Ecohealth
A health check for our waterways

Design, Methods and Reporting of Waterway Health in Coastal NSW, Australia

University of New England

Aquatic Ecology and Restoration RESEARCH GROUP

Acknowledgements
Special thanks to the Ecohealth Technical Reference Group for providing valuable information and guidance, and for their ability to help overcome hurdles along the way. The people below provided significant support for the development of the program, our thanks to each of them.

Max Osborne, Peter Corlis, Tony Broderick, Nigel Blake: NCLLS

Michael Healey: NSW Office of Water

John Schmidt, Geoff Code, Peter Scanes: NSW Office of Environment and Heritage

Thor Aaso: Port Macquarie Hastings Council.

Malcolm Robertson: Coffs Harbour City Council

Peter Wilson: Clarence Valley Council

This report should be cited as:
Ryder, D, Mika, S and Vincent, B. (2016). Ecohealth: A health check for our waterways. Design, methods and reporting of waterway health in coastal NSW, Australia. University of New England, Armidale.

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Ecohealth – An aquatic ecosystem health check for our waterways

Summary

The Ecosystem Health Monitoring Program (Ecohealth) is a comprehensive estuarine and freshwater monitoring program that reports on the health of our waterways. The Ecohealth program includes a number of physical, chemical and biological indicators to determine the health of waterways. The combination of waterway health indicators that identify short-term (water chemistry), intermediate-term (zooplankton, macroinvertebrates), and long-term responses (fish, geomorphology and riparian vegetation) provides a robust program for quantifying, reporting and communicating waterway health, and prioritising management actions.

The Ecohealth Monitoring Program outlines a framework for the development of a catchment-based aquatic health monitoring program for rivers and estuaries with the aim of providing consistency in monitoring and reporting, and establishing the partnerships required for local and regional dissemination of outcomes. The development and application of specific monitoring frameworks, and standardised data collection, analysis and reporting underpins the Ecohealth program. This standardised approach facilitates an effective reporting mechanism to communicate water quality and resource condition information to the wider public, stakeholders and managers.

Ecohealth enhances the ability of natural resource managers to monitor, measure and report on ecosystem health by establishing a statistically-valid and quality assured sampling regime. The benefits of a standardised, region-wide system include:

- consistency and efficiency in project design, sampling, analysis and reporting
- improved management, access, sharing and interpretation of data among all partners
- catchment-wide reporting – from upland streams, large rivers, coastal lagoons, estuaries and near-shore marine areas
- improved evidence-based decision making on NRM activities and investment, including improved long-term management of catchments and waterways through undertaking Ecohealth monitoring at regular intervals
- enhanced communication about waterway health between NRM agencies, local government, other stakeholders and the community
- improved public information on waterway health and management actions in local catchments through the production of Report Cards.

The products generated by the Ecohealth program cover high-level scientific technical reports that provide an in-depth presentation and analysis of data collected, as well as Ecohealth Report Cards that aim to clearly disseminate waterway health outcomes and management initiatives to engage with local communities. In addition to communication products, Ecohealth also provides a scientifically robust dataset as the basis for State of Catchment (SoC) and State of Environment (SoE).

1. Background

1.1 Setting the scene: Northern Rivers region

The Northern Rivers region is located in the north-east corner of NSW and covers over 50,000 km^2, of which 60 % is freehold tenure and 21,500 km^2 is managed as Crown land, National Park or State forest.The region extends from the Queensland border, south to the Camden Haven River and inland to the New England Tablelands (Figure 1). Aboriginal nations within the region include the Bundjalung, Anaiwan, Birpai, Dunghutti, Gumbainggar, Gwaegal, Guyambal and Yaegl people. The marine environment of the region extends from mean high water mark to three nautical miles to sea, and includes the Lord Howe Island Group. This area, of more than 300,000 ha, supports a biologically diverse and unique mix of temperate and tropical habitats including numerous reefs, inter-tidal rocky shores and sandy beaches that provide important habitat for threatened and protected species. The region also includes the Solitary Islands Marine Park, the first marine park established in NSW, covering an area of approximately 72,200 ha from Muttonbird Island in the south to the Sandon River in the north. The marine park incorporates estuaries to their tidal limit, foreshores to the mean high water mark and extends offshore to the 3 nautical mile state waters boundary. The river, estuary and marine regions are important to the region's economy, providing the natural resources that support industries such as tourism, and recreational and commercial fishing.

There are nine major river catchments in the region - the Tweed, Brunswick, Richmond, Clarence, Coffs Harbour Waterways, Bellinger-Kalang, Nambucca, Macleay and Hastings-Camden Haven, including 196 sub-catchments within these major valleys. The region also includes significant coastal lakes, estuaries and river systems, such as the lagoons of the Camden Haven River, Lake Cathie and Lake Innes, Lake Ainsworth, the Tweed's Terranora Broadwater, and Lake Hiawatha and Minnie Water in the Clarence valley. Nearly all the rivers in the region are unregulated (they do not have dams) resulting in predominantly natural flow regimes that contribute to the maintenance of local biodiversity. The region has a diversity of landscapes, natural resource values and land use types, ranging from tableland grazing and cropping in tableland areas to sugar cane, animal and tropical fruit production in the coastal regions. Agriculture, timber and urban settlement dominate the land uses in the region.

The Northern Rivers region is known for its extensive coastal river systems and high level of biodiversity. The region is a National Biodiversity Hotspot, as the third most biodiverse region in Australia and home to 380 species, 5 populations as well as 13 communities listed as endangered or vulnerable under the NSW Threatened Species Conservation Act (TSC) 1995. The region has a number of significant sites including 2 World Heritage Areas (the Lord Howe Island group and the Central Eastern Rainforest Reserves of Australia (CERRA)), Ramsar Wetlands including Little Llangothlin Lagoon on the northern Tablelands, and 25 wetlands listed on the Directory of Nationally Important Wetlands. There are 196 reserves and conservation areas within the Northern Rivers region.

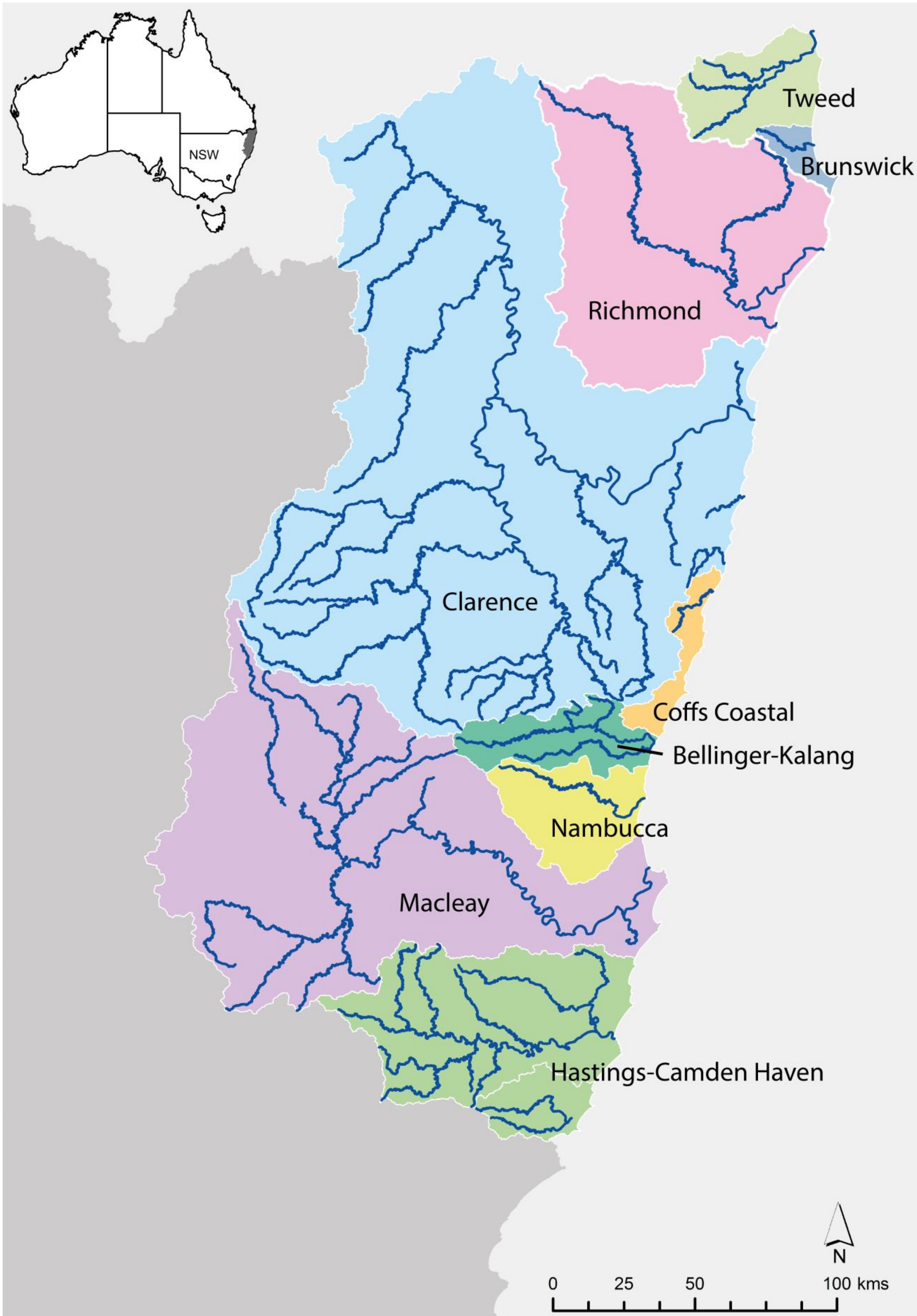


Figure 1. Northern Rivers region covering an area of over 50,000 km^2 contains 9 major river catchments.

1.2 What is Ecohealth? – Aim, partnerships, defining ecosystem health

River, estuarine and coastal lagoon systems are focal points for the cumulative impacts of changed catchment land-use, and increasing urbanisation and development in coastal zones. As a result, these ecosystems have become sensitive to nutrient enrichment and pollution, and degraded through habitat destruction and changes in biodiversity. The development of a standardised protocol for collecting, analysing and presenting riverine, coastal and estuarine assessments of ecological condition has been identified as a key need for coastal Local Government Areas and government agencies who are required to monitor and report natural resource condition.

The Ecosystem Health Monitoring Program (Ecohealth) is a comprehensive estuarine and freshwater monitoring program that reports on the health of our waterways. It is modelled on the South East Queensland Healthy Waterways Partnership and the NSW State Monitoring, Evaluation and Reporting program. Outputs from the program align with reporting requirements for State of Catchment and State of Rivers reporting. It aims to bring together the aquatic sampling programs of government and other natural resource management agencies and partners into a standardised, region-wide system.

Ecosystem health can be defined in terms of measureable characteristics that represent the physical, chemical and biological components of aquatic ecosystems (Rapport et al. 1998; Karr 1999). Healthy freshwater and estuarine/marine ecosystems have the following attributes (after EHMP Smith 2001, Bunn 2010):

- Vigour: maintaining rates of key ecosystem processes such as primary production and nutrient turnover). Key processes operate to maintain stable and sustainable ecosystems (e.g. there is an absence of blue-green algal blooms)
- 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
- Zones of human impacts do not expand or deteriorate (e.g. a reduction in the spatial extent of bank erosion or nutrient enrichment)
- Critical habitats remain intact (e.g. riffles, woody debris, seagrass meadows)

The Ecohealth program includes a number of physical, chemical and biological indicators to determine the health of waterways. The combination of waterway health indicators that identify short-term (water chemistry), intermediate-term (zooplankton, macroinvertebrates), and long-term responses (fish, geomorphology and riparian vegetation) provides a robust program for quantifying, reporting and communicating waterway health, and prioritising management actions.

Water chemistry identifies trends in nutrient (nitrogen and phosphorus), chlorophyll *a*, suspended solids, dominant ions contributing to water quality issues (e.g., sulphur and aluminium linked to acid sulphate soils) and coliform values, as well as static variables such as pH, salinity, dissolved oxygen and temperature. *Macroinvertebrate* assemblages collected biannually from freshwater sites in Autumn and Spring are used to assess long-term condition of water quality and instream habitats. The taxonomic richness, abundance and diversity are reported, as well as health indicators using SIGNAL2 scores and percent EPT (Ephemeroptera, Plecoptera, Trichoptera) to identify taxa sensitive to disturbance. *Fish* assemblages are recorded from freshwater sites and reported as indicators of Expectedness (relative to pre-European disturbances), Nativeness (native vs introduced taxa), Recruitment (size distribution) and an overall health score. *Zooplankton* assemblages are used as biological indicators in estuary reaches and coastal lagoons, measuring the abundance of size categories, rather than taxa or trophic levels, as an indication of the health of the system and response to disturbances such as nutrient enrichment, algal blooms and floods. *Riparian Condition* assessments provide information for freshwater and estuarine sites on the cover, composition, structure, habitat and connectivity of streambank and instream vegetation. *Geomorphic Condition* provides information on the physical condition of banks and channels at site, reach and catchment scales.

Scientifically robust, quality-assured data generated by Ecohealth gives a complete picture of the current state of waterways, connecting the condition of upstream freshwater reaches with the condition of estuaries. The information generated allows local government and other natural resource managers to better manage aquatic ecosystems and evaluate natural resource management activities for their effectiveness. Report cards are an important part of the program and provide a regional assessment of each catchment, highlighting where the health of a waterway is improving and where management action may be required.

The Ecohealth program is designed so that it can be tailored to systems throughout coastal NSW. A technical reference group (TRG), comprising scientific peers from state government agencies and universities, along with local government representatives, has been established to provide advice on aspects of the program such as sampling procedures, a base set of indicators, strategic sampling locations and data analysis, reporting and management procedures. An advisory committee has also been established with representation from local and state government, and Local Government Areas (LGAs) to provide advice on the overall direction of the Ecohealth program.

Ecohealth enhances the ability of natural resource managers to monitor, measure and report on ecosystem health by establishing a statistically-valid and quality assured sampling regime. The benefits of a standardised, region-wide system include:

- consistency and efficiency in project design, sampling, analysis and reporting across government
- improved management, access, sharing and interpretation of data among all partners
- catchment-wide reporting – from upland streams, large rivers, coastal lagoons, estuaries and near-shore marine areas
- improved evidence-based decision making on NRM activities and investment, including improved long-term management of catchments and waterways through undertaking Ecohealth monitoring at regular intervals

- enhanced communication about waterway health between NRM agencies, local government, other stakeholders and the community
- improved public information on waterway health and management actions in local catchments.

2. Design of Ecohealth Monitoring Program

The design of the Ecohealth catchment monitoring program is based on the NSW Monitoring, Evaluation, Reporting (MER) protocols for Rivers and Estuaries (Roper et al. 2011, NSW OEH 2011), and aligned for reporting outcomes used in the South-East Queensland Ecosystem Health Monitoring program (EHMP) methodologies, as well as building on previous ecosystem health assessments undertaken within local regions. The number and location of sample sites must be designed to be statistically robust, and as such, provides a data set that can be used to assess spatial and temporal variability of individual catchments, as well as place this in a regional context. In time, it will be possible to further optimise the monitoring program for indicator selection and cost.

The aim of developing and applying criteria for site selection is to facilitate the reporting of waterway health (and therefore identify management actions required) at a number of spatial scales. Using the criteria below, it is possible to provide scientifically robust health scores at region, catchment, sub-catchment, river/estuary/lagoon, reach and site scales.

2.1 Freshwater reaches

The location of the freshwater monitoring sites should be based on the following selection criteria to:

An Ecohealth freshwater reach monitoring site representative of a River Style common in headwaters of catchments.

- Represent major named tributaries of each main river system, or where identified by stakeholders as tributaries of interest for management.
- Identify longitudinal change within the main stem of each river system, where practical, through the use of multiple sites (preferably 3) from headwaters to confluence. Priority is given to multiple sites along a longitudinal gradient on the main river system in each catchment. Multiple locations along tributaries with sub-catchment areas of greater than 600 km^2 allows the identification of key areas within these larger catchments in need of management actions.
- Identify end-of-system flows from rivers joining the main catchment river or entering the estuarine environment. As a minimum requirement if the sub-catchment is <600 km^2, a single site should be located at the end-of-system. Sites located adjacent to hydrometric NoW gauges will allow the calculation of 'water quality loads' such as the amount of nutrients or sediments

exported from the system; these are important data for prioritising management actions to specific areas.

- Locate sites within dominant and representative River Styles, Condition and Recovery Potential, and elevations within and across catchments. Prioritising freshwater sites within the dominant River Style and understanding the spatial extent of this geomorphic setting allows the data collected from a site to be applied to a larger reach of river.
- Facilitate comparison with historical datasets and additional information (e.g., discharge gauges).
- Locate ecological changes at the point of the tidal limit. The inclusion of a monitoring site at the tidal limit is essential, as this is often the most-impacted reach in a catchment.

2.2 Estuarine reaches

Estuaries are important environments that link freshwater and marine systems that promote biodiversity, and support productive industries and urban centres.

The location of the estuarine monitoring sites should be based on the following selection criteria to:

- Represent a minimum of one site within salinity categories of the tidal limit, 0-15 ppt, 15-30 ppt and 30+ ppt at base flow river conditions. Where large islands occur or channels are divided for large distances (kms), monitoring sites should be established before and after the channel divides and in all distributary channels.
- Identify longitudinal change within estuarine reaches of the main stem of each river system, and end of system flows with priority to one site at the river mouth.
- Locate sites within dominant and representative River Styles, Condition and Recovery Potential, and elevations within and across catchments. Prioritising sites within the dominant River Style and understanding the spatial extent of this geomorphic setting allows the data collected from a site to be applied to the broader estuary.
- Locate ecological changes at the point of the tidal limit.

2.3 Coastal lagoons

The location of the monitoring sites within coastal lagoons should be based on the following selection criteria to:

- Represent a minimum of one site within salinity categories of 0-15 ppt, 15-30 ppt and 30+ ppt if present. Alternatively, multiple sites should be located based on major areas defined by tidal flushing or residence time of water within the lagoon.
- Identify longitudinal change where necessary, major habitats (defined by vegetation or depth) within lagoons, and/or entry and discharge points within lagoons.

Coastal lagoons are shallow bodies of water within estuary and marine systems that provide important habitat for migrating birds and nursery grounds for fish.

2.4 Temporal considerations

Three approaches to sampling frequency have been trialled for the Ecohealth monitoring program. Monthly sampling over a 12 month period for water chemistry has been used in the Bellinger, Hastings, Richmond (estuary) and Coffs Ecohealth programs and helped reveal detailed responses to base flow and high flow conditions. Bi-monthly sampling constrained by monitoring only when flows are above the 80^{th} percentile at gauged sites was implemented in the Clarence, Macleay and Richmond (freshwater) Ecohealth programs. This reduced frequency of sampling permits more sites to be sampled in larger catchments, but only reports on waterway health in low flow conditions. Alternatively, our current recommendation based on 6 years of region-wide data is to sample 8 times (two per season) over a 2-year period only when flows are above the 80^{th} percentile at gauged sites. This approach has the advantages of flexibility in sampling periods that guarantee all collected data can be used in reporting (flood periods cannot be used), seasonal responses can be assessed, and cost savings are evident in reduced frequency of sampling without loss of data that affect reporting outcomes.

The bi-annual sampling for freshwater macroinvertebrates in Spring and Autumn is an established protocol for this indicator (e.g., AUSRIVaS) and is used by Ecohealth to collect macroinvertebrates on two occasions within a project. A once-off assessment of riparian (Spring/Summer) and geomorphic condition assessment is undertaken at all sites, and linked to remotely sensed information on the spatial distribution of catchment vegetation (riparian, mangroves, salt marsh and seagrass) and channel condition.

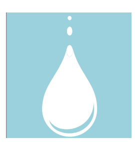
Estuarine sites are sampled consistently on an ebb tide within the constraints of boat access. The average 20 minute difference in mean high tide on consecutive days facilitates comparable data collection, and requires adjusted start times for each sampling event.

3. Ecohealth Indicators of Aquatic Ecosystem Health

The Ecohealth program uses a number of physical, chemical and biological indicators to determine the health of waterways. The combination of waterway health indicators that identify short-term (water chemistry), intermediate-term (zooplankton, macroinvertebrates), and long-term responses (fish and riparian vegetation) provides a robust program for quantifying waterway health and prioritising management actions. This section provides a detailed outline of each indicator – what it is and why we measure it as well as field methods and laboratory analyses (Boulton et al. 2014).

Integrating a number of physical, chemical and biological indicators in freshwater and estuarine reaches can be used to provide an assessment of aquatic ecosystem health at site, river and catchment scales.

3.1 Physical and Chemical Indicators



3.1.1 pH

What is it and why do we measure it?

'pH' is an abbreviation of the term 'potential Hydrogen' and is a measure of the acidity or alkalinity of a solution. In water, a small number of the H_2O molecules dissociate: some of these molecules lose a hydrogen atom and become hydroxyl ions (OH^-); other molecules accept the free hydrogen atoms and become hydronium ions (H_3O^+; or simply referred to as H^+). The pH scale is based on the negative logarithm of [H^+] and ranges from 0.0 (highly acidic; H^+ ions >> OH^- ions) to 14.0 (highly alkaline; H^+ ions << OH^- ions). Pure water has equal numbers of hydrogen and hydroxyl ions: it is 'neutral' with a pH of 7. As the pH scale is logarithmic, each integer represents a tenfold increase in acidity or alkalinity (e.g. a pH of 5.0 is ten times more acidic than a pH of 6.0 and 100 times more acidic than 7.0). pH is temperature-dependent and decreases as temperature increases.

pH is used as an indicator of water quality because it determines both the solubility (the amount that can be dissolved in water) and biological availability (the amount that can be utilized by aquatic life) of nutrients (nitrogen, phosphorus and carbon) and heavy metals (lead, aluminium, iron, etc). Thus, pH determines the species and concentrations of nutrients, and the toxicity of contaminants. The pH of rivers and estuaries is determined primarily by catchment geology and vegetation, but can also be impacted by agricultural and urban runoff (generally by acidifying receiving waters). The juvenile stages of many species of fish and the larval stages of many species of aquatic insects are sensitive to low pH or acidic conditions. Sea water typically has a high pH (i.e. alkaline) due to dissolved bicarbonate, carbonate and hydroxide compounds. Thus, estuarine pH varies spatio-temporally with tidal flushing. Despite the buffering capacity of sea water, algal blooms and drainage from acid sulfate soils can cause significant short-term fluctuations in pH. Most species cannot survive outside the range of pH 5.0 to 9.0.

Field and laboratory methods

Measurements of pH are taken *in situ* with a calibrated water quality multi-probe (accuracy ± 0.2 and resolution 0.01). At freshwater sites, pH is measured at the surface (0.1 m depth) and 0.1m above the sediment surface if less than 1m deep. At estuarine sites, pH is measured at the surface (approx. 0.1 m) and at successive 1-m intervals through the water column to a depth of 0.1 m above the bottom. The probe should be calibrated each day prior to use in the field. The majority of multi-probes automatically calibrate for temperature and measurements must be taken once the probe has stabilised.

3.1.2 Conductivity

What is it and why do we measure it?

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity is determined by the concentrations of inorganic dissolved solids, primarily mineral salts such as chloride, sodium, calcium sulfates and magnesium. Because most of the dissolved solids are salts, conductivity is closely related to salinity. Conductivity is temperature-dependent and increases as temperature increases.

Conductivity is used as an indicator of water quality as it affects floral and faunal community structure: many species are adapted for a limited range of salinity. Elevated conductivity (and thus, salinity) decreases the ability of water to hold oxygen, affects nutrient cycling and rates of primary production and respiration. Conductivity (and salinity) is determined by catchment geology, precipitation, surface runoff and evaporation. In estuaries, conductivity is strongly tidal. Human impacts to conductivity include agricultural fertilizer use, urban and industrial runoff, sewage discharge and flood mitigation works that modify tidal limits.

Field and laboratory methods

Conductivity should be measured *in situ* simultaneously with pH, using the same multi-probe and sampling procedure. The majority of probes automatically calibrate for temperature and measurements must be taken once the probe has stabilized. Conductivity is reported as milliSiemens per centimetre (mS/cm) with an accuracy of ± 0.01 PSS (Practical Salinity Scale) and a resolution of 0.01 PSS.

3.1.3 Temperature

What is it and why do we measure it?

Temperature exerts a major control on aquatic ecosystems, both directly through regulating metabolic activity, and indirectly through influencing water chemistry. Aquatic and estuarine biota including fish, amphibians, macroinvertebrates, zooplankton and phytoplankton have adapted to specific temperature ranges, and survival and reproduction are reduced at temperatures outside these ranges (e.g. sensitivity to parasites and diseases increases when organisms are temperature-stressed). Water at higher temperatures can dissolve more mineral salts, increasing its electrical conductivity; but holds less dissolved gasses including oxygen and carbon. The latter reduces primary productivity and respiration. Also, the toxicity of some contaminants increases directly as water temperature increases, or synergistically as DO decreases.

A hydrolab water quality meter is used to measure in-situ variables such as water temperature, salinity, pH, turbidity and oxygen.

Although temperature fluctuates diurnally and seasonally, human activities can change these natural cycles. Impacts include the loss of stream shading through the removal of riparian vegetation, thermal pollution (either cold water from dams, or warm water from power plants) and the extent of impervious surfaces within a catchment (by both heating runoff and accelerating its arrival into the stream network). The circulation of water in estuaries is controlled by density differences due to changes in temperature and salinity, in turn driven by riverine inflows, tidal flushing, rainfall and wind. Large vertical differences in water temperature are indicative of stratification.

Field and laboratory methods

Temperature should be measured *in situ* simultaneously with pH and conductivity, using the same calibrated multi-probes. Temperature is reported as degrees Celsius (°C), with an accuracy of ± 0.15 °C and a precision of 0.01 °C.

3.1.4 Dissolved Oxygen

What is it and why do we measure it?

The concentration of dissolved oxygen (DO) is a measure of the availability of oxygen in water. Oxygen is fundamentally important for all organisms that respire aerobically, including fish, invertebrates, algae and macrophytes. Motile organisms (e.g. fish and some invertebrates) actively avoid areas where DO falls below 4 mg/L and most biota cannot survive DO concentrations less than 2 mg/L. Thus, DO directly regulates the survival and distribution of biota in rivers and estuaries. Oxygen mainly diffuses into water from the atmosphere, in rivers increasing with water velocity and turbulence, and in estuaries through the mixing of surface waters by wind and waves. DO is also produced during photosynthesis. DO is consumed through respiration and decomposition, so low flows and excess organic matter can lead to critically low concentrations of DO (hypoxia), that may lead to fish kills. DO decreases with increasing water temperature, salinity and altitude.

Anoxia also reduces water quality through its effects on decomposition and nutrient processes. In anoxic conditions, bacterial decomposition uses sulfate instead of oxygen, increasing the concentration of sulfide, which is toxic to many organisms including benthic invertebrates and seagrass. Nitrification/denitrification processes are inhibited by sulfide, increasing the concentration of nitrogen (ammonium) in benthic sediments. When benthic sediments become anoxic, they may release iron and phosphorus into the water column, potentially leading to algal blooms.

Field and laboratory methods

DO should be measured *in situ* using a calibrated multi-probe following the same methods as above. The majority of probes automatically calibrate for temperature, and measurements must be taken once the probe stabilizes. DO should be recorded both as percent saturation (% Sat; the amount of DO in a litre of water relative to the total amount of DO that the water can hold at that temperature) and as milligrams per Litre (mg/L), with an accuracy of ± 0.2 mg/L and a resolution of 0.01 mg/L.

Water quality being measured in-situ in a freshwater reach.

3.1.5 Turbidity and total suspended solids

What is it and why do we measure it?

Turbidity is a measure of the relative clarity of a solution. It is an optical characteristic that expresses how much light is scattered by suspended and colloidal materials in the water column, such as inorganic sediments (clay, silt and sand), fine organic matter (algae, detritus), and microscopic organisms (plankton). By definition, turbidity is caused primarily by suspended particles smaller than 1 µm in diameter, while suspended solids (see below) refers to particles that typically range from 10-100 µm in diameter. In addition to turbidity, water colour also affects the clarity of water, as coloured components absorb light energy by preventing light from penetrating as deeply as in colourless water and by reflecting certain wavelengths back out of the water. Water colour has several sources including natural metallic ions (iron and manganese), the tannins and dissolved organic carbon from humus and peat materials, plankton and some macrophytes such as *Myriophyllum*, weeds and industrial wastes.

In rivers and estuaries, turbidity and total suspended solids are primarily affected by catchment geology, rainfall and runoff; erosion in the catchment, stream bed and banks; flow; discharge of stormwater and wastewaters; floodplain and wetland retention and deposition; excessive nutrients causing algal blooms; and disturbance of benthic sediments by flooding, dredging or boating activities. In estuaries, tidal currents also re-suspend fine sediments.

Because suspended particles absorb heat, water temperature rises faster in turbid water than clear water; thus, increases in turbidity and temperature synergistically decrease the concentration of DO. Light penetration decreases as turbidity increases, restricting photosynthesis (decreasing primary productivity and DO). High turbidity can favor the growth of blue-green algae as these can both photosynthesise in low light and control their position in the water column. Where high turbidity is caused by high levels of organic matter, bacterial decomposition may also further deplete DO concentrations.

While the particles remain suspended, they clog the filter-feeding and digestive systems of invertebrates and damage the gills of fish, reducing their growth rate and resistance to disease. High turbidity also reduces the effectiveness of visual predators, changing predator-prey relationships. As the particles settle, they smother benthic sediments reducing coarse or hard substrate habitats and clog sediment interstices (called 'colmation'), impairing surface water – groundwater exchange. Nutrients and contaminants adsorb onto suspended particles and are thus carried by turbid water and concentrated in depositional areas.

In estuaries, reduced light penetration reduces the ability of seagrasses to photosynthesize: if light limitation reaches the point where the products produced by photosynthesis equal the products consumed in respiration, (called the light compensation point), the plant does not accumulate biomass and cannot reproduce. Beyond this point, the plant consumes more than it produces and begins to die-off until its biomass reaches a threshold that can be sustained by the low levels of photosynthesis. Seagrasses typically require much more light for photosynthesis than terrestrial plants and algae. Thus, suspended solids directly reduce macroinvertebrate and fish diversity and abundance through reduced feeding and increased disease risk, and indirectly through increased temperature, lower DO, and reduced macrophyte habitat and food resources.

Field and laboratory methods

Measurements of turbidity should be taken *in situ* using a calibrated multi-probe (or secchi disc). Turbidity is reported as NTU (Nephelometric Turbidity Units). The probe uses a near infrared LED (860 nm ± 30 nm) light source and measures scattered light at 90 ° as per ISO standards. Accuracy is ± 1 NTU and resolution is 0.1 NTU. Measurements of Total Suspended Solids (TSS) should also be taken by thrice rinsing a 1-L PET bottle and filling with unfiltered sample. Samples are transported to the laboratory where each 1-L sample is filtered using an Aspirator through a pre-weighed 934-AH RTU glass microfibre filter paper with an effective pore size of 1 µm. The filter paper and its retained material are then placed into an oven and dried at 60 °C for 48 hours, and re-weighed to record the total suspended solids as mg/L (total dry weight of filter paper and sediment minus the filter paper weight all divided by the volume of sample). The organic component of TSS (organic matter %) can be determined by placing the filter papers into a muffle furnace at 500 °C for 4 hours and re-weighing the filter papers.

3.1.6 Nitrogen and Phosphorus

What is it and why do we measure it?

Nitrogen and phosphorus are macronutrients vital for plant and animal growth. Nitrogen (N) is a key component in organic compounds such as amino acids, proteins, DNA and RNA, while phosphorus (P) is an integral component of nucleic acids, phospholipids (e.g. cell walls) and many intermediary metabolites (e.g. adenosine phosphates). As such, nitrogen and phosphorus typically limit primary productivity in rivers and estuaries (specifically, their ratio to each other and to carbon, i.e. C:N:P). Nitrogen and phosphorus are derived naturally from sources external to the river or estuary such as geological weathering, terrestrial leaf litter and oceanic upwelling, or through internal processes such as nitrogen fixation, recycling by heterotrophs, and denitrification.

However, anthropogenic inputs from urban stormwater and wastewater, industrial wastewater, agricultural runoff (from fertilizer use and livestock wastes), and aquaculture have significantly increased nutrient concentrations (eutrophication). Typically, this causes a shift in autotrophic communities from macrophytes to fast-growing macroalgae or phytoplankton (i.e. nuisance algal or dynoflagellate blooms), which can cause critically low concentrations of DO (hypoxia or even anoxia) as the phytoplankton decompose. Some blooms are toxic to fauna. Overall, eutrophication causes excessive primary productivity to the detriment of secondary production, changes community structure and function including reducing diversity (e.g. of benthic invertebrates and fish), and changes energy flow and nutrient dynamics. Additionally, excessive nutrients rarely occur in isolation, but are usually accompanied by increases in suspended sediments, microbial pathogens and toxins.

Total nitrogen (TN) is a measure of all forms of dissolved nitrogen (nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+ + NH_3)and dinitrogen gas(N_2) and particulate nitrogen (within plants and animals, contained in proteins, or adsorbed onto detritus or mineral particles) present in a water sample. Total phosphorus (TP) is a measure of all forms of dissolved (inorganic orthophosphates ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}) and organic phosphorus-containing compounds (DOP) and particulate phosphorus (within organisms, mineral phosphates e.g. fluorapatite, and adsorbed onto detritus or minerals e.g. iron oxyhydroxides) present in the water.

Field and laboratory methods

Water samples for TN and TP should be collected in three replicate pre-labelled 125-mL polyethylene (PET) bottles each thrice rinsed and filled from water collected at 0.1 m depth using a handheld sampling device. Samples should be immediately placed into a cool, dark esky and analysed as soon as possible or frozen if laboratory analysis cannot be performed within 3 days. TN and TP must be analysed by an accredited laboratory with established QA/QC procedures.

Water samples collected from Ecohealth sites are analysed for a variety of water chemistry measures including nitrogen and phosphorus, which are essential for plant and animal growth.

Three water samples for bioavailable N (NO_x-N) and P (SRP; soluble reactive phosphorus) should be collected and filtered in the field through GF/C 0.7 µm glass fibre filter papers (Whatman International Ltd, Maidstone, UK) into pre-labelled, acid-washed 125 mL PET bottles that had been rinsed three times in filtered sample. Samples must then be placed immediately into a cool, dark esky and frozen until laboratory analysis.

3.1.7 Major anion and cation composition

What is it and why do we measure it?

Major ions are naturally very variable due to local geological, climatic and geographical conditions. River water is typically dominated by Ca^{2+}, Na^{+} and HCO_3^{-} while estuarine water is dominated by Na^{+} and Cl^{-} from seawater input. However, wastewater (Na^{+}, Ca^{2+}, SiO_2, H_4SiO_3), sewerage discharge (Na^{+}, Cl^{-}), agricultural (K^{+}, $B[OH]^{4-}$,) and industrial runoff (K^{+}, Ca^{2+}, Cl^{-}, SO_4^{2-}, F^{-}) can fundamentally alter the ionic balance of rivers and estuaries, through dilution, concentration or introduction of toxicants. Aquatic and estuarine biota have physiological mechanisms to balance water and ion concentrations in their bodies and these mechanisms are metabolically expensive. Long-term changes to the ionic composition of river or estuarine water can cause chronic, sub-lethal stress that reduces growth and reproduction, while sudden acute changes in the ionic balance can be fatal. Some ions are toxic to biota, either due to excessive concentrations of common ions (potassium, bicarbonate and magnesium, or potassium and bicarbonate are generally the most toxic to aquatic or marine biota, respectively), or due to highly toxic forms of heavy metals and metaloids (Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Mercury, Selenium and Zinc).

Aluminium is the most abundant metallic element in soils, but has little known biological function (Gensemer and Playle 1999). The toxicity of Aluminium to amphibians, fish and aquatic invertebrates increases with low (<5.5) and high pH (9.0), increased temperatures and the presence of other metals. Aluminium is most toxic over pH 4.4-5.4 with maximum toxicity occurring at pH 5.0-5.2, and the toxicity of Aluminium is greatly reduced over neutral pH values. Under alkaline conditions, the solubility of Aluminium is enhanced, with acute toxicity at pH 9. Concentrations 100 µg/L are deleterious to aquatic life (CCREM 1987) and drinking water must comply with levels <200 µg/L. A low reliability trigger value of 0.8 µg/L was derived for pH <6.5 for an LC_{50} for trout. A moderate reliability trigger of 55 µg/L for pH >6.5 is also recommended. Aluminium availability may be elevated in acidic streams, with depauperate macroinvertebrate numbers being attributed to the change in food supply resulting from these acidic conditions. Fish and amphibians are generally more sensitive to Aluminium than macroinvertebrates. Aluminium is a gill toxicant to fish and is most toxic to fish in mixing zones where aluminium-rich acid water is neutralized. Hatching success of amphibians is also reduced by high loads of Aluminium. Outbreaks of QX disease, a paramyxean pathogen of the Sydney rock oyster, *Saccostrea commercialis*, have been linked to a decrease in pH caused by drainage from acid-sulfate soils. Laboratory-based toxicity tests have found oyster embryos to be sensitive to environmental contaminants.

Field and laboratory methods

Anion and cation composition of key elements determined during the project development phase should be sampled at both freshwater and estuarine sites. Samples should be filtered in the field by first passing a sample through a GF/C 0.7 µm glass fibre filter paper and then through a 0.45 µm GF/C glass fibre filter paper (both Whatman International Ltd, Maidstone, UK) into three pre-labelled 125-mL PET bottles that had been acid washed and thrice rinsed in double-filtered sample. The filtered samples must be immediately placed in a cool, dark esky and transported to the laboratory. Samples can be frozen until analysis. Analysis of soluble basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Si^{+}, NH_4^{+}), acidic cations (Al^{3+} and Fe^{2+}) and anions (HCO_3^{-}, Cl^{-}, F^{-}, Br^{-}, NO_3^{-}, HPO_4^{2-}, SO_4^{2-}, $H_2SiO_4^{2-}$) can be determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES), which uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths specific to individual elements. The intensity of the emissions indicates the concentration of elements within the sample.

3.1.8 Water Quality Trigger Values

The ANZECC Water Quality Guidelines (the guidelines) established in 1992 under the Commonwealth's National Water Quality Management Strategy (NWQMS), provide a scientifically informed framework for the water quality objectives required to maintain current and future water resources and environmental values (ANZECC, 2000). The ANZECC guidelines were created in response to growing understanding of the potential for water quality to be a limiting factor to social and economic growth.

The guidelines were derived from reviewing water quality guidelines developed overseas. However, Australian guidelines were also incorporated where available (ANZECC, 2000).

The ANZECC *Australian Water Quality Guidelines for Fresh and Marine Waters* was released in 1992, and developed using two approaches:

1. An empirical approach which used the Precautionary Principle to create conservative trigger values from all available and acceptable national and international data. This method implemented data from only the most sensitive taxa in order to ensure the protection of these species.
2. The modelling of all available and acceptable national and international data into a statistical distribution with the confidence intervals of 90% and 50%.

Trigger values are conservative thresholds or desired concentration levels for different water quality indicators. When an indicator is below the trigger value there is a low risk present to the protection of that environment. However, when an indicator is above the trigger value there is a risk that the ecosystem will not be protected. In cases where the trigger value is exceeded further research and remediation of the risk identified should be conducted. Where a numerical value cannot be derived for a water quality indicator a target load may be set, for example the salinity guideline, or a descriptive statement, for example for oil there should be no visible surface film, or an index of ecosystem health for example percentage cover of an algal bloom. The Australian and New Zealand Environment Conservation Council (ANZECC) Guidelines (2000, 2006) provide threshold values for freshwater and estuarine systems for pH, dissolved oxygen (DO%), electrical conductivity (EC), salinity and nutrients such as nitrogen (N) and phosphorus (P). In addition, Ecohealth uses regional-based trigger values for estuarine chlorophyll *a* and turbidity developed as part of the NSW State MER program.

3.2 Biological Indicators

3.2.1 Chlorophyll a

What is it and why do we measure it?

Chlorophyll *a* is a green pigment essential for energy fixation in all photosynthetic organisms. The concentration of water column chlorophyll *a* is an indication of the abundance and biomass of suspended phytoplankton such as unicellular algae and cyanobacteria, trophic status (the rate at which organic matter is supplied) and maximum photosynthetic rate (P-max). Phytoplankton account for a significant proportion of primary production and are the direct and indirect food source of most fauna; thus, moderate levels of phytoplankton are vital to ecosystem health. Since algal production affects the entire biological structure of aquatic and estuarine ecosystems, chlorophyll *a* measurements are an empirical link between nutrient concentrations and biological phenomena. Phytoplankton integrate fine-scale changes in water quality (hours and meters) into scales appropriate for managers to utilize (days). Elevated concentrations of chlorophyll *a* can reflect poor water quality caused by an increase in nutrient loads (eutrophication), as well as provide warning of nuisance algal blooms and the associated risk of hypoxia due to bacterial decomposition of the algae. Chlorophyll *a* concentrations are regulated by nutrients (predominantly N and P), physico-chemical boundary conditions including temperature, light and salinity, advective effects (wind and water transport, turbulence, tidal mixing), reproduction and conspecific behavior within and among species. In estuaries, chlorophyll a concentrations are reduced by strong tidal mixing (by diluting nutrients, reducing the residence time of algae in the photic zone, or increasing turbidity (and thus, decreasing light) through resuspension of fine-grained sediments).

Field and laboratory methods

Chlorophyll *a* should be sampled at both freshwater and estuarine sites by collecting an integrated 1-L of unfiltered water sample from a 0.1-0.5 m depth using a handheld sampling device. The sample must be placed into pre-labelled, acid-washed 1-L PET bottles that had been thrice rinsed in sample, and the samples immediately placed into a cool, dark esky for transport to the laboratory. Samples must be processed within 48 hours of collection, by filtering each through a 934-AH RTU glass microfibre filter paper with an effective pore size of 1 µm using an Aspirator until the filter paper returns a green colour or until flow slowed to a trickle through the filter paper at approximately 7 PSI. The volume of filtrate is then recorded. The filter paper is then drained until no signs of moisture remain, placed into the bottom of a pre-labelled culture tube, wrapped in aluminium foil and stored below -4 °C. When analysed, 10 mL of

Chlorophyll a concentration is an indication of the abundance and biomass of photosynthetic organisms, primary producers that are a vital link in the food web.

90 % aqueous acetone is added and the solution refrigerated for 24 hours. The samples are then centrifuged and the absorption spectra (663 and 750 nm) are analysed using a UV-visible spectrometer.

3.2.2 Zooplankton

What is it and why do we measure it?

Zooplankton, microscopic invertebrates that swim or drift in the water column, hold a central position in the pelagic food chain as the primary consumers of phytoplankton and the main prey of larval and juvenile fish. Zooplankton communities mostly comprise filter feeders that strain algae, bacteria and fine detrital particles from the water column, but also include predators that feed on smaller zooplankton. Zooplankton abundance, diversity, productivity and fecundity are influenced by temperature, salinity, light, phytoplankton dynamics and predation levels. Eutrophication of estuaries generally leads to an increase in the total abundance of zooplankton, but a decrease in the abundance of large species (macrozooplankton). Zooplankton grazing and predation assimilate heavy metals and synthetic organics from the water column into higher trophic levels (some socially and economically important such as fish and shellfish species) as well as sediments.

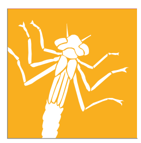
The biomass size spectrum (BSS, or size frequency distribution) is a method of measuring the abundance of zooplankton and can indicate health conditions of the estuarine ecosystem (Suthers and Rissik 2008). The size frequency distribution of zooplankton reveals a declining slope of abundance with increasing size, from larval crustaceans to krill and other large shrimps. The size distribution is a product of the supply of nutrients, and the removal of zooplankton by predation. Thus, it represents the trophic status of the estuary's water. Top-down forcing (predation) by small fish is evident by the absence of larger, rare zooplankton biomass. Increased nutrient availability can cause rapid exponential growth of phytoplankton which in turn leads to an increase in abundance of zooplankton. Size is easily measured by automated particle counters, such as image analysis or by an optical plankton counter (OPC).

Core to the pelagic food chain are microscopic invertebrates found in the water column, or Zooplankton. These are the primary consumers of algae and the main prey of larval and juvenile fish.

Field and laboratory methods

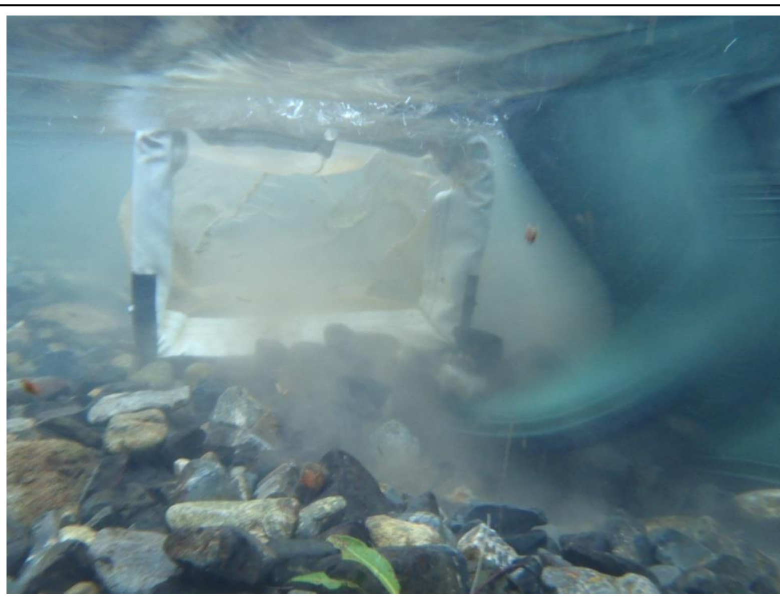
Estuarine zooplankton communities are sampled during summer using the methods of Moore and Suthers (2006). A net with a 40-cm diameter and mesh size of 100 µm is towed at 1.5 m/sec for 5 min (total volume is 113.1 m^3) in a 100-m diameter circle. The depth of the tow is 0.5 m. Net zooplankton are concentrated and preserved in 5 % formalin solution to maintain their form, and transported to the laboratory. In the lab, detritus (leaves and twigs) are removed with fine forceps and the sample diluted into 1 L of water. Samples are then slowly added to the Optical Plankton Counter (OPC) at the rate of 35 L/min and 5-20 counts/sec. Samples are reported as number of particles per m^3, divided into 24 size classes from 240-1482 µm ESD (Equivalent Spherical Diameter). ESD values are converted into biomass estimates assuming the volume of a sphere and the density of water; zooplankton densities are reported as mg/m^3 for each size class. Normalised biomass is calculated by dividing the biomass of size class by the size class interval (per m^3). The total biomass and productivity of zooplankton are then assessed by the estimated slopes (regression coefficients) and zero intercepts from regression plots of $\log_{10}$-normalised biomass (per m^3) against $\log_{10}$ body mass (mg) using ordinary least squares regression (Moore and Suthers 2006).

3.2.3 Macroinvertebrates



What is it and why do we measure it?

Aquatic macroinvertebrates are large (> 1mm) insects, worms, leeches, crustaceans and snails that require aquatic habitats for at least some of their life cycle. They are commonly used as indicators of ecosystem health because they usually occur in great abundance and diversity, with extreme sensitivity but differential susceptibility to different pollutants, they have short life cycles so that many life stages (e.g. larvae, pupae, adults) may be captured simultaneously providing a quick and continuous response to the stressor(s), they are relatively immobile and therefore unable to escape the effects on instream environmental stressors, they are relatively easily sampled, and their taxonomy and biology are well understood. Norris and Thoms (1999) suggest biotic effects are usually the final point of environmental degradation and pollution and thus, are an important indication of ecosystem health, as they integrate physico-chemical,



As a major food resource of freshwater ecosystems, macroinvertebrates are important indicators of ecosystem health as they integrate physical, chemical and biological responses to stressors such as habitat loss and water pollutants.

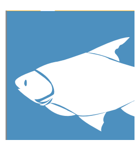
biological and ecological responses to stressors. Macroinvertebrates are also biologically relevant as they form a major component of freshwater ecosystems, through their contribution to organic matter processing and nutrient cycling, and provision of food resources for fish, amphibians and waterfowl.

Field and laboratory methods

Freshwater macroinvertebrate communities are sampled once each in Spring and Autumn by sampling 10-m transects of riffle, edge (kick-sampling) and pool (sweep-netting) habitats. The net has a mesh size of 250 µm. Samples are immediately preserved in 70 % ethanol and transported to the laboratory. In the laboratory, samples are washed through 2 mm, 1 mm and 250 µm sieves. All taxa from the 2 and 1 mm sieves are recorded and material on the 250 µm sieve is sorted for a standard 30-minute period. Macroinvertebrates are identified to family/genera using a stereo dissecting microscope. Three community indices are calculated from the diversity and abundance data: SIGNAL score, EPT abundance and Family-level richness (EPT refers to the pollution-sensitive groups Ephemeroptera, Plecoptera and Trichoptera, commonly known as mayflies, stoneflies and caddisflies).

SIGNAL scores (Stream Invertebrate Grade Number – Average Level) are based on the average sensitivity of individual taxa present in a sample calculated using SIGNAL 2.1iv sensitivity grades and unweighted arithmetic averaging (Chessman 2003). SIGNAL scores range from 1.0 (pollution tolerant) to 10.0 (pollution intolerant) with higher scores indicating 'healthier' conditions. When considered together with macroinvertebrate richness, SIGNAL scores can indicate the types of pollution and other physico-chemical factors affecting the ecological condition of the stream (i.e. rivers with high SIGNAL scores are likely to have low levels of salinity, turbidity and nutrients, and high DO).

3.2.4 Fish



What is it and why do we measure it?

Fish communities are commonly used as biological indicators, because they are socially and economically significant, are conspicuous when large numbers die off in response to poor water quality, and represent a variety of trophic levels including many top-order predators that are susceptible to biomagnification and bioaccumulation of pollutants. Fish potentially record the effects of transient events that may be missed by regular water quality sampling protocols, but they are mobile and can seek refuge in tributaries or pockets of favourable water quality. Also, because

Fish are ideal indicators of aquatic ecosystem health as they are socially and economically important, long-lived and highly responsive to disturbances that impact entire aquatic food webs.

they comprise several trophic levels, reductions in fish biodiversity and abundance can cascade to other levels of the food web, where it may manifest in altered ecological states, increased disease incidence, and shifts in dominant species and trophic structure. Pragmatically, fish are relatively easy to sample and their taxonomy is well known. The abundance, diversity and population dynamics of alien species are also relevant, as alien species are both a cause and symptom of declining river health.

Field and laboratory methods

Riverine fish communities may be sampled once during the Ecohealth program using methods modified from the Sustainable Rivers Audit (SRA, Murray-Darling Basin Authority). Fish are collected by electrofishing (hand-held and boat) and light-traps, and the following variables recorded: species diversity and abundance, and length, health and condition (parasites, lesions, diseases and abnormalities) of individuals (length and health are sub-sampled for up to 70 fish per species per site). Length:weight relationships are calculated for individual species to determine the native/alien biomass ratios. Three fish condition indicators are calculated from the five fish metrics derived from the raw data collected at each site as per SRA methods (Davies et al. 2010); the three condition indicators are then combined using Index Expert Rules (Davies et al. 2010) to calculate an overall Fish Condition Index (SR-FI). The three condition indicators are the Nativeness Indicator representing the proportion of native verses alien fishes incorporating diversity, abundance and biomass; the Expectedness Indicator that represents the proportion of native species present that historically occupied the river; and the Recruitment Indicator to determine if individual fish are juveniles or sexually mature.

3.2.5 Riparian Condition Index

What is it and why do we measure it?

Healthy riparian zones maintain bank stability and support critical ecological functions for both river and terrestrial ecosystems.

Riparian zones are broadly defined as the interface between terrestrial and aquatic ecosystems. They are dynamic transition zones that regulate energy and material fluxes between ecosystems and support diverse habitats that contain high levels of biodiversity. Riparian zones support critical ecological functions including nutrient flux, litter input, geomorphic control, habitat diversity and extent, and the regulation of temperature and light. Because riparian zones may also comprise the most fertile soils in the landscape and are the point of access to riverine resources, they are socially and economically valuable and historically have been the focus of human settlement and land use with their associated disturbances.

Field and laboratory methods

Riparian condition is assessed at freshwater and estuarine sites during Spring and early Summer to coincide with growth and flowering events. Complete methods are given in past Ecohealth Technical Reports (see references). On-ground data are collected at the reach scale (100 m) and at three 5 m^2 quadrats within each reach. The Ecohealth riparian condition assessment comprises 29 indicators which are grouped into five sub-indices that are combined into a multi-metric index of riparian condition (Table 1). The five sub-indices identify the components that contribute to the condition at a site:

(1) HABITAT: Refers to the extent and quality of vegetation, and provision of habitat within the riparian zone. This is assessed by quantifying riparian vegetation continuity and proximity to larger tracts of forest at a landscape scale, channel:riparian width ratio, structural complexity, and the presence of both large and hollow bearing native trees, otherwise known as 'habitat trees'. Riparian zones play a crucial role in supporting wildlife by providing services such as nesting and roosting habitats, food and shelter, and transport networks. The quality of such services is dependent upon structural complexity, stand age and vegetation continuity and connectivity.

(2) NATIVE SPECIES: The originality and overall quality of the riparian vegetation is assessed at each structural layer with regards to native plant versus weedy plant species. The layers assessed are canopy, midstory, herbs and forbs, graminoids, and macrophytes. The identification of the dominant floristics of each structural layer is a valuable additional measure of stand quality and condition, and allows for the important distinction between native and exotic plant species. Invasive exotic plant species have the potential to threaten the ecological integrity and productivity of a riparian zone ecosystem by excluding native species, altering nutrient, light and moisture levels, and can have detrimental effects on natural processes such as terrestrial and aquatic invertebrate food webs.

(3) COVER: Refers to the extent of the riparian vegetation footprint. Each of the five riparian structural layers, canopy, midstory, herbs and forbs, graminoids, and macrophytes, is assessed for its completeness. The contribution that each layer adds to the system is quantified and provides an overall indication of the presence of riparian vegetation, its structural complexity and its resilience to major flood and other disturbance events.

(4) DEBRIS: Refers to the presence of dead and decaying vegetative material and fringing vegetation in the riparian zone. Debris is assessed by quantifying woody debris - dead standing and fallen trees, logs and branches, and leaf litter from both native and exotic species. Fringing vegetation and woody debris not only aid river bank stabilisation, but also provide core habitat and are an important foraging resource for a variety of mammals, birds, reptiles, invertebrates and microorganisms alike. Debris assists with the regeneration of native woody species with the provision of protected habitats, while leaf litter and woody debris are essential for maintaining nutrient cycles and other aquatic and terrestrial ecological processes such as food webs.

5) MANAGEMENT: Considers both current and historic anthropogenic influences on the riparian zone. Tree clearing, fencing, animal impact, noxious weeds, exposed roots and woody regeneration are assessed. If left unchecked, human induced impacts may be detrimental to the health and the complexity of the plant and animal species of the riparian zone, and accelerate the deterioration of riparian condition. The extent and success of site-level measures taken to improve the ecological condition and function of the riparian zone are considered.

Table 1: Riparian Condition sub-indices, their indicators and scores.

Sub-indices & Indicators	Assessments & Scores		
Habitat		**Total Score**	**20**
Channel width	Riparian vegetation width ÷ channel width		4
Proximity	Distance to closest stand of native vegetation		4
Continuity	Longitudinal continuity of riparian vegetation		4
Layers	Presence/absence of integral growth forms		4
Large native trees	Presence/absence of large trees (>30cm dbh)		2
Hollow-bearing trees	Presence/absence of hollow-bearing trees		2
Native Species		**Total Score**	**20**
Native canopy species	Percentage of woody native species >5m tall		4
Native midstory species	Percentage of woody native species <5m tall		4
Native herb/forb species	Percentage of non-woody understory plants		4
Native graminoid species	Percentage of grass & grass-like plants		4
Native macrophyte species	Percentage of in-stream waterplants		4
Species Cover		**Total Score**	**20**
Canopy species	Percentage cover of woody native species >5m tall		4
Midstory species	Percentage cover of woody native species <5m tall		4
Herb/forb species	Percentage cover of non-woody understory plants		4
Graminoid species	Percentage cover of grass & grass-like plants		4
Macrophyte species	Percentage cover of in-stream waterplants		4
Debris		**Total Score**	**20**
Total leaf litter	Percentage cover of total leaf litter		3
Native leaf litter	Percentage cover of native leaf litter		3
Dead trees standing	Presence/absence of dead trees standing		3
Dead trees fallen	Presence/absence of dead trees fallen		3
Lying logs	Presence/absence of lying logs		4
Fringing vegetation	Presence/absence of graminoids		4
Management		**Total Score**	**20**
Tree clearing	Clearing and age of stand assessment		4
Fencing	Presence/absence of riparian fencing		3
Animal impact	Evidence of livestock grazing		3
Species of interest	Presence of uncommon &/or noxious weed species		2
Exposed tree roots	Extent of exposed tree roots due to erosion		4
Native woody regeneration	Presence/absence of native woody species		2
Weedy woody regeneration	Presence/absence of weedy woody species		2

3.2.6 Mangrove, seagrass and saltmarsh cover

Riparian and in-stream vegetation in estuaries also perform many functions by providing habitat for a wide range of organisms, preventing erosion of banks from storm surge and tidal action, and acting as a buffer to filter nutrients entering estuaries. In estuaries, mangroves are common in the riparian zone, providing crucial nursery habitat to many aquatic organisms including commercially important fish and prawn species. Seagrasses are also a critical part of estuaries and coastal lagoons. They provide primary production and stability to habitats, and support nurseries and food webs for important species including fish, prawns and invertebrates. One of the most common factors leading to the loss of seagrass is direct human disturbance (hauling nets, boat anchors) or indirect effects from increasing water turbidity and reducing light penetration.

Mangroves in estuary systems provide important functions such as habitat and bank protection, and provide important resources to estuary food webs.

Field and laboratory methods

The aerial coverage of mangroves, seagrass and saltmarsh for estuarine sites can be calculated using spatial datasets if they are available. Each site location should be used as a centroid from which the cover of mangroves, seagrass and saltmarsh can be determined for a 1000-m reach of river bank upstream and downstream from the central point on both sides of the river. These data are used to calculate total proportion of cover for the study reach. Maximum and minimum width of each vegetation type within the study reach can also be calculated using the spatial data. In addition, we include measures of mangrove, seagrass and saltmarsh cover in our site-level riparian condition assessment.

3.2.7 Geomorphic Condition Index

What is it and why do we measure it?

Fluvial geomorphology refers to the sediment dynamics of river systems, from the configuration of entire stream networks within catchments to the organisation of sediment particles within a single feature in a stream reach. These complex sediment erosion and transport processes form the physical template that regulates ecological habitat and processes in rivers. Human disturbances can negatively affect the equilibrium of these sediment erosion and transport processes. For example, catchment and riparian clearing can accelerate erosion and delivery of sediment to the stream channel, where it is stored and transported slowly over many floods. However, while the sediment is stored within the channel, it may negatively impact stream ecology by physically smothering habitat, releasing nutrients and contaminants into the streambed or water column, or damaging stream biota.

The condition of the geomorphic template is assessed once for each site during a low-flow period, usually concurrent with the riparian condition assessment. The assessment considers the condition of stream banks (freshwater and estuary sites), stream bed (freshwater sites), and local management that directly impacts reach-scale geomorphic condition. The assessment is conducted within the River Styles framework that classifies stream reaches according to the shape of the surrounding river valley, the shape and mobility of the channel within the valley and the dominant sediment size of the channel.

Field and laboratory methods

Geomorphic condition is assessed at the subcatchment and site spatial scales. Subcatchment scores and grades are calculated using the entire stream network for each subcatchment using the most recent River Styles GIS data layer (supplied by NC LLS). The proportions of total subcatchment stream length in Good, Moderate and Poor Condition are calculated and weighted (3, 2, and 1 for Good, Moderate and Poor, respectively). These are then summed to a total score, divided by 3 and converted to a proportion for each subcatchment. The standard Ecohealth grading structure is applied to each subcatchment.

Geomorphic condition examines sediment erosion, deposition and transport processes in river channels and banks to assess the physical template that provides ecological habitats and processes.

Site-level geomorphic condition is assessed by field surveys using the geomorphic indicators in Table 2. Field assessments are conducted over a 100-m reach for each site. Both bank and bed condition are assessed at freshwater sites and bank condition is assessed at estuarine sites. Both these site-level geomorphic sub-indices comprise several indicators. All indicators are assessed on a scale of 1-5 where 1 is poor and 5 is very good, and indicators are equally weighted when calculating sub-indices.

The representativeness of sites in reporting geomorphic condition is considered at the subcatchment scale and for the site-specific River Style within the subcatchment. In practice, site-level grades are usually consistent with subcatchment grades, but may under-estimate the condition of specific River Styles (e.g. headwaters) due to the logistical constraints of accessing reaches in better condition.

Table 2. Indicators used to assess site-level geomorphic condition of stream banks and beds. All indicators are assessed on a scale of 1-5 and equally weighted to calculate the BED and BANK sub-indices.

Sub-index or Indicator	Factors assessed within each indicator
BANK CONDITION	
- Undercutting	Combined length of undercutting as a proportion of the total reach length
- Slumping	Combined length of slumping as a proportion of the total reach length
- Exposed tree roots	Extent of exposed tree roots due to erosion: combines proportion of trees with exposed roots and the severity of exposure
- Active erosion	Combined length of active erosion as a proportion of the total reach length: includes active facies along water's edge (excluding undercutting or slumping), knick points in gullies entering the channel and active facies above the base flow channel (i.e. on gravel bars or macrochannel boundaries)
- Active deposition	Combined area of active deposition as a proportion of the total reach area: specifically targeting smothering of banks by fine sediments or large gravel deposits as indications of accelerated deposition
- Management	
- Tree clearing	Absence or presence where presence considers extensity and intensity
- Fencing	Absence or presence: land tenure is considered in grading this score
- Livestock	Evidence of livestock includes presence of stock and evidence of pugging, trampling, compaction and active erosion along stock tracks
- Riparian riverworks	Presence and success of riverworks to stabilise banks: time since installation is considered
BED CONDITION	
- Active erosion	Combined length of active erosion as a proportion of the total reach length: includes active facies below water's edge and knick points in the stream bed
- Active deposition/smothering	Combined area of active deposition as a proportion of the total reach area: specifically includes smothering of beds by fine sediments or large gravel deposits as indications of accelerated deposition
Management	
- Instream riverworks	Presence and success of riverworks to stabilise beds: time since installation is considered
- Livestock	Evidence of livestock includes presence of stock and evidence of pugging and compaction
- Human access	Extent of human access (e.g. 4wd tracks) through reach and intensity of compaction and erosion

3.2.8 Summary of Indicators

The Ecohealth program includes a number of physical, chemical and biological indicators to determine the health of waterways. The combination of waterway health indicators that identify short-term (water chemistry), intermediate-term (zooplankton, macroinvertebrates), and long-term responses (fish, geomorphic and riparian vegetation) provides a robust program for quantifying waterway health and prioritising management actions. Tables 3, 4 and 5 provide a detailed summary for each indicator – what it is, why we measure, how it is measured and trigger value calculations.

Table 3 Physical and chemical biological indicators used in Ecohealth.

Variable	What is it?	Why do we measure it?	How was it measured?	Trigger values
pH	pH is a measure of the acidity of the water. The pH scale ranges from 1 (highly acidic to 14 (highly alkaline). A pH of 7 is neutral.	Changes in pH can indicate acid soils, and can impact aquatic animals such as fish.	A handheld multi-probe lowered into the water, and measurements taken every 1m depth. Units: pH	*Freshwater*: 6.5-8.0 *Estuary*: 7.0-8.5
Electrical Conductivity	EC is a measure of the ability of the water to conduct an electric charge, and is used as a measure of salinity.	High salinity can affect all plants and animals living in rivers and estuaries, and may indicate the presence of pollutants.	A handheld multi-probe lowered into the water, and measurements taken every 1m depth. Units: mS/cm	*Freshwater*: 0.125 – 2.2 mS/cm *Estuary*: n/a
Temperature	Ambient water temperature measured.	Water temperature is important to regulate the metabolism, mobility, and reproduction of all plants and animals in rivers and estuaries.	A handheld multi-probe lowered into the water, and measurements taken every 1m depth. Units: °C	*Freshwater* and *Estuary*: 15-35°C
Dissolved Oxygen	DO is a measure of the availability of oxygen to aquatic life.	The amount of oxygen in the water regulates the distribution, activity, movement, and behaviour of all aquatic animals.	A handheld multi-probe lowered into the water, and measurements taken every 1m depth. Units: % and mg/L	*Freshwater* and *Estuary*: 80-110%
Turbidity	Turbidity is the measure of light scattering by suspended particles in the water column, and provides an indication of light penetration depth.	Increases turbidity can lead to low light to prevent plant growth, smothering of habitats such as seagrass, irritation of fish gills, and transport of nutrients.	A handheld multi-probe lowered into the water, and measurements taken every 1m depth. Units: NTU	*Freshwater*: <50NTU *Estuary*: <10NTU
Nitrogen and Phosphorus	Nitrogen and Phosphorus are present in water in both dissolved (available to biota) or particulate (bound up in silt, organic matter and living plants and animals).	Nitrogen and Phosphorus are naturally occurring nutrients that originate from plant and animal matter. Excess nutrients from run-off can cause algal blooms.	Dissolved nutrients are collected from the surface water at each site, and filtered and stored/frozen in 125mL vials. Particulate nutrient samples are collected from the surface water at each site and remained unfiltered and stored/frozen in 125mL vials. Units: µg/L	*Freshwater* TN - 500 µg/L, TP - 50 µg/L Dissolved N - 40 µg/L, Dissolved P - 20 µg/L *Estuary* TN - 300 µg/L, TP - 30 µg/L Dissolved N - 15 µg/L, Dissolved P - 5 µg/L

Table 4 Biological indicators used in Ecohealth.

Variable	What is it?	Why do we measure it?	How was it measured?	Trigger values
Chlorophyll *a*	Water column chlorophyll *a* is a measure of the biomass of algae/phytoplankton in the water.	Algae are largely influenced by temperature, light and nutrients, and provide a measure of the biological effect of these influences.	Water samples collected on site and filtered. Filter papers containing algae are analysed for chlorophyll *a* concentration. Units: µg/L	Freshwater: <4 µg/L Estuary: <3.3 µg/L
Macroinvertebrates	Aquatic macroinvertebrates are animals without backbones that live in freshwater and are large enough to see with the naked eye, such as worms, snails, beetles and shrimps.	Macroinvertebrates are one of the most commonly used biological indicators as they are widely distributed and easily sampled. They are sensitive to pollution and changes in water quality and habitat, providing us with valuable information on the health of aquatic ecosystems.	Sweep net samples are taken from pool, riffle and edge habitats (where available) at all freshwater sites in Autumn and Spring.	Regional trigger values must be developed from literature and past studies for taxa richness (number of families), SIGNAL2 Score (pollution tolerance index), EPT taxa (number of mayflies, stoneflies and caddisflies).
Zooplankton	Zooplankton are microscopic invertebrates such as krill, copepods and mollusks that swim or drift in the water column of estuaries.	Zooplankton are central position to the pelagic food chain in estuaries as the primary consumers of phytoplankton and the main prey of larval and juvenile fish. The size distribution of zooplankton reveals a declining slope of abundance with increasing size, from larval crustaceans to large shrimps. The size distribution results from nutrient supply and predation.	Estuarine zooplankton are sampled using a net with a 20-cm diameter and mesh size of 100 µm towed behind a boat at 1.5 m/sec for 10 min. Samples are added to an Optical Plankton Counter (OPC) and reported as number particles per m^3, divided into 24 size classes from 240-1482 µm to determine size class distribution.	Reported as the index of zooplankton production (slope of size distribution). Slope <-0.75 was scored as very poor to > -1.75 scored as very good.
Fish	Richness, abundances and length:mass of native and introduced fish.	Fish are important components of aquatic biodiversity, reflecting long-term changes in waterway condition. Fish communities provide an integrated measure of condition as they are highly mobile, long-lived and are high order consumers in aquatic food webs.	Fish communities are measured at freshwater sites using backpack and boat electro-fishing and trapping techniques.	Nativeness Index (proportion of native to introduced taxa), Expectedness index (predicted fish occurrence in undisturbed site versus caught).

Table 5 Biological indicators used in Ecohealth.

Variable	What is it?	Why do we measure it?	How was it measured?	Trigger values
Riparian Condition	Riparian vegetation is the plant communities along rivers and estuaries where the land and water meet, often referred to as streambank vegetation, or the interface between terrestrial and aquatic ecosystems.	Healthy riparian vegetation is important for maintaining good water quality and habitat for waterbugs, fish, and terrestrial animals, as well as reducing erosion along streambanks. By monitoring vegetation communities for the spread of weeds, growth of native trees, we gain a better understanding of their condition and influence on water quality, macroinvertebrate and fish communities.	The Ecohealth program assesses riparian vegetation for Habitat (channel:vegetation width ratio, connectivity and continuity, number of strata, habitat trees), Native Species (native versus weedy species for each strata), Species Cover (strata footprint & completeness), Debris (woody debris, leaf litter & fringing vegetation), and Management (tree clearing, fencing, animal impact, species of interest, exposed roots, woody regeneration). These are measured using site-based assessments and GIS spatial data for site, reach and sub-catchment assessment.	Regional trigger values are developed for each Index with the condition assessment from the literature and a study on regional reference condition.
Mangrove, seagrass and saltmarsh	Mangroves are the dominant riparian vegetation in estuarine reaches and coastal lagoons. Similarly, seagrasses provide in-stream habitat and is often used as a surrogate for estuary fish assemblages.	Mangrove, seagrass and saltmarsh vegetation in estuaries perform many functions by providing habitat for a wide range of organisms, preventing erosion of banks from storm surge and tidal action, and acting as a buffer to filter nutrients entering estuaries. In estuaries, mangroves and seagrass provide crucial nursery habitat to many aquatic organisms including commercially important fish and prawn species.	The aerial coverage of mangroves, seagrass and saltmarsh are calculated using spatial datasets. These are measured using site-based assessments and GIS spatial data for site, reach and sub-catchment assessment.	Regional trigger values must be developed from available data for cover, width and extent of each vegetation type.
Geomorphic Condition	Geomorphic condition examines sediment erosion, deposition and transport processes in river channels and banks	Geomorphic condition assesses the physical template that provides the diversity of ecological habitats for biota and stability of banks that regulate erosion processes.	Geomorphic condition assesses Bank Condition (undercutting, slumping, exposed tree roots, active erosion, active deposition), Management (tree clearing, fencing, livestock, riparian riverworks, instream riverworks, livestock, human access), Bed Condition (active erosion & deposition). These are measured using site-based assessments and GIS spatial data for site, reach and sub-catchment assessment.	Regional trigger values must be developed from available data at site and subcatchment scales.

4. Calculation of Grades

The calculation and reporting of Ecohealth grades involves the synthesis of up to 14 different indicators each with regionally-developed trigger values. A robust and consistent method for summarizing these data is required because of the large number of ecological values and the difficulties in their interpretation. Scores are calculated for individual sites, but also must fulfill the broader aims of wider-scale reporting at river, sub-catchment, catchment and regional scales.

To produce an Ecohealth grade, the value for each index – Water Quality, Zooplankton, Macroinvertebrates, Fish, Geomorphology and Riparian – must be transformed into standardized score that takes into account differing physical conditions, scales of measurement among indices and prevailing climate conditions. The result is a scoring system from 0 to 1, where 0 represents the most 'unhealthy' condition and 1 indicates a 'healthy' waterway. Each Ecohealth program can determine if weightings should be applied to a particular indicator based on local reference conditions. For the procedure outlined below, a simple sequence of averaging all indices is applied to the data.

4.1 Water Quality

A trigger value is formally the value that compliance against a guideline value is commonly used to assess the ecological condition of a waterbody indicates that a variable is outside the expected range. Triggers are likely to be recalculated periodically as additional data from reference systems becomes available. A combination of ANZECC (2000, 2006) and NSW MER developed trigger values are used to explore water quality across sites and sampling occasions (Table 6). For water quality variables with only upper limits for trigger values, the number of times each indicator recorded a value between 1-1.5 times, and greater than 1.5 times each sample event is used to examine changes in water quality. Exceedance of trigger values by less than 0.5 times or between 1-1.5 times, and greater than 1.5 times each sample event is used for variables that have both upper and lower thresholds (e.g., pH and dissolved oxygen).

Calculating non-compliance is the proportion of time that the measured values of the indicator are outside the adopted trigger values (number of samples non-compliant with trigger value divided by the total number of samples (expressed as a value between 0 and 1 with 0 equal to all values being compliant and 1 equal to all values non-compliant). For indicators where there are large temporal and spatial datasets specific to regions, alternative methods for calculating exceedance of trigger values such as using percentile distributions to calculate the 'distance from trigger value' approach rely on the setting of a Worst Expected Value (WEV).

The result of these processes is a score between 0 and 1 for each individual water quality parameter measured as part of Ecohealth monitoring. These scores can be averaged or weighted to determine an overall score between 0 and 1 for Water Quality.

Table 6. ANZECC and NSW MER water quality guidelines for freshwater (above and below 150m elevation) and estuarine systems of south-east Australia.

ANZECC Guidelines (2000) and NSW MER - Min. and Max Values											
	pH		DO %	EC µS/cm	Turbidity NTU	Chl *a* µg/L	N0x µg/L	SRP µg/L	TN µg/L	TP µg/L
Freshwater sites >150m	6.5	7.5	80-110	30-350	25	4	25	15	250	20
Freshwater sites <150m	6.5	8	80-110	125-2200	50	4	40	20	500	50
Estuary sites	7	8.5	80-110	no values	10	3.3	15	5	300	30

4.2 Zooplankton

Two indices of water quality are developed from the zooplankton size data (see Suthers et al. 2012). Firstly the slope of the NBSS (from the least-squares regression) was used as an index of zooplankton production (Zhou & Huntly 1997). The theoretical slope is around -1 (Zhou 2006) and is observed in clear tropical waters (Suthers et al. 2006), but steeper slopes up to -2.5 are apparent in estuaries (Moore & Suthers 2006). Steeper slopes indicate greater predation and transfer to large size categories, and is an index of production. The slopes are therefore assigned scores from 1 to 5 where a shallow slope of <-0.75 is scored as “very poor”, as such a slope indicates a low rate of biomass transfer to higher trophic levels and ultimately fish. A typical slope of -1 to -1.25 is scored as “fair”, and a slope steeper than -1.75 (i.e. more negative) is scored as “very good”. The score ranging from 0 to 5 are then converted to a score ranging from 0 to 1 through simply division.

Secondly the concentration of chlorophyll-a relative to zooplankton is used as an index of assimilation of nutrient input. If zooplankton are not grazing the phytoplankton, then eutrophication may become apparent and chlorophyll concentrations increase. In this study, environmental assimilation of chlorophyll-a is indexed by a ratio of chlorophyll to the normalised biomass of small zooplankton, estimated from the NBSS regression at a size of x=-1.5. This size is approximately 0.4 mm ESD (equivalent spherical diameter) which approximates the biomass of nauplii, copepodites and cyclopoid copepods. A larger ratio indicates excess phytoplankton relative to zooplankton, indicating that zooplankton are not responding to the nutrient supply. Scores are assigned as a low ratio of <0.5 is scored as “very good - 5”, while a ratio of 1.5 to 3 is scored as “fair – 2 to 4” and a ratio >5 is scored as “very poor - 1”. The score ranging from 0 to 5 is then standardised to a score ranging from 0 to 1 through simple division.

Scores for each index are calculated for each sample collection date. Each index is standardized to a score ranging from 0 to 1, and standardised to an overall Zooplankton score ranging from 0 to 1 through simple division.

4.3 Macroinvertebrates

Regional trigger values must be developed from literature and past studies for taxa richness (number of families), SIGNAL2 Score (pollution tolerance index), EPT taxa (number of mayflies, stoneflies and caddisflies) for each study. In the absence of these the default threshold values reported in Chessman (2003) can be used for SIGNAL2. Alternatively, it should be determined if one or more sites sampled during the Ecohealth program in a specific catchment can be used as a 'reference condition' for Family richness and EPT grade. In addition to a trigger value, a Worst Expected Value (WEV) must be calculated for Family Richness, SIGNAL2 and EPT score. The WEV scores are derived from either the 10^{th} and/or the 90^{th} percentile of data for all relevant available data, and represent a site that is the 'unhealthiest'.

Calculation of a standardized score involves the comparison of each macroinvertebrate attribute against corresponding guideline value and WEV scenario. The score for Family-level richness, SIGNAL2 and EPT is calculated using the following formula:

Score = 1.0 – {site value – guideline value/WEV – guideline value}

4.4 Fish

Reference condition estimates (Reference Condition for Fish (RC-F)) for fish community is derived using similar protocols as applied in the Sustainable Rivers Audit (SRA) Program. The process involves estimating the presence/absence and rarity (the probability of collecting a species at a selected site if it is sampled using the standard protocol prior to 1770) for each fish species within each valley and altitude zone based on historical and current data, reference material, museum collections and expert knowledge (Davies et al. 2008). Rarity is scored as: 0.05 (estuarine/marine vagrants = low probability of occurrence), 1 (rare = median probability of occurrence of 0.1), 3 (occasional = 0.45) or 5 (common = 0.85). The score ranging from 0 to 5 is then standardised to a score ranging from 0 to 1 through simple division.

The Expectedness Indicator (SR-FIe) represents the proportion of native species that historically occupied the river that are still present and is calculated by combining two input metrics; the observed native species richness (at sites) over the zones RC-F value corrected for rarity (OE) and the total native species richness within zones over the zones uncorrected RC-F (OP) using Expectedness Indicator Expert Rules (Davies et al. 2008). The Nativeness Indicator (SR-FIn) represents the proportion of native versus alien fishes within the river and is calculated from three input metrics; proportion native biomass, proportion native abundance and proportion native species, combined using Nativeness Indicator Expert Rules (Davies et al. 2008). The Recruitment Indicator represents the three indicators and are combined using Index Expert Rules (Davies et al. 2008) to calculate an overall Fish Condition Index (SR-FI). Expert Rules analysis was undertaken using the Fuzzy Logic toolbox in MatLab (The Mathworks Inc. USA). Sites are rated individually for each of the four Indicators and scored as either "Excellent" (81-100), "Good" (61-80), "Moderate" (41-60), "Poor" (21-40), or "Very Poor" (0-20). The score ranging from 0 to 100 is then standardised to a score ranging from 0 to 1 through simple division.

All indices are afforded equal weighting for the calculation of the Ecohealth grade, with the 3 scores standardised to a score ranging from 0 to 1 through simple division.

4.5 Riparian and Geomorphic Condition

The assessment of each site affords each indicator an average site score, where a minimum value of 0 represents a poor state and a maximum value represents pristine condition. These scores assessed both in the field and using a desktop data assessment are combined to produce summary scores for each sub-index, and an overall condition index (Table 1). Indicators that are assessed at three points along the transect required averaging to give only one number for each indicator, those recorded at the transect level have only one value for each site. The indicators are then grouped into the five sub-indices and summary scores for each grouping are calculated through simple averaging to produce a condition score out of 20 for each sub-index (i.e. Habitat, Native Species, Species Cover, Debris, and Management). These scores are then summed to a total score out of 100, standardised to a score ranging from 0 to 1 through simple division and assigned a final Ecohealth Report Card grade for riparian condition.

Site-level geomorphic condition is assessed by field surveys using the geomorphic indicators in Table 2. Both these site-level geomorphic sub-indices comprise several indicators. All indicators are assessed on a scale of 1-5 where 1 is poor and 5 is very good, and indicators are equally weighted when calculating sub-indices.

4.6. Spatial Scales

The above process provides the methods for calculating standardized scores for each indicator used in a particular Ecohealth monitoring program for an individual site. Total scores for a site are simply calculated as an average of the 0 to 1 range of scores across all indicators used. The scores can then be 'pooled' at spatial scales relevant to reporting requirements such as site, river/lagoon, sub-catchment, freshwater or estuarine, catchment and region.

4.7 Calculating Grades

The condition scores are grouped in ranges and given a corresponding grade (see Table 7). This scoring and grading system is based on the traditional format of a school report, with primary ratings ranging from a high of 'A', through intermediate ratings of 'B', 'C' and 'D', to the lowest possible score of an F Secondary grades of + and – are included to provide greater resolution within a grade, and to better help show improvements over time.

Table 7. Standardised scores from 0 to 1 and corresponding Ecohealth grade

Score	Grade	Condition	
≥0.95/1	A	Excellent	Environmental values met (The indicators measured meet all of the benchmark values for almost all of the year)
0.85/1	B	Good	Most environmental values met (The indicators measured meet all of the benchmark values for most of the year)
0.70/1	C	Fair	Some of the environmental values met (The indicators measured meet some of the benchmark values for some of the year)
0.55/1	D	Poor	Few of the environmental values met (The indicators measured meet few of the benchmark values for some of the year)
≤0.45/1	F	Very Poor	Very few of the environmental values met (The indicators measured meet very few of the benchmark values for almost all of the year)

4.8 Data Storage, QA/QC and standardized methods

All field data should be collected following the protocols identified in the NRCMA Ecohealth Sampling Protocols document. This document outlines QA/QC protocols for data collection, transport and analysis, and OHS requirements for Ecohealth participants. Proformas for: Field Equipment Checklist (Appendix 1), Multi-parameter Probe Maintenance Log (Appendix 2), Field Data Sheets (Appendix 3) Sample Chain of Custody (Appendix 4), and Ecohealth Participant Contact List (Appendix 5) are included.

Data collected as part of any monitoring program should be stored in appropriate databases accompanied by metadata that complies with an agreed standard Metadata should be stored by the individual regions undertaking the Ecohealth monitoring, as well as by relevant state agencies responsible for environmental monitoring and reporting.

5. Reporting and Outputs

5.1 Reporting

The NSW Natural Resources Monitoring Evaluation and Reporting (MER) Strategy was prepared by the Natural Resources and Environment CEO Cluster of the NSW Government in response to the Natural Resources Commission Standard and Targets and was adopted in August 2006. The purpose of the Strategy is to assess the allocation of resources by NSW natural resource and environment agencies and coordinate their efforts with LLS's, local governments, landholders and other natural resource managers to establish a system of monitoring, evaluation and reporting on natural resource condition.

The Ecohealth Monitoring Program outlines a framework for the development of a catchment-based aquatic health monitoring program for rivers and estuaries with the aim of providing consistency in monitoring and reporting, and establishing the partnerships required for local and regional dissemination of outcomes. The development and application of specific monitoring frameworks, and standardised data collection, analysis and reporting underpins the Ecohealth program. This standardised approach facilitates an effective reporting mechanism to communicate water quality and resource condition information to the wider public, stakeholders and managers.

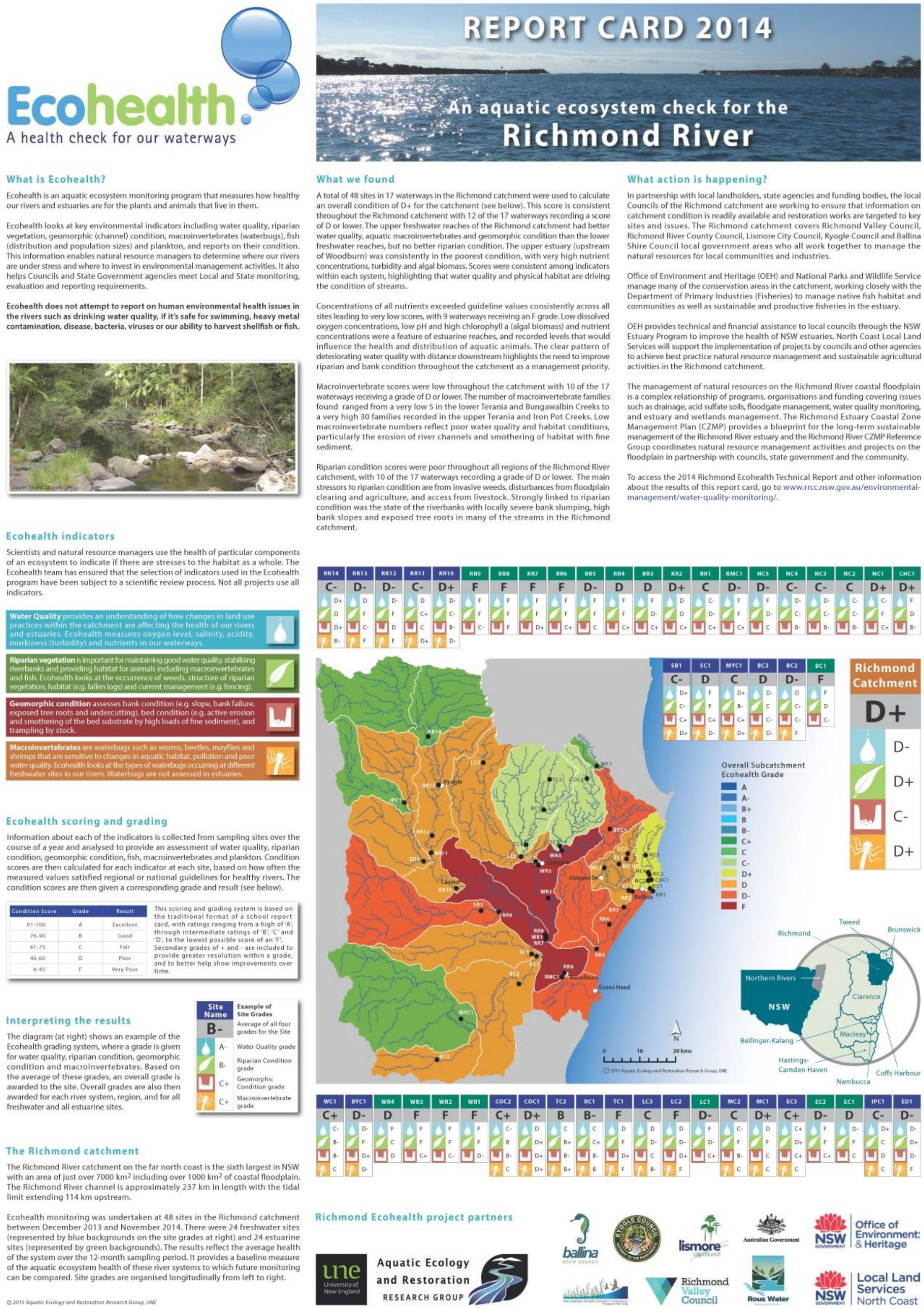
The long-term goal of the Ecohealth program is to return to monitoring sites within catchments on a regular cycle (3-4 years) to ensure future catchment development does not impact on natural resource condition, to demonstrate the outcomes of actions to improve the health of degraded waterways and to protect areas of high ecological values. In addition, as climate variability increases, we face the added challenge of maintaining good ecosystem health in our waterways. There is a need to prepare our catchments for flood events that bring high loads of sediment and nutrients to estuaries as well as water quality issues from prolonged low flow periods. Ecohealth aims to understand the issues that will make our waterways more resilient to the impacts of climate change.

In addition to improved management of waterways, Ecohealth also provides a scientifically robust dataset for use in State of Catchment (SoC) and State of Environment (SoE) reporting. The NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015 (www.environment.nsw.gov.au) guides the efforts of LGA's and Local Land Services (LLS) to better understand whether the overall health of the natural resources of NSW are changing and to assess the effectiveness of remedial action in reversing observed trends. The NSW State-wide natural resource condition targets provide the structure for the SoE and SoC reporting requirements. The study design and reporting of catchment-based Ecohealth monitoring programs are developed in conjunction with state-wide MER programs and can provide LGAs and other agencies with a dataset and reports to fulfil these requirements. Employing the Ecohealth monitoring program on a 3-4 year cycle within a catchment will provide information for report card production to inform local communities, technical information to guide on-ground management, and provide SoE and SoE reporting requirements.

5.2 Ecohealth Products and Outputs

The products generated by the Ecohealth program cover high-level scientific technical reports that provide an in-depth presentation and analysis of data collected, as well as Ecohealth Report Cards that aim to clearly disseminate waterway health outcomes and management initiatives to engage with local communities. Regular sampling updates and factsheets are also provided to partner organizations throughout the program.

The Ecohealth Report Card is designed to inform communities about the health and specific needs of waterways in their local catchments. It provides quality information in an easy to understand summary format. Report Cards are developed in conjunction with each partner, and can be designed to report on catchment, freshwater and estuary, river, reach and site scales. Report Cards have been designed as folded flyers to partner with rates notices mailed to ratepayers, A4 flyers to sit at council offices, through to A0 posters that have been sent to schools and community groups. All Report Card outputs are also hosted by project partner websites. The Aquatic Ecology and restoration Group at UNE are responsible for the design and production of the Report cards.



Example of an A3 flyer produced for the Richmond River Ecohealth program.

About Ecohealth

Ecohealth is an aquatic ecosystem monitoring program that measures how healthy our rivers and estuaries are for the plants and animals that live in them.

Ecohealth looks at key environmental indicators including water quality, riparian (riverbank) vegetation, geomorphic (channel) condition and macroinvertebrates (waterbugs), and reports on their condition.

This information enables natural resource managers to determine where our rivers are under stress and where to invest in environmental management activities. It also helps Councils and State Government agencies meet local and state monitoring, evaluation and reporting requirements.

Ecohealth does not attempt to report on human environmental health issues in the rivers such as drinking water quality, if it's safe for swimming, heavy metal contamination, disease, bacteria, viruses or our ability to harvest shellfish or fish.

Ecohealth indicators

Scientists and natural resource managers use the health of particular components of an ecosystem to indicate if there are stresses to the habitat as a whole. The Ecohealth team has ensured that the selection of indicators used in the Ecohealth program have been subject to a scientific review process.

Water Quality provides an understanding of how changes in land use practices within the catchment are affecting the health of our rivers and estuaries. Ecohealth measures oxygen level, salinity, acidity, murkiness (turbidity) and nutrients in our waterways.

Riparian vegetation is important for maintaining good water quality, stabilising riverbanks and providing habitat for animals including macroinvertebrates and fish. Ecohealth looks at the occurrence of weeds, structure of riparian vegetation, habitat (e.g. fallen logs) and current management (e.g. fencing).

Geomorphic condition assesses bank condition (e.g. slope, bank failure, exposed tree roots and undercutting), bed condition (e.g. active erosion and smothering of the bed substrate by high loads of fine sediment), and trampling by stock.

Macroinvertebrates are waterbugs such as worms, beetles, mayflies and shrimps that are sensitive to changes in aquatic habitat, pollution and poor water quality. Ecohealth looks at the types of waterbugs occuring at different freshwater sites in our rivers. Waterbugs are not assessed in estuaries.

Ecohealth scoring and grading

Information about each of the indicators was collected from 48 sites across the Richmond catchment over the course of 12 months. These were used to calculate scores for each indicator at each site, based on how often the measured values satisfied regional and national guidelines for healthy rivers. The condition scores were then given a corresponding grade (see below).

This scoring and grading system is based on the traditional format of a school report card, with ratings ranging from a high of 'A', through intermediate ratings of 'B', 'C' and 'D', to the lowest possible score of an 'F'. Secondary grades of + and - are included to provide greater resolution within a grade, and to help show improvements over time.

Condition Score	Grade	Result
91-100	A	Excellent
76-90	B	Good
61-75	C	Fair
46-60	D	Poor
0-45	F	Very Poor

Interpreting the results

The diagram to the right shows the Ecohealth grading system, where a grade is given for water quality, riparian condition, geomorphic condition and aquatic macroinvertebrates. Based on the average of these grades, an overall grade is awarded to the site. Overall grades are then also awarded for each river system, subcatchment, and for all freshwater and estuarine sites.

Site Name	Example of Site Grades
B-	Average of all four grades for the Site
A-	Water Quality grade
B-	Riparian Condition grade
C+	Geomorphic Condition grade
C+	Macroinvertebrate grade

What we found

A Total of 48 sites in 17 waterways were used to calculate an overall condition of D+ for the Richmond catchment (see overleaf). This grade is consistent throughout the Richmond catchment with 12 of the 17 waterways recording a grade of D or lower. The upper freshwater reaches had better water quality, aquatic macroinvertebrates and geomorphic condition than the lower freshwater reaches, but no better riparian condition. The upper estuary (upstream of Woodburn) was consistently in the poorest condition, with very high nutrient concentrations, turbidity and algal biomass. Scores were consistent among indicators within each waterway, highlighting that water quality and physical habitat are driving the condition of streams.

Concentrations of all nutrients exceeded guideline values consistently across all sites leading to very low scores, with 9 waterways receiving an F grade. Low dissolved oxygen concentrations, low pH and high chlorophyll a (algal biomass) and nutrient concentrations were a feature of estuarine reaches, and recorded levels that would affect the health and distribution of aquatic animals. The clear pattern of deteriorating water quality with distance downstream highlights the need to improve riparian and bank condition throughout the catchment as a management priority.

Macroinvertebrate scores were low throughout the catchment with 10 of the 17 river systems receiving a grade of D or lower. The number of macroinvertebrate families found ranged from a very low 5 in the lower Terania and Bungawalbin Creeks to a very high 30 families recorded in the upper Terania and Iron Pot Creeks. The poor macroinvertebrate grades reflect poor water quality and habitat conditions, particularly the erosion of river channels and smothering of habitat with fine sediment.

Riparian condition scores were poor throughout all regions of the Richmond River catchment, with 10 of the 17 river systems recording a grade of D or lower. The main stressors to riparian condition are from invasive weeds, disturbances from floodplain clearing and agriculture, and access from livestock. Strongly linked to riparian condition was the state of the riverbanks with severe bank slumping, high bank slopes and exposed tree roots in many of the streams in the Richmond catchment.

What action is happening?

In partnership with local landholders, state agencies and funding bodies, the local councils of the Richmond catchment are working to ensure that information on catchment condition is readily available and restoration works are targeted to key sites and issues.

Richmond Valley Council, Richmond River County Council, Kyogle Council, Lismore City Council and Ballina Shire Council all work together to manage the natural resources for local communities and industries. Office of Environment and Heritage (OEH) and National Parks and Wildlife Service manage many of the conservation areas in the catchment, working closely with the Department of Primary Industries (Fisheries) to manage native fish habitat and communities. OEH provides technical and financial assistance to local councils through the NSW Estuary Program to improve the health of NSW estuaries. North Coast Local Land Services supports the implementation of projects by councils and other agencies to achieve best practice natural resource management and sustainable agriculture in the Richmond catchment.

The management of natural resources on the Richmond coastal floodplain is a complex arrangement of programs, organisations and funding covering issues such as drainage, acid sulfate soils, floodgate management, water quality monitoring, and estuary and wetlands management.

The Richmond Estuary Coastal Zone Management Plan (CZMP) provides a blueprint for the long-term sustainable management of the estuary. A management focus on the estuary and floodplain has resulted in the formation of the Richmond River Coastal Zone Management Reference Group to coordinate natural resource management activities and projects on the floodplain in partnership with councils, state government and the community.

Further information

To access the 2014 Richmond Ecohealth Technical Report and other information about the results of this report card, go to www.rrcc.nsw.gov.au/environmental-management/water-quality-monitoring/

For more information about the Ecohealth program go to www.aerlab.com.au and click on Coastal Projects.

To see the improvements happening in your local area, go to the environment section on your local council's website.

Project partners

ballina shire council

Kyogle Council

lismore city council

Richmond River County Council

Richmond Valley Council

Australian Government

NSW Government Local Land Services North Coast

Rous Water

NSW Government Office of Environment & Heritage

une University of New England

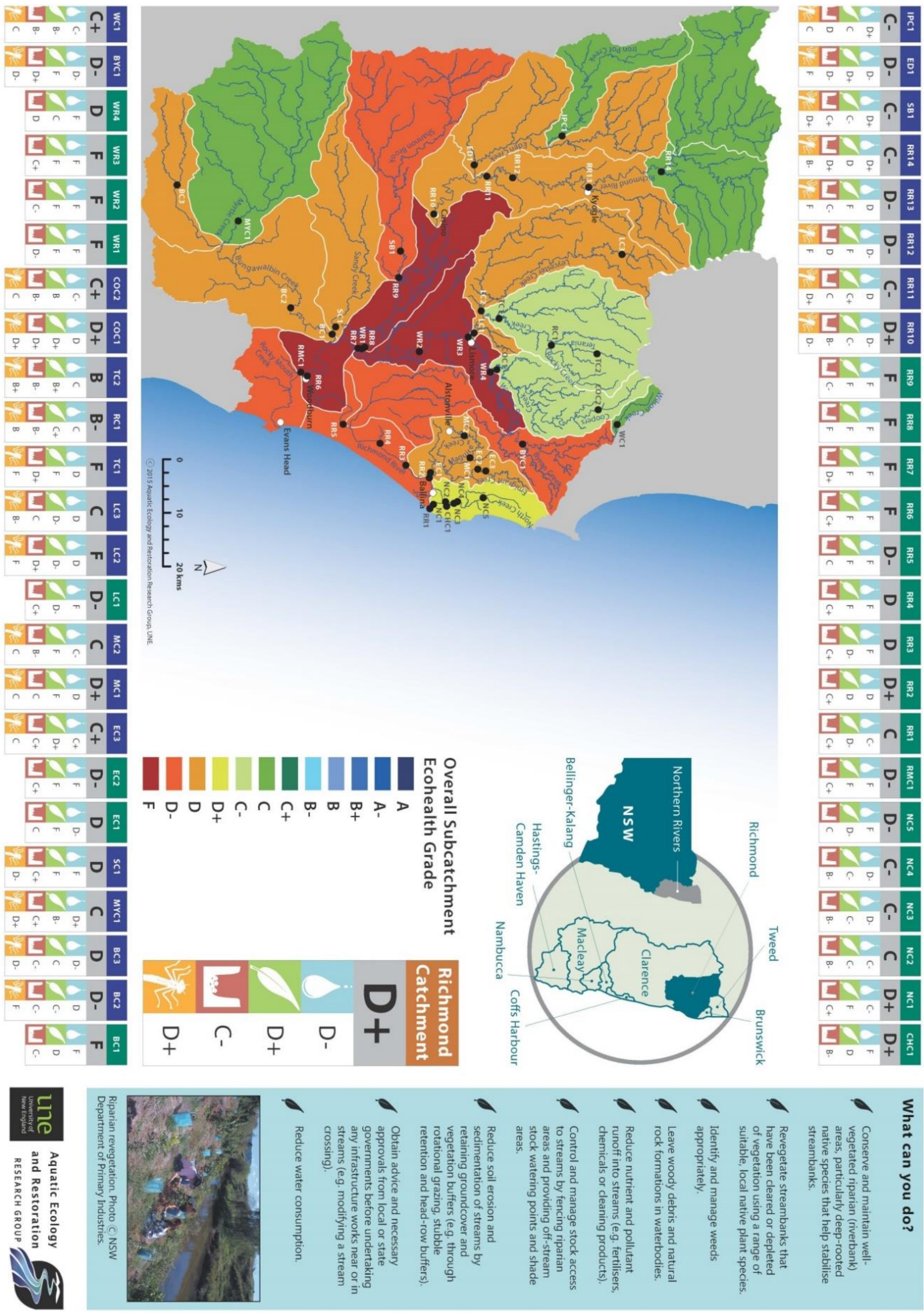
Aquatic Ecology and Restoration RESEARCH GROUP

Ecohealth

A health check for our waterways

Richmond Catchment REPORT CARD 2014

Example of a folder flyer (page 1) for distribution with rates notices produced for the Richmond River Ecohealth program.



Example of a folder flyer (page 1) for distribution with rates notices produced for the Richmond River Ecohealth program.

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Appendix 1. Field Equipment Checklist for Ecohealth

Equipment	No. per site	
All sites		
GPS	1	
Multi-probe water quality meter; minimum 5m length on cord – *0.5 m demarkations on cord*	1	
Calibration fluids	1	
Field data sheet	1	
Clipboard and pen/pencil	1	
Deionised water and squeeze bottle	1	
Secchi disk	1	
10 – 30m tape and weight or Sonar attached to boat. (Depth measurement)	1	
Extendable sampling pole and holder	1	
Eski with ice for transport (and labelled for destination)	1	
Sample bottles (labelled)	4 x 125mL 2 x 1L	
Filter holder and filters for water samples	1	
Tide Chart (if applicable)		

Appendix 2 - Multi-parameter Meter Maintenance Log

This Log Sheet to be kept with Meter at all times.

Owner of Meter:

Make and model: **Serial number:**

Date of purchase (if known): **Date of Last Service:**

Date	Time	Field Officer	Standard/Reagent Expiry date or lot number	Calibration 1 (auto or manual; one or multi-point)	Parameters calibrated	Comments (variation in values/drift)

Appendix 3 - Ecohealth Water Quality Data Sheet

Date:________________________________

Site Name:___________________________ Site ID:_________________________

Location: Easting__________________ Northing____________ Datum _________

Decimal degrees - Lat _________ Long____________Elevation _______

Field Personnel ____

Start Time (24 hr) ________________________ End time (24hr) _________________

High Tide Time/Height _____________________ Low Tide Time/Height ____________

Equipment: (Make/Model)_____________________ Serial/ID number________________

Calibrated by: __________________________ Calibration Log Complete? Y N

Air Temp _________________________

Weather Conditions

Water Surface: ☐ flat ☐ choppy ☐ rough

Wind: ☐ nil ☐ light ☐ moderate

Rainfall: ☐ nil ☐ light ☐ moderate ☐ heavy in last ☐ 24 hours ☐ 2-5 days

Sky: ☐ sunny ☐ overcast

Depth (m)	Temp (C)	pH	Cond (mS/cm)	Salinity (ppt)	DO (mg/L)	DO (% sat)	Turb (NTU)
0.1							
1.0							

Ecohealth Water Quality Data Sheet

Secchi Depth (m)	
Maximum depth (m)	
Water Velocity ($m.sec^{-1}$) – *freshwater sites only*	

Bacterial sample – *At mouth of estuary only*	Yes	No	Sample ID:	
Duplicate TN/TP sample	Yes	No	Sample ID:	
Duplicate SRP/NOx sample	Yes	No	Sample ID:	
Chl a volume filtered (mL)			Sample ID:	
TSS volume filtered (mL)			Sample ID:	

Samples Forwarded to (Lab Name): ____

Chain of custody form completed: Y N

Comments

Ecohealth
A health check for our waterways

Appendix 4 - Ecohealth Sample Chain-of-Custody Form

Field sampling staff: ____

Project name/ID and location: ____

Sample dates included:

____

List of sample sites included:

____________	______________	______________
____________	______________	______________
____________	______________	______________
____________	______________	______________
____________	______________	______________
____________	______________	______________
____________	______________	______________

Samples sent by:

Time: __________________ a.m./p.m. Date ____________________________

Location: ____

Sample quantity:____

Samples unaltered: yes/no

Signed: ___________________________

Courier company: ____

Receiving laboratory

Receipt of sample by laboratory from sampling officer or courier:

Time: __________________ a.m./p.m. Date ______________________

Location: ____

Sample quantity:____

Samples unaltered: yes/no

Samples received by: ____

Signed: ___________________________ _________________________

Name	Agency	email	Phone (incl. mobile)	Responsibilities		
				Sites/Locations	Equipment	Sample collection
Sarah Mika	UNE	Sarah.mika@une.edu.au	67732146	Sampling Coordinator	All	yes
Darren Ryder	UNE	dryder2@une.edu.au	677305226 0457 513 296	Sampling Coordinator	All	yes