstream and downstream of the two broadwaters.
- Concentrations of $\delta^{15}N$ were highest near the treated wastewater discharge point in Terranora Creek, and declined with distance from the discharge point. Concentrations of $\delta^{15}N$ above background levels were detected in mangrove leaves within the Terranora broadwater.
- Seagrass depth range survey results may indicate a slight decline in seagrass depth range compared with data from the 2000-01 surveys. However, there is not sufficiently regular data to verify this possible trend.

Contents

Background

Setting the scene

The Tweed River's catchment and many of its waterways have been significantly altered since European settlement, including widespread clearing of natural vegetation and the establishment of farms, extensive dredging of waterways to establish and improve navigation, and training of riverbanks to control erosion.

This has resulted in an overall decline in aquatic species, habitat diversity and water quality. Widespread land clearing has resulted in changed flows, increased erosion and significant increases in the loads of nutrients and sediment entering the waterways.

Tweed Shire is one of the fastest growing local government areas along the NSW coast. Land use within the region ranges from high density urban and residential along the coast, to low density rural and bushland in the upper reaches of the catchment. Rapid growth places the area under increasing pressure from development. A growing population brings increasing demands for potable water, greater recreational pressure on natural assets and greater demands for goods and services such as food and transport.

Without careful management these precious waterways will suffer further degradation. Continued planning and management investments are required to make sure that these natural resources continue to sustain the lifestyles and livelihoods of the community.

To continue to gain the services and values that these waterways provide, it is essential that they are able to maintain their innate function and health. To achieve this, there is a need to manage human impacts on these waterways so that the biodiversity (organisation) is maintained and as a result they retain productive vigour and resilience to change.

It is important to recognise that management actions can destroy or in some cases re-build resilience, depending on how the system responds to management actions. These waterways are a part of a large set of complex systems involving land-based activities, both human-influenced and natural. This level of complexity means that it is not always easy to see either immediate or direct effects of management actions and therefore to know if these actions are having a positive or a negative effect on ecosystem health.

In reading this report it is important to remember that waterways such as the Tweed estuary are composed of a diverse array of components that interact through different processes to maintain themselves as a viable ecosystem. Because of their complexity and inter-connection, these processes and components may themselves vary naturally but, under human impacts, may significantly alter their performance and capacity. It may also be the case that some processes and components are removed altogether such that the ecosystem is unable to function as it has normally. In this context, the report seeks to highlight where such changes may be occurring or are in risk of this happening so that preemptive management action can be taken.

A vision for the Tweed River

The Tweed River and its tributaries will be a healthy ecosystem and sustain the lifestyles and livelihoods of the community which works to protect them.

What is ecosystem health?

Ecosystem health is a concept that has been used to describe environmental systems in terms of their capacity to maintain biodiversity and therefore resilience to change. Ecosystem health is defined in terms of measurable characteristics (Rapport *et al.*, 1998; Dennison and Abal, 1999). Healthy freshwater and estuarine ecosystems have the following attributes:

Freshwater

- Vigour (the activity or rate of processes, e.g. slow/steady primary production)
- Organisation (healthy ecosystems have a complex structure, e.g. high biodiversity, complex food webs)
- Resilience (a system's capacity to maintain structure and function in the presence of stress; healthy ecosystems can recover after a disturbance, e.g. following a flood event)

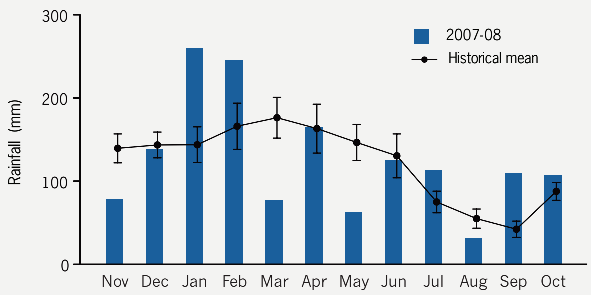
Estuarine

- Key processes operate to maintain stable and sustainable ecosystems (e.g. there is an absence of blue-green algal blooms)
- Zones of human impacts do not expand or deteriorate (e.g. a reduction in the spatial extent of sewage nitrogen)
- Critical habitats remain intact (e.g. seagrass meadows)

Climate and rainfall

The Tweed region has a temperate to sub-tropical climate with higher rainfalls generally occurring during the summer and autumn months, compared with winter. However, rainfall patterns in the region can vary greatly, both temporally from year to year, and spatially between and within catchments.

In the 2007-08 EHMP monitoring period, the study area received higher than average rainfall during the months of January and February, and a lower than average rainfall for August. Rainfall data was sourced from the Bureau of Meteorology weather station at Coolangatta airport.



Monthly rainfall data over the monitoring period 2007-08 and 23 year historical means (BoM Coolangatta Stn. No. 4071).

Determining Report Card Grades

Grades—what do they mean?

Ecosystem Health Report Card Grades ('A' to 'F') are generated for four freshwater sub-catchments and the Cobaki / Terranora estuary. Parameters for freshwater and estuarine habitats are assessed against guidelines which results in the application of a single grade for each waterway.

A **Excellent**

Conditions meet all set ecosystem health values; all key processes are functional and all critical habitats are in near-pristine condition.

B **Good**

Conditions meet all set ecosystem health values in most of the reporting region; most key processes are functional and most critical habitats are intact.

C **Fair**

Conditions meet some of the set ecosystem health values in most of the reporting region; some key processes are functional but some critical habitats are impacted.

D **Poor**

Conditions are unlikely to meet set ecosystem health values in most of the reporting region; many key processes are not functional and many critical habitats are impacted.

F **Fail**

Conditions do not meet set ecosystem health values; most key processes are not functional and most critical habitats are severely impacted.

Environmental goals

Freshwater

- Protect/restore riparian vegetation and habitat
- Protect fish and macroinvertebrates
- Minimise nuisance algal blooms and growth of aquatic weeds
- Minimise sediment and nutrient inputs

Estuarine

- Protect/restore estuarine habitats; seagrass, mangroves, saltmarsh and riparian vegetation
- Protect fish and macroinvertebrates
- Minimise nuisance algal blooms and growth of aquatic weeds
- Minimise sediment and nutrient inputs

UQ, CRM

UQ, CRM

Rivers and estuaries which are failing to meet ecosystem health values have severely impacted habitats with key processes not functional.

UQ, CRM

UQ, CRM

Rivers and estuaries with excellent ecosystem health maintain key processes with key habitats intact and must be protected.

Freshwater Methods

The design of the Freshwater Ecosystem Health Monitoring Program (EHMP) for the Cobaki and Terranora system is based on the methods designed and implemented by the South East Queensland Healthy Waterways Partnership. The initial design of the Freshwater EHMP methodology arose from the recommendations of the Design and Implementation of Baseline Monitoring (DIBM3) program conducted during 1998–2001 (Smith & Storey 2001). The DIBM3 program involved a series of studies investigating key aspects of the ecological condition assessment of rivers and streams in South East Queensland (SEQ). Potential indices of freshwater ecosystem health were identified and evaluated, and reference conditions for a robust combination of indices were quantified using data from minimally-disturbed reference sites. A method was developed for standardising results across different indices, which use different measurement scales, and across streams with different biophysical conditions. A protocol for the selection of assessment sites was also developed. This information provided the requirements for the implementation of a comprehensive, scientifically robust, and cost-effective, ecological monitoring program.

The SEQ Freshwater EHMP has been reporting on the ecological health of the freshwater streams of South East Queensland on a yearly basis since 2003, including Currumbin and Tallebudgera creeks immediately to the north of the Tweed River catchment. This extensive data set from similar streams nearby has made it possible to replicate the SEQ EHMP in the Tweed River catchment.

The freshwater EHMP as reported here, marks the first ever ecological assessment of the four primary streams draining into the Cobaki and Terranora Broadwaters. The assessment was undertaken during one sampling event in spring (Oct. - Nov.) 2007 and included a total of 15 sites across four streams.

Samples and/or data for each of the 15 indices used in the Freshwater EHMP are collected at a representative location within a 600m section of stream (i.e. 300m upstream to 300m downstream of a specified location) at each site. All assessments are made by suitably trained and experienced staff using rigorously maintained equipment, and in accordance with written standard operating procedures. The following provides a brief synopsis of the five ecological indicators and 18 component indices used in the Freshwater EHMP, and the methods by which they are evaluated.

Physical and chemical indicator

pH

The term pH is an abbreviation for potential hydrogen. It is a measure of the concentration of free hydrogen ions [H+] or the acidity of the water. The pH scale is based on the logarithm of the reciprocal of [H+] and ranges from 1.0 (highly acidic) through 7.0 (neutral) to 14.0 (highly alkaline). As such, water with a pH of 5.0 has ten times the concentration of free hydrogen ions as water with a pH of 6.0.

Why do we measure it?

The pH of streams usually varies naturally between catchments due primarily to differences in catchment geology and vegetation. Rapid changes in pH associated with the disturbance of acid-sulphate soils are known to have adverse effects on the ionic balance and respiratory efficiency of fish and aquatic invertebrates. Agricultural runoff has also been shown to cause reductions in stream pH, which can lead to increases in the toxicity of ammonia and heavy metals within stream sediments and a reduction in the survival rates of aquatic organisms, particularly juvenile stages. Some species, such as the endangered Oxleyan Pigmy Perch *Nannoperca oxleyana*, have specific pH requirements for survival.

Methods

Assessments of pH are undertaken using a handheld TPS WP-81 Conductivity-pH-Temperature meter fitted with a (K=1.0) pH sensor. The pH calibration of the meter is checked daily against 4.0 and 6.87 pH standards and the meter is re-calibrated if readings vary more than ±0.1 pH units from the true value. Field pH measurements are determined *in situ* by lowering the pH sensor to a depth of approximately 10cm and recording the value once the meter reading has stabilised.

Electrical conductivity

Conductivity is a measure of the ability of water to conduct an electrical charge, which is primarily dependent upon the concentration of ions in the water. Those ions are commonly associated with minerals salts, so electrical conductivity is usually closely related to salinity.

Why do we measure it?

Conductivity can affect both the community structure and function of freshwater ecosystems. Elevated conductivity levels are known to influence nutrient cycling, rates of primary production and respiration and the survival of riparian vegetation, aquatic macroinvertebrates and fish. Increased conductivity may also reflect the presence of pollutants from sources such as wastewater treatment plants (WWTPs), urban road runoff and agricultural runoff.

Methods

As for pH, conductivity is measured using a handheld TPS WP-81 Conductivity-pH-Temperature meter fitted with a (K=1.0) conductivity sensor. The calibration of the meter is checked daily and the meter is re-calibrated using a two point (0 and 1,413µS cm^{-1}) calibration procedure if readings vary more than ±15µS cm^{-1} from the true value. Field conductivity measurements are determined *in situ* by lowering the conductivity sensor to a depth of approximately 10cm and recording the value once the meter reading has stabilised.

Ambient water temperature – diel maximum and range

The diel maximum and range of ambient water temperature refers to the highest (95th percentile) water temperature, and change in water temperature, of typical stream water over a 24 hour period.

Why do we measure it?

Like conductivity, water temperature regulates aspects of both the community structure and function of aquatic ecosystems. For example, chemical attributes such as oxygen solubility and pH are sensitive to changes in water temperature. High temperatures cause a decrease in the level of dissolved oxygen (DO) available for aquatic organisms and such changes have a strong influence on ecosystem functions such as primary production and respiration. Fish and aquatic invertebrates are also sensitive to temperature changes with large temperature variations having deleterious effects on reproduction and survival.

Water temperature varies naturally as part of normal daily and seasonal cycles. However, more dramatic changes in temperature often occur as a result of human activities. Such changes are particularly noticeable in small streams where the loss of overhanging riparian stream side vegetation can lead to a marked increase in both water temperature and temperature range. High maximum temperatures and large temperature ranges can have adverse effects on an organism's growth, metabolism, reproduction, mobility and migration, which may lead to a decline in species richness and diversity.

Methods

Water temperature is measured using TPS WP-82Y Dissolved Oxygen-Temperature meters fitted with an YSI 5739 DO probe with in-built thermistor. The water temperature feature of these meters is checked weekly and calibrated against a laboratory-grade mercury thermometer.

Ambient water temperature is recorded at each site every 10 minutes for a 24 hour period. Due to a need to ensure a flow of water past the DO sensor carrying the thermistor used to assess water temperature, that sensor is placed in a PVC housing fitted with a small water pump that expels water from the housing. Inlet ports, fitted with a foam filter to prevent the passage of debris into the housing, provide for the flow of water through the housing. This assembly is attached to a stake to hold it above the substrate when deployed in the field. Water temperature data recorded by the Dissolved Oxygen-Temperature meters are downloaded to a desktop computer, and minimum and maximum water temperatures are calculated as the 5th and 95th percentiles to reduce the effect of any spurious records. The diel (24 hour) range of water temperature is calculated as the difference between the maximum and minimum values.

Ambient dissolved oxygen concentration – diel minimum and range

The diel minimum and range of ambient DO refers to the lowest DO concentration (5th percentile), and change in DO concentration, recorded within typical stream water over a 24 hour period.

Why do we measure it?

DO concentration is a measure of the availability of oxygen to aquatic organisms. Oxygen is a fundamental requirement for aquatic organisms that respire aerobically; and the concentration of DO affects the distribution, physiological activity and behaviour of aquatic animals. A DO concentration of less than 2mg L^{-1} is likely to have deleterious effects on aquatic invertebrates and fish.

The concentration of DO limits, and is limited by, the ecological processes of primary production and respiration that produce and consume oxygen, respectively. DO concentration is highly dependent on temperature, and fluctuates over a 24 hour period under natural conditions. Under some conditions (e.g. low flow, high temperatures), high biological oxygen demand associated with plant respiration and microbial decomposition can lead to very low DO concentrations and a large diel DO range. Large daily fluctuations in DO place pressure on ecological function.

Methods

Ambient DO concentration is measured using TPS WP-82Y Dissolved Oxygen-Temperature meters fitted with an YSI 5739 DO probe. The DO feature of these meters is re-calibrated weekly using a two-point (0 and 100% oxygen saturation) calibration procedure, and then tested against several other newly calibrated WP-82Y meters. The calibration of each meter is then tested again before and after use in the field. All calibration data is recorded for quality assurance purposes.

DO concentration is recorded at each site every 10 minutes for a 24 hour period as previously described for ambient water temperature: Diel maximum and range. Minimum and maximum DO concentrations are calculated as the 5th and 95th percentiles to reduce the effect of any spurious records. The diel (24 hour) range of DO concentration is calculated as the difference between the maximum and minimum values.

Nutrient cycling indicator

Nitrogen stable isotope signature ($\delta^{15}N$)

The quantity $\delta^{15}N$ describes the ratio of ^{15}N to ^{14}N stable isotopes within a substance. These isotopes consist of atoms with the same nucleus and number of electrons, but differing numbers of neutrons. The two stable isotopes of nitrogen are the 'heavy' isotope ^{15}N with eight neutrons, and the 'light' isotope ^{14}N with seven neutrons. Other nitrogen isotopes exist but are unstable.

Why do we measure it?

Changes in $\delta^{15}N$ can be used to detect changes in the cycling of nitrogen in a stream environment. An increase in the rate at which nitrogen is processed by aquatic microbes, and/or a decrease in the efficiency of denitrification due to changes in water chemistry, will result in an increase in the $\delta^{15}N$ of aquatic plants and detritus. For example, aquatic plants that absorb and incorporate sewage nitrogen during growth have an elevated $\delta^{15}N$. Increases in the $\delta^{15}N$ of aquatic plants can also occur in freshwater streams that do not have any identifiable point source of N enrichment, but have been subjected to disturbance of the nitrogen cycle caused by vegetation removal. The ratio of ^{15}N to ^{14}N (i.e. $\delta^{15}N$) in aquatic plants can therefore be used to identify changes to the natural cycling of nitrogen in streams due to both point source and diffuse sources.

Method

The $\delta^{15}N$ of submerged filamentous algae, and/or aquatic plants, is used as the source of $\delta^{15}N$ in the Freshwater EHMP. Samples of these organisms are collected and frozen on-site using dry ice for transportation to the laboratory. Collected samples are then identified, cleaned, and oven-dried at 60ºC for 24 hours, before being ground with a mortar and pestle. Ground samples are oxidised at high temperatures and the gases released are analysed using a Micromass Isoprime continuous-flow ratio mass spectrometer. Resulting ratios of ^{15}N to ^{14}N are expressed in delta (δ) notation as the relative parts per thousand (‰) difference between the sample and a conventional standard (ambient atmospheric nitrogen) as per the following equation:

$$\delta^{15}N = \left[\left(\frac{R_{sample}}{R_{standard}}\right) - 1\right] \times 1000, \text{ where } R = {}^{15}N/{}^{14}N$$

Nutrient concentrations in water samples

Nutrients in the water column exist both as organic and inorganic species and occur as dissolved and particulate forms. Total nutrients, such as total nitrogen (TN), is the sum of the nutrient in all its forms (i.e. dissolved + particulate). Whereas dissolved nutrients are those species that are dissolved within the water after the removal of particulates via filtering with a pore size typically of 45 µm.

Why do we measure it?

Nutrients within the water column can promote the growth of aquatic plants such as phytoplankton, which may form blooms if excess nutrients are present. The form of the nutrient is also important as dissolved nutrients are more readily available for plant uptake.

Sources of nutrients to freshwater streams include point source discharges such as sewage effluent, and diffuse sources such as urban runoff and agricultural land use.

Method

Three water samples are collected at each site using standardised sampling protocols and quality control measures. One unfiltered sample is collected for the quantification of total nitrogen (TN) and total phosphorus (TP), one field filtered sample is collected for the quantification of nitrogen oxides (NOx = nitrate + nitrite), ammonia (NH_3) and filterable reactive phosphorus (FRP); and another filtered sample is collected for the quantification of dissolved organic carbon (DOC).

All water samples are stored on dry ice (frozen) immediately following collection, and maintained frozen until delivery to the laboratory for analysis.

Ecosystem processes indicator

Carbon stable isotope signature ($\delta^{13}C$)

The quantity $\delta^{13}C$ describes the ratio of ^{13}C to ^{12}C stable isotopes within a substance. These isotopes consist of atoms with the same nucleus and number of electrons, but differing numbers of neutrons. The two stable isotopes of carbon are the 'heavy' isotope ^{13}C with seven neutrons, and the 'light' isotope ^{12}C with six neutrons. Other carbon isotopes exist but are unstable (e.g. the radioactive isotope ^{14}C used in carbon dating).

Why do we measure it?

While the $\delta^{13}C$ of atmospheric CO_2 is essentially constant, the assimilation of ^{13}C and ^{12}C by plants, during processes such as photosynthesis, occurs at different rates as environmental conditions vary and biochemical pathways are modified. Changes in the $\delta^{13}C$ of aquatic plants have been associated with high rates of primary production, respiration and methane production, and changes in stream flow.

Method

The carbon stable isotope signature of samples of submerged filamentous algae and/or aquatic plants is quantified similarly to that for nitrogen stable isotope signatures ($\delta^{15}N$, see earlier). Where available, those samples are collected in the field, placed in labelled zip-lock bags and frozen using dry ice. Samples are then oven dried at 60ºC for 24 hours in the laboratory, before being ground with a mortar and pestle. Ground samples are oxidised at high temperatures and analysed with an IsoPrime Micromass continuous-flow ratio mass spectrometer. Resulting ratios of ^{13}C to ^{12}C are expressed in delta (δ) notation as the relative parts per thousand (‰) difference between the sample and a conventional Australian National University sucrose standard as per the equation:

$$\delta^{13}C = \left[\left(\frac{R_{sample}}{R_{standard}}\right) - 1\right] \times 1000, \text{ where } R = {}^{13}C/{}^{12}C$$

Benthic metabolism: respiration (R_{24}) and gross primary production (GPP)

Benthic metabolism refers to the rates of respiration and primary production (i.e. photosynthesis) occurring at, and just below, the sediment-water interface of water bodies. The primary organisms responsible for these processes in this microhabitat are algae and bacteria.

Primary production (photosynthesis)

$$\underset{(6\ CO_2)}{\text{Carbon dioxide}} + \underset{(6\ H_2O)}{\text{Water}} \underset{\text{Energy}}{\overset{\text{Light}}{\rightleftharpoons}} \underset{(C_6H_{12}O_6)}{\text{Glucose}} + \underset{(6\ O_2)}{\text{Oxygen}}$$

Respiration (decomposition)

Why do we measure it?

Rates of instream respiration and production increase with anthropogenic disturbance such as riparian vegetation removal and agricultural runoff. The removal of stream-side vegetation, for example, results in less shading, increases in instream light intensity, and consequent increases in algal production. Increased amounts of algae are then available for decomposition, resulting in an increased rate of respiration.

Method

Both GPP and R_{24} are quantified from the net change in DO within two transparent plastic, dome-shaped chambers each isolating a portion of the stream bed and its associated benthos. Depending on the dominant substrate at a site, either one or more cobbles are sealed within the chamber using a plastic 'lid', or the chambers are pushed into the sediment to a measured depth to create a water-tight seal. A TPS WP-82Y Dissolved Oxygen-Temperature meter fitted with a YSI 5739 DO probe records DO and temperature within each chamber every ten minutes for 24 hours. A Whale 12V in-line pump re-circulates water through the chambers and past the DO sensor to account for minor consumption of O_2 by the sensor. Prior to and during fieldwork, sensors are calibrated weekly and serviced fortnightly. Calibration of the sensors involves both a temperature and two-point (0% and 100%) DO calibration, followed by a cross-check of their calibration against other sensors.

Rates of change in DO concentration over time (g O_2 L^{-1} hr^{-1}) are multiplied by chamber volume and divided by substrate surface area to obtain rates of oxygen consumption and production (g O_2 m^{-2} hr^{-1}) associated with the processes of respiration and production, respectively. Respiration rates are calculated by converting the rate of consumption of DO during the night to a rate of carbon release (g C m^{-2} day^{-1}), assuming that one mole of carbon is equivalent to one mole of oxygen (i.e. 1 g O_2 = 0.375 g C). Net primary production is calculated similarly and, assuming respiration to be constant during the 24 hour period of data recording, gross primary production (GPP, g C m^{-2} day^{-1}) is calculated by adding the amount of carbon fixed during the day to the amount released during the night by respiration.

Aquatic macroinvertebrate indicator

Why do we measure it?

Aquatic macroinvertebrates are animals without back-bones that live in the water and are large enough to see with the naked eye (e.g. beetles, bugs, shrimp, snails). This is one of the most commonly used biological indicators of stream ecological condition. These animals are ideally suited to biological monitoring because they are common, widespread, and easily sampled.

Number of taxa

Number of taxa is a direct measure of taxa richness, which generally increases with ecological condition. A high number of taxa within a site indicates that the various water quality, habitat, and food requirements of those taxa have been met locally in recent times. This index is calculated simply as the number of macroinvertebrate taxa collected; excluding cladocerans, ostracods, copepods and spiders.

PET richness

PET richness refers to the number of families in a sample belonging to one of the three particularly sensitive orders of aquatic insects: Plecoptera (stoneflies), Ephemeroptera (mayflies) and Trichoptera (caddisflies). The abundance of individuals within PET taxa shows a marked decline with anthropogenic disturbance and is thus useful as an early warning indicator of a decline in stream health. This index is calculated simply as the number of taxa belonging to the Plecoptera, Ephemeroptera and Trichoptera orders.

SIGNAL score

SIGNAL, or 'Stream Invertebrate Grade Number—Average Level', is a simple scoring system for quantifying the ecological health of streams. It is based on the average sensitivity to disturbance of the aquatic macroinvertebrate taxa present in a sample based on a predetermined set of 'sensitivity grades' allocated to individual taxa. SIGNAL scores theoretically range from 1.0 to 10.0, with higher scores indicating 'healthier' conditions. When used in conjunction with data on the richness of aquatic macroinvertebrate taxa, SIGNAL scores provide an indication of the types of pollution and other physical and chemical factors affecting the ecological condition of a stream. This index is calculated by averaging the sensitivity grades for taxa collected in a sample, using SIGNAL 2.1iv sensitivity grades and simple (unweighted) arithmetic averaging.

Method

A representative sample of the aquatic macroinvertebrate fauna is collected from 'edge' habitat at each site and the presence/absence of (primarily family-level) taxa is determined. Edge habitat is defined as habitat along the water's edge, including backwaters and undercuts, where there is little or no flow, and few or no submerged/emergent macrophytes. Each sample is collected from a 10m length of 'edge' habitat. The length need not be continuous as all forms of edge habitat are required to be sampled in proportion to spatial occurrence over a 100m length of stream within which the sample is collected.

Samples are collected with a 250µm mesh dip net fitted to a 250mm x 250mm x 250mm triangular frame attached to a 2m handle. Three short, upward sweeps of the net are made perpendicular to the bank for every metre of stream bank sampled. Once collected, the sample is rinsed, emptied into a bucket and then evenly divided into two sorting trays. Two people pick macroinvertebrates from separate trays for 30 minutes with the objective of collecting the greatest diversity of taxa, and about ten individuals of each taxon. No formal identifications are undertaken in the field, so 'taxa' at this stage essentially refers to 'visually similar animals'. The animals picked by each person are placed into separate labelled vials containing 70% methylated spirits and transported back to the laboratory for further processing. The residues from 10% of field processed samples are retained for assessment of the representativeness of each field worker's picking.

In the laboratory, all animals picked from samples by each person in the field are identified and counted using a stereo dissecting microscope. The only aquatic macroinvertebrates not identified to family level are: Porifera, Nemertea and Nematoda (identified to phylum); Oligochaeta, Polychaeta, Ostracoda, Copepoda and Branchiura (identified to class); Cladocera, Collembola and Acarina (identified to order); and Chironomidae (identified to sub-family). The laboratory identifications and counts of all staff are tested via independent identification and enumeration of taxa within a random 10% subsample of preserved samples.

A single set of taxa presence/absence data is obtained for each site by pooling the results obtained from each of the two worker's samples. Three different indices are calculated based on this data: (1) Number of Taxa, (2) PET richness, and (3) SIGNAL score.

Fish indicator

Why do we measure it?

Fish are a common and familiar component of freshwater environments, and fish communities reflect a range of natural and human-induced disturbances through changes in abundance and species composition. Ecological assessments based on fish community structure have the advantage over more traditional physical and chemical indices (e.g. conductivity, turbidity, nutrients) in that fish provide an integrated measure of stream condition due to the mobility, relatively long-life, and high trophic level of the animals involved. Data on fish communities is also valuable as it is of direct public interest, especially to recreational fishers and aquarium fish hobbyists, and required for the conservation of biodiversity.

Percentage of native species expected (PONSE)

Percentage of Native Species Expected refers to the number of native fish species observed to occur at a site expressed as a percentage of the number of native fish species expected to occur at a physically similar site under minimally-disturbed conditions. The expected number of native fish species is predicted by a static numeric model, which uses details of each site in terms of elevation, distance from river mouth, distance from source, and stream width as input. This underlying model was developed using regression tree analysis and, as it uses several abiotic parameters as input, results inherently account for the primary source of natural spatial variation.

Ratio of observed to expected native species (O/E_{50})

Ratio of observed to expected native species refers to the native fish species observed to occur at a site in relation to the native fish species expected to occur at a physically similar site under minimally-disturbed conditions. The native fish species expected to occur is predicted by a static numeric model, which uses details of each site in terms of elevation, upstream catchment area, distance from river mouth, stream width, stream depth and flow velocity as input. This underlying model was developed using a combination of classification and discriminatory function analysis as per AusRivAS modelling methods. As this model uses several abiotic parameters as input, results inherently account for the primary source of natural spatial variation.

The O/E_{50} index differs from the preceding index, PONSE, in that observed and expected species are compared on a species-by-species basis rather than simple counts of species. This greater resolution allows better interpretation of what changes in fish communities may have occurred.

Proportion alien fish

Proportion alien fish refers to the number of individual fish of species originating from outside of Australia expressed as a percentage of total fish catch at each site. Individuals of species translocated from elsewhere in Australia, e.g. golden perch *Macquaria ambigua*, were included as part of total catch as native species.

Method

A combination of backpack electrofishing, followed (where practical) by seine-netting, is used to determine the relative abundance of individual fish species at each site. Electrofishing is conducted using a Smith-Root model 12, or LR-24, backpack electrofisher fitted with a 28cm anode ring supporting a dip net of 10mm (stretched) mesh. Pulse width and frequency are kept fixed at 2μs and 100Hz respectively, and output voltage is varied according to the conductivity of water at each site. A table of conductivity-voltage settings is used as a starting point for setting output voltage on each sampling occasion. Seine-netting is conducted using a 10m long (1.5m drop) pocket seine of 10mm (stretched) mesh. All fishing is undertaken in accordance with Animal Ethics approval to ensure, as far as practical, that fish are not injured in any way.

The extent of fishing at each site is based on dividing the habitat at each site into different units based primarily on flow conditions (e.g. riffle, run, pool), and ensuring that at least one full habitat unit of each type is fished intensively. If only one habitat unit is present at a site, two examples of that habitat unit are fished in an attempt to maintain an average length of fished stream of 75m (about 20 stream widths) and an electrofishing 'power-on' time of 900secs. Where streams within the study area only flow intermittently, two sections of pool habitat are most commonly fished. Seine-netting can generally only be used infrequently due to a high abundance of woody debris and other obstacles hindering effective hauling of the net.

As backpack electrofishing involves field staff wading through water whilst surrounded by a dangerous (400 W continuous) electric field, this activity is led only by highly trained and experienced staff. All electrofishing is conducted in strict accordance with the *Australian Code of Electrofishing Practice* as a minimum standard.

Counts of the number of each fish species caught are recorded as fish are captured. Captured fish are retained in temporary storage until the completion of fishing within each habitat unit to prevent the occurrence of recaptures. When fishing has been completed, or recaptures are deemed to be improbable, fish are released alive back into the stream near where they were caught. A small number of specimens of any fish unable to be confidently identified at the time of capture are euthanised and retained for laboratory identification. Specimens of several difficult to identify genera are routinely retained for this reason; notably *Ambassis, Hypseleotris, Mugil* and *Philypnodon*.

A single set of relative abundance data is obtained for each site on each sampling occasion by pooling the results obtained for each habitat unit and mode of fishing (electrofishing, seine netting). Three different indices are calculated based on this data: (1) Percentage of Native Species Expected, (2) Ratio of observed to expected native species, and (3) Proportion of alien fish.

Reporting

To produce summary results, the value of each index for each site is transformed into a score standardised for both natural spatial variation in index values across streams with different physical conditions, and differences in the scale of measurement across indices. The resulting standardised scores range from 0.0 to 1.0, where 0.0 is indicative of 'unhealthy' conditions and 1.0 is indicative of 'healthy' conditions.

Calculation of standardised scores

The calculation of standardised scores for Freshwater EHMP indices involves the use of a static table of 'ecosystem health guideline' (guideline) and 'worst case scenario' (WCS) values. Guideline values were derived from either the 20^{th} and/or 80^{th} percentile of empirical data for minimally-disturbed reference sites as part of the DIBM3 project, or from theoretical limits. These values indicate the expected values of each index for streams in 'healthy' condition. Worst case scenario values were derived from either the 10^{th} and/or 90^{th} percentile of data for all sites and assessment periods associated with the SEQ Freshwater EHMP, or theoretical limits of the index. Worst case scenario values indicate the expected value of each index for streams in the 'unhealthiest' condition.

Ecosystem health guidelines and worst case scenarios (WCS) used in the Freshwater EHMP

Indicator	Lowland or Coastal Guideline	WCS	Operand	Unit
Physical & Chemical				
pH (min.)	6.5	4.5	≥	$[H^+]$
pH (max.)	8.5	10.5	≤	$[H^+]$
Conductivity	400	1,870	≤	$\mu S\ cm^{-1}$
Temp. (max.)	22	NA	≤	°C
Temp. (range)	4	NA	≤	°C
DO (min.)	20	NA	≥	% saturation
DO (range)	50	NA	≤	% saturation
Nutrient Cycling				
$\delta^{15}N$	5	10	≤	‰
Ecosystem Processes				
$\delta^{13}C$	-28	-50	≥	‰
R_{24}	0.35	1.2	≤	$g\ C\ m^{-2}\ day^{-1}$
GPP	0.5	1.3	≤	$g\ C\ m^{-2}\ day^{-1}$
Aquatic Macro-invertebrates				
No. of taxa	22	0	≥	Number
PET richness	4	0	≥	Number
SIGNAL score	4	2.4	≥	Number
Fish				
PONSE	100	0	≥	%
O/E_{50}	1	0	≥	ratio
Prop. alien fish	0	100	=	%

Operands indicate if guidelines are upper or lower limits.
Note that values are presently identical for lowland and coastal streams.

Both guideline and WCS values were derived independently for different groups of streams with similar physical conditions (i.e. stream classes) so that standardised scores account for the majority of natural spatial variation in the values of each index. The stream classes that were identified within the Tweed study belong to 'coastal' and/or 'lowland' stream types. Index values for each site are only compared to guideline and WCS values for the same stream class.

Calculation of each standardised score involves an initial comparison of each index value against the corresponding guideline and WCS value. Index values satisfying the criteria specified in the table of guideline values (i.e. <operand> <guideline value>) are awarded a score of 1.0, whilst any 'worse' than/equal to the WCS value are awarded a score of 0.0. The score for all other values is calculated using the equation:

$$\text{Score}_{ij} = 1.0 - \left| \frac{(x_{ij} - \text{Guideline}_{ij})}{(\text{WCS}_{ij} - \text{Guideline}_{ij})} \right|$$

where: x_{ij} is the value of index i at a site within stream class j,

Guideline_{ij} is the corresponding 'ecosystem health guideline' value, and

WCS_{ij} is the corresponding 'worst case scenario' value.

This equation has three main components, each with a distinct function. The amount that an index value deviates from guideline or 'minimally-disturbed' conditions is provided by '(x_{ij} – Guideline_{ij})', and that deviation is expressed as a proportion of the range of values for the index (excluding 'reference conditions') by dividing by '(WCS_{ij} – Guideline_{ij})'. This latter calculation makes results comparable across indices with different scales of measure, e.g. pH (1.0–14.0 units) and conductivity (20–20 000 μS cm^{-1}). Final subtraction of the absolute value of the preceding result from 1.0 scales scores to the range 0.0–1.0.

Two examples of the calculation of standardised scores follow:

Conductivity

Index value = 1 000μS cm-1

Guideline = 400μS cm-1

WCS = 1 870μS cm-1

$$1.0 - \left| \frac{(1000 - 400)}{(1870 - 400)} \right| \equiv 1.0 - \left| \frac{(600)}{(1470)} \right| \equiv 1.0 - |0.41| = 0.69$$

Number of taxa

Index value = 17 taxa

Guideline = 22 taxa

WCS = 0 taxa

$$1.0 - \left| \frac{(14\text{-}22)}{(0\text{-}22)} \right| \equiv 1.0 - \left| \frac{(\text{-}5)}{(\text{-}22)} \right| \equiv 1.0 - |0.23| = 0.77$$

Reduction of temperature and DO scores

An additional step is taken in the calculation of standardised scores to reduce the two scores for each of water temperature and DO to a single score for each parameter. That reduction provides more equitable emphasis on temperature and DO in relation to pH and conductivity, which are the other components of the physical and chemical indicator.

The reduction of temperature and DO scores is accomplished using tables based on whether observed values pass or fail in relation to guideline values. More emphasis is placed on whether or not temperature range and minimum DO scores, rather than temperature maximum and DO range scores, passed ecosystem health guideline criteria. Failure in either of these indices represents more deleterious conditions than failure in terms of the other two measures. As an example of the use of these tables, index values yielding standardised scores of 0.7 (i.e. <1.0 = fail) for diel temperature range and 1.0 (= pass) for diel temperature maximum would be awarded a final water temperature score of 0.5.

Water temperature

		Temp. (maximum)	
		Pass	Fail
Temp.	Pass	1.0	0.8
(range)	Fail	0.5	0.0

Dissolved oxygen

		DO (minimum)	
		Pass	Fail
DO	Pass	1.0	0.3
(range)	Fail	0.8	0.0

Summarising standardised scores

Scores generated within the Freshwater EHMP are directly comparable across indices and sites as they are standardised for the major sources of spatial variation and differences in scale across indices. This allows valid summaries of results to be produced using simple arithmetic averaging at a range of scales. Perhaps the most important of the averaging sequences used are those leading to the derivation of Report Card Grades. This process involves the following steps:

Standardised scores are calculated using the methods described above: 15 indices x 15 sites

Scores for each indicator are averaged across indices: 5 indicators x 15 sites

Scores are averaged across sites within each reporting area: 5 indicators x 4 reporting areas

Scores averaged across indicators: 4 reporting areas

Derivation of report card grades

Summarisation of Freshwater EHMP results culminates with the derivation of a single rating of ecological health for each of the four reporting areas. These Report Card Grades are probably the single most valuable tool used in the communication of results to natural resource managers and the general public.

The rating system used for Report Card Grades is based on the format of a traditional school report card, with primary ratings ranging from a high of ‘A’; through intermediate ratings of ‘B’, ‘C’ and ‘D’; to a low of ‘F’. Grades of ‘A’ indicate that all five ecosystem health indicators return results equivalent to those observed at minimally-disturbed reference sites, and a grade of ‘F’ denotes that results fail ecosystem health guidelines. Plus (+) and minus (-) secondary grades are added to provide greater resolution (e.g. A-), but A+ is not used as results cannot be ‘healthier’ than reference conditions. Secondary grades are not assigned to grades of ‘F’, as a fail is taken to be absolute.

The derivation of Report Card Grades is essentially an objective process based firstly on the single score for each reporting area, and secondly on the five component indicator scores. To attain an ‘A’ grade, a reporting area must yield a score of ≥0.90, and score well for both biological indicators (aquatic macroinvertebrates and fish) and ecosystem processes. Emphasis is placed on these three key indicators as they tend to integrate results for both the physical and chemical, and nutrient cycling indicators. A reporting area is only awarded an ‘F’ rating if it yields a score of ≤0.70, and scores poorly for the key indicators. Boundaries for other grades are equally distributed between ‘A’ and ‘F’ grades.

Estuarine Methods

The EHMP measures the ecosystem health of the two broadwaters; Cobaki and Terranora, and Terranora Creek to the mouth of the Tweed River. The program monitors a suite of traditional water quality parameters complemented by a range of biological indicators. All of the water quality parameters are measured at 28 sites monthly throughout the system. Sites are visited on a neap tide approximately two hours before and after the low tide. At each site the following water quality parameters are measured:

- Water column physical and chemical properties: turbidity, dissolved oxygen (DO), salinity, pH and temperature.
- Water depth
- Phytoplankton biomass: by measuring the amount of chlorophyll *a* in a sample
- Water clarity: by analysis for total suspended solids
- Surface water nutrients: total nitrogen (TN), total phosphorus (TP), oxides of nitrogen (NO_x), ammonium (NH_4^+) and filterable reactive phosphorus (FRP).
- The biological indicators monitored by the program are generally measured less frequently.
- Tracking the spatial extent of processed nitrogen (sewage plume mapping): measured once in November at selected sites
- Measuring the variation in seagrass depth range: measured once in October at three sites
- Reviewing existing seagrass distribution maps where available
- Assessing the condition of the riparian vegetation along the entire estuary: undertaken once in November

The rest of this section provides further details of the methods used by the Estuarine EHMP to measure the above indicators.

Water column: physical and chemical indicators

Turbidity

Turbidity is the measure of light scattering by suspended particles in the water column, providing an indirect indication of light penetration.

Why do we measure it?

Excess amounts of suspended particles can contribute to environmental damage, including, reduced light penetration through the water column, smothering of benthic organisms like seagrass, irritation of fish gills and transportation of contaminants. Changes to the availability of light within the water column influences the ability of aquatic plants to photosynthesise and fix energy. Sediment enters our waterways through erosion and runoff accelerated by catchment alterations. Once in the waterways, fine sediments are readily resuspended by wave and tidal energy.

Methods

Turbidity is measured with a TPS turbidity sensor which is in the form of a handheld portable probe connected to a data recorder. The turbidity sensor consists of a light source for illuminating the sample and a photodiode to detect the intensity of light scattered by suspended particles in the water column. The wavelength of light used is between 830 and 890nm as specified by the International Standards Organization (ISO). The photodiode detects scattered light at 90^0 from the light source in accordance with ISO standards. The output from the sonde's turbidity sensor is processed by the sonde's software and is recorded in Nephelometric Turbidity Units (NTUs).

UQ, CRM

Sediment runoff entering the waterbody during a rainfall event causing changes in turbidity levels.

Salinity

Salinity is a measure of the total concentration of inorganic ions, usually mineral salts, in the water column. Clean oceanic water has a salinity of around 36 parts per thousand.

Why do we measure it?

Salinity affects the type of organisms present in aquatic systems. Aquatic organisms can be broken up into two types: those that can only adapt to a narrow range of salinities (stenohaline) and those that can adapt to a wide range of salinities (euryhaline). Estuarine organisms are generally euryhaline due to the seasonal and daily tidal differences in salinity to which they are subjected. Adverse biological effects on marine and estuarine organisms are most likely to result from reductions in salinity and generally come from pulsed riverine discharge events like floods.

Methods

Salinity is measured indirectly with a TPS conductivity sensor which is in the form of a handheld probe connected to a data recorder. The sensor comprises two platinised platinum plates. The measured voltage drop across the plates is converted into a conductance value in micro-Siemens per centimetre (μS/cm).

The conductivity of a waterbody is highly dependent on temperature, varying as much as 3% for each change of one degree Celcius. To calculate salinity from conductivity, the meter's software automatically compensates for temperature readings according to algorithms found in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

Water temperature

Temperature is a measure used to determine the thermal characteristics of a waterbody, and hence is a good way to identify stratification.

Why do we measure it?

Many estuarine ecosystem functions are closely regulated by water temperature. Oxygen solubility, hydrophobic interactions and primary production are all sensitive to temperature changes. Temperature variations in our waterways may occur naturally as part of normal tidal or seasonal cycles, or as a consequence of human activities.

Excess heat or cold within a waterbody are considered forms of thermal pollution. Human impacts, such as loss of riparian vegetation, pulse discharges from dams or weirs and discharge from WWTPs, may all cause rapid changes to water temperature.

At an individual level, an organism's growth, metabolism, reproduction, mobility and migration are all altered by changes in ambient water temperature.

Methods

Temperature is measured with a TPS temperature sensor which is incorporated into the dissolved oxygen probe connected to a data recorder. The sensor comprises a thermistor of sintered metallic oxide that changes in resistance with temperature variation. The algorithm for conversion of resistance to temperature is built into the meter's software, and accurate temperature readings in degrees Celsius are produced.

Total suspended solids

Total suspended solids is a measurement of the amount of suspended particulate matter that is present in the water column at the time of sampling.

Why do we measure it?

Light penetration is dependent on the amount of suspended particulate matter (including phytoplankton) and coloured dissolved organic matter (e.g. tannins) in the water column. For example, marine plants, such as seagrasses, are reliant on receiving sufficient light for growth and survival. If the availability of light declines due to decreased water clarity, seagrass loss can occur.

Methods

Total suspended solids is determined in the laboratory from samples taken from the field. A sample is filtered through a weighed standard glass fibre filter and the residue retained on the filter is dried to a constant weight at 105°C.

UQ, VISION AND REMOTE SENSING

Sediment runoff from adjacent land development.

Dissolved oxygen

Dissolved oxygen (DO) concentration is a measure of the oxygen in a waterbody.

Why do we measure it?

Many estuarine processes are dependent on the concentration of DO in the water. DO concentration in a waterbody is affected primarily by the rate of transfer from the atmosphere but also by oxygen-consuming (e.g. respiration) and oxygen-releasing (e.g. photosynthesis) processes. Organic matter, such as sewage effluent or dead plant material that is readily available to microorganisms has the greatest impact on DO concentrations. Microorganisms use water column DO during decomposition of the organic matter. DO concentration in the water column is highly dependent on temperature, salinity and biological activity. Consequently, DO concentrations under natural conditions may change substantially over a 24 hour period.

Variations in DO concentrations may affect many organisms such as fish, invertebrates and microorganisms, which depend upon oxygen for survival. The oxygen requirements of aquatic organisms vary widely depending on which species, their life stage and different metabolic requirements.

Methods

DO is measured with a TPS DO sensor which comprises a handheld probe attached to a data recorder. The sensor consists of a membrane covered Clark-type probe. The probe measures the current associated with the reduction of oxygen as it diffuses across a Teflon membrane that is proportional to the partial pressure of oxygen in the sample. DO is measured as a concentration in mg/L and recalculated using temperature to return percentage saturation (%).


UQ

Dissolved oxygen probe.

pH

pH is a measure of the acidity or alkalinity of a substance. The pH scale ranges from 0 (acidic) to 7 (neutral) through to 14 (alkaline). Pure distilled water is neutral at pH 7 but values vary with temperature.

Why do we measure it?

The pH of most marine waters is close to 8.2 and is primarily controlled by the strong presence of the carbonate-bicarbonate buffer system but is also affected by naturally occurring organic matter. Excess catchment runoff from various land uses may cause acidification of natural waters. For example, agricultural runoff over surface soils with a low pH has been shown to cause reductions in stream pH. Decomposition of nitrogen fixing legumes and the use of nitrogen fertilisers contribute significantly to the acidification of surface soils through the addition of nitrate ions. Areas prone to acid sulfate soils may also affect the acidity of estuarine waters. Exposure of acid sulfate soils through clearing, drainage, dredging or lowering of the water table results in oxidation of iron sulfide to sulfuric acid. Following rainfall, runoff from these areas flows into coastal and estuarine waters where it can have direct effects on aquatic organisms.

Changes to the pH of estuarine waters can affect fish, marine plankton and benthic invertebrates. Changes in pH can also lead to indirect toxic effects on aquatic organisms through changes in the toxicity of several contaminants. For example, a reduction in pH can increase the toxicity of cyanide and aluminium while increased pH increases the toxicity of ammonia.

Methods

pH is measured with a TPS pH sensor which comprises a hand-held probe attached to a data recorder. The sensor consists of a field replaceable pH electrode for the determination of hydrogen ion concentration. The probe is a combination electrode consisting of a proton selective glass reservoir filled with buffer at approximately pH 7 and an electrode that utilises gelled electrolyte. Protons (H^+ ions) on both sides of the glass set up a potential gradient across the glass membrane. This potential difference is proportional to the pH of the media.

TLS

Field officer taking measurements using a water quality meter.

Nutrient indicators

Nitrogen and phosphorus are nutrients essential to biota in waterways. Nitrogen is present in animal and plant tissue chiefly as proteins while phosphorus is contained in cell walls and energy transporting molecules.

Nitrogen

Nitrogen is present in waters in both dissolved and particulate forms. Particulate forms include those bound up in living organisms, organic compounds like proteins, and those bound to suspended particulate matter like clay and detritus. Dissolved nitrogen may either be inorganic nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+) or organic (e.g. urea; dissolved proteins). EHMP measures dissolved inorganic nitrogen (DIN = $NO_3^- + NO_2^- + NH_4^+$) and total nitrogen (TN) concentrations (dissolved + particulate forms).

Phosphorus

Phosphorus is present in water in both dissolved and particulate forms. Particulate forms include those incorporated into plant and animal matter, and those bound to suspended particulate matter like clay and detritus. Dissolved phosphorus includes inorganic orthophosphates, polyphosphates, organic colloids and low molecular weight phosphate ethers. EHMP measures the concentration of total phosphorus (TP) and filterable reactive phosphorus (FRP), which is similar to dissolved phosphorus.

Why do we measure it?

Nitrogen and phosphorus are derived from natural ecological events such as oceanic upwelling, litter fall, weathering, and from human sources (e.g. sewage effluent, leaching from cleared land, fertiliser runoff, and industrial and agricultural effluents).

Excess nutrients in our waterways can stimulate the growth of macrophytes and algae (including cyanobacteria) to nuisance proportions. Blooms of these can displace endemic species, diminish light availability to benthic species (e.g. seagrass communities), and cause excessive fluctuations in pH and DO which can stress and eliminate sensitive species.

The EHMP monitors water column nutrient concentrations to assess the spatial and temporal extent of nutrient loads in the estuary and determine if biological processes are able to sequester nutrients at the same rate they are being delivered. Biologically available nutrients are precursors to algal blooms, especially when those nutrients are normally limiting. They can be compared with biological indicators like phytoplankton growth, seagrass maximum depth limit and seagrass distribution.

Methods

Samples for nutrient analyses are collected on a monthly basis at each of the 28 estuarine EHMP sites by Tweed Laboratory field officers and analysed by Tweed Laboratory Services.

Field sampling and storage

Water samples taken from a site are separated into total nutrient samples and soluble nutrient samples.

- A clean plastic bucket is used to collect the sample. The bucket is cleaned thoroughly before sampling and is rinsed rigorously in sample water at least three times at each site. The sample is taken from just below the surface. Care is taken to keep the bucket free of contaminants from skin and motor exhaust with a lid that is placed on top.
- Total nutrient samples are poured directly from the bucket into an appropriately prepared plastic bottle. The bottle, including the lid, is rinsed with at least 60ml of sample water at each site before sampling.
- Soluble nutrient samples are filtered for the determination of FRP and dissolved nitrogen. Water samples are filtered under pressure from a 60ml syringe through a 0.45µm membrane filter. The syringe is rinsed prior to sample collection three times with sample water from the bucket. At sites with large amounts of suspended sediments, a glass fibre pre-filter is used to remove large particles.

TLS

Field officer taking nutrient samples

- All samples are trans-ported on ice in a dark insulated container and are placed in a freezer immediately upon return to the laboratory.

Sample analysis

- Soluble nutrient samples are analysed for FRP, NO_3^-, NO_2^- and NH_4 simultaneously using an automated flow injection analyser (FIA) using photochemical methods.
- Total nutrient samples analysed for TN and TP are oxidised/digested using a simultaneous persulfate procedure at 121°C with an initial pH of 13 and a final pH of about 2. After digestion, analyses for TN and TP are performed using the FIA and photochemical methods (APHA, 1998).

Chlorophyll *a* indicator

Chlorophyll *a* (chl *a*) is a pigment found in photosynthetic organisms. It is an essential molecule for the process of photosynthesis (the conversion of light energy to chemical energy resulting in the consumption of carbon dioxide and the production of oxygen). In surface waters, chl *a* is present in phytoplankton such as cyanobacteria, diatoms and dinoflagellates. Because chl *a* occurs in all phytoplankton it is commonly used as a measure of phytoplankton biomass.

Why do we measure it?

Chlorophyll *a* is measured as an indicator of phytoplankton biomass. Phytoplankton biomass is largely influenced by the availability of nutrients, light and optimal water temperature. By measuring phytoplankton biomass we are provided with an indication of the nutrient and light conditions present at the time of sampling and their resulting biological effect. Under certain environmental conditions, in particular elevated light and high nutrients, phytoplankton blooms can result. When phytoplankton blooms decay, the resulting bacterial activity can reduce DO concentrations in the water column, possibly leading to fish kills.


EPA

Elevated phytoplankton levels turn water green.

Methods

Field collection

Phytoplankton is collected in the field by filtering a known volume of water through a Whatman 1µm GFC glass microfibre filter paper. The sample is filtered through the paper under suction, with care taken to ensure that the pressure does not exceed half atmospheric pressure. Too much suction can disrupt the chloroplasts within the phytoplankton cells, potentially degrading the chlorophyll.

The amount of water filtered is subject to the level of turbidity at the sampling site. The greater the particulate matter in the water column, the less water can be filtered. Water is filtered until the flow through the filter paper at half atmospheric pressure is reduced to a trickle. The paper is then removed and blotted dry to remove excess moisture. The filter paper is placed into a 15ml graduated screw cap polypropylene tube. Each tube contains 0.01g magnesium carbonate which acts as a buffer during the extraction process.

During collection and storage, exposure of the samples to light is avoided. Samples are immediately wrapped in aluminium foil after filtering and placed on ice in a dark, insulated container to lower the sample temperature and prevent chlorophyll degradation. In the laboratory the samples are placed into a freezer for storage before analysis.

Chlorophyll *a* extraction

The following procedures have been developed in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

All tubes are inspected for weaknesses that may allow liquid to leak. 6ml of 90% acetone is added to each sample. Samples are placed in a freezer for 10 to 15 minutes to lower the temperature of the acetone.

Samples are removed and macerated using a mechanical tissue grinder at approximately 2000rpm for 20 seconds. Grinding the sample disrupts the cells containing chlorophyll and allows the complete extraction of the pigment. The sample is kept cold during maceration by a chilled water bath below 5°C.

90% acetone is then added to the sample tube to reach a volume of 10ml.

Samples are placed back into a freezer for 12 to 24 hours before analysis to allow for full extraction of chlorophyll.

Analysis

To prevent sediment affecting the analysis, each sample is centrifuged for five minutes at 3900rpm. This ensures that all sediment is concentrated at the base of the tube and allows the supernatant to be decanted from the tube with a relatively low risk of sediment transfer.

After centrifugation, the supernatant is transferred into a thoroughly clean glass cuvette. The absorbance of the extract is measured at a wavelength of 663nm, followed by the absorbance at 750nm. This accounts for any absorbance at 663nm that is due to turbidity. Chlorophyll *a* concentration is then calculated according to the equation stated in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998) and reported in µg/L.

Processed nitrogen tracking indicator

Processed nitrogen[1] tracking is used to assess the extent of wastewater treatment plant discharges into the Cobaki / Terranora estuary through measurements of the uptake of the stable nitrogen isotope ^{15}N by the mangrove *Avicennia marina*.

Why do we measure it?

It is important to trace the source and extent of sewage effluent in receiving waters to broadly gauge the contribution of wastewater to nitrogen pools in the receiving waters. Nitrogen stable isotopes are a tool to distinguish sewage-derived nitrogen from other nitrogen sources.

Nitrogen exists as two stable isotopes, ^{14}N and ^{15}N. ^{14}N is the most abundant form (99.6%) while ^{15}N is heavier and rarer (0.4%). The ratio of ^{15}N to ^{14}N is termed the $\delta^{15}N$ value and is measured in parts per thousand (‰) as a deviation from a standard. Treated sewage is enriched in the heavier ^{15}N isotope and therefore displays $\delta^{15}N$ values of approximately +10‰. Marine plants incorporate nitrogen from the surrounding water column and reflect the isotopic signature of the source nitrogen. The common mangrove species *Avicennia marina* is used as a tool to detect the presence of sewage-derived nitrogen. $\delta^{15}N$ values typically range from 2‰ in non-sewage impacted waters through to 10‰ adjacent to sewage discharge sites. By evaluating the changes in $\delta^{15}N$ values in mangrove leaves, it is possible to determine the extent of processed nitrogen in the waterway.

1 Processed nitrogen refers to nitrogen that has undergone biological processing and is derived from anthropogenic sources such as sewage effluent, septic tank or on-site wastewater treatment systems, and animal faecal pollution.

Methods

Collection of mangrove leaves

At each sampling location, the second youngest leaf of a rosette was selected from the upper canopy of at least five fringing *Avicennia marina* trees.

The leaves chosen were sun-exposed, physically mature and continuously free of insectivorous galls or fungal infection. Leaves from each sampling location were split into two replicate samples. All samples are placed on ice and transported to the laboratory for processing.

Processing of mangrove leaves for ^{15}N concentration

All samples are rinsed twice with distilled water to remove any attached sediment and biota. Samples are then dried at 60°C for 72 hours or until all moisture has been removed. After drying, the material is ground in a mortar and pestle until it is of a fine, homogeneous 'dust-like' consistency.

A small quantity of dried, ground sample is weighed into a tin capsule and oxidised at high temperatures. Samples are combusted in a EuroEA 3000 (EuroVector, Italy) elemental analyser and the resulting N_2 and CO_2 gasses are chromatographically separated and fed into IsoPrime (Micromass, UK) isotope ratio mass spectrometer. This measures the ratio of heavy and light isotopes in a sample and compares them to a standard. Ratios are expressed in %N by mass as well as δ notation and are parts per thousand (‰).

UQ, CRM

Estuarine section of Cobaki Creek showing a mix of mangrove and terrestrial riparian vegetation.

Seagrass depth range indicator

The seagrass depth range (SDR) is the difference in elevation (m) between the upper and lower depth record of the seagrass *Zostera muelleri* at a site. The use of SDR as an indicator of ecosystem health is based on the assumption that the shallow distributional limit of seagrass is determined by the tolerance of the seagrass to dessication at low tide, and that the deeper distributional limit is determined by light availability.

Why do we measure it?

Seagrasses are critical components of coastal ecosystems. They increase primary productivity, support complex food webs, provide habitat for numerous species including fish, prawns and other invertebrates and provide sea floor stability.

The most common factor leading to seagrass loss is an increase in suspended sediments from terrestrial inputs and sediment resuspension leading to a long-term reduction in light.

The SDR provides an indication of water clarity at a site, as the depth to which seagrass can grow is directly dependent on the penetration of light through the water. By regularly measuring the depth range, the effect of temporal changes in water quality on seagrass meadows can be inferred. This provides the EHMP with a link between changes in water quality throughout the estuary and the effects it has on biological systems.

Methods

Site selection

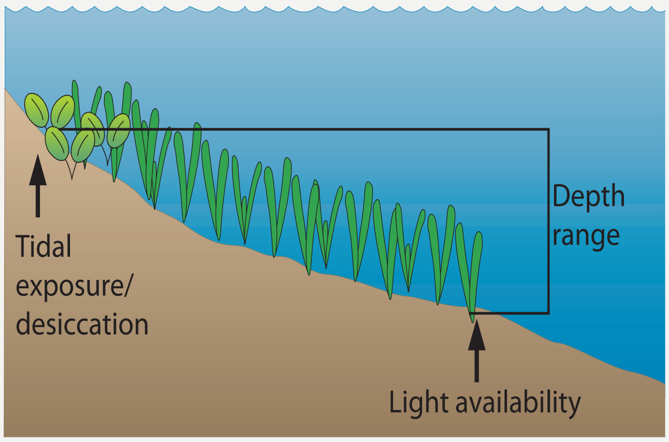
The EHMP surveyed three sites in the Cobaki and Terranora estuary. Two of these three sites have been surveyed previously, back in 2000. Suitable survey sites are limited within the estuary due to the shallow nature of the waterway.

Species

Zostera muelleri is used as the indicator species as it is the most abundant seagrass in the estuary, has minimal seasonal variation in distribution and responds to changes in light availability.

Measuring the depth range

- An autoset level (dumpy level) and graduated staff are used to calculate elevations and distances.
- The depth range and general profile of the seagrass bed is determined along a main transect using basic surveying techniques. Ten replicate transects, approximately 10m apart, five on either side of the main transect, are surveyed to record the upper and lower distributional limits (i.e. no profile information is recorded).
- All transects at a site are related back to a Permanent Survey Mark (PSM) to give absolute elevations relative to Australian Height Datum (AHD).



UQ, CRM

Schematic diagram illustrating how seagrass depth range is measured.

Riparian habitat assessment indicator

Riparian vegetation provides the interface between the land and a waterbody.

Why do we measure it?

Riparian vegetation performs many functions by providing habitat for a wide range of organisms, preventing erosion of riverbanks and acting as a buffer zone to minimise nutrients and sediments entering the waterway. Removal of riparian habitat in estuaries reduces the biodiversity and productivity of the system and can lead to a reduction in water quality and ecosystem health as a result.

In estuaries, mangroves are common in the riparian zone, providing crucial nursery habitats to many aquatic organisms including commercially important fish and prawn species. Riparian habitats in the Tweed estuaries are under considerable threat from modification associated with urbanisation and agriculture.

UQ, CRM

The riparian assessment technique evaluates the condition of the riparian zone by taking a video recording of the bank and vegetation community.

Methods

The EHMP uses a Linear Estuarine Habitat Video Assessment (LEHVA) technique that records the structure and condition of fringing riparian vegetation, and the physical condition of the bank and tidal zone to provide a score of estuary bank condition. The bank condition score relates to the ability of that area to provide ecosystem services and its resilience to future pressures.

The LEHVA method relies on qualitative assessments of habitat structure and condition determined from continuous video recordings of the riparian and intertidal zone along both sides of the main channel throughout the entire estuary. The video is analysed for a number of features that relate to the 'health' of the estuary. Simultaneous GPS data enables these features to be mapped to give a spatial representation of riparian habitat types and their condition. Qualitative interpretations made during analysis are based on quantitative baseline studies. Video interpretation of riparian vegetation relates only to the first 15m of bank above the mean low-water spring tide mark as this area has the greatest relationship with the estuarine waters.

Summary of features measured for condition index:

Inter-tidal vegetation

- Density and height – biomass
- Number of dead trees
- Crown dieback – no. of trees affected and intensity of dieback

Terrestrial vegetation

- Density and height – biomass
- Number of dead trees
- Visual tree health assessment.

Bank type and condition

- Substrate type – natural or unnatural
- State – eroded, stable or depositional
- Slope

Detractors

- Man-made structures (e.g. drains, wharfs, boat ramps)
- Litter
- Weeds (e.g. bitu bush, camphor laurel and lantana)

Other features such as biodiversity, species type and adjacent land usage were recorded but not used to generate the condition score.

Determining report card grades for estuarine regions

The Cobaki and Terranora estuary has been divided into four distinct reporting zones. Ecosystem Health Report Card Grades ('A' to 'F') are generated for each of these four regions. The reporting zones were selected because they are distinctive geographically or by other attributes, such as water depth and/or the degree of exchange with the ocean.

Cobaki / Terranora estuary reporting zones are:

1. Cobaki Broadwater
2. Terranora Broadwater
3. Terranora Creek
4. Tweed River mouth

Report Card Grades are calculated by combining the outcomes of two separate data analysis processes and expert assessment of the data outputs. The most important process (accounting for 80% of grade) is the Ecosystem Health Index (EHI) value for each reporting zone, a process applied to the indicators that are measured at the 28 monthly estuarine water quality sites. The data collected from these sites is also analysed and presented spatially and temporally.

The second process (accounting for 20% of the grade) is to calculate a Biological Health Rating (BHR), a process that incorporates indicators that do not conform to spatial analysis and presentation.

Generating an ecosystem health index (EHI)

The Ecosystem Health Index is a measure of how much of a waterway's area complies with the defined water quality objectives adopted by the EHMP. The water quality objectives used for this EHMP are those that have been adopted by the Tweed River Committee as set out in the Tweed River and Catchments Interim Water Quality Management Plan (October 2000).

Seven carefully selected indicators are used for determining EHIs. Similar indicators have been used extensively within the estuaries for the SEQ EHMP.

Three key stages are involved in the generation of EHIs.

1. Annual medians of each of the indicators used in the EHI are calculated for each of the 28 monthly sites. Statistical and spatial analysis is also undertaken to assess the validity of the EHI.
2. Compliance scores for all of the EHI indicators in each of the systems are generated using the adopted guidelines. A score of 1 equals 100% compliance.
3. An EHI is then calculated for each reporting zone by averaging the compliance of all the indicators.

Tweed EHMP water quality objectives for each EHI indicator.

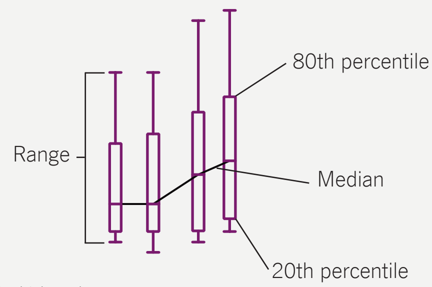
Performance Indicator	EHMP Objective
pH	7-9
chl *a*	< 10 µg/L
TN	< 0.5 mg/L
TP	< 0.05 mg/L
DO	> 6mg/L
Turbidity	< 20 NTU
Suspended solids	< 10 mg/L

Generating a biological health rating (BHR)

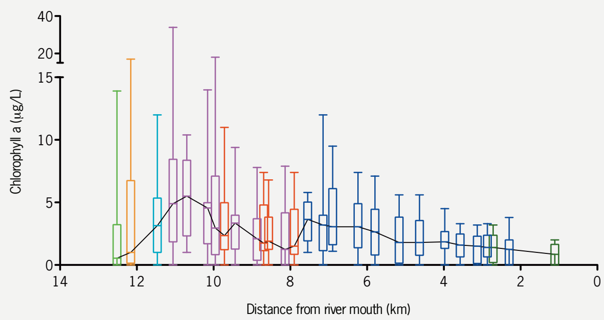
The Biological Health Rating (BHR) is applied to those indicators that do not conform to spatial prediction/presentation or those without water quality guidelines. These indicators are: seagrass depth range, seagrass distribution, riparian condition, and sewage plume mapping (processed nitrogen tracking). Each indicator is rated (1 to 4 or 5) according to health status of the indicator, with a higher rating indicating better health. The BHR and EHI values are then combined (20% BHR: 80% EHI) to provide a single value used to assign a Report Card Grade.

Spatial and temporal trends

Box and whisker plots are used to display the median value and the amount of variability in the data set. Data is also presented spatially to show trends along a distance, and also temporally to show trends in time.



Key to box and whisker plots



Box and whisker plot showing spatial trends (above example shows Chlorophyll *a* with distance from the Tweed River mouth).

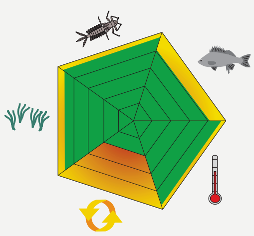
Guide to Ecosystem Health Reporting

Freshwater reporting

The freshwater EHMP results are calculated and reported on a creek sub-catchment scale. The results are presented as an overall grade and also graphically as EcoH plots. The EcoH plots provide a summary of the results for each of the five indicators, upon which ecological assessments and the overall report card grades are based. These plots are used to show results at the reporting region scale.

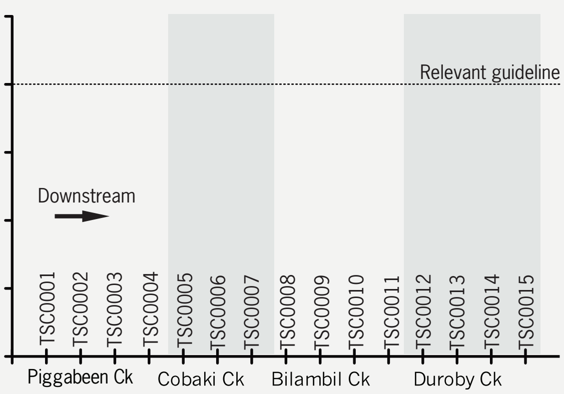
Ecosystem health (EcoH) plots

An EcoH plot comprises of five triangular 'bars' or wedges, with each wedge displaying the result for one of the five indicators. The centre of the plot is its origin (score = 0), and the outer edge a score of 1.0. Green fill within each wedge is used to display the score for the given indicator, and a background of red to orange fill highlights the severity of associated ecological impacts. When an indicator yields a score of 1.0, the entire wedge is filled green with none of the background showing (=no ecological impact).



Spatial data summary

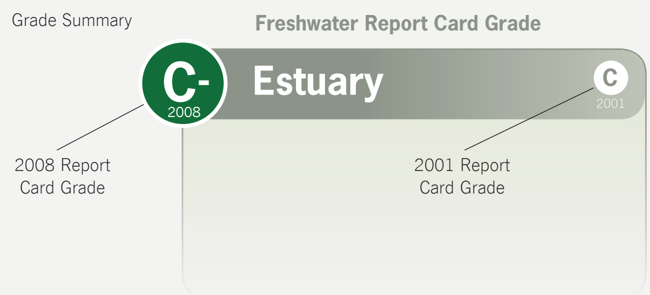
The following graphs are used to show the results of the freshwater EHMP for each sampling site. The data is also spatially represented by creek (ie. sites are arranged from left (upper stream) to right (lower stream). The location of each sampling site is shown on a map contained in the Appendix.



Example of freshwater spatial summary graph (dotted line represents relevant guideline objectives).

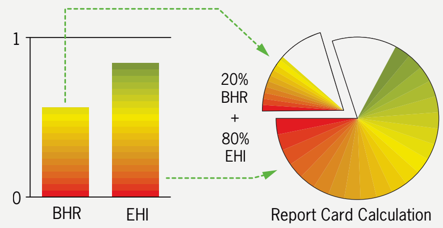
Estuarine reporting

A single EHI value and a single BHR value are calculated for each reporting region. These two values are combined with expert opinion to provide a single value used to assign a Report Card Grade. The results of both the EHI and BHR are presented as bar charts, with the size and colour of the bar representing the degree to which the estuary complies with set water quality objectives and the results of the biological assessment. These charts are used to show results at the reporting region scale.



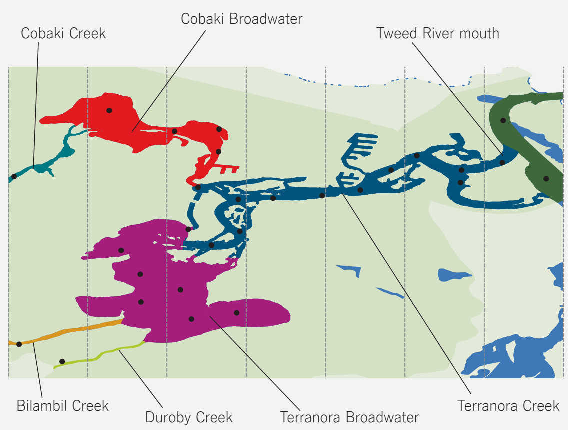
Ecosystem health bar charts

The Ecosystem Health bar charts are used to display the results of estuarine water quality monitoring compliance (EHI) and the results of biological assessment (BHR). Similar to the concept of EcoH plots above, the bar charts range from 0 = no compliance and very poor ecological health; to 1 = full compliance and excellent ecological health. The same colour scheme of red-orange-green is used to convey the severity of the associated ecological impacts.



Spatial data summary

Colour coordinated box and whisker plots are used to show the spatial trends in estuarine water quality data. The following map of the estuary shows the location of all estuarine sampling sites, divided into colour coordinated reporting regions.



Estuarine spatial map key for box and whisker plot graphs.

Freshwater Results Overview

Physical and chemical indicators

Generally, all four freshwater creeks performed well for the physical and chemical indicators, only one site, TSC-0008 on Bilambil Creek, passed Ecosystem Health Guidelines for all six indices within the Physical and Chemical indicator set.

Stream water at all sites along Piggabeen, Cobaki, Bilambil and Duroby creeks was at least slightly acidic, with pH equalling or less than the lower guideline value of 6.5 at eleven of the fifteen assessment sites. However, these pH results were only marginally below the guideline value and hence, still yielded a relatively high score for the pH index (standardised score, see graph below).

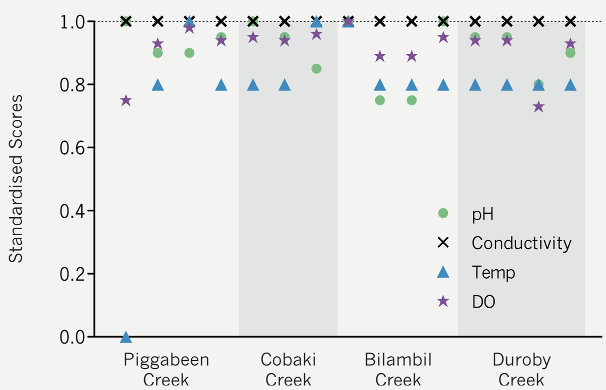
The temperature index however, was strongly influenced by the lowest possible score (0.00) for site TSC 0001 on Piggabeen Creek. Both the maximum and range of temperature at that site exceeded the guideline values of 22°C and 4°C, respectively.

The majority of sampling sites across all creeks showed temperatures in excess of the guideline maximum of 22°C. These elevated water temperatures are likely to be a result of a lack of riparian vegetation cover along the creek edges, that would otherwise shade the stream and help to maintain lower water temperatures.

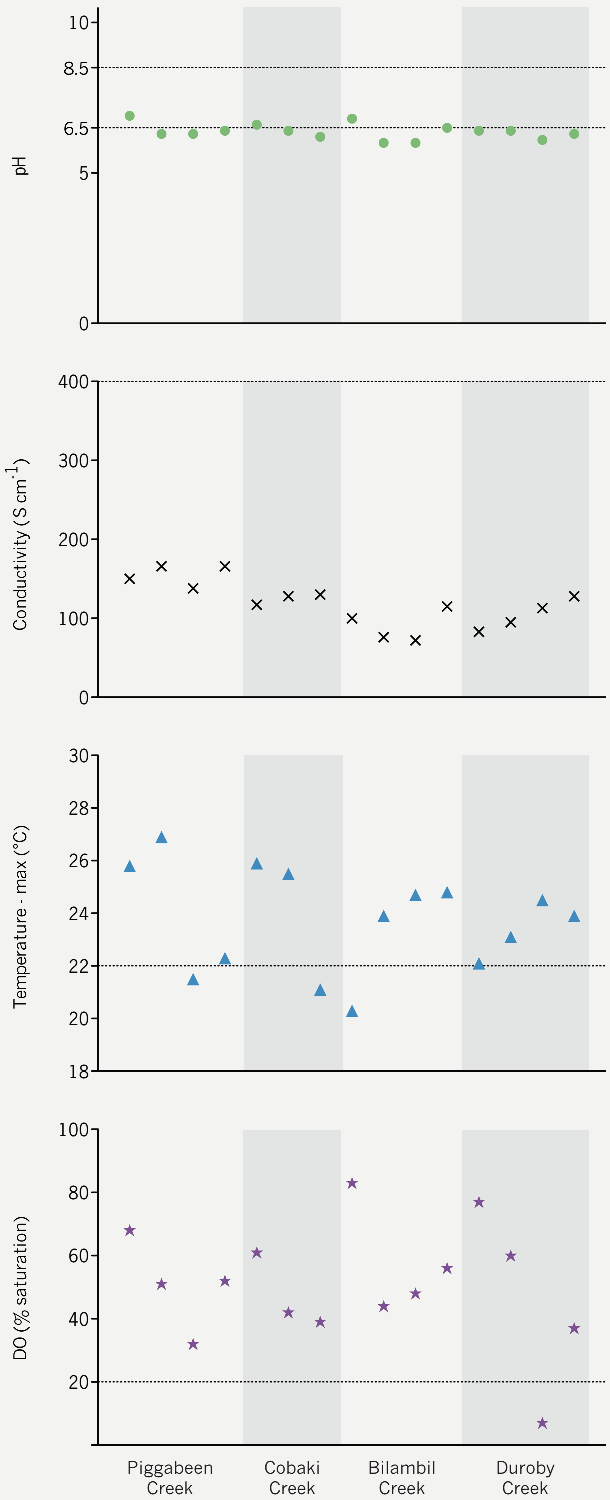
The only other notably low score for indices within the Physical and Chemical indicator set was that for dissolved oxygen (DO) at site TSC-0014 on Duroby Creek. At this location the 24 hour minimum value for DO was 7 % saturation which is widely considered to be deleterious to gill breathing aquatic organisms, No other sites showed this result.

Minimum DO concentrations were always higher at the most upstream site on each stream, partly due to the relatively high velocity of water flow at those sites (c.f. sites further downstream). The only other consistent pattern of change in water ‘quality’ along the streams investigated was that pH was also highest at the most upstream site on each stream.

The conductivity at all sampling sites, within all creeks, was below the guideline objective of 400μS cm^{-1}.



The above figure shows a summary of standardised scores for each physical and chemical indicator. A score of 1 = 100% compliance with ecosystem health objectives.



The above graphs show the results of each physical and chemical indicator by creek (dotted lines indicate relevant ecosystem health guideline objectives).

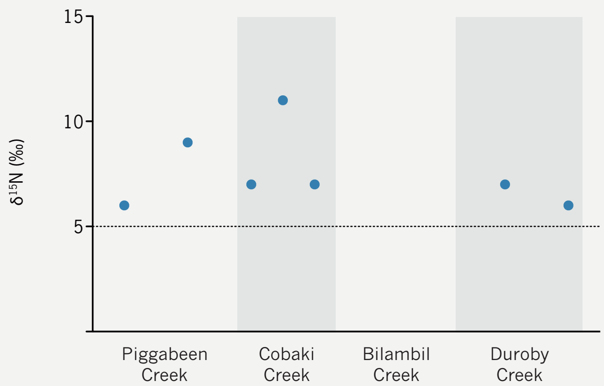
Nutrient cycling indicator

Filamentous algae used to quantify the $\delta^{15}N$ index were unavailable at eight of the fifteen sites assessed. None of the filamentous algae samples that were collected yielded nitrogen stable isotope signatures greater than the guideline value of 5 ‰, and consequently all scores for the $\delta^{15}N$ index were < 1.00 and indicate some level of influence from human inputs. High levels of $\delta^{15}N$ were detected in samples from site TSC-0006 on Cobaki Creek, and site TSC-0003 on Piggabeen Creek. The source of $\delta^{15}N$ is likely to be either sewage related, such as leaky septic systems, and/or from faecal pollution from livestock.

The results of water sample analysis supported the $\delta^{15}N$ index results, with concentrations of total nitrogen (TN) and total phosphorous (TP) generally exceeding the NSW DEC (2006) guideline objectives.

Concentrations of TN and TP varied between creeks and between sampling locations along each creek. Concentrations of dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium) and filterable reactive phosphorous (FRP) also varied spatially. The concentrations of DIN and FRP measured are considered to be elevated according to the Queensland EPA water quality guidelines, however, no NSW guidelines exist for DIN and FRP.

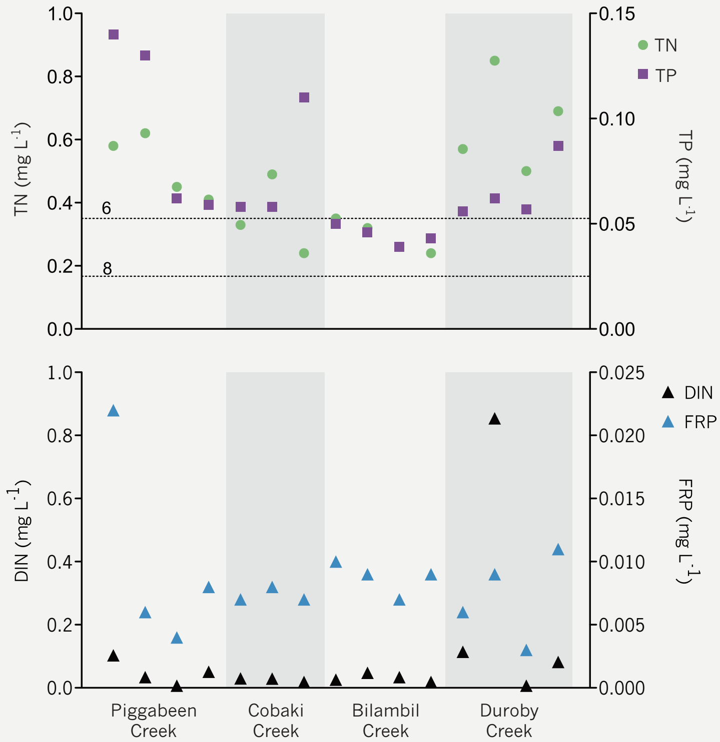
Typical sources of nitrogen and phosphorous from rural / semi-rural catchments are usually derived from activities such as agriculture (livestock and fertiliser use) and domestic septic sewage systems.



The above figure shows the results of the $\delta^{15}N$ indicator by creek (dotted line indicates relevant ecosystem health guideline value).

State	TN	NO_X	NH_3	TP	FRP	DOC
QLD	0.5	0.06	0.02	0.05	0.02	–
NSW	0.35	–	–	0.025	–	–

Table: Water quality guidelines (objectives) (mg L^{-1}) for the protection of aquatic ecosystems in both Queensland (EPA 2007) and the Tweed River catchment per se (DEC 2006). Unspecified values denoted by a dash.



The above graphs show the results of nutrient analysis of water samples taken from each sampling site (dotted lines for TN and TP indicate NSW DEC 2006 water quality guideline objectives).

UQ, CRM

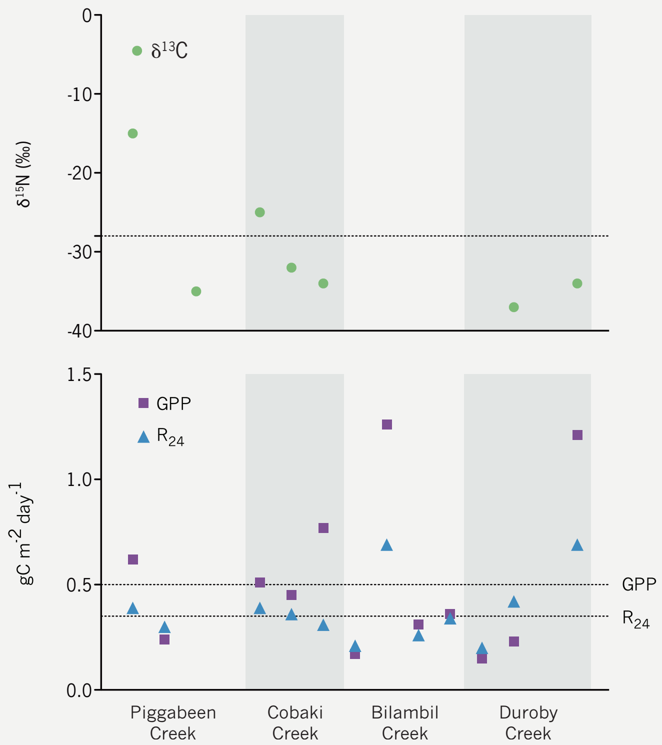
Livestock in and adjacent to Cobaki Creek.

Ecosystem processes indicator

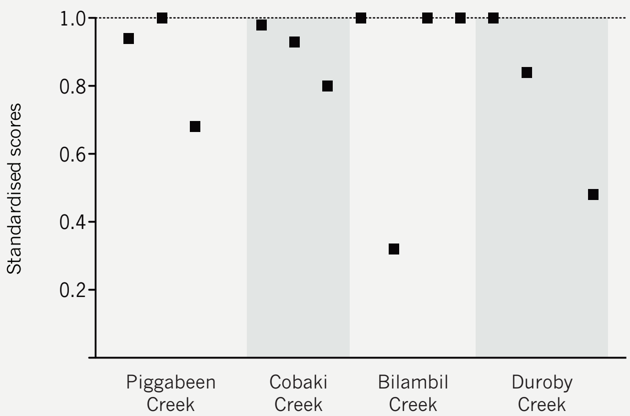
As noted for the nutrient cycling indicator set, filamentous algae were unavailable at eight of the fifteen sites assessed, and the inability to collect samples of that material resulted in missing values for the $\delta^{13}C$ index. Results for the benthic respiration (R_{24}) and gross primary production (GPP) indices were indeterminate at three sites as DO concentrations within the benthic metabolism chambers deployed at those sites fell to 0 mg L^{-1} prior to dusk, and hence estimates of respiration and primary production could not be derived.

Only five of the thirteen assessment sites for which ecosystem processes indicator scores could be calculated passed ecosystem health guidelines for all three indices. One site on each of Bilambil and Duroby creeks (sites TSC-0009 and TSC-0015 respectively) yielded very low scores (<0.20) for the GPP index, and both of these sites also yielded the lowest scores for the R_{24} index.

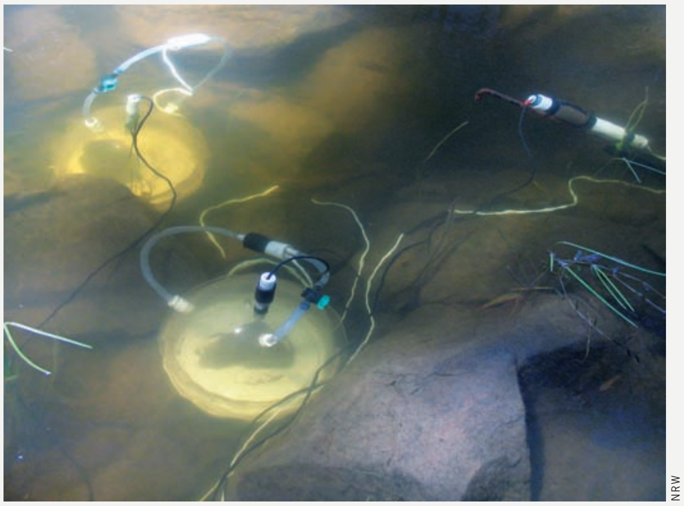
Had respiration rates been calculable at the three sites where chamber DO concentrations fell rapidly to 0 mg L^{-1}, those sites were likely to have also returned low scores for R_{24}, and perhaps GPP. The rapid decrease in chamber DO concentration to 0 mg L^{-1} at those sites indicates a high level of biological activity consuming oxygen within the entire community both in/on the sediments.



The above graphs show the results of ecosystem process indicator by creek (dotted lines indicate relevant ecosystem health guideline objectives).



The above figure shows a summary of standardised scores for the ecosystem processes indicator set. A score of 1 = 100% compliance with ecosystem health guidelines.



Benthic respiration and gross primary productivity are measured using plastic, dome shaped chambers placed on the stream bed.

Aquatic macroinvertebrate indicator

More than 2,850 individual aquatic macroinvertebrates representing 68 different taxa (primarily families) were recorded in samples from the fifteen assessment sites (see Appendix). Bilambil Creek yielded the most taxa (52 taxa), followed by Piggabeen Creek (51 taxa), Duroby Creek (41 taxa), and Cobaki Creek (35 taxa).

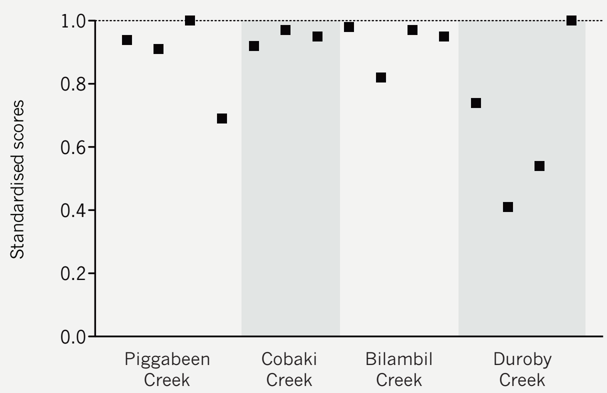
The closest data set to which this information can be compared is the SEQ EHMP database. In this context, only one aquatic macroinvertebrate taxon was recorded that had not previously been recorded during Freshwater EHMP assessments of South East Queensland streams. That taxon, Corophiidae (Crustacea, Amphipoda), was represented by only a single individual from site TSC-0004 on Piggabeen Creek.

Only two of the fifteen assessment sites, TSC-0003 on Piggabeen Creek and TSC-0015 on Duroby Creek, passed ecosystem health guidelines for all three indices within the Aquatic Macroinvertebrate indicator (i.e. standardised score = 1). However another eight sites yielded indicator scores of > 0.90, including at least one site on each creek (see standardised score graph opposite).

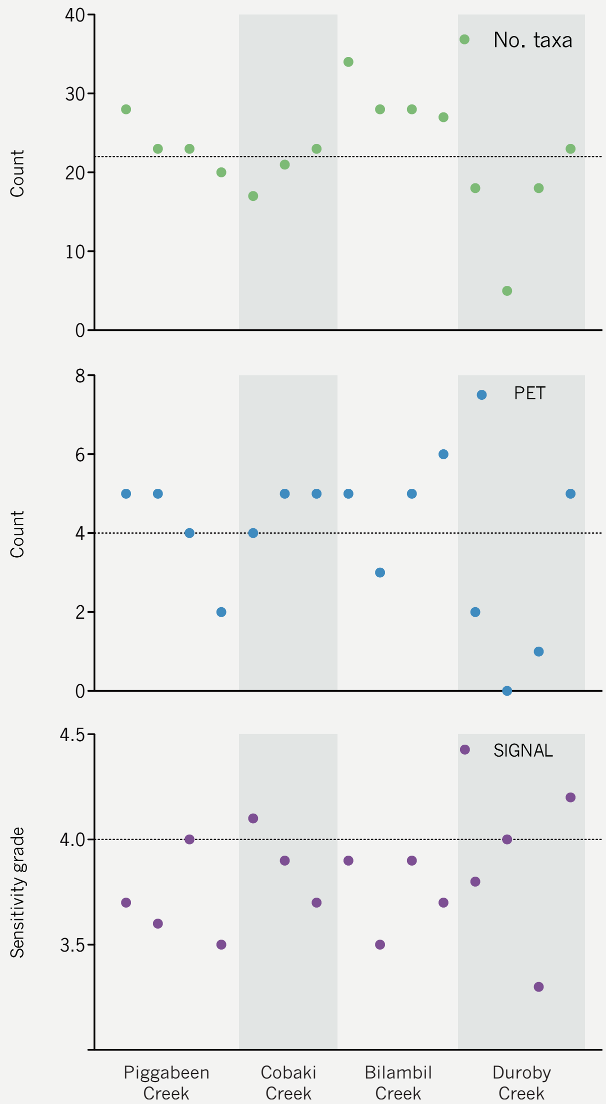
Only two sites returned particularly low Aquatic Macroinvertebrate indicator scores, and both of those were located on Duroby Creek (sites TSC-0013 and TSC-0014).

NRW

Macroinvertebrates are counted and identified using a stereo dissecting microscope in the laboratory.



The above figure shows a summary of standardised scores for the macroinvertebrate indicator. A score of 1 = 100% compliance with ecosystem health guidelines.



The above graphs show the results of each macroinvertebrate indicator by creek (dotted lines indicate relevant ecosystem health guideline objectives).

Fish indicator

A total of 1,567 fish were collected across the fifteen assessment sites. This catch included eighteen native and two exotic freshwater species as well as one marine species. (see Appendices). All of the species collected had been previously reported as part of the Freshwater EHMP in south east Queensland.

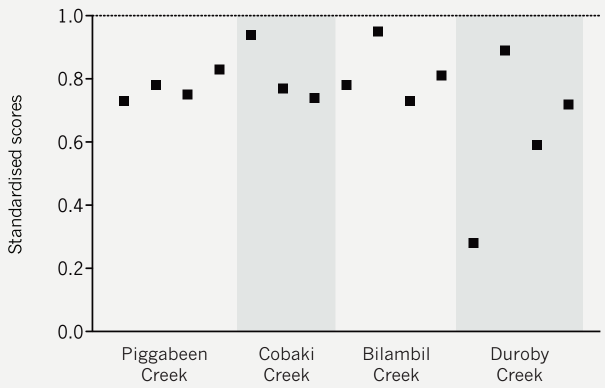
Bilambil Creek yielded the most native freshwater fish species (13 species), followed by Piggabeen Creek (12 species), Cobaki Creek (11 species) and Duroby Creek (7 species). Note that only three sites were assessed on Cobaki Creek as opposed to four on each of the remaining streams. None of the species recorded during fishing were listed as endangered or vulnerable in New South Wales.

The only native freshwater fish species that were notably absent from catches were the olive perchlet (*Ambassis agassizi)* and ornate rainbowfish (*Rhadinocentrus ornatus*). However, both of these species have been uncommon in the adjacent Currumbin Creek catchment so may have been present in insufficient density to be recorded in catches during the present work. Ornate rainbowfish are presently common in the Currumbin Creek catchment, but their wider spatial distribution is very patchy. They have not been recorded during Freshwater EHMP assessments of the Tallebudgera Creek catchment adjacent to the Currumbin Creek catchment to the north.

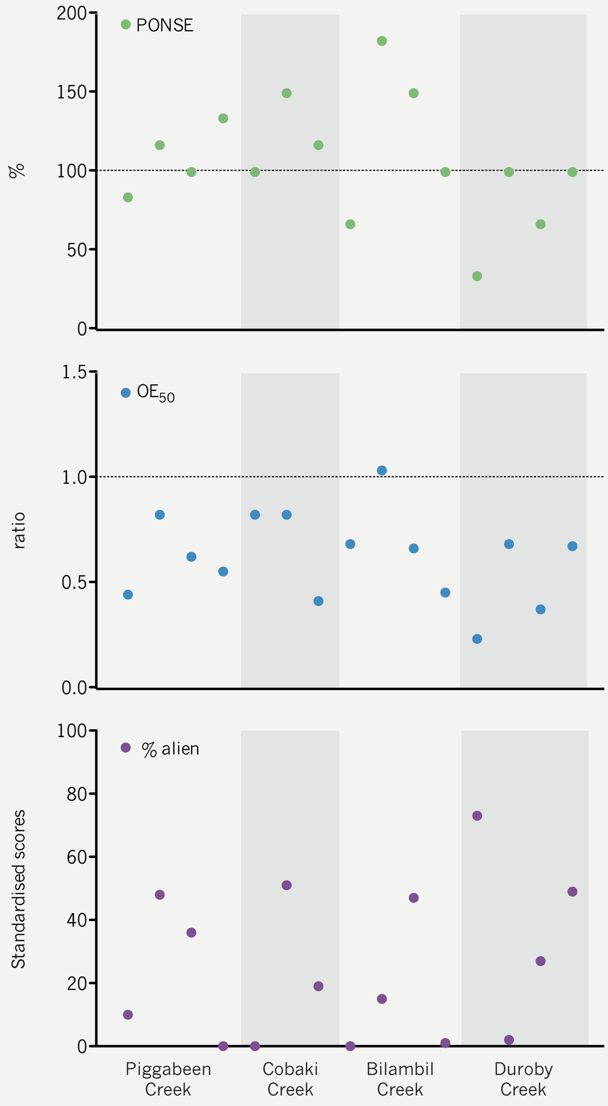
The two alien freshwater fish recorded, gambusia (*Gambusia holbrooki)* and/or swordtail (*Xiphophorus helleri*), were caught at twelve of the fifteen sites assessed, and represented 26 % of total fish catch. The only sites where these species were not recorded was one site on each of Piggabeen, Cobaki and Bilambil creeks (sites TSC-004, TSC-005 and TSC-0008, respectively). Swordtail were only caught within Duroby Creek, and at only two sites within that stream (sites TSC-0013 and TSC-0015).

Amongst the most notable index scores within the fish indicator were recorded at site TSC-0009 on Bilambil Creek, which yielded the highest possible score (1.00) for both PONSE and OE indices. Scores for site TSC 0012 on Duroby Creek were the lowest for each of the three indices within the fish indicator, and consequently also the Fish indicator score. Another site on Duroby Creek, site TSC-0014, yielded the second lowest Fish indicator score of 0.59.

Fish are sampled using electrofishing and then returned to the waterway.



The above figure shows a summary of standardised scores for the fish indicator. A score of 1 = 100% compliance with ecosystem health objectives.



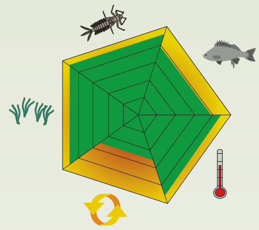
The above graphs show the results of each fish indicator by creek (dotted lines indicate relevant ecosystem health guideline values).

Freshwater Report Card Grades

Freshwater Report Card Grade

C- 2007 Piggabeen Creek

UQ, CRM



Four freshwater sites were assessed in the Piggabeen Creek sub-catchment. The report card grade for Piggabeen Creek was calculated as C-, which equates to a condition of 'fair' ecological health.

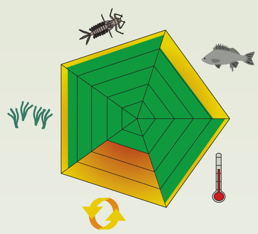
The report card grade of C- is the average score of all five indicators. The worst performing indicator was that of nutrient cycling, which was responsible for lowering the overall report card grade score. This trend was evident across all creeks with the exception of Duroby Creek.

The nutrient cycling indicator results show the presence of processed nitrogen ($\delta^{15}N$) above background levels. These results suggest that a significant source of nitrogen to Piggabeen Creek is likely to be from on-site wastewater treatment systems and/or manure from livestock within the catchment. Elevated concentrations of water column nutrients (nitrogen and phosphorous) were observed at most sites sampled within Piggabeen Creek.

Freshwater Report Card Grade

C- 2007 Cobaki Creek

UQ, CRM



Three freshwater sites were assessed in the Cobaki Creek sub-catchment. The report card grade for Cobaki Creek was calculated as C-, which equates to a condition of fair ecological health.

The report card grade of C- is the average score of all five indicators. Similar to Piggabeen Creek, the worst performing indicator was that of nutrient cycling, which was responsible for lowering the overall report card grade score. One sample from Cobaki Creek yielded the highest $\delta^{15}N$ value, and therefore the lowest nutrient cycling indicator score across all four creeks.

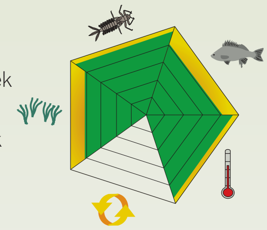
Again, these results suggest that a significant source of nitrogen to Cobaki Creek is likely to be from on-site wastewater treatment systems and/or manure from livestock within the catchment. Elevated concentrations of water column nutrients (nitrogen and phosphorous) were observed at most sites sampled within Cobaki Creek.

Freshwater Report Card Grade

C- 2007

Bilambil Creek

UQ, CRM



Four freshwater sites were assessed in the Bilambil Creek sub-catchment. The report card grade for Bilambil Creek was calculated as C-, which equates to a condition of fair ecological health.

No nutrient cycling indicators could be measured for Bilambil Creek due to the absence of filamentous algae that is used to quantify the $\delta^{15}N$ index. Consequently, an initial report card grade of B was calculated using the remaining indicator results. Through expert opinion, this score was later revised and lowered to a C-. This lower score is considered more realistic, as the results of nutrient cycling (if it was able to be measured) would have lowered the summary scores in a similar way to that observed in all other creeks investigated.

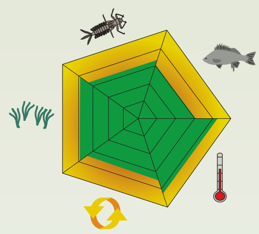
Elevated concentrations of water column nutrients (nitrogen and phosphorous) were observed at most sites sampled within Bilambil Creek. These concentrations were similar to that measured in all other creeks and supports the notion that $\delta^{15}N$ concentrations are also likely to be similar.

Freshwater Report Card Grade

D 2007

Duroby Creek

UQ, CRM



Four freshwater sites were assessed in the Duroby Creek sub-catchment. The report card grade for Duroby Creek was calculated as D, which equates to a condition of poor ecological health.

The report card grade of D is the average score of all five indicators. Scores for Duroby Creek were lower than those of all other streams for all indicators, and particularly for both of the biological indicators: Aquatic Macroinvertebrates and Fish.

The results indicate that the general ecological condition of Duroby Creek is less than that of Piggabeen, Cobaki, and Bilambil creeks, and it may have been particularly poor in terms of the requirements of higher organisms (i.e. fish). One site on Duroby Creek (TSC-0014) yielded the lowest observed diel minimum DO concentration (7 % saturation), which was substantially below the minimum value considered to be deleterious to gill-breathing aquatic organisms (20 % saturation).

Freshwater Report Card Grade

D+
2007

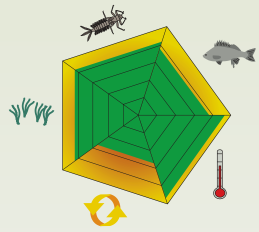
Combined Creeks

UQ, CRM

UQ, CRM

UQ, CRM

UQ, CRM



All creeks displayed low scores for the nutrient cycling indicator, which demonstrated a breakdown of natural nitrogen cycling processes, caused by inputs of nitrogen from sources such as sewage and/or livestock.

Concentrations of Total N and particularly Total P commonly exceeded water quality guidelines. Exceedence Percentages for the Upper Tweed River with respect to Total N and Total P guidelines (0.10 and 0.75 mg L-1, respectively) have been reported to be ≤ 3% (TSC 2007), which appears to be far better performance than that found during the present study for Piggabeen, Cobaki, Bilambil and Duroby creeks.

Clearing of streamside vegetation was the most visually noticeable activity influencing the condition of streams during the collection of field data and samples. A high proportion of the Piggabeen, Cobaki, Bilambil and Duroby creek catchments has been cleared of native vegetation, and in many areas this has allowed extensive proliferation of Camphor Laurel (*Cinnamomum camphora)*, including directly along the banks of waterways. The presence of those trees has the potential to significantly alter natural ecological processes in many ways, including changes in each of stream shading, the identity and quantity of in-stream leaf litter and woody debris, and stream-side ground cover. Camphor Laurel also potentially have direct toxic effects upon aquatic organisms, although this does not appear to have been the subject of comprehensive study.

Higher than expected (c.f. natural) in-stream silt loads were observed and are a potential issue with respect to local stream condition at many sites, and in some cases was exacerbated by trampling of stream banks and beds by livestock.

One of the primary influences of silt is to smother critical habitats for fish and aquatic macroinvertebrates, and scores for those biological indicators were the second and third lowest (respectively) of the five indicators presented here. A large number of stream road crossings featuring enclosed concrete culverts were also observed, and those culverts were likely to have a negative effect on the movement of native fish species within and between streams.

Estuarine Results Overview

Nitrogen indicator

The estuarine component of the EHMP measures total nitrogen (TN) and dissolved inorganic nitrogen (DIN) in surface waters. TN includes all dissolved forms of nitrogen (inorganic and organic), nitrogen bound to non-living particles (e.g. suspended clay and silt), and nitrogen contained in small living organisms (e.g. bacteria). DIN comprises nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+).

The EHMP has a water quality objective of 500 µg/L for TN. There is no equivalent objective for DIN as it is highly correlated to, and a major component of ,TN. However, DIN is measured along with TN as it is useful in determining the overall composition of the nitrogen pool within the estuary and it gives a good estimate of the amount of nitrogen that is involved in immediate processes such as phytoplankton uptake.

This water quality data is input to models that assess the fate of nitrogen within the estuary, which are then used to predict the overall response of the system to potential changes in nitrogen loads. Such ecosystem response modelling has been undertaken during the development of the management plan for the Cobaki and Terranora estuary.

Spatial trends

The following graphs show the trend in water column nitrogen (TN and DIN) with distance from the Tweed River mouth. The location of wastewater treatment plant (WWTP) discharges into Terranora Creek is also shown, as this represents a major point source of nitrogen into the estuary.

The results show that both TN and DIN concentrations tend to become less variable with increasing distance from the broadwaters, towards the Tweed River mouth. Concentrations of TN tend to decrease with increasing distance from the broadwaters, where as DIN appears to be constant for the bulk of the estuary, with the exception of one or two sites upstream of the broadwaters.

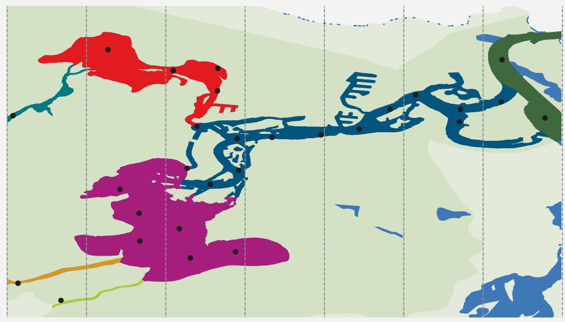
The difference in the variability between upper and lower estuary sites probably reflects both the variable but often intense inputs (e.g. agricultural diffuse and urban development point sources) as well as the inability of the system to process it as rapidly as the lower estuary. It may also suggest, relative to the lower estuary, that the level of denitrification (a process of nitrogen removal) being undertaken compared to load is lower.

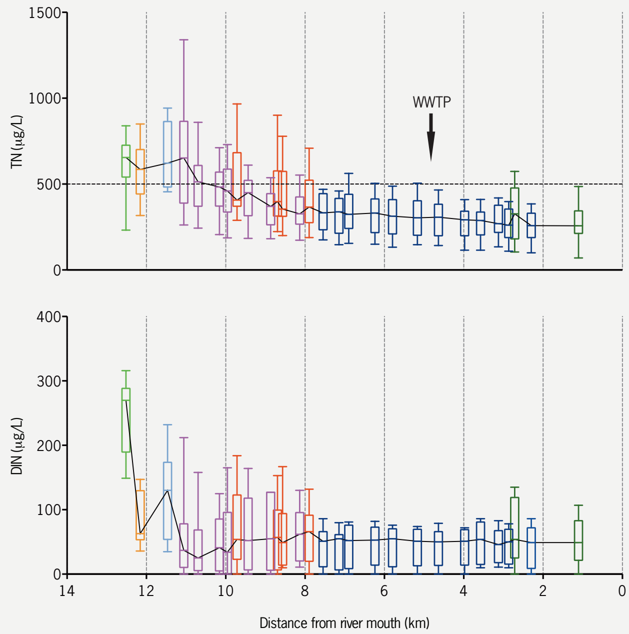
The box plots also show that the range of TN concentrations downstream of the broadwaters (within Terranora Creek and the Tweed River mouth) are generally below the adopted EHMP water quality objective.

These apparent spatial trends are influenced by a combination of factors such as nutrient inputs and hydrodynamics. These features can differ considerably between the different components of an estuary. For example, water within the Terranora Creek and the Tweed River mouth has a much lower residence time compared to water within the broadwaters. In other words, there is a lot more flushing and oceanic exchange at the lower section of the estuary than that which occurs within the broadwaters.

The trend in lower water column nitrogen levels downstream of the broadwaters may also suggest an uptake, or natural removal, of nitrogen by the broadwaters themselves. Benthic communities (such as sediments and seagrass beds), as well as tidal riparian vegetation communities (such as mangroves), are known to play an important role in the cycling and processing of nutrients within an estuary.

These functional ecological communities are very important to maintain and are integral to the health of the system as a whole. They are, in a sense, functioning like a set of human kidneys by removing pollutants from the system. Any decline in the health of these important ecological communities will therefore compromise the ability of the system to maintain this “cleansing” capacity.





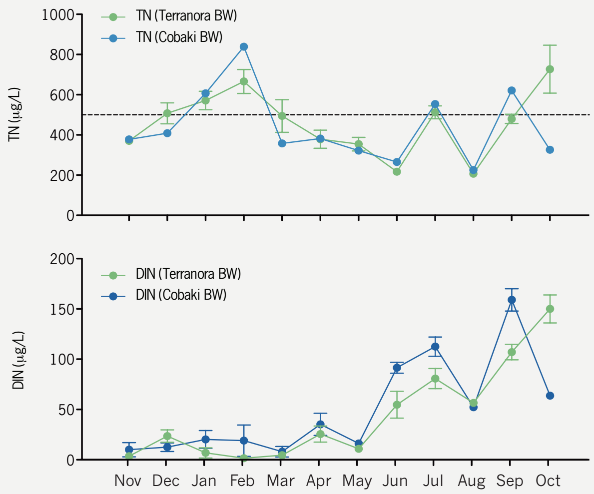
Box and whisker plots showing spatial trends in water column TN and DIN (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

Temporal trends

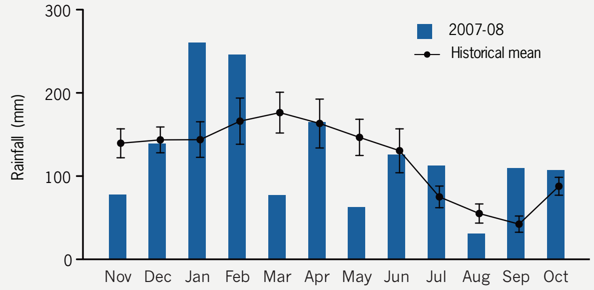
Temporal (or seasonal) trends are also evident for TN and DIN (see graphs opposite), and appear to differ between water bodies (broadwaters compared with creek and river mouth). There are clear differences in water column DIN concentrations between summer and winter months within the broadwaters. By comparison, there appears to be less of a temporal difference in DIN within Terranora Creek and the Tweed River mouth during the same period. This difference between water bodies may be due to greater uptake rates for DIN within the broadwaters during summer months compared with winter. Continued monitoring is needed to confirm these apparent temporal trends.

Such trends may be related to rainfall events during the wetter summer months, which tend to bring higher inputs of nitrogen into the system via catchment and stormwater runoff. This may contribute to the higher peaks in TN concentrations seen during January and February 2008. To elucidate this linkage between rainfall and TN concentrations, further investigation and monitoring based around rainfall events is required.

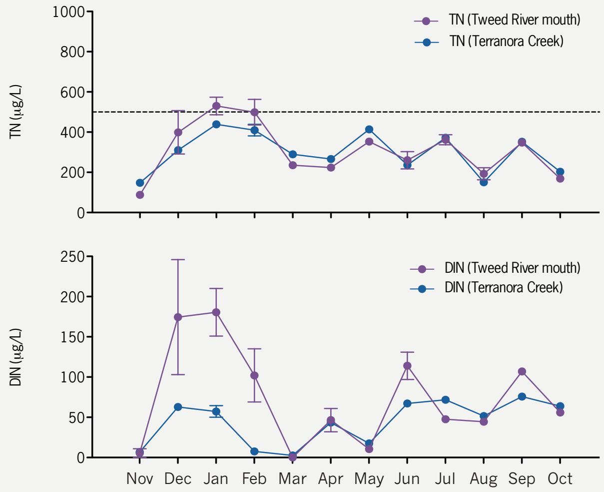
The differences in DIN concentrations between seasons may be related to nitrogen cycling processes, which are driven by factors such as water temperature, light availability and water column dissolved oxygen concentrations. Further process measurements would help to elucidate these relationships.



Mean (± standard error) TN and DIN plots showing temporal trends within Terranora and Cobaki Broadwaters (dotted line indicates relevant ecosystem health guideline objective). (monthly sampling; Nov 2007 to Oct 2008).



Monthly rainfall data over the monitoring period 2007-08 and 23 year historical means (BoM Coolangatta Stn. No. 4071).



Mean (± standard error) TN and DIN plots showing temporal trends within the Tweed River mouth and Terranora Creek (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

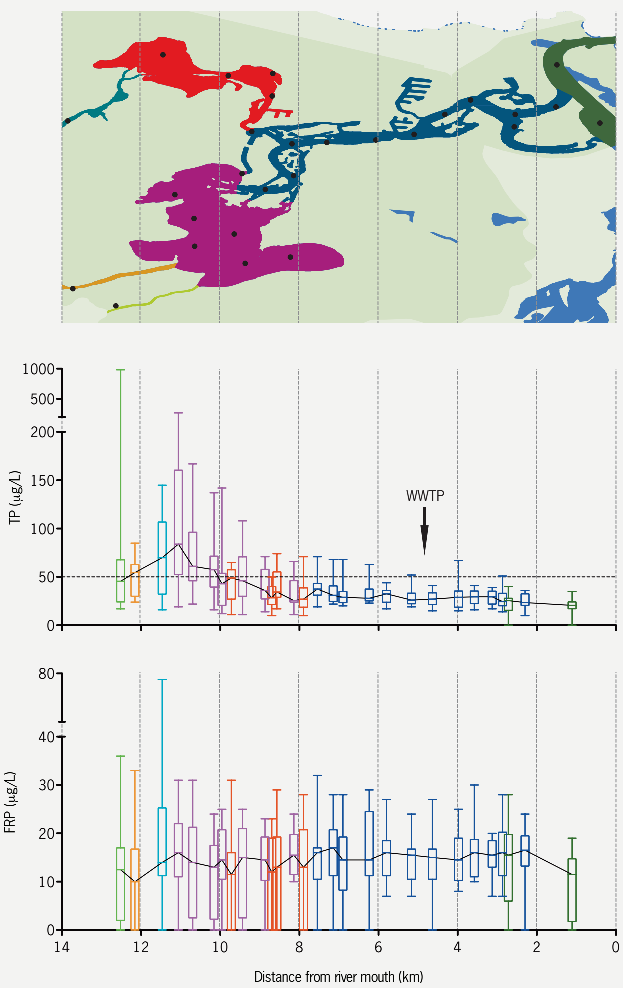
UQ, CRM

Land runoff laden with sediment entering Cobaki Creek during a rainfall event.

Phosphorus indicator

The estuarine component of the EHMP measures both total phosphorus (TP) and filterable reactive phosphorus (FRP). TP includes both the particulate form (those bound to inorganic matter like clay and organic compounds such as plankton, proteins, and detritus) and dissolved phosphorus forms (including inorganic orthophosphates, polyphosphates and organic colloids). It is this FRP that is immediately available for plants and microorganisms to use, and is also the pool of phosphorus that most reflects the immediate likelihood that phosphorus is a limit (or not) for plant growth in the water. Phosphorus is discharged into estuaries from wastewater treatment plants and from land-based runoff.

To indicate the likely effect of phosphorus in the estuarine waterways, the EHMP Team assess measured phosphorus levels against established water quality guidelines. The water quality objective for TP is 50 µg/L.



Box and whisker plots showing spatial trends in water column TP and FRP (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

UQ, CRM

Runoff from urban areas is a source of nutrients to waterways. (Canal estate in Terranora Creek)

Spatial trends

The box plots show the spatial water column concentrations of phosphorous (TP and FRP) within the estuary. The location of wastewater treatment plant (WWTP) discharges into Terranora Creek is also shown, as this represents a major point source of phosphorous to the estuary.

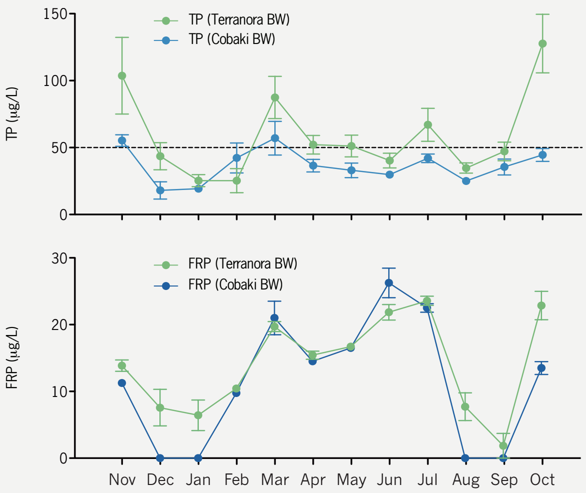
The results show that TP concentrations tend to become lower and less variable with increasing distance from the broadwaters in the direction of the Tweed River mouth. The box plots also show that the range of TP concentrations downstream of the broadwaters (within Terranora Creek and the Tweed River mouth) are generally below the adopted EHMP water quality objective. The spatial trend in water column TP concentrations is similar to that of TN.

There doesn't seem to be any clear spatial trend in FRP concentrations along the estuary. However, there does seem to be greater variability in concentrations within the broadwaters compared to that of the lower estuary. The higher concentrations of TP within the broadwaters may be related to the higher levels of suspended solids within these water bodies. Phosphorous tends to adsorb onto particulate matter such as clay particles, in preference to remaining in its dissolved forms.

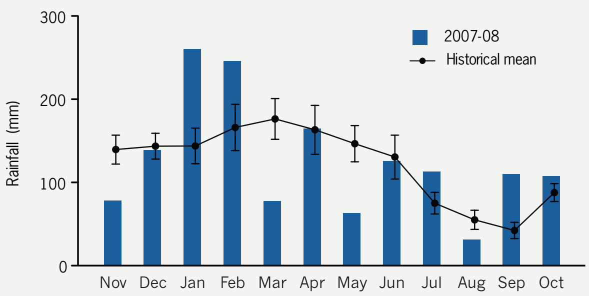
Importantly, and in stark comparison to nitrogen, FRP concentrations are strongly influenced by the chemistry of the water it is in (e.g. salinity) such that it may be bound or released from particles as they move around the ecosystem. This adds to the variability that is evident in FRP concentrations.

Temporal trends

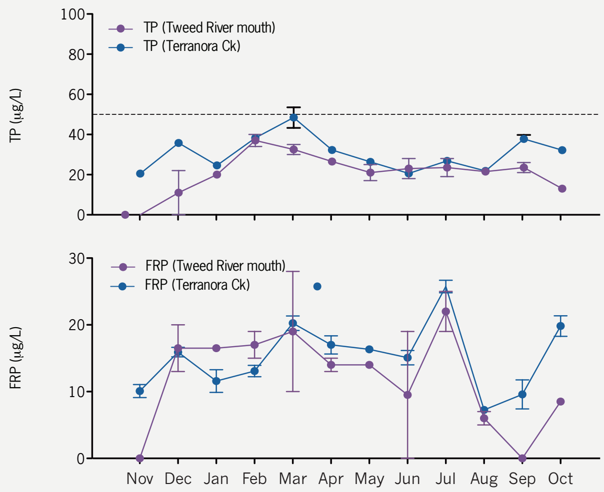
There is some suggestion in the data that TP and FRP concentrations vary across temporal scales. However, these temporal trends within the current data set are unclear. The level of sampling frequency may not be sufficiently sensitive to capture any trends, given that processes, which influence phosphorous cycling within an estuary, are often operating at much finer scales of time and space. Again, event-based monitoring may help to elucidate linkages between phosphorous concentrations and rainfall events.



Mean (± standard error) TP and FRP plots showing temporal trends within Terranora and Cobaki Broadwaters (dotted line indicates relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).



Monthly rainfall data over the monitoring period 2007-08 and 23 year historical means (BoM Coolangatta Stn. No. 4071).



Mean (± standard error) TP and FRP plots showing temporal trends within the Tweed River mouth and Terranora Creek (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

UQ, CRM

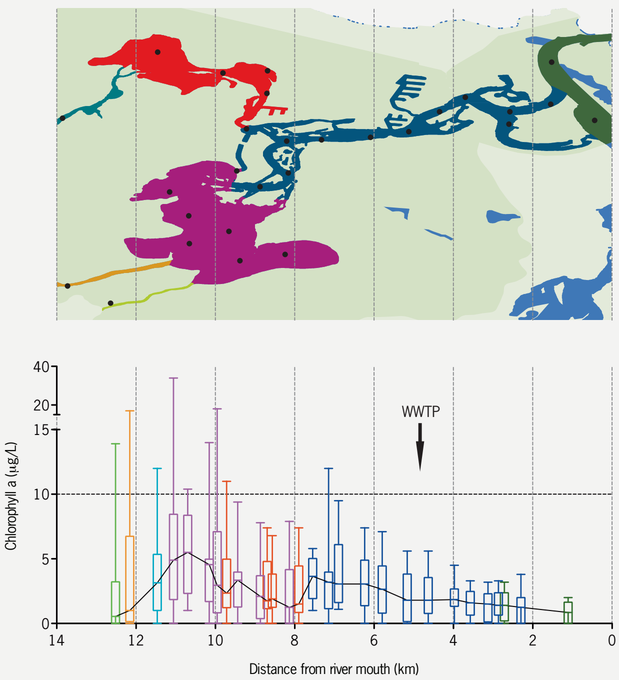
Land use practices influence the load of particulates and nutrients that enter the waterways. (Bilambil Creek catchment).

Chlorophyll *a* indicator

Chlorophyll *a* (chl *a*) is used as a measure of phytoplankton biomass. Its levels are primarily controlled by light and nutrients, and are influenced by temperature and zooplankton grazing. A combination of increased nutrient loading and clear waters can therefore lead to the development of phytoplankton blooms. High levels of chlorophyll *a* are often indicative of poor water quality. However, elevated chlorophyll *a* concentrations are not necessarily a bad thing, in some ecosystems, Chl a may reach elevated levels seasonally as a natural response to changes in water chemistry brought about by rainfall and other seasonal changes. The long-term persistence of elevated levels is of greater concern and is a reflection of poor ecosystem health.

Spatial trends

Median concentrations of chlorophyll *a* at all sampling sites were below the EHMP guideline objective of <10 µg/L. Higher ranges of concentrations were measured in samples taken from the Terranora broadwater, compared with other parts of the estuary. The data clearly shows a spatial trend in chlorophyll *a* levels, with median concentrations decreasing at distances closer to the lower estuary (towards the Tweed River mouth). This trend is likely to be a result of increased water mixing caused by tidal flushing and oceanic exchange at the Tweed River mouth. Lower concentrations of chlorophyll *a* were observed in the Cobaki broadwater compared to that of the Terranora Broadwater. This trend suggests that the source of chlorophyll *a* within the Terranora Creek may be the Terranora Broadwater where the levels of both FRP and DIN are elevated. Further, since it is shallow, any phytoplankton in the waters here are likely to get sufficient light despite turbidity as they are rotated through the surface and bottom layers by the mixing that occurs.

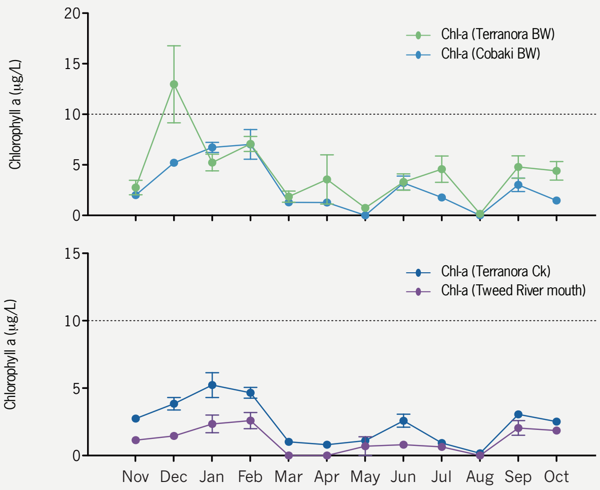


Box and whisker plots showing spatial trends in Chlorophyll *a* (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

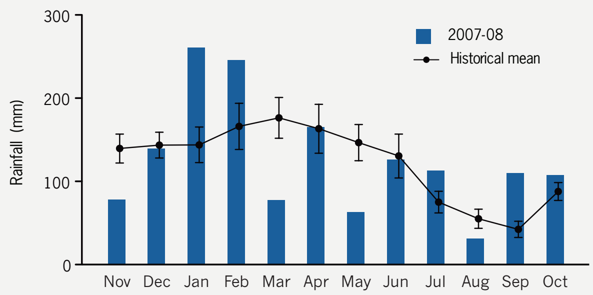
Temporal trends

All regions show a trend in chlorophyll *a* concentrations, with higher levels recorded during the summer months compared with winter. This seasonal trend is common for chlorophyll *a*, with summer providing higher rainfalls and therefore nutrients, and also higher water temperatures and light intensities, all providing favourable conditions for phytoplankton growth.

Fluctuations in chlorophyll *a* concentrations can occur at smaller temporal scales. For example; the action of wind in shallow water bodies like that of the broadwaters can cause the resuspension of fine sediments, which will affect the availability of light needed for phytoplankton growth.



Mean (± standard error) Chlorophyll *a* plots showing temporal trends within Terranora and Cobaki Broadwaters, Terranora Creek and Tweed River mouth (dotted line indicates relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).



Monthly rainfall data over the monitoring period 2007-08 and 23 year historical means (BoM Coolangatta Stn. No. 4071).

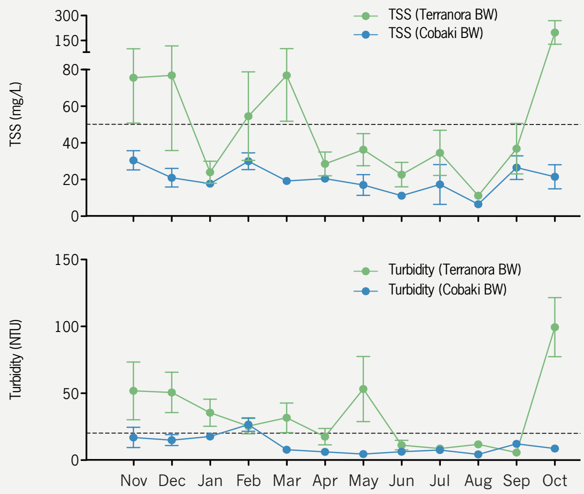
Turbidity and total suspended solids indicators

The EHMP assesses water clarity by measuring light penetration into the water column and by the amount of suspended material contained within water samples. Light penetration is measured by assessing the amount of light scattered by suspended particles (nephelometry), whereas the amount of suspended material is measured analytically by sampling the water column (total suspended solids). Nephelometers quantify the water clarity as a function of turbidity in units of NTU (Nephelometric Turbidity Units). Total suspended solids (TSS) are expressed in units of milligrams per litre.

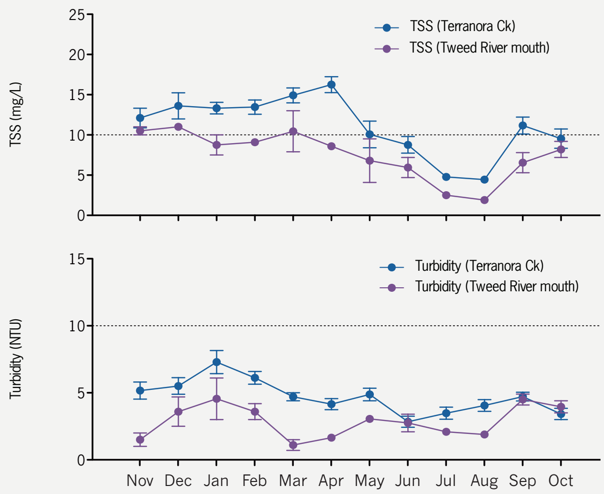
Spatial and temporal trends

Similar trends are observed between turbidity and TSS both spatially and temporally. Consistently higher suspended solids concentrations (and turbidity) are observed in the broadwaters compared with the downstream sites within the lower estuary. However, the majority of sampling sites show median TSS concentrations above the EHMP water quality objective of <10 mg/L.

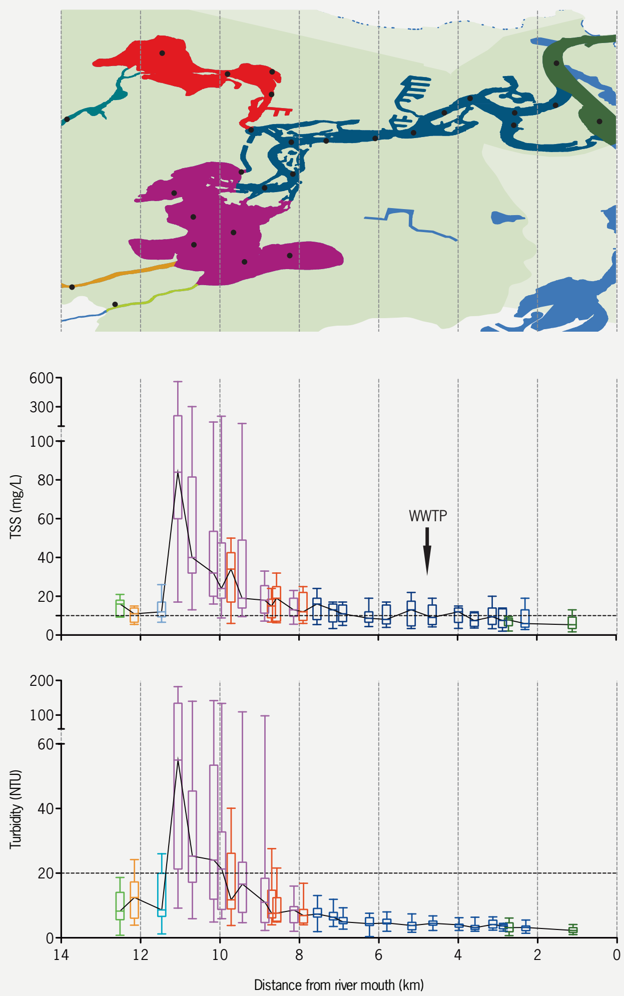
Temporal trends in TSS and turbidity are more apparent in Terranora Creek and the Tweed River mouth, with higher levels occurring during the wetter months. Such temporal trends are not as clear for the shallower broadwaters because of factors such as sediment resuspension.



Mean (± standard error) TSS and Turbidity plots showing temporal trends within Terranora and Cobaki Broadwaters (dotted line indicates relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).



Mean (± standard error) TSS and Turbidity plots showing temporal trends within Terranora Creek and Tweed River mouth (dotted line indicates relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

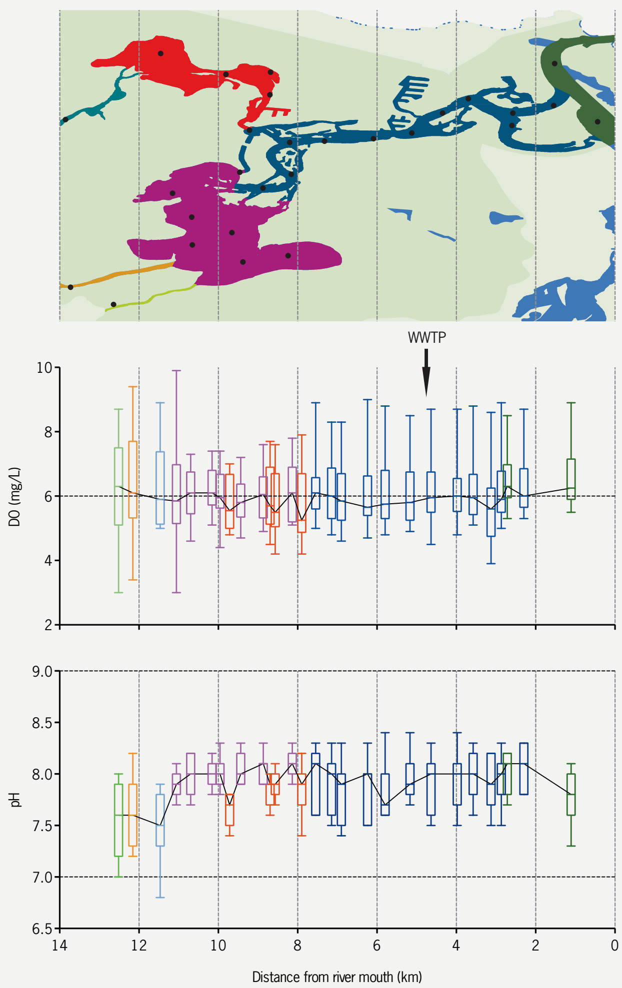


Box and whisker plots showing spatial trends in water column TSS and Turbidity (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

Dissolved oxygen and pH indicators

Aquatic plants and animals, as well as a range of biochemical processes, depend on dissolved oxygen (DO) in the water column. Photosynthesis (O_2 producing) and respiration (O_2 consuming) are biological processes that affect DO levels in the water column. Oxygen is consumed during respiration not only by plants and animals but also by bacteria when breaking down organic matter, such as that from treated wastewater and dead plant and animal matter. Rapid consumption of organic matter can lead to depleted water column DO levels. Reduced DO can lead to fish kills and poor health in other aquatic organisms. Abiotic factors such as salinity and temperature influence DO saturation, as can the availability of light which influences photosynthetic rates, and hence, rates of oxygen production.

Similarly, most aquatic organisms have evolved to tolerate a specific range in pH. If the pH changes above or below this preferred range, then this could have direct or indirect deleterious effects on the organism.



Box and whisker plots showing spatial trends in DO and pH (dotted lines indicate relevant ecosystem health guideline objectives). (monthly sampling; Nov 2007 to Oct 2008).

Spatial trends

There are no clear spatial trends in DO or pH across the estuary apart from the higher variability in DO in the upper reaches compared with the lower estuary. This variability indicates an interaction between the potential organic load (particulate load) and DO levels.

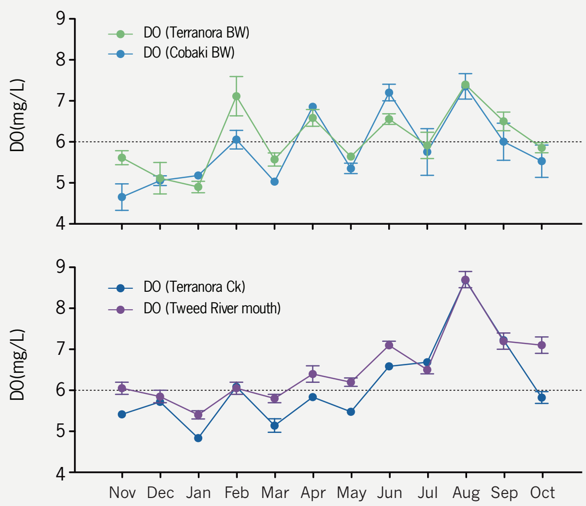
All sites showed periods where DO was measured below the EHMP objective of 6 mg/L. Some sites showed lower ranges in DO (such as sites within both broadwaters), while others showed higher maximums. These trends may be a result of higher rates of water exchange and mixing that occurs towards the lower estuary, and/or higher rates of respiration occurring in the broadwaters due to biological processes.

pH was generally consistent across the estuary and for the majority of sites, and within the EHMP water quality objective range of 7.0 to 9.0 pH.

Temporal trends

Dissolved oxygen concentrations tended to be lower in summer and higher in winter. This trend is typical for DO as the concentration of DO in water is temperature dependent.

Problems with faulty pH probes prevented the accurate measurement of pH for the first five months of the monitoring program. Therefore no meaningful spatial relationships could be determined.



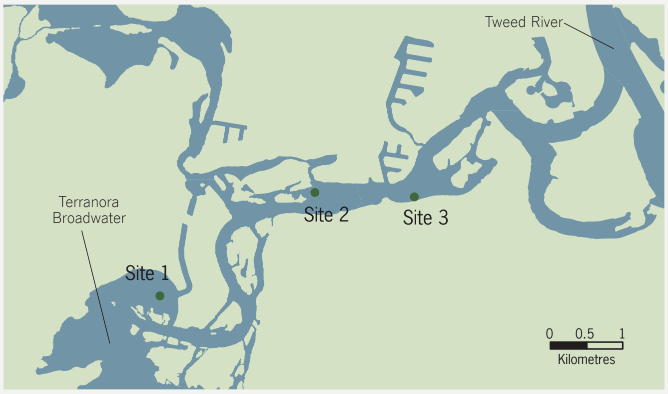
Mean (± standard error) DO plots showing temporal trends within Terranora and Cobaki Broadwaters, Terranora Creek and Tweed River mouth (dotted line indicates relevant ecosystem health guideline objective). (monthly sampling; Nov 2007 to Oct 2008).

Seagrass depth range indicator

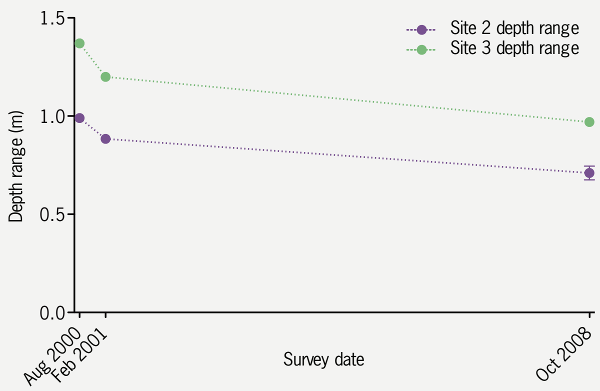
Seagrass depth range (SDR) of the seagrass species *Zostera muelleri*, was measured at three locations during spring (October) 2008. Sites 2 and 3 were also surveyed for SDR during 2000-2001, while site 1 is a new site with no historical data.

The 2008 survey shows consistent depth range results for sites 1 and 3, with a mean SDR of 0.93 m and 0.97 m respectively. A lower mean depth range was recorded for site 2 (0.71 m). Site 2 also showed a larger variation in depth range across the surveyed area. These results are consistent with historical data for sites 2 and 3.

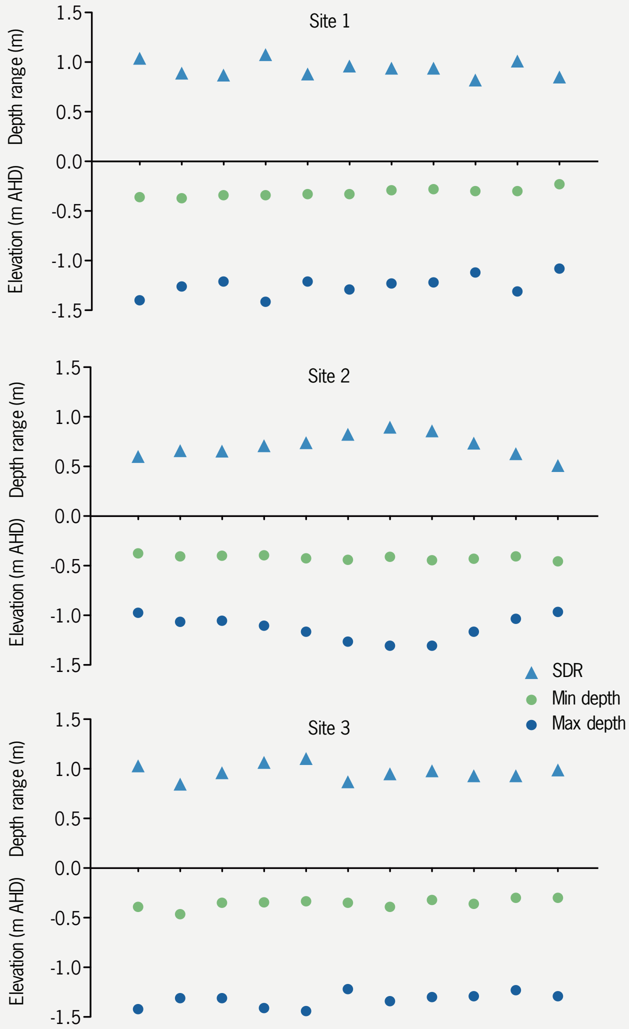
Comparisons between survey years may suggest a reduction in the seagrass depth range at both sites 2 and 3. However, the lack of regular measurements makes it difficult to establish any apparent trend outside of what could be natural variations. Further and more frequent surveys are needed to confirm any declining trends in SDR.



Location of SDR survey sites.



Historical seagrass depth range results from site 2 and site 3.



Seagrass depth range at three sites showing the maximum range depth and minimum range depth relative to Australian Height Datum (AHD) (n=11) .

Riparian assessment indicator

The riparian habitat assessment method adopted for the EHMP provides an accurate and quantitative assessment of the structure and condition of the riparian zone within an estuary. The method is based on a rapid assessment technique that records the structure and condition of fringing riparian vegetation, and the physical condition of the bank and tidal zone, to provide a score of riparian bank condition. The riparian bank condition score relates to the ability of that area to provide key ecosystem services now and into the future.

Data that is recorded in the field is analysed for a number of features that relate to the structure and condition of the fringing vegetation and the bank type and condition. These features are scored from qualitative observer-based assessments using a ranking system from 0 to 5 to provide an index score. Riparian vegetation is identified as either intertidal vegetation or terrestrial vegetation. These two vegetation types are then combined to provide a total vegetation condition score. The contribution of each vegetation type to the overall vegetation score is weighted according to the relative ratio of their biomass. The presence of structures, litter and weeds act as detractors to this score.

Intertidal vegetation includes all plants that only occur below the high tide mark, consisting of mangroves (trees) and saltmarsh (shrubs, reeds and grass). These plants are both salt-tolerant and can withstand regular flooding. Mangroves are the most common intertidal vegetation in the Cobaki-Terranora estuary.

In the Cobaki-Terranora estuary, mangroves dominate where tidal influence is greatest. Tidal forces generate gently sloped tidal flats that provide perfect habitat for mangrove colonisation. The presence of intertidal vegetation is reduced at the mouth of the estuary due to wave action and strong currents. The banks along the mouth and lower parts of the estuary are also highly modified. This lack of vegetation and natural bank condition is reflected in the riparian condition index scores for the Terranora Creek and the Tweed River mouth.

Within the broadwaters, the riparian condition index scores are much higher due to existing natural bank conditions that are well vegetated by mangrove species. Some areas along the Terranora Broadwater have been modified, and these areas are reflected in their corresponding riparian condition index scores.

Upstream of the broadwaters, mangrove numbers decline due to the presence of steeper banks and reduced salinity. Terrestrial vegetation then tends to dominate within this riparian zone. The estuarine sections of the three creeks that drain into the broadwaters received much lower riparian condition index scores, compared to the broadwaters. Much of the riparian zone within these areas has been modified, and shows signs of stress caused by urban and rural development, and from the impacts of grazing livestock.

Riparian habitat condition for the Cobaki and Terranora estuary.

Processed nitrogen tracking indicator

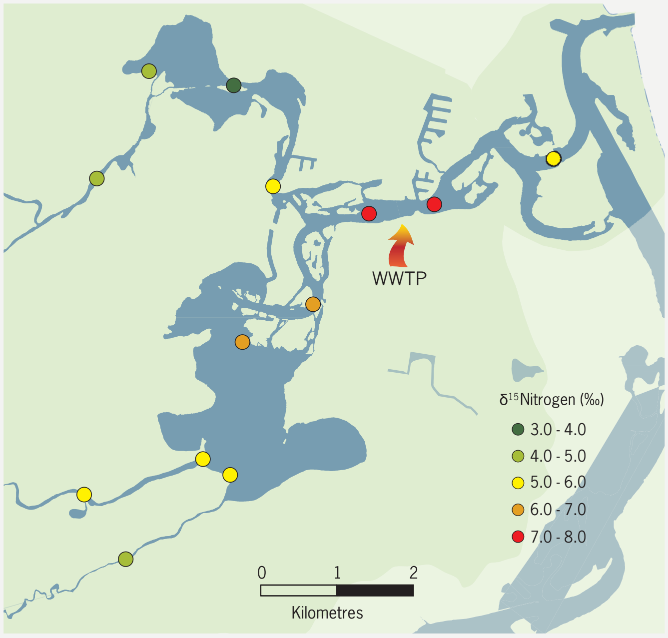
Mature leaves taken from the common mangrove species *Avicennia marina* are analysed for the presence of sewage-derived nitrogen in the form of $\delta^{15}N$. $\delta^{15}N$ values typically range from 2‰ in non-sewage impacted waters through to 10‰ adjacent to sewage discharge sites. Therefore, $\delta^{15}N$ levels above 4‰ are indicative of some influence by processed nitrogen and concentrations greater than 6‰ indicate a high level of impact.

The results of processed nitrogen tracking clearly show elevated levels of $\delta^{15}N$ in the immediate area adjacent to the wastewater treatment plant (WWTP) discharge point in Terranora Creek. The concentrations of $\delta^{15}N$ then tend to decrease with increasing distance from the effluent discharge point. Concentrations of $\delta^{15}N$ also tend to be lower within the Cobaki broadwater, compared to that of the Terranora broadwater. This is a similar trend as that observed during the 2000-01 monitoring event. Since the 2000-01 monitoring event, the EHMP has increased the number of $\delta^{15}N$ sampling locations to provide a higher level of spatial coverage.

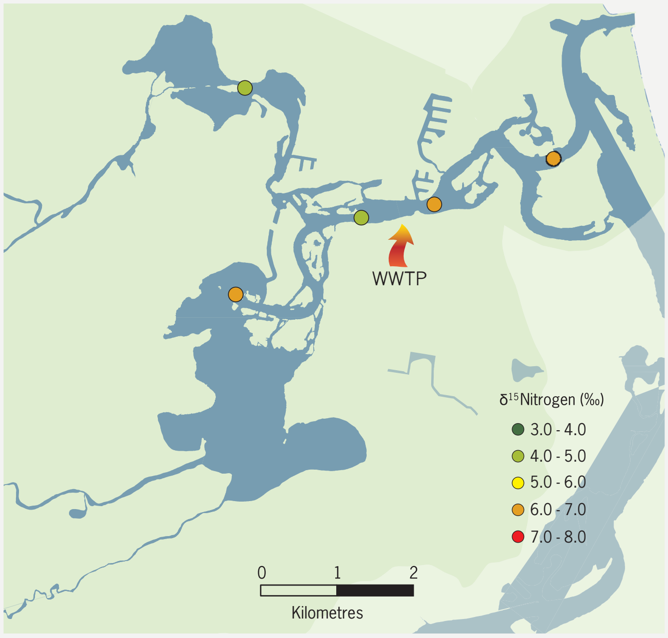
Comparisons between the 2000-01 and 2008 monitoring events potentially show an increase in $\delta^{15}N$ concentrations adjacent to the WWTP discharge point. A higher frequency of sampling is needed to determine if this is an accurate and representative result or if differences are attributed to natural variations or seasonal differences between sampling years.

It should also be noted here that other sources of human derived nitrogen inputs are also likely to be playing a role in other reaches of the ecosystem. These may include stormwater runoff from urban areas, and the release of materials via agricultural and septic tank systems. In this regard it is notable that levels of $\delta^{15}N$ increase upstream of the broadwaters (within the freshwater creeks) despite the absence of an WWTP point source. This suggests an anthropogenic input and helps to underpin the summations made earlier about the different nutrient sources from the catchment.

Mangrove vegetation in Terranora Creek sampled for processed nitrogen tracking.



2008 $\delta^{15}N$ results, showing the location of wastewater treatment plant (WWTP) discharge into Terranora Creek (average of 2 replicates from each sampling site).



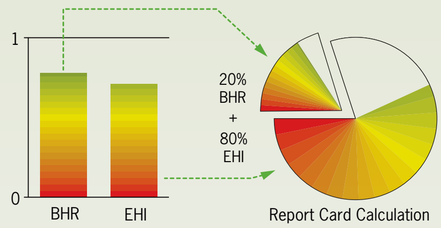
Historical $\delta^{15}N$ results from 2001, showing the location of wastewater treatment plant (WWTP) discharge into Terranora Creek (average of 2 sampling events—wet and dry).

Estuarine Report Card Grades

Estuarine Report Card Grade

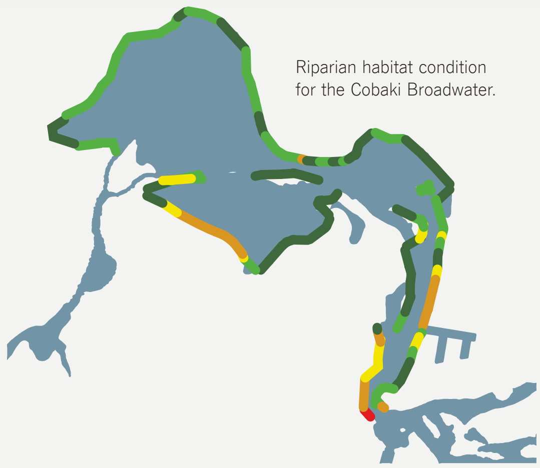
C 2008 Cobaki Broadwater C 2001

UQ, VISION AND REMOTE SENSING



Biological health rating (BHR)

The biological health rating (BHR) for the Cobaki broadwater (not including Cobaki Creek) was derived from the results of processed nitrogen tracking ($\delta^{15}N$) and the riparian assessment. No seagrass beds were present in the Cobaki Broadwater, therefore seagrass depth range surveys could not be undertaken. The BHR for the Cobaki Broadwater rated the highest of all the four areas assessed, with an overall score of 0.78. This rating resulted from low levels of $\delta^{15}N$ recorded and a good overall condition assessment of the riparian zone.



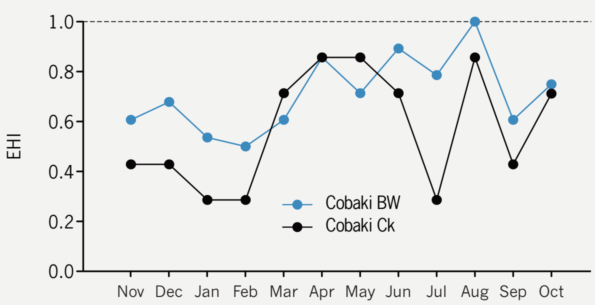
Riparian habitat condition for the Cobaki Broadwater.

Water quality indicators and EHI

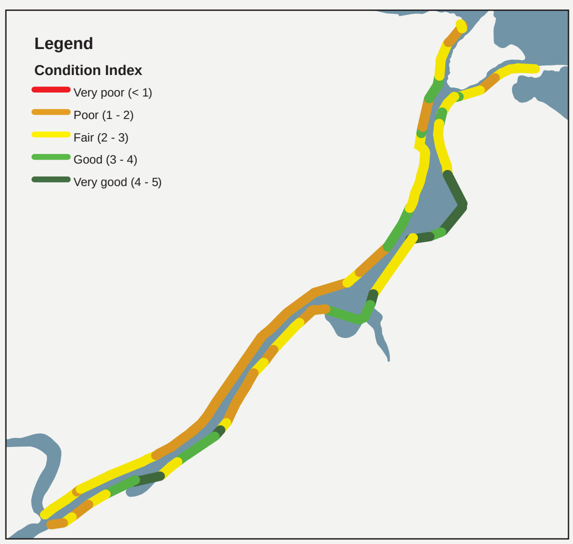
The monthly ecosystem health index (EHI) for Cobaki Broadwater shows lower water quality indicator compliance during the wetter summer months and a high in compliance during August, which was the lowest rainfall month across the monitoring period. These trends suggest that water quality within the Cobaki Broadwater is influenced by rainfall within the catchment. The EHI for Cobaki Creek is also shown here for comparison, given that it is the main creek that drains into the broadwater. The EHI results for Cobaki Creek were not used to derive the EHI for Cobaki Broadwater.

The water quality indicators that appear to have the highest influence on the resulting EHI for the Cobaki Broadwater are: total suspended solids, turbidity, dissolved oxygen and total nitrogen. All of these indicators showed a lower compliance during summer months compared to winter months.

The derivation of the report card grade uses the average of all monthly EHIs for all sites within the reporting region. For the Cobaki Broadwater, the average EHI was 0.711 (or 71.1% compliance to water quality objectives, averaged across all months).



Water quality indicator compliance expressed as Ecosystem Health Index (EHI) for each sampling month between November 2007 and October 2008, for Cobaki Broadwater and the estuarine section of Cobaki Creek.

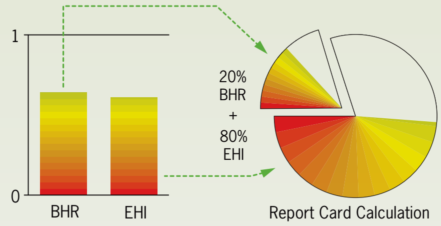


Riparian habitat condition for the estuarine section of Cobaki Creek immediately upstream of the Cobaki Broadwater.

Estuarine Report Card Grade

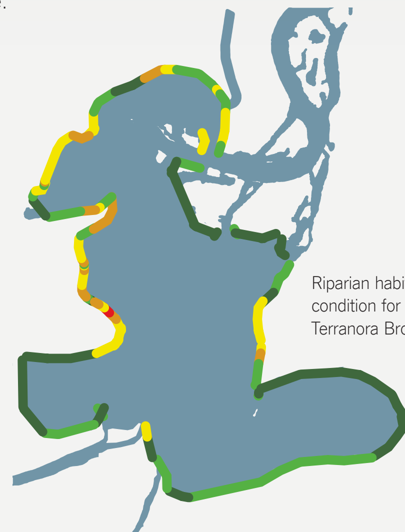
D+ 2008 Terranora Broadwater C 2001

UQ, VISION AND REMOTE SENSING



Biological health rating (BHR)

The biological health rating (BHR) for the Terranora Broadwater (not including Bilambil or Duroby Creeks) was derived from the results of processed nitrogen tracking ($\delta^{15}N$), riparian assessment and seagrass depth range. The BHR for the Terranora Broadwater rated the second highest of all the four areas assessed (second to Cobaki Broadwater), with an overall score of 0.64. This rating resulted from moderate levels of $\delta^{15}N$ recorded, stable seagrass beds, and a good overall condition of the riparian zone.



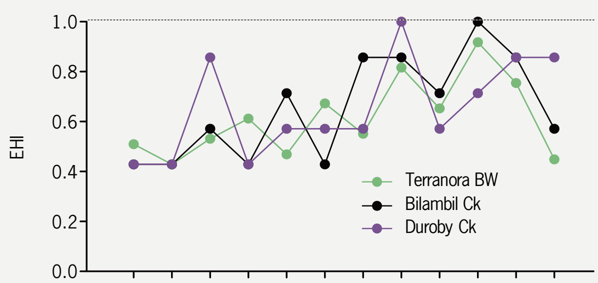
Riparian habitat condition for the Terranora Broadwater.

Water quality indicators and EHI

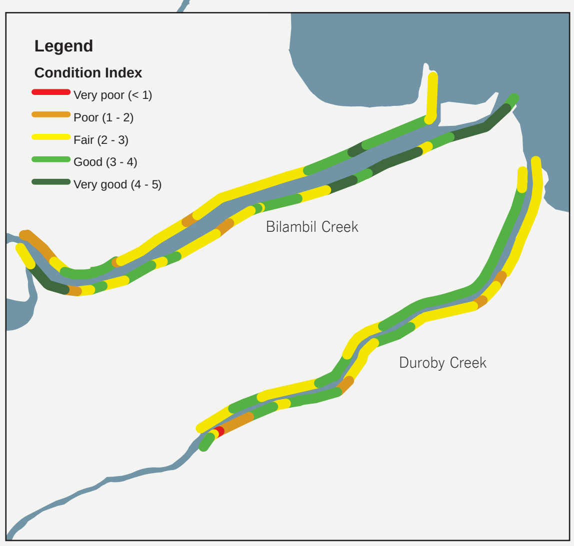
The monthly ecosystem health index (EHI) for the Terranora Broadwater shows a similar trend to that of the Cobaki Broadwater, with lower compliance during the wetter summer months and a high in compliance during August 2008. These trends suggest a strong link between water quality and rainfall within the catchment. The EHIs for Bilambil Creek and Duroby Creek are also shown here for comparison, given that these are the main creeks that drain into the broadwater. The EHI results for Bilambil and Duroby Creeks were not used to derive the EHI for Terranora Broadwater.

The water quality indicators that appear to have the highest influence on the resulting EHI for the Terranora Broadwater are: total suspended solids, turbidity, dissolved oxygen, total nitrogen and total phosphorous. All of these indicators showed a lower compliance during the wetter summer months compared to the drier winter months.

The derivation of the report card grade uses the average of all monthly EHIs for all sites within the reporting region. For the Terranora Broadwater, the average EHI was 0.614, which is the lowest EHI of all the four areas assessed.



Water quality indicator compliance expressed as Ecosystem Health Index (EHI) for each sampling month between November 2007 and October 2008, for Terranora Broadwater and the estuarine sections of Bilambil and Duroby Creeks.



Riparian habitat condition for the estuarine sections of Bilambil and Duroby Creeks, immediately upstream of the Terranora Broadwater.

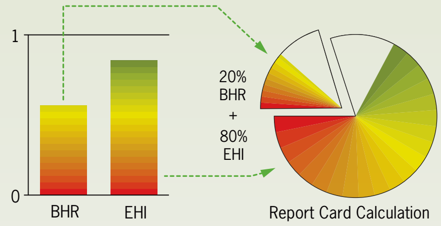
Estuarine Report Card Grade

C+ 2008

Terranora Creek

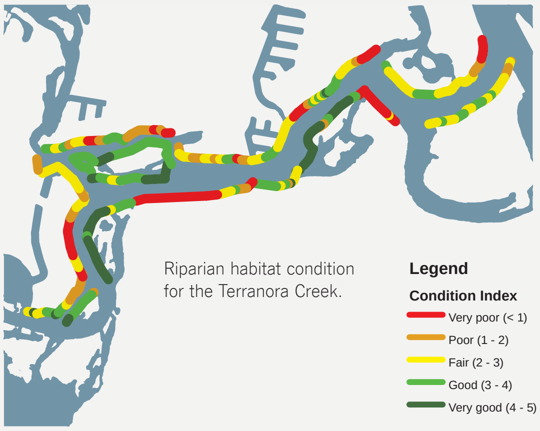
C/B- 2001

UQ, VISION AND REMOTE SENSING



Biological health rating (BHR)

The biological health rating (BHR) for the Terranora Creek was derived from the results of processed nitrogen tracking ($\delta^{15}N$), riparian assessment and seagrass depth range. The BHR for the Terranora Creek rated the second lowest of all the four areas assessed, with an overall score of 0.56. This rating resulted from high levels of $\delta^{15}N$ (highest recorded of all four areas), stable seagrass beds, and a fair to good riparian condition.



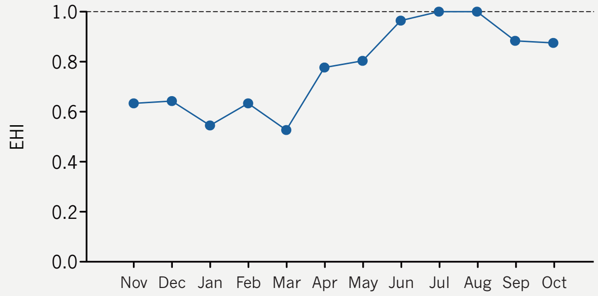
Riparian habitat condition for the Terranora Creek.

Water quality indicators and EHI

The monthly ecosystem health index (EHI) for the Terranora Creek shows a distinctive seasonal trend, with lower compliance during the wetter summer months compared to the drier winter months, where 100% compliance was achieved during the July and August sampling events. The average EHI for Terranora Creek was 0.833 (or 83.3% compliance to water quality objectives, on average).

The water quality indicators that appear to have the highest influence on the resulting EHI for Terranora Creek are: total suspended solids, and to a lesser extent, dissolved oxygen. Both these indicators showed a lower compliance during the summer months compared to the winter months.

The discharge of treated wastewater into Terranora Creek does not appear to have influenced the resulting EHI. However, the EHI is based on ambient monthly sampling and does not take into account cumulative loads of pollutants into the system. The presence of sewage related nitrogen is assessed within the derivation of the biological health rating (BHR).

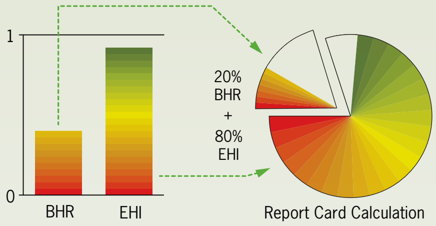


Water quality indicator compliance expressed as Ecosystem Health Index (EHI) for each sampling month between November 2007 and October 2008, for the Terranora Creek.

Estuarine Report Card Grade

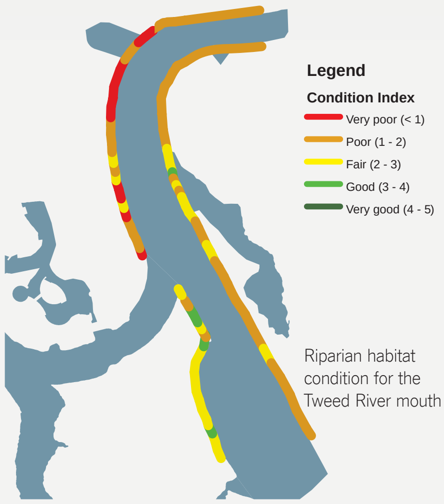
B- 2008 Tweed River Mouth B+ 2001

UQ, VISION AND REMOTE SENSING



Biological health rating (BHR)

The biological health rating (BHR) for the Tweed River mouth was derived from the results of the riparian assessment only, as there were no seagrass beds in the assessment area (downstream of the Terranora Creek confluence). The BHR for the Tweed River mouth rated the lowest of all four areas assessed, with an overall score of 0.4. This rating directly resulted from a poor score for the riparian assessment.

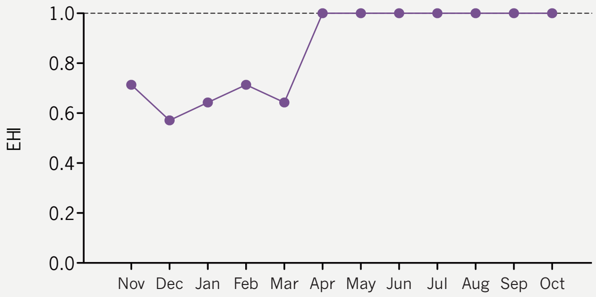


Riparian habitat condition for the Tweed River mouth

Water quality indicators and EHI

The monthly Ecosystem Health Index (EHI) for the Tweed River mouth also shows a distinctive seasonal trend, with lower compliance during summer months compared to winter months, where 100% compliance was achieved between April and October sampling events. The average EHI for the Tweed River mouth was 0.917, which equates to excellent water quality, and is the highest EHI grade of all four areas assessed.

The water quality indicators that appear to have negatively influenced the EHI during the summer months are: total suspended solids, dissolved oxygen, and to a very minor extent, total nitrogen.



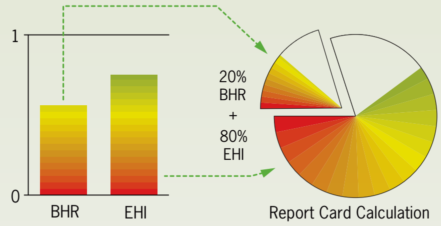
Water quality indicator compliance expressed as Ecosystem Health Index (EHI) for each sampling month between November 2007 and October 2008, for the Tweed River mouth.

Estuarine Report Card Grade

Overall Estuarine System

C
2008

UQ, VISION AND REMOTE SENSING



Biological health rating (BHR)

The biological health rating (BHR) for the Cobaki-Terranora estuary is the average of all the combined BHR results for each reporting region. The resulting BHR for the overall estuary was 0.55.

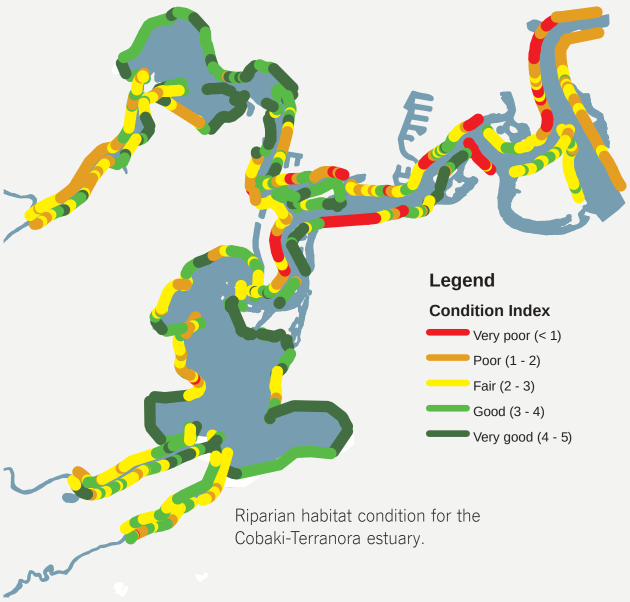
A large component of the BHR was the riparian condition assessment. The results of the riparian assessment clearly show poorer riparian conditions in the estuarine creeks upstream of the two broadwaters, and along the urban developed reaches of Terranora Creek and the Tweed River mouth. The linkage between riparian condition and water quality is widely known and has been demonstrated throughout the literature. Improvements to the riparian condition within the estuary would help to improve water quality and the overall ecological health of the system.

Water quality indicators and EHI

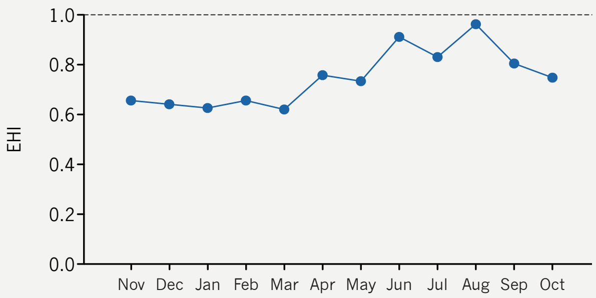
The monthly ecosystem health index (EHI) for the Cobaki-Terranora estuary shows a lower compliance during the wetter summer months compared to the drier winter months. The average EHI for the overall estuary was 0.747 (or 74.7% compliance to water quality objectives, on average).

The results of the estuarine EHMP show that water quality in some parts of the estuary respond differently than others. This is particularly apparent when comparing the water quality in the upper estuary to that of the lower estuary. However, the data also suggests that similar temporal trends in water quality exist across the entire system.

The entire data set as a whole suggests that the particulate load (with associated organic and nutrient load) during rainfall events is likely to be the main driver effecting water quality in the estuary.



Riparian habitat condition for the Cobaki-Terranora estuary.



Water quality indicator compliance expressed as Ecosystem Health Index (EHI) for each sampling month between November 2007 and October 2008, for Cobaki-Terranora estuary.

Appendix

Abbreviations

AMTD	Adopted middle thread distance (distance upstream from mouth)
BHR	Biological health rating
Chl *a*	Chlorophyll *a*
$\delta^{13}C$	Carbon stable isotope ratio
$\delta^{15}N$	Nitrogen stable isotope ratio
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
EcoH Plot	Ecosystem Health plot
EHI	Ecosystem Health Index
EHMP	Ecosystem Health Monitoring Program
FRP	Filterable reactive phosphorus
GPP	Gross primary productivity
NO_x	Nitrite
NH_4	Ammonium
NRW	Natural Resources and Water
NTU	Nephelometric turbidity units
O/E_{50}	Ratio of observed to expected species
PET	The number of stonefly [Plecoptera], mayfly [Ephemeroptera] and caddisfly [Trichoptera] families
PONSE	Proportion of native species expected
R_{24}	Respiration over a 24 hour period
SDR	Seagrass depth range
SEQ	South East Queensland
SIGNAL	The average sensitivity score of taxa present in samples
WWTP	Wastewater treatment plant
TN	Total nitrogen
TP	Total phosphorus

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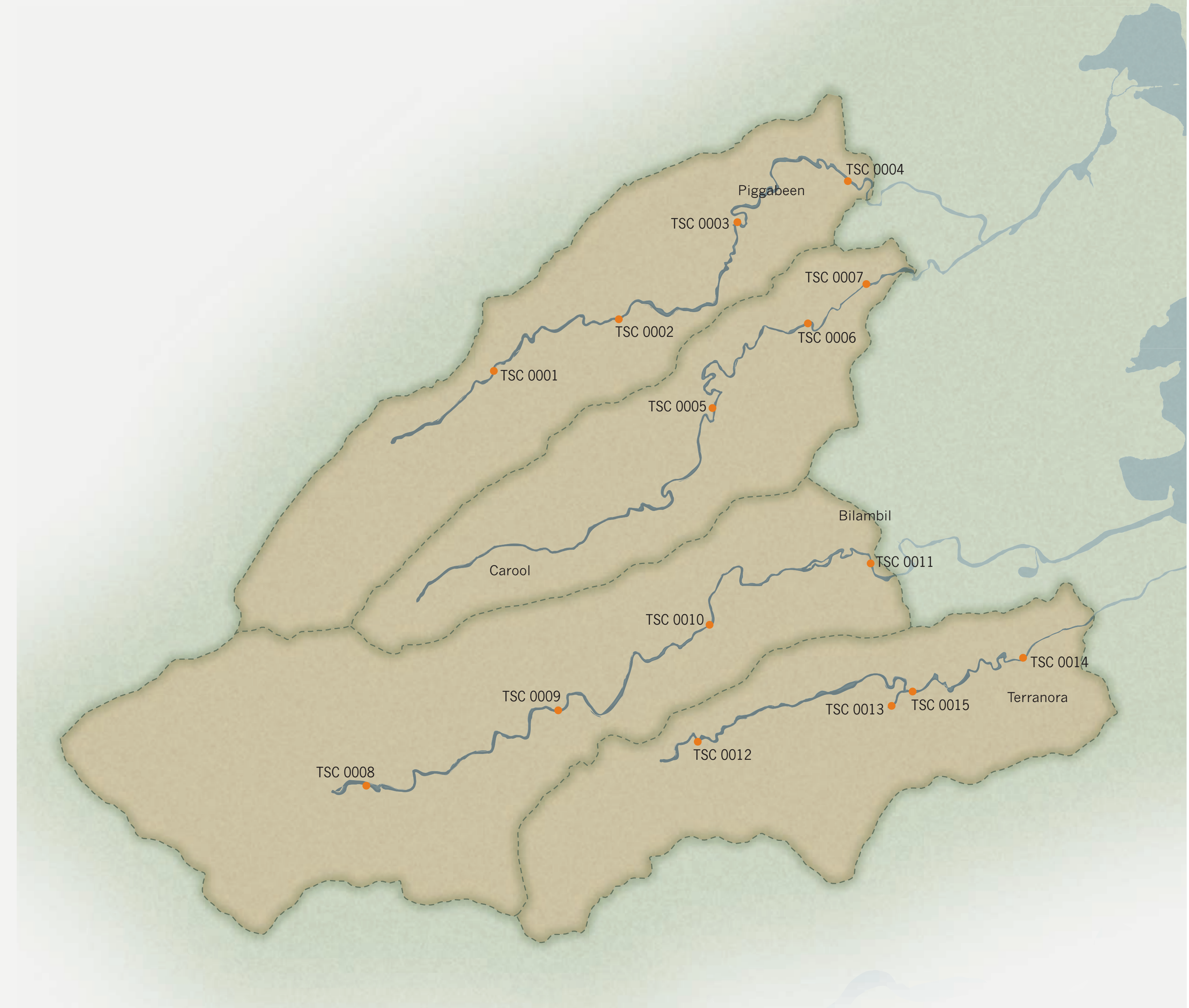
Freshwater monitoring sites 2007-08



Counts of aquatic macroinvertebrates recorded at each site along Piggabeen, Cobaki, Bilambil and Duroby Creeks during spring 2007

			Piggabeen Creek					Cobaki Creek				Bilambil Creek					Duroby Creek					
Class	Order	Taxa	TSC-0001	TSC-0002	TSC-0003	TSC-0004	Total	TSC-0005	TSC-0006	TSC-0007	Total	TSC-0008	TSC-0009	TSC-0010	TSC-0011	Total	TSC-0012	TSC-0013	TSC-0014	TSC-0015	Total	Overall Total
Arachnida	s.o. Acariformes	Acarina	13	14	22	4	53	4	4	50	58	30	4	26	55	115	0	7	7	6	20	246
Arachnida	Araneae	Araneae	0	0	0	0	0	0	0	1	1	1	3	1	2	7	0	0	1	0	1	9
Bivalvia	s.c. Paleoheterodonta	Hyriidae	0	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	Veneroida	Corbiculidae	0	1	1	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3
		Sphaeriidae	2	0	0	0	2	2	1	0	3	0	1	0	2	3	0	1	4	0	5	13
Branchiopoda	Cladocera	Cladocera	1	14	13	4	32	0	3	2	5	4	7	10	2	23	10	0	6	5	21	81
Copepoda	-	Copepoda	1	10	26	11	48	8	2	13	23	18	8	25	14	65	3	0	8	5	16	152
Gastropoda	Basommatophora	Ancylidae	2	0	0	0	2	0	0	0	0	0	0	1	1	2	10	0	0	10	20	24
		Lymnaeidae	1	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	2	1	4	6
		Physidae	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	2	0	2	4
		Planorbidae	0	0	0	1	1	0	0	0	0	0	1	0	0	1	1	0	0	2	3	5
	Mesogastropoda	Hydrobiidae	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	36	0	36	38
s.c. Hirudinea	-	Glossiphoniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Hydrozoa	Hydroida	Hydridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Insecta	s.o. Anisoptera	Cordulephyidae	0	0	4	1	5	1	0	1	2	9	0	1	0	10	0	0	0	3	3	20
		Gomphidae	6	1	1	1	9	0	2	1	3	5	6	1	1	13	3	0	0	1	4	29
		Hemicorduliidae	2	0	2	0	4	0	0	2	2	2	5	1	0	8	0	0	5	0	5	19
		Libellulidae	0	1	0	0	1	0	0	2	2	1	1	1	1	4	0	0	0	0	0	7
		Lindeniidae	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1
	Coleoptera	Dytiscidae	0	4	2	0	6	0	0	0	0	17	15	3	1	36	1	0	1	0	2	44
		Elmidae	0	0	0	0	0	0	0	0	0	12	2	0	0	14	0	0	0	1	1	15
		Gyrinidae	4	0	0	0	4	0	0	0	0	0	0	0	0	0	1	0	0	1	2	6
		Hydraenidae	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	2
		Hydrophilidae	2	0	0	0	2	0	0	0	0	3	2	0	0	5	0	0	0	0	0	7
		Scirtidae	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	Collembola	Collembola	0	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	2	2	4
	Diptera	Ceratopogonidae	1	0	0	0	1	0	0	0	0	7	1	1	1	10	0	0	0	2	2	13
		Culicidae	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Dixidae	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	2
		Psychodidae	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1
		s.f. Chironominae	20	39	39	52	150	31	23	32	86	35	26	44	59	164	26	17	23	71	137	537
		s.f. Orthocladiinae	0	0	1	0	1	0	0	1	1	0	1	0	0	1	0	0	0	0	0	3
		s.f. Tanypodinae	8	16	17	6	47	36	15	22	73	52	15	13	9	89	9	2	9	20	40	249
		Stratiomyidae	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Tipulidae	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	Ephemeroptera	Baetidae	1	3	0	1	5	1	1	2	4	0	9	2	1	12	0	0	0	1	1	22
		Caenidae	5	2	0	0	7	0	0	1	1	5	0	4	16	25	0	0	0	0	0	33
		Leptophlebiidae	1	1	1	0	3	1	0	0	1	2	0	0	0	2	16	0	0	22	38	44
	Hemiptera	Corixidae	57	22	3	1	83	18	44	8	70	27	22	2	2	53	0	0	0	0	0	206
		Gelastocoridae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1

Counts of aquatic macroinvertebrates recorded at each site cont'd.

			Piggabeen Creek					Cobaki Creek				Bilambil Creek					Duroby Creek					
Class	Order	Taxa	TSC-0001	TSC-0002	TSC-0003	TSC-0004	Total	TSC-0005	TSC-0006	TSC-0007	Total	TSC-0008	TSC-0009	TSC-0010	TSC-0011	Total	TSC-0012	TSC-0013	TSC-0014	TSC-0015	Total	Overall Total
		Gerridae	1	0	0	0	1	1	0	1	2	3	0	1	4	8	0	0	2	0	2	13
		Hebridae	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1
		Hydrometridae	3	1	0	1	5	0	0	1	1	0	0	0	1	1	0	0	0	0	0	7
		Mesoveliidae	0	0	0	0	0	0	2	0	2	0	0	1	0	1	0	0	0	1	1	4
		Notonectidae	4	0	0	0	4	0	0	0	0	7	2	0	0	9	8	0	0	0	8	21
		Veliidae	13	11	4	7	35	3	8	24	35	10	4	4	16	34	0	0	9	4	13	117
	Lepidoptera	Pyralidae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
	Megaloptera	Sialidae	0	1	0	0	1	0	0	0	0	6	1	0	1	8	1	0	0	0	1	10
	Trichoptera	Calamoceratidae	0	0	1	0	1	0	2	0	2	0	0	2	2	4	0	0	0	5	5	12
		Ecnomidae	1	3	5	0	9	17	2	2	21	1	0	4	1	6	0	0	0	0	0	36
		Hydroptilidae	0	0	0	0	0	0	1	1	2	14	3	0	2	19	0	0	0	1	1	22
		Leptoceridae	3	2	5	5	15	2	3	2	7	13	1	5	2	21	1	0	3	21	25	68
	s.o. Zygoptera	Coenagrionidae	0	2	1	0	3	1	2	2	5	2	10	1	1	14	0	0	0	0	0	22
		Isostictidae	1	9	9	6	25	2	1	5	8	1	3	7	7	18	1	0	6	8	15	66
		Megapodagrionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	4	4
		Protoneuridae	0	0	1	0	1	0	0	0	0	2	1	1	0	4	0	0	0	0	0	5
		Synlestidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	11	11
Malacostraca	Amphipoda	Corophiidae	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Decapoda	Atyidae	27	4	20	0	51	13	31	2	46	24	22	23	0	69	34	0	0	24	58	224
		Palaemonidae	9	0	13	0	22	0	6	1	7	4	0	5	2	11	1	0	0	4	5	45
	Isopoda	Cirolanidae	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Sphaeromatidae	0	0	0	22	22	0	0	0	0	0	0	0	13	13	0	0	0	0	0	35
phy. Annelida	cl. Polychaeta	Polychaeta	0	0	0	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
phy. Nematoda	-	Nematoda	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2
phy. Platyhelminthes	cl. Temnocephalidea	Temnocephalidea	6	0	3	0	9	0	0	0	0	13	0	1	0	14	0	0	0	6	6	29
Ostracoda	-	Ostracoda	1	40	18	19	78	1	6	2	9	6	9	10	0	25	5	0	17	2	24	136
s.c. Oligochaeta	-	Oligochaeta	2	10	4	3	19	0	3	0	3	0	1	3	1	5	2	10	5	0	17	44
Turbellaria	Seriata	Dugesiidae	2	21	0	0	23	8	3	3	14	4	3	0	1	8	0	0	4	0	4	49
		No. taxa	31	26	26	23	51	19	24	27	35	38	32	32	30	52	21	5	22	26	41	68

Counts of fish caught at each site along Piggabeen, Cobaki, Bilambil and Duroby Creeks during spring 2007

		Piggabeen Creek					Cobaki Creek				Bilambil Creek					Duroby Creek					
Species	Common name	TSC-0001	TSC-0002	TSC-0003	TSC-0004	Total	TSC-0005	TSC-0006	TSC-0007	Total	TSC-0008	TSC-0009	TSC-0010	TSC-0011	Total	TSC-0012	TSC-0013	TSC-0014	TSC-0015	Total	Overall total
Acanthopagrus australis[M]	Silver bream	0	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Anguilla australis	Short-finned eel	1	0	0	0	1	0	0	0	0	2	1	2	0	5	0	2	0	1	3	9
Anguilla reinhardtii	Long-finned eel	22	3	13	1	39	7	8	23	38	16	9	4	7	36	8	3	1	26	38	151
Gambusia holbrooki[A]	Gambusia	3	16	54	0	73	0	33	30	63	0	25	97	2	124	29	0	27	16	72	332
Gobiomorphus australis	Striped gudgeon	2	2	25	1	30	2	4	4	10	0	4	7	13	24	0	3	2	6	11	78
Gobiomorphus coxii	Cox's gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	3
Hypseleotris compressa	Empire gudgeon	0	4	54	35	93	0	10	75	85	0	2	12	223	237	0	14	68	8	90	505
Hypseleotris galii	Fire-tail gudgeon	2	2	0	3	7	12	2	0	14	0	7	21	0	28	0	0	0	0	0	49
Leiopotherapon unicolor	Spangled perch	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Macquaria novemaculeata	Australian bass	0	4	2	0	6	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7
Melanotaenia duboulayi	Rainbow fish	0	0	0	0	0	0	0	0	0	25	54	14	9	102	0	17	0	1	18	120
Mugil cephalus	Sea mullet	0	0	0	1	1	0	3	4	7	0	2	0	29	31	0	0	0	0	0	39
Myxus petardi	Freshwater mullet	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	2
Notesthes robusta	Bullrout	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	2
Philypnodon grandiceps	Flat-head gudgeon	0	0	0	30	30	0	0	0	0	0	1	0	0	1	0	0	1	0	1	32
Philypnodon macrostomus	Dwarf flat-head gudgeon	0	0	0	0	0	0	0	18	18	0	0	42	0	42	0	0	0	0	0	60
Pseudomugil signifer	Pacific blue-eye	0	0	0	1	1	0	0	0	0	0	0	0	3	3	0	0	0	0	0	4
Redigobius macrostomus	Large-mouth goby	0	0	0	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Retropinna semoni	Australian smelt	0	1	2	0	3	7	1	0	8	2	57	6	0	65	0	12	0	19	31	107
Tandanus tandanus	Freshwater catfish	1	1	2	0	4	3	2	3	8	0	1	0	0	1	0	0	0	0	0	13
Xiphophorus helleri[A]	Swordtail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	43	44	44
	No. species	6	8	7	9	14	6	10	8	12	4	12	10	7	14	3	7	5	8	9	21

Estuarine monitoring sites 2007-08