Richmond River Estuary Processes Study

Executive Summary

Organisations involved in funding, management and production of the study

Contents

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Background

This report presents the primary findings of the Richmond River Estuary Processes Study (EPS) carried out by WBM Oceanics and updated / amended by Aquatic Biogeochemical and Ecological Research (ABER). The Richmond River estuary extends from the ocean entrance at Ballina, to near Casino on the Richmond River and to Lismore on the Wilsons River. The EPS study area includes all tidal waterways, foreshores and lands immediately adjacent to the estuary and considers the wider Richmond River catchment insofar as it affects issues relating to the estuary.

The broad objective of the EPS is to describe the key physical, chemical and biological patterns and processes operating within the estuary. Details have been provided on how these processes interact and influence each other. The EPS has been carried out in accordance with the State Government's Estuary Management Program, and will be used as a platform to develop a comprehensive Estuary Management Plan in the near future.

Photo WBM Oceanics

Artificial drainage channels through acid sulfate soils in the Tuckean Swamp

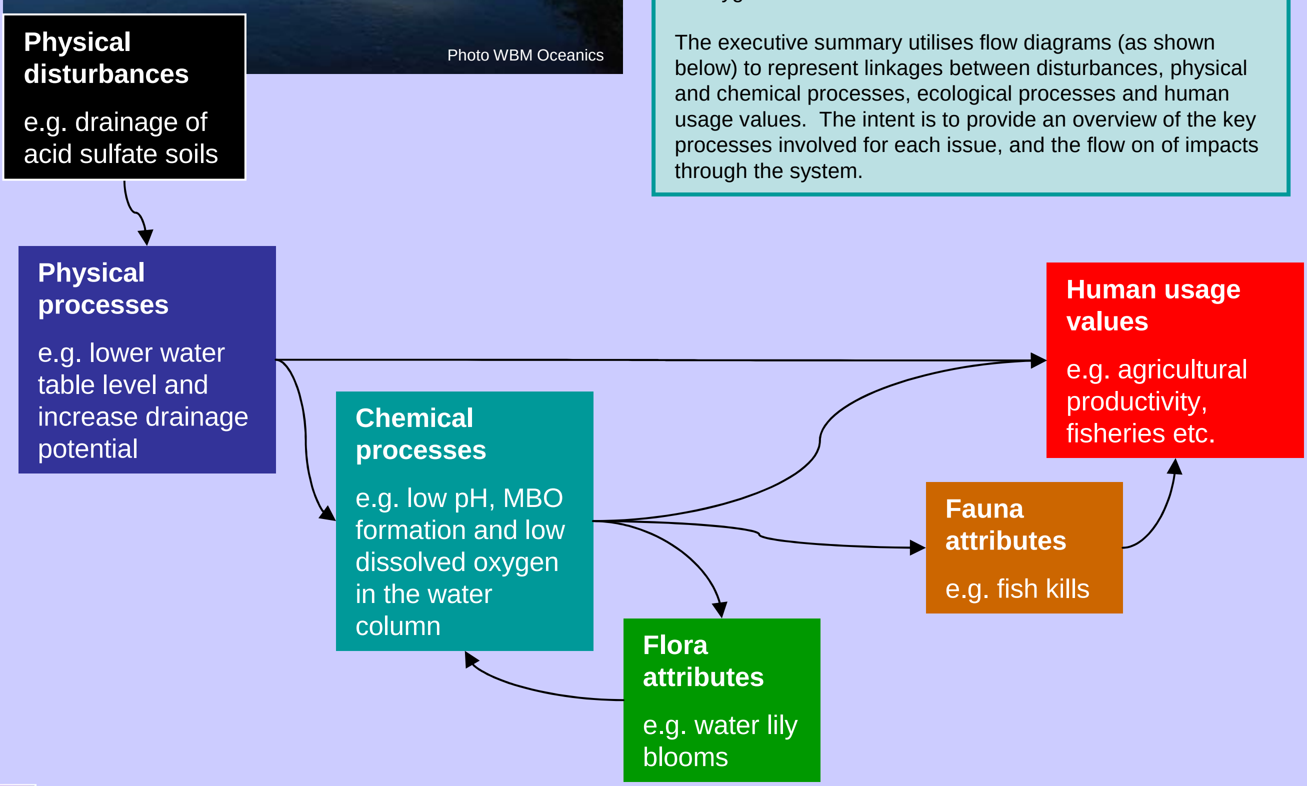
Photo WBM Oceanics

Interactions between environmental processes

The impacts of environmental disturbances / influences on the estuarine ecosystem depend on complex interactions between various physical, chemical and biological factors. In general, influences such as catchment inputs and entrance conditions are the highest order processes, impacting on all other processes including hydrodynamics, sedimentation, water quality, and estuarine ecology.

In some cases, impacts are propagated through a number of levels within the ecosystem, and feedbacks may also occur between biotic and abiotic components. For example, chronic acidification may lead to water lily blooms, which in turn result in monosulfidic black ooze [MBO] formation. Subsequent resuspension of MBOs during floods can result in severe deoxygenation of water and fish kills.

The executive summary utilises flow diagrams (as shown below) to represent linkages between disturbances, physical and chemical processes, ecological processes and human usage values. The intent is to provide an overview of the key processes involved for each issue, and the flow on of impacts through the system.



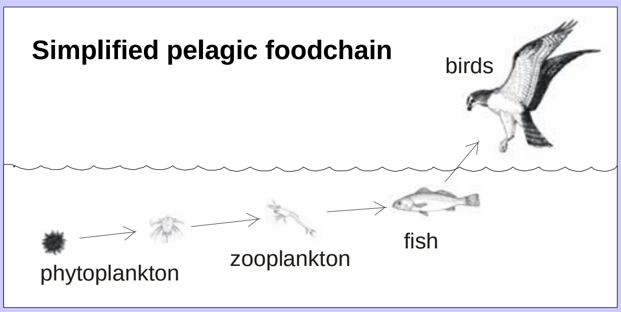
The Estuarine Foodweb

Foodweb overview

Foodwebs are descriptions of what eats what, and attempt to map the flow of energy through an ecosystem, from the primary producers (plants) at the base of the foodweb through to the high order predators. An estuarine foodweb is made up of various different foodchains within distinct sub-environments (e.g. the water column and sediments).

A functional understanding of foodwebs is essential for sustainable environmental management, given that important higher order species (e.g. threatened shorebirds or commercially important fish) depend on viable foodwebs to meet their food requirements. As such, threats to nature of primary production in a system can translate to threats throughout the foodweb and ultimately impact on the diversity of the system.

The Richmond River estuary supports a diverse array of foodchains that vary on both spatial and temporal scales, however no work to date has been done to describe patterns. In general, foodwebs within the estuary can be broadly delineated according to the zones identified for the open water and benthic biotopes. Within each of theses zones exist a variety of different foodchains determined by a number of environmental controls. These controls vary as a function of the cross sectional gradient from fringing wetlands - intertidal shoals - sub-tidal shoals - channel.



Foodchains in different environments of the Richmond River estuary

Marine delta shoals - Good water clarity and extensive shoals result in productive foodwebs based on benthic microalgae (BMA) productivity. BMA biomass is rapidly grazed/consumed by microbes and invertebrates (e.g. soldier crabs), which in turn support various fish and bird predators.

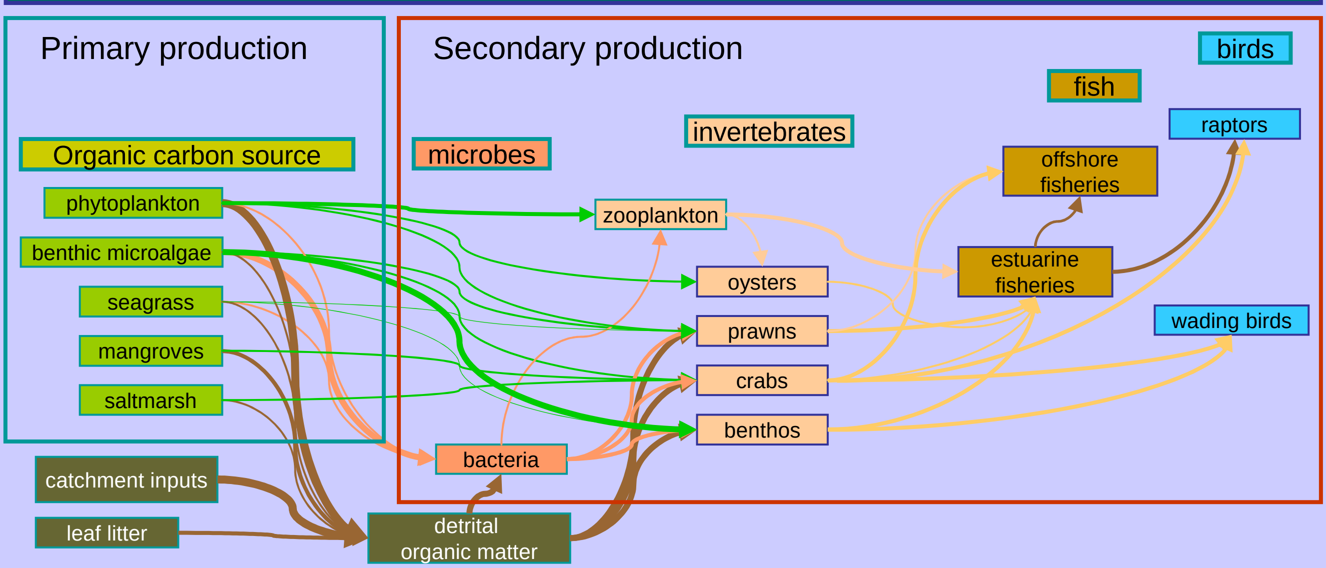
Seagrass beds – While not quantitatively important in terms of ecosystem organic carbon (OC) production, seagrasses provide unique habitat and support foodchains based on the grazing of seagrass leaves and epiphytic algae by invertebrates (e.g. prawns) and fish. Deposition of seagrass material results in high OC sediments within the bed supporting a productive fauna foodchain.

Water column – Phytoplankton production is likely to be one of the largest inputs of OC to the Richmond River estuary driving both pelagic and detrital foodchains, especially in the middle to upper estuary and tidal pool. Phytoplankton is grazed/consumed by microbes and invertebrate zooplankton which in turn support various fish. Deposition of "phyto-detritus" is likely to be a major input into the important detrital foodchain supporting prawn and crab productivity.

Depositional shoals – Foodchains in these environments are largely based on OC inputs from catchment runoff and phyto-detritus deposition. Breakdown of this material supports high microbial productivity which in turn supports both benthic and pelagic invertebrates (e.g. bivalves, polychaetes, and prawns)

Mangroves – Leaf litter fall and microalgal production in mangrove systems support highly productive detrital foodchains flowing onto invertebrates (e.g. crabs) and juvenile fish.

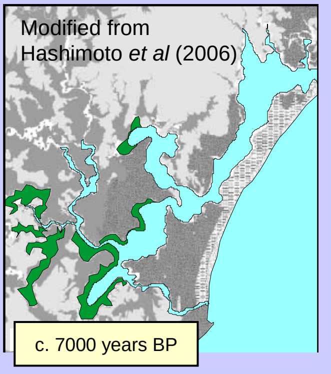
Key components of the Richmond River estuary foodweb

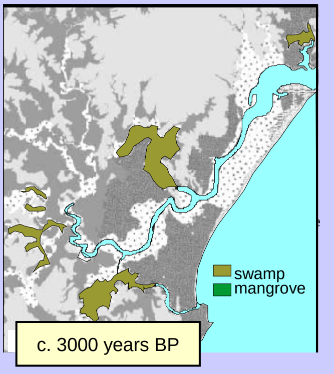


Sediment Processes

Evolution of the Richmond River estuary

Deposition of sediment from catchment runoff over millions of years has slowly filled the lower Richmond River valley and floodplain. The current landscape and estuary evolved during the infilling of an estuarine embayment since sea levels reached their current level c.7000 years ago. Acid sulfate soil environments formed in mangrove-backswamp areas, which eventually infilled to become freshwater wetlands. The Richmond River estuary is now considered to be "mature" (i.e. infilling is complete) and river surveys between Coraki and the entrance suggest little current sedimentation or infilling of the river channel reflecting the efficient transport of sediment to the ocean.





Shoaling

Shoaling (accumulation of shallow sediments) in the lower estuary area is primarily determined by a balance between freshwater flows and tidal range. It is likely that the distribution of shoals and associated biotic communities shifted dynamically in accordance with this channel migration. Training of the estuary mouth, and Mobbs and Shaws Bays, has restricted the dynamic nature of shoaling in this zone. The river has adjusted to the modified entrance conditions, and shoals within the entrance are mostly stable, other than fluvial reworking during major floods and some wave stirring and tidal movement near the entrance.

Entrance Condition and Modification

Before entrance modification, the location of the estuary mouth migrated over a considerable area between lighthouse hill and south Ballina in response to scouring by flood events. The entrance was also subject to periodic closure during extended dry periods. Between 1889 and 1912, rock-training walls were constructed at the river entrance and within the lower estuarine reaches to stabilise shifting sands and create a permanently navigable waterway. The training works were also accompanied by extensive dredging. Since construction, there has been numerous periods of repairs and rock replacements.

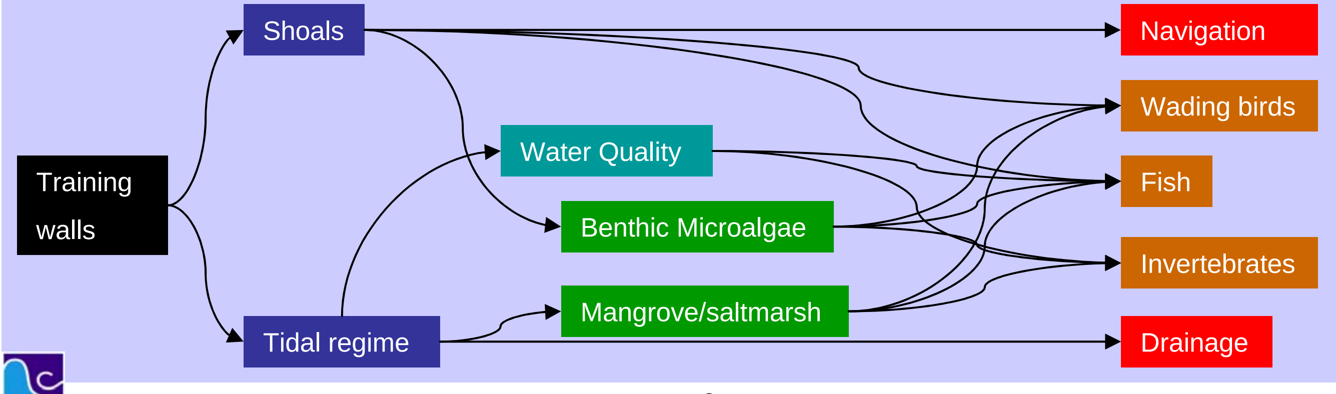
Hydrodynamic impacts of walls and entrance modification

The entrance modifications are likely to have altered hydrodynamics throughout the whole estuary, in particular creating a consistent tidal range within the estuary. This has had significant follow-on effects, particularly in respect to water quality and ecology, including:

- promoted colonisation of mangroves and saltmarsh
- increased tidal induced drainage across the floodplain
- .increased tidal flushing of the estuary and hence export of nutrients
- increased larval and fish exchange between the estuary and ocean
- increased nutrient inputs from the ocean during dry seasons

Training walls

Internal training walls include the continuation of the northern breakwater in front of 1) Shaws Bay, and 2) the mid-tide training walls in front of Mobbs Bay. Reclamation of some former estuarine areas has also occurred, including East Ballina (north of the northern breakwater) and areas around North Creek.



Climate change

Global Warming

Global warming due to increased greenhouse gas emissions is now recognised as a major environmental problem. Observed changes in Australia show increased continental annual average temperature by 0.76°C from 1910 to 2000 with most of this increase occurring since 1950. The NSW and southern Qld coast have experienced relatively high increases in temperature.

Projections for NSW and southeast Qld indicate a tendency for decreased rainfall in winter/spring and increased rainfall during summer. Extreme rain events are projected to increase north of Cape Byron. The intensity and frequency of tropical cyclones will most likely increase. The occurrence of East Coast Lows is expected to increase. Sea level rise is anticipated to be a major impact of global warming.

Sea level rise

Global sea levels have been generally rising since accurate records began, with an average recorded rise of 0.94 mm per annum at Fort Denison in Sydney Harbour.

Sea level around Australia is projected to rise between 100 and 400 mm by 2050, depending on scenarios. The frequency of extreme sea-level events reaching 2.1m has doubled and those reaching 2.2m has tripled since 1950.

Impacts of sea level rise

Sea level rise adjacent to the Richmond River estuary would cause a rise in estuary water levels resulting in impacts including, but not limited to:

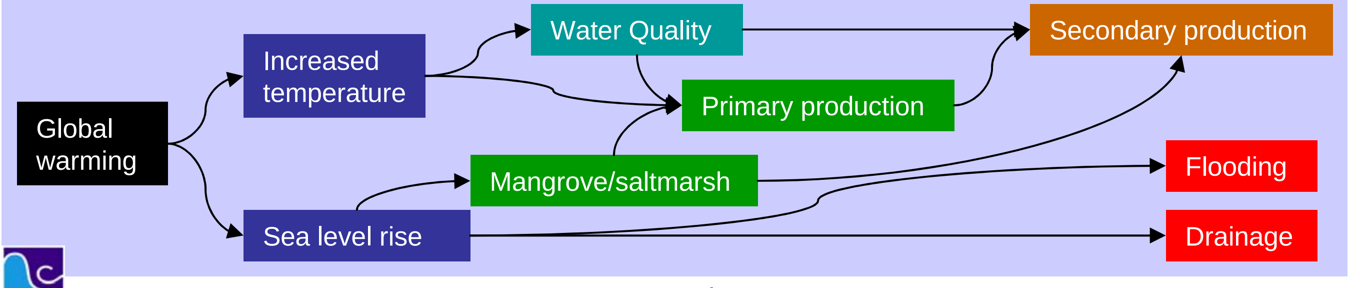
- shoreline recession
- inundation of low lying ecosystems
- implications for drainage in urban and agricultural areas
- implications for flooding in urban and agricultural areas
- increased salt penetration into tidal pools or freshwater wetland systems

Other ecosystem responses

Increased summer rainfall may cause changes to ecosystem functioning due to increased organic matter deposition and lower light penetration throughout the estuary. This may result in negative impacts on key habitats such as marine delta shoals and seagrasses. Changes in salinity and organic matter supply to intertidal wetlands may have ramifications up the foodchain, with predicted initial increases in secondary production followed by subsequent collapses in fauna biomass

Landward migration of ecological communities

Some riparian communities may face local extinction if the altered sea level regime does not simply translocate their habitat requirements upward and landward, for example wetland communities may become constrained by elevation or development on their landward edge. Mangrove transgression will be at the expense of threatened saltmarsh communities. There may be a loss of intertidal emergent mud flats and other valuable habitats.



Water quality – Primary influences

Water quality in the Richmond River estuary

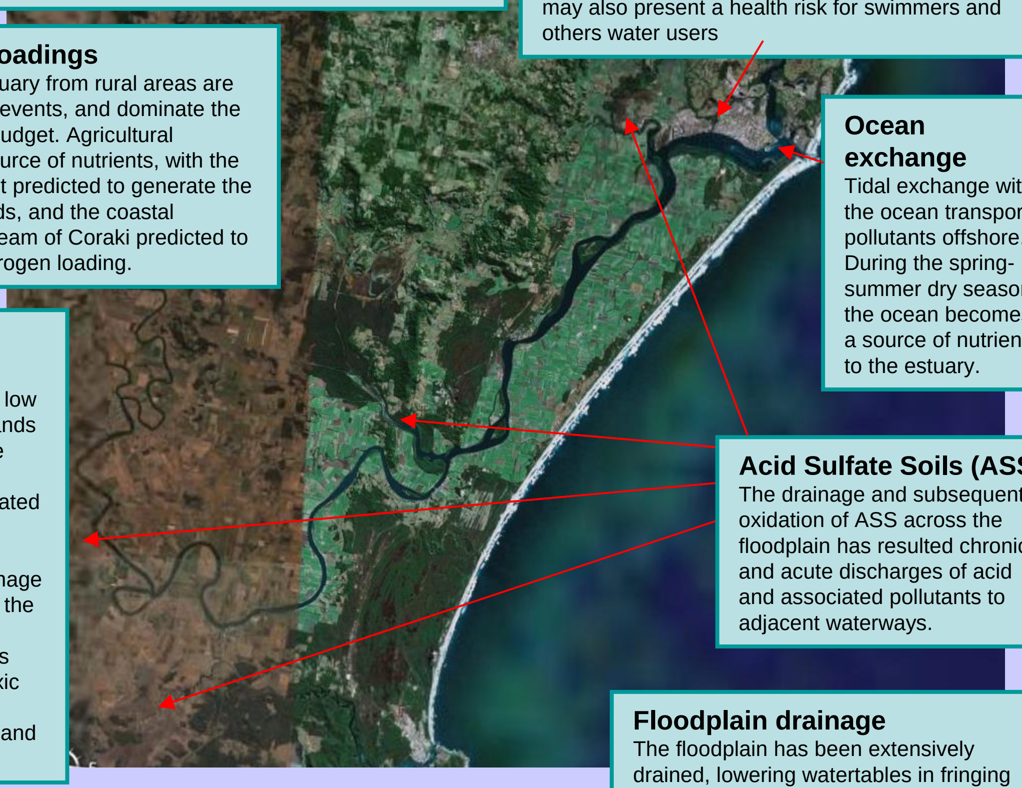
A review of water quality data for the estuary has found levels of several water quality parameters (including dissolved oxygen, pH, turbidity, nitrogen, phosphorus, chlorophyll-a and faecal coliforms) were outside desired ranges. As a result, some environmental and human health values of the Richmond River estuary are currently being compromised. Key factors degrading the water quality of the Richmond River estuary include acid sulfate soils (ASS), diffuse pollutant runoff (from agricultural and urban areas), deoxygenation due to pasture inundation and MBOs, and floodplain management. This page provides an overview of primary influences on water quality and more detail on each is provided in subsequent pages.

Catchment disturbance

Catchment inputs and their impacts on the estuary have changed significantly since European settlement. The catchment has been modified from a (Pre-European) heavily timbered forest to (current) a mix of intensive agriculture, grazing and urban development. These changes have substantially increased the amount of pollutants discharged to the estuary, which has resulted in a range of water quality issues.

STP and urban inputs

Pollutant loadings from these sources become relatively more important to water quality during the dry season when catchment inputs wane. High faecal coliform concentrations within the lower estuary affect the operation of the local oyster industry by extending closure times, and may also present a health risk for swimmers and others water users



Diffuse pollutant loadings

Nutrient loads to the estuary from rural areas are significant during runoff events, and dominate the overall annual nutrient budget. Agricultural fertilisers are a major source of nutrients, with the Wilsons River catchment predicted to generate the highest phosphorus loads, and the coastal subcatchments downstream of Coraki predicted to generate the highest nitrogen loading.

Ocean exchange

Tidal exchange with the ocean transports pollutants offshore. During the spring-summer dry season the ocean becomes a source of nutrients to the estuary.

Deoxygenation of flood water

Prolonged inundation of low lying pastures and wetlands during floods causes the decay of grassland vegetation and accumulated organic matter, thereby depleting the water of oxygen. The mass drainage of this ponded water via the drainage network and tributaries as floodwaters recede can cause hypoxic conditions along large stretches of the estuary and result in major fish kills.

Acid Sulfate Soils (ASS)

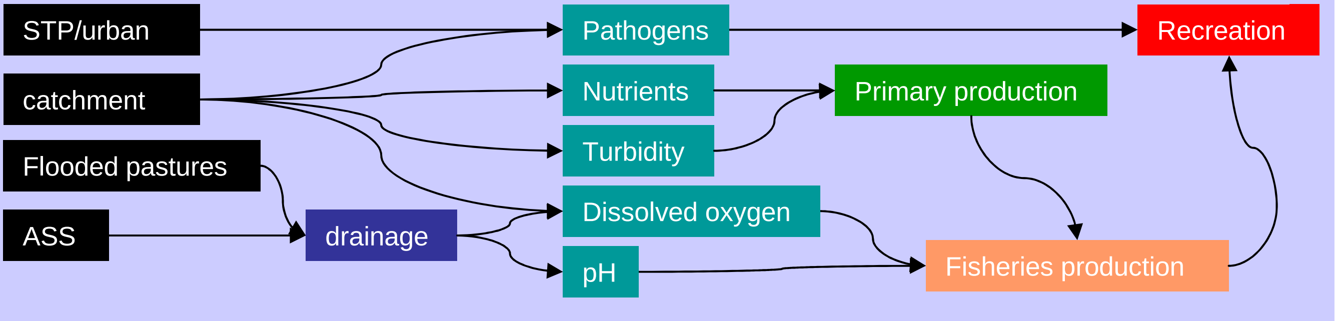
The drainage and subsequent oxidation of ASS across the floodplain has resulted chronic and acute discharges of acid and associated pollutants to adjacent waterways.

Floodplain drainage

The floodplain has been extensively drained, lowering watertables in fringing wetlands and exposing ASS to oxidation. The drainage network provides a conduit to more effectively convey pollutants to the estuary. Floodgate and groundwater management is an important influence on drain water quality and pollutant loadings to the estuary.

Need for monitoring

Water quality monitoring across the estuary is disjointed and sporadic and fails to provide the level of information that could be used to measure ecosystem health. Effective ecosystem health indicators are needed to assess the effectiveness of natural resource management programs



Water Quality - Recovery Processes

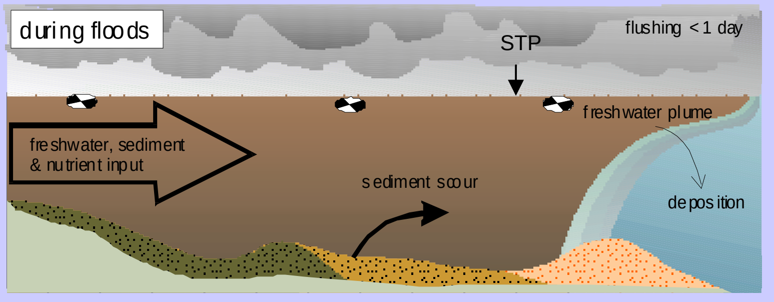
Estuaries - a dynamic environment

The estuarine system is dynamically changing throughout time within a set of natural extremes. Estuarine ecology has evolved to cope with this highly changeable environment, however when anthropogenic stresses cause a widening of environmental extremes (e.g. higher nutrient loadings, lower pH and hypoxia), the ecosystem can be changed (sometimes permanently) in various ways. The term "eutrophication" refers to the process of organic enrichment in an aquatic ecosystem, commonly caused by elevated nutrient loadings. Organic enrichment leads to higher rates of decay resulting in a decline in dissolved oxygen throughout the system and potentially leading to the local extinction of higher orders of the foodweb

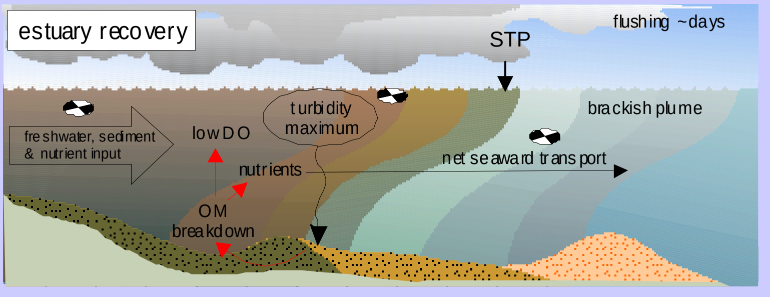
Seasonal cycles within the Richmond River estuary

The Richmond River estuary ecosystem has evolved with episodic pulses of high nutrients and organic matter to the system during floods, followed by opportunistic increases in primary (phytoplankton) and secondary (benthic invertebrates, detritivores, fish, birds) productivity during the months following the flood event. This seasonal process is a primary influence on water quality throughout the estuary and can be summarised into the four distinct stages illustrated below.

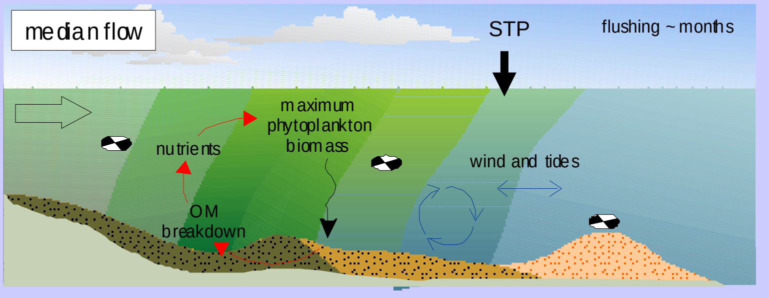
Flood/high flow - During floods and high flow conditions when flushing times are less than 1 day, internal estuarine processes are bypassed and dissolved and particulate materials are delivered to the nearshore coastal zone.



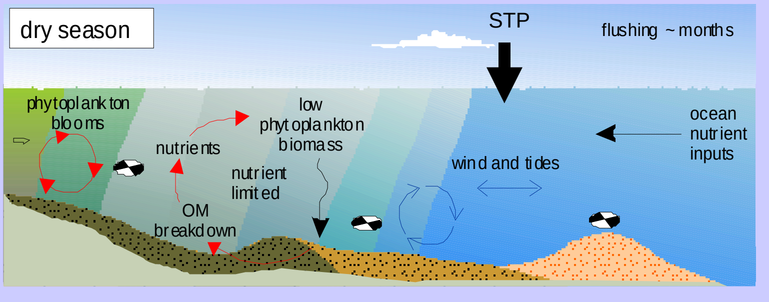
Post flood recovery - As tidal influence returns to the estuary, particulate organic matter/nutrients are deposited and bacterial remineralisation of this material in the sediments ("benthic fluxes") and in the water column recycles bio-available nutrients and depletes dissolved oxygen. At this stage, water column (inorganic) nutrients and light attenuation are high, and phytoplankton productivity is limited by light availability.



Median flow – Phytoplankton productivity increases as light climate improves. Benthic fluxes of bio-available, dissolved inorganic nitrogen (DIN) become relatively more important to phytoplankton productivity as flushing times increase, up to the point where sediment nitrogen stores become depleted and benthic fluxes decrease to zero. The depletion of sediment nitrogen is due to a combination of factors associated with the processing of organic matter by the benthic foodchain, all of which increase with improved water clarity towards low flow (dry season) conditions.



Dry season - Flushing times increase to >190 days, riverine inputs of nutrients all but cease and DIN becomes tightly recycled within the sediments and water column. Phytoplankton becomes N-limited and DIN concentrations in the water column approach zero. Inputs of nitrate from the ocean may be the primary driver of new productivity in the estuary at this time. The upper estuary/tidal pool commonly experiences algal blooms during the dry season due to: 1) light limitation of benthic communities resulting in persistent benthic nutrient fluxes; and 2) the occurrence of cyanobacteria ("blue-green algae") blooms which are able to fix atmospheric nitrogen to supply their needs and can therefore persist in nitrogen-limited environments.



Light attenuation is a key factor influencing biogeochemical and ecological processes in the estuary. It determines the spatial and temporal nature of nutrient recycling processes, and controls key ecological communities such as benthic microalgae and seagrasses. Light attenuation is controlled by two primary factors: 1) suspended sediments during and immediately post flood, and 2) phytoplankton biomass as productivity increases in response to high nutrient loadings. An additional control is wind and tide-driven resuspension of sediments during the dry season.

Acid Sulfate Soils

Acid Sulfate Soils in the lower Richmond River floodplain

Approximately 68,000 ha of Richmond River floodplain is classified as either high or low risk ASS. Disturbance of these areas by historical and ongoing agricultural practices has resulted in chronic and acute acidification of the estuary. ASS priority areas have been identified as Tuckean Swamp, Sandy Creek, Bungawalbin Creek, Rocky Mouth Creek and upper North Creek. There are a number of State and Federal programs and initiatives being implemented to manage and mitigate ASS impacts.

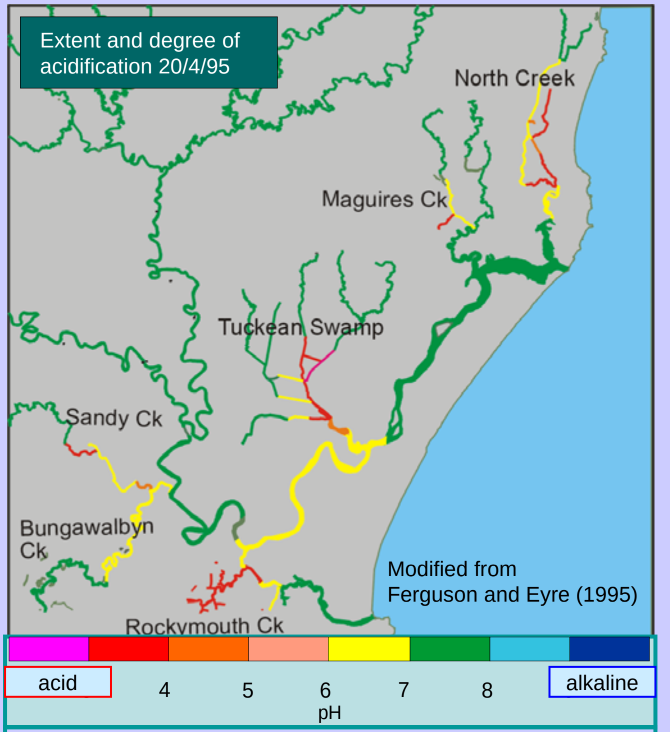
ASS runoff impacts are controlled by a complex interaction between various climatic and environmental factors including:

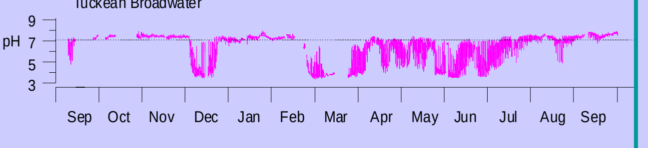
- rainfall patterns across ASS areas and the greater catchment
- antecedent rainfall and groundwater conditions
- the nature of ASS distributions within the landscape
- degree of pyrite oxidation
- vegetation types
- local hydrology
- artificial drainage and tide-gates,
- tidal influence
- salinity regime of the adjacent estuarine environment
- the vulnerability of adjacent estuarine biotopes
- landuse patterns
- management initiatives

Physico-chemical impacts on the estuarine/aquatic environment include:

- acidity (low pH)
- high concentrations of toxic dissolved iron and aluminium
- smothering of benthic environments by metal flocculants
- formation of monosulfidic black ooze (MBO) in drains
- low dissolved oxygen due to MBO mobilisation

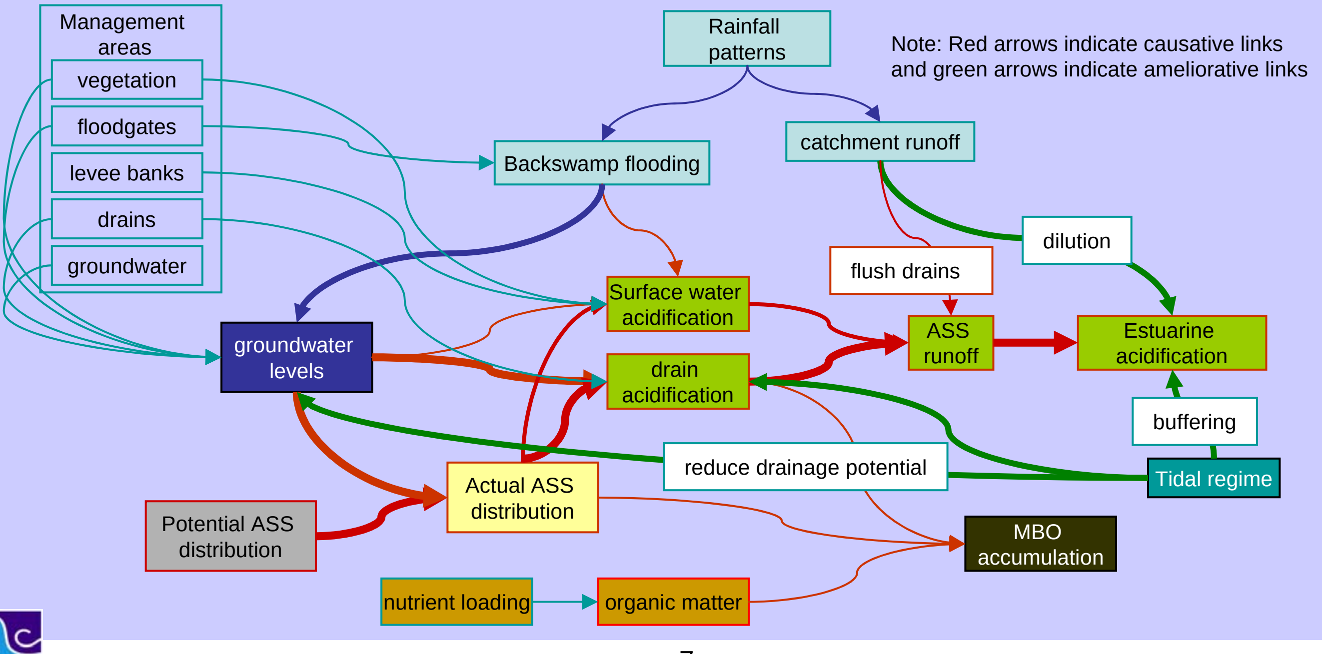
Spatial and temporal patterns in ASS runoff impacts are characterised by acute phases during and following runoff events, and longer term chronic impacts associated with the recovery phase. Impacts tend to be greatest close to the source and diminish with distance according to the assimilative capacity of the receiving environment relative to the volume of ASS runoff. As such, impacts tend to be more apparent in the middle to upper estuary compared to the lower estuary where tidal exchange and seawater buffering are greatest.





Chronic acidification in the Tuckean Broadwater (1994-95)
Note: critical pH is generally less than pH 5

Factors associated with ASS impacts



Fish kills

Fish kill occurrence in the Richmond River estuary

Fish kills occur periodically in the Richmond River estuary primarily in response to post-flood hypoxia events and ASS runoff events. Three main factors are involved – toxicants/pollutants, environmental factors (e.g. salinity, temperature, acidity and dissolved oxygen), and disease pathogens. The frequency and extent of kills is determined by a complex interaction between these factors. As such, prediction of fish kills is difficult, however an understanding of primary drivers is important to inform mitigation strategies.

Climatic patterns

The timing and distribution of rainfall across the catchment and floodplain determines the extent and duration of floodplain inundation. Prolonged flooding during warm summer months significantly increases the risk of fish kills due to increased breakdown rates of organic matter.

Floodplain inundation

Prolonged ponding of flood waters causes decay of grassland vegetation and organic matter stored on the floodplain. Key factors in determining deoxygenation potential are depth and duration of inundation, vegetation type, and temperature. Many low lying swamps have been drained and the dominant drier vegetation communities are less tolerant to inundation than naturally occurring wetland communities. Extensive flooding of the Richmond floodplain can deoxygenate enough water to completely flush the estuary.

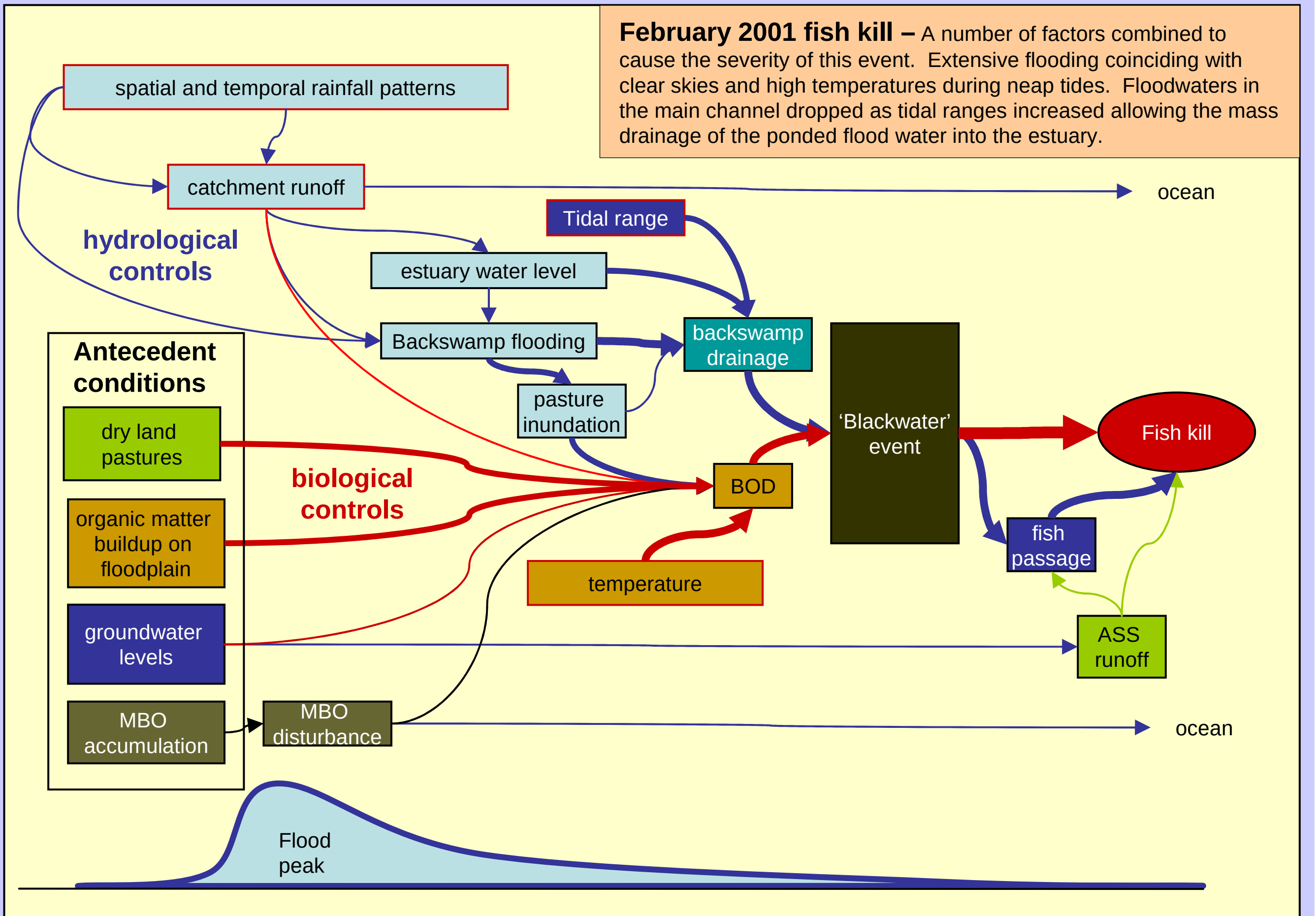
Floodplain drainage structures

Under natural (undrained) conditions the low lying swamps adjacent to the estuary would remain inundated for long periods during the wet season, however less of this ponded water would impact on the estuary due to the lack of natural drainage lines in these environments. Drainage structures have greatly increased the runoff of ponded floodwater to the estuary once main channel floodwaters recede. Fish also utilise drains during periods of good water quality and can become trapped behind floodgates during runoff events.

Runoff from ASS environments

Discharges from ASS environments such as the Tuckean Swamp are commonly extremely acid (pH ~3.2) and contain high concentrations of toxic metals such as dissolved aluminium. Exposure to ASS runoff can impair gill function and increase susceptibility to disease. Initial flushes of floodwaters in ASS environments can mobilise large amounts of monosulfidic black oozes (MBOs) from drain sediments which can cause local hypoxia events.

February 2001 fish kill – A number of factors combined to cause the severity of this event. Extensive flooding coinciding with clear skies and high temperatures during neap tides. Floodwaters in the main channel dropped as tidal ranges increased allowing the mass drainage of the ponded flood water into the estuary.



Note: 1) read diagram as a timeline: the position of factors along the flood hydrograph indicates the period of their peak relevance 2) the main processes responsible for the February 2001 event are indicated by thicker arrows.

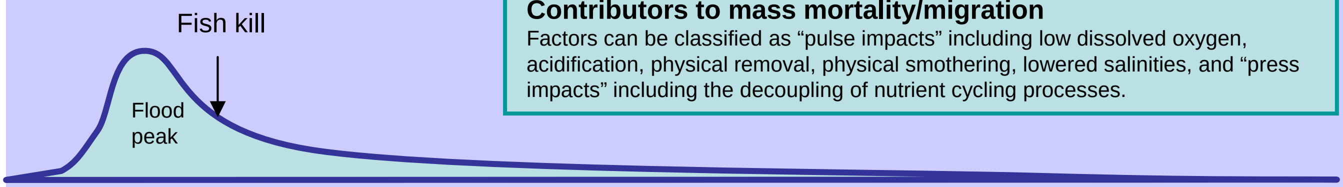
Fish kills – recovery processes

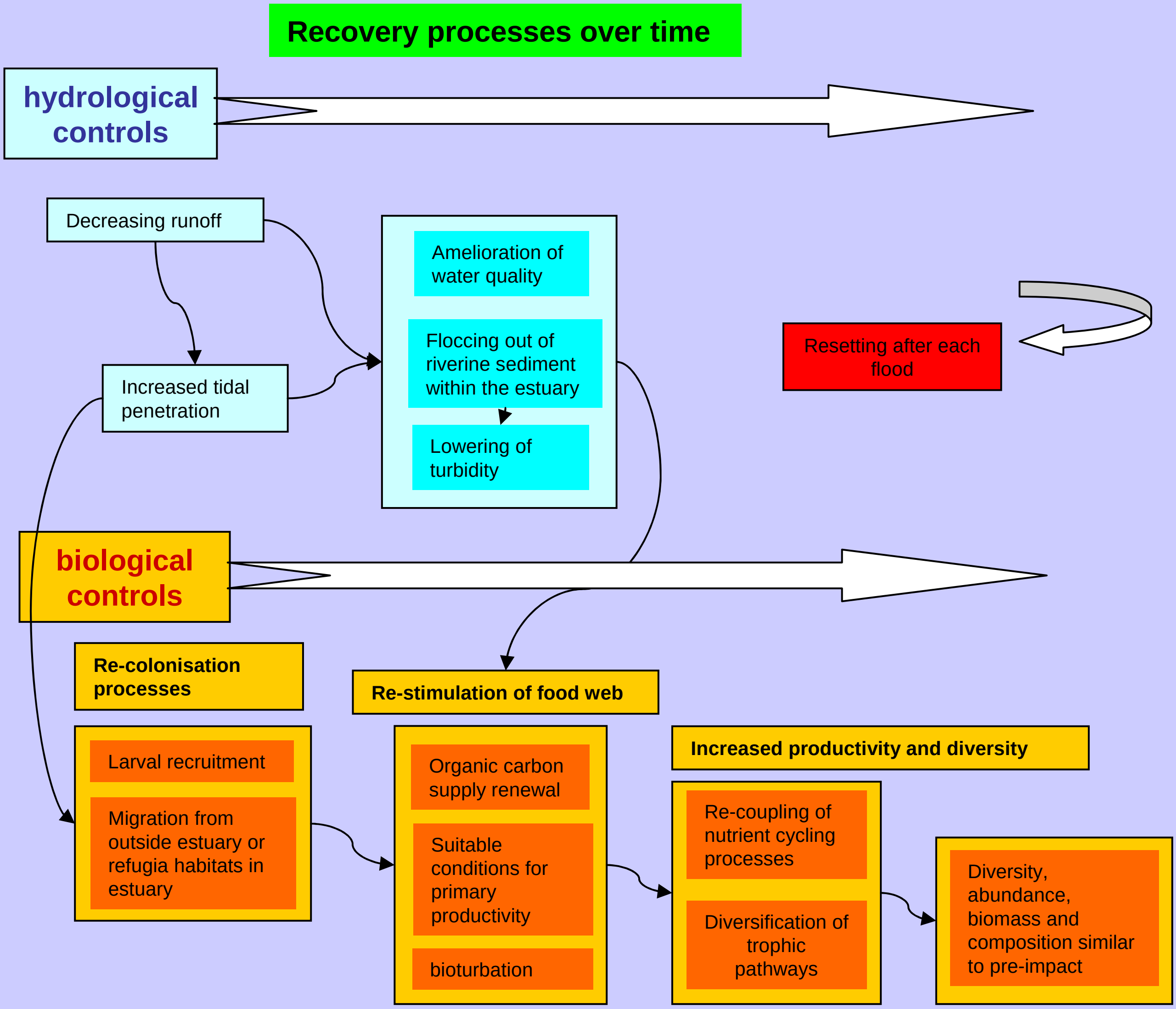
Overview

The Richmond estuary ecosystem has evolved in a highly dynamic physico-chemical environment and was most likely subjected to periodic extreme fluctuations in water quality under natural conditions. Factors such as catchment disturbance and floodplain drainage have increased the severity and frequency of these events and subsequent impacts on biota. In general, biota will avoid poor water quality if safe passage to a refuge exists, and re-colonisation of areas affected by poor water quality proceeds rapidly once conditions improve. In some areas (such as the Tuckean Broadwater) poor water quality may persist for extended periods, thereby hindering the recovery of the ecosystem and ultimately leading to shifts in biogeochemical cycles and the ecology.

Contributors to mass mortality/migration

Factors can be classified as “pulse impacts” including low dissolved oxygen, acidification, physical removal, physical smothering, lowered salinities, and “press impacts” including the decoupling of nutrient cycling processes.





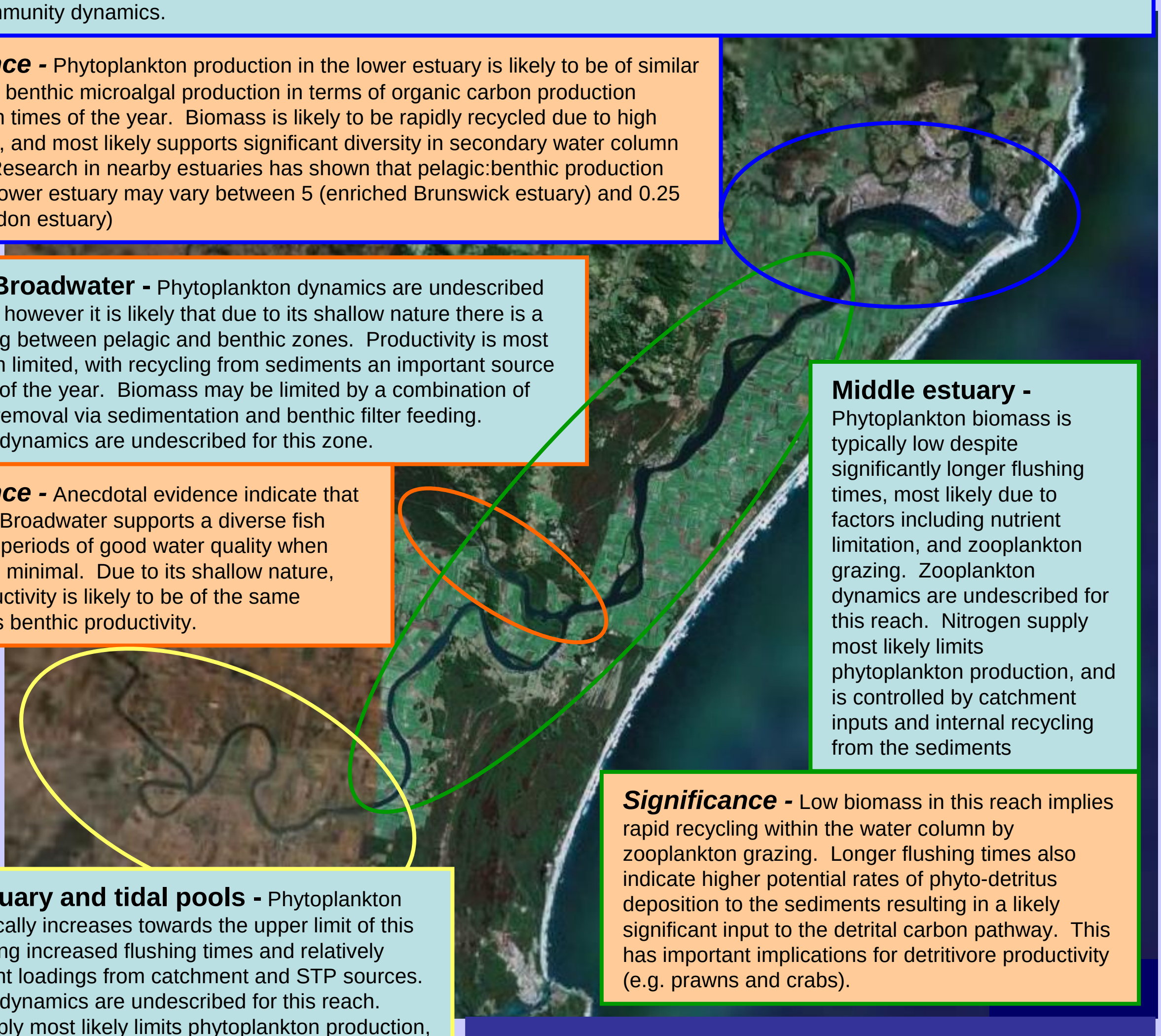
Ecological Processes – the water column

Overview

The water column represents the largest biotope (by area) of the Richmond River estuary, and is one of the most dynamic environments within the system due to highly variable water quality. Phytoplankton production is driven primarily by nutrient loadings and flushing times, and can represent the primary driver of the estuarine foodchain in different reaches/zones at certain times of the year. Phytoplankton may be either grazed directly by microbes, zooplankton, and benthic filter feeders, or settle to the sediments and contribute to the detrital pathway.

Lower estuary - Phytoplankton biomass is typically the lowest of all estuarine zones, due to factors including nutrient limitation, zooplankton grazing and short flushing times. Oceanic inputs of nitrate during the spring-early summer season are likely to be extremely important to primary production and hence the lower estuarine foodweb. Zooplankton communities in the lower estuary are commonly diverse due to proximity to the ocean and more stable water quality. Tidal exchange and salt wedge intrusion are key processes influencing plankton communities in this reach and any future development that influences these will also influence plankton community dynamics.

Significance - Phytoplankton production in the lower estuary is likely to be of similar magnitude to benthic microalgal production in terms of organic carbon production during certain times of the year. Biomass is likely to be rapidly recycled due to high grazing rates, and most likely supports significant diversity in secondary water column production. Research in nearby estuaries has shown that pelagic:benthic production ratios in the lower estuary may vary between 5 (enriched Brunswick estuary) and 0.25 (pristine Sandon estuary)



Tuckean Broadwater - Phytoplankton dynamics are undescribed for this zone, however it is likely that due to its shallow nature there is a close coupling between pelagic and benthic zones. Productivity is most likely nitrogen limited, with recycling from sediments an important source during much of the year. Biomass may be limited by a combination of grazing and removal via sedimentation and benthic filter feeding. Zooplankton dynamics are undescribed for this zone.

Significance - Anecdotal evidence indicate that the Tuckean Broadwater supports a diverse fish fauna during periods of good water quality when ASS runoff is minimal. Due to its shallow nature, pelagic productivity is likely to be of the same magnitude as benthic productivity.

Middle estuary - Phytoplankton biomass is typically low despite significantly longer flushing times, most likely due to factors including nutrient limitation, and zooplankton grazing. Zooplankton dynamics are undescribed for this reach. Nitrogen supply most likely limits phytoplankton production, and is controlled by catchment inputs and internal recycling from the sediments

Significance - Low biomass in this reach implies rapid recycling within the water column by zooplankton grazing. Longer flushing times also indicate higher potential rates of phyto-detritus deposition to the sediments resulting in a likely significant input to the detrital carbon pathway. This has important implications for detritivore productivity (e.g. prawns and crabs).

Upper estuary and tidal pools - Phytoplankton biomass typically increases towards the upper limit of this zone, reflecting increased flushing times and relatively higher nutrient loadings from catchment and STP sources. Zooplankton dynamics are undescribed for this reach. Nitrogen supply most likely limits phytoplankton production, and is controlled by inputs from the tidal pool and internal recycling from the sediments. The occurrence of Cyanobacteria blooms in this zone may reflect a (temporary) shift towards phosphorus limitation during the dry season. High rates of productivity within this zone may commonly result in elevated pH in the water column due to CO_2 fixation.

Significance - Long flushing times and high phytoplankton biomass indicate high potential rates of phyto-detritus deposition to the sediments resulting in a likely significant input to the detrital carbon pathway. This has important implications for detritivore productivity (e.g. prawns and crabs).

Threats

- Increased nutrient loadings due to diffuse and point sources may increase phytoplankton productivity and hence organic carbon loading (“eutrophication”). This has implications for dissolved oxygen concentrations, invertebrate, and fish ecology.
- Increased phytoplankton biomass and turbidity associated with catchment-derived TSS will cause an increase in light attenuation, and in extreme case may result in dissolved oxygen stratification, with hypoxic conditions persisting in bottom waters.
- Chronic exposure to ASS runoff may cause shifts towards acid-tolerant pelagic assemblages.
- The upper estuary and tidal pool are the zones most susceptible to eutrophication due to long flushing times. Sediment stores of nutrients are likely to be high and a net lowering of dissolved oxygen may lead to enhanced release of nutrients to the water column.

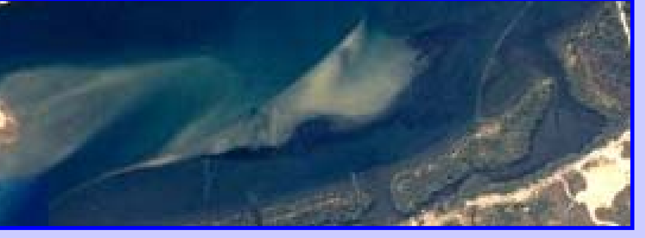
Ecological Processes – the benthic zone

Overview

The benthic zone (unvegetated sediment habitats) comprises a diverse assemblage of bio-facies roughly equivalent in area to the water column biotope. Recent research has shown that benthic productivity may account for the bulk of organic carbon at the base of estuarine and shallow embayment foodchains. In addition, the biogeochemical cycling of organic carbon and nutrients in benthic habitats provides important feedbacks to pelagic productivity and ecology. The biogeochemical and ecological function of these habitats is broadly controlled by factors including: light climate; organic carbon loading; and grain size/sediment disturbance climate. These factors vary as a function of cross sectional depth and position along the estuarine gradient.

Lower estuary - This zone includes channel sediments, inter-tidal and sub-tidal shoals of the active marine delta, deposition shoals associated with North Creek and Emigrant Creek inputs, and inter-tidal and sub-tidal shoals associated with mangrove and seagrass environments. Marine delta shoals are subject to frequent disturbance associated with tidal and flood currents, and their biogeochemical and ecological function is adapted to these dynamic controls. These stable shoals commonly exhibit high rates of benthic productivity which is rapidly turned over (recycled) by secondary (invertebrate) production on a daily basis. The structure and function of these habitats are also biologically controlled by the occurrence of 'keystone' species such as yabbies in sub-tidal shoals and soldier crabs in inter-tidal shoals. Depositional shoals have higher organic carbon contents and tend to support detrital foodchains, however significant benthic productivity still occurs due to their relatively shallow nature. Sediments associated with mangrove and seagrass communities are more stable, and higher organic carbon loading associated with these communities leads to an overall predominance of detrital pathways. However, significant benthic production occurs in sediments and associated with epiphytic microalgae on vegetation substrates.

Significance - The lower estuary supports a high diversity of benthic habitats and estuarine foodchains. Benthic productivity in this zone most likely provides the base of one of the largest and most diverse foodchains in the Richmond River estuary, ultimately supporting important commercial and recreational fish species (e.g. whiting, flathead etc.) wading and raptor bird species. Detrital pathways in mangrove sediment may provide close links to higher order organisms due to the predation of crabs by fish and raptors.



Significance – Despite low diversity of benthic habitats, the detrital pathway supports significant prawn and crab productivity. Recycling of nutrients from the sediments to the water column most likely supports pelagic productivity in this zone.

Middle estuary - This zone includes channel sediments, inter-tidal and sub-tidal shoals, and inter-tidal and sub-tidal shoals associated with mangroves. Deposition of flood-borne organic matter and phyto-detritus throughout low flow periods results in higher organic carbon contents, and detrital foodchains most likely dominate. Higher turbidity and phytoplankton biomass result in light limitation of benthic productivity, however benthic microalgae communities commonly adapt to low light climates and productivity may still be significant. The occurrence of filter feeding bivalves suggest that benthic and pelagic productivity may be roughly equal in this zone. In addition the primary source of organic carbon is likely to be temporally dynamic, given the presence of the dual suspension-deposit feeding benthos species such as bivalve *Theora fragilis* and "blood worms" *Australonereis ehlersii* . Such plasticity in feeding is often an adaptation to variation in the nature of food supply.

Tuckean Broadwater - Due to its shallow and stable nature, productivity by benthic microalgae in this zone is likely to be more significant relative to the detrital pathway than in the adjacent middle estuary zone. However, due to high rates of phyto-detritus deposition the detrital pathway is likely to be still important. More extensive mangrove communities in the Tuckean Broadwater indicate that benthic processes associated with this habitat (as described for the lower estuary) are also likely to be important.

Significance - Due to close pelagic-benthic coupling, the benthic habitats of the Tuckean Broadwater are likely to be integral to its high ecological value as fishery habitat

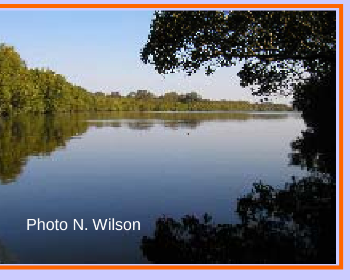


Photo N. Wilson

Upper estuary and tidal pools – Relatively low diversity of benthic habitats, including channel sediments, with narrower bands of fringing inter-tidal and sub-tidal shoals. Higher organic carbon loading and light attenuation would result in an overall dominance of detrital foodchains. Benthic productivity may still be significant in littoral zones and may influence biogeochemical processes in these areas.

Significance - Biogeochemical functioning and nutrient recycling within this zone has direct implications for overlying and downstream pelagic processes, due to the potential control over the availability of limiting nutrients. Secondary productivity is undescribed for this zone.

Threats

- Turbidity and phytoplankton blooms associated with point and diffuse sources will lower the relative importance of benthic production and cause a shift towards the detrital pathway.
- Smothering of benthic communities may occur regularly due to the deposition iron and aluminium hydroxide floccs.

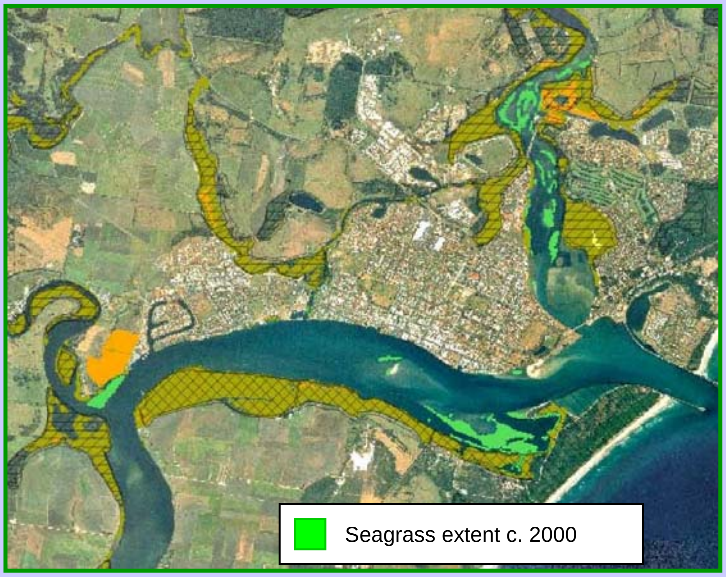
Ecological Processes – Seagrass

Overview

Seagrass is of limited extent in the Richmond River and is concentrated in the lower estuary, with current estimates of total seagrass area at 32 hectares in 2000 . The most common and visible species is *Zostera muelleri* subsp. *capricorni.* Seagrass range is generally limited by light availability in river-dominated estuaries, and this is likely to be the case in relative turbid systems like the Richmond River estuary. Within the photic zones, the stability of the substrate and the energy of water movement are the likely limiters.

Processes driving spatial and temporal variability -

Seagrass is temporally and spatially variable over ecologically short time frames, primarily driven by clarity of water and/or the stability of the habitat. Seagrass patterns can be spatially variable even within a suitable area of estuary due to natural processes such as the migration of channels, and sediment changes associated with flood scouring and deposition. Monitoring seagrass can benefit from a fine scale approach to stand dynamics, as well as estuary wide indications. In addition, small patches can be assessed, which would be lost with coarser mapping scales. Further, the variability of seagrass over ecologically short time frames means that relatively frequent assessment is valuable if the aim is to determine 'normal' flux, as opposed to the impact of particular actions.



Current status in the Richmond

- There are strong indications that seagrass is relatively stable in the Richmond River estuary, although there is likely to be flux in individual patches. The training of the entrance has stabilised some of the hydrological and geomorphological variability of the lower estuary barrier system in historical times and this may have led to the relative stability of some seagrass patches.

- Overall temporal trends in seagrass distribution between 1942 and 2000 have recently been assessed, although incomplete mapping from 1942 means only changes from 1986 to 2000 are given. The minor decrease (2.9%) during this period is likely to be natural variability or mapping error, so can not be taken as an indicator of trends in seagrass extent.

- Major patches at Mobbs Bay are relatively stable, but areas in North Creek are more dynamic, with an increase from 1942 to 2000. The relative stability of seagrass distribution at Mobbs Bay is likely to relate to the influence of the training walls, although there are geomorphic changes occurring in this area which may change flow patterns in the future.

Significance

- Seagrass has numerous ecological values, particularly contributions to primary productivity, habitat for biota and stabilising sediments. Seagrass in the Richmond is particularly important as fisheries habitat (for spawning, nursery, shelter and feeding) with 27 fish species captured in seagrass areas of the lower estuary (Gray ref).

- While the limited extent of seagrass in the Richmond River limits its overall contribution to estuarine processes and production, its 'rarity' adds to the significance of the individual areas present now or in the future and all seagrass should be considered as high value vegetation.

- Generally, larger patches will contribute larger values, but association with other habitats may also be of significance. For example, the relatively large patch in Mobbs Bay is close to valuable mangroves and mud flat habitat and this proximity may provide some particular interactions, such as migration of fish and other biota on the tidal cycles from seagrass to mangrove on the high tide and the reverse on the low tide. Other interactions are likely in other situations in the estuary.

Threats

- Poor water quality (specifically the frequency of high turbidity runoff)
- Direct removal through dredging or indirect impact through changes in hydrology or geomorphology (as possibly identified for the Broadwater area).
- Nutrient impact is not likely to be greatly significant in the Richmond River due to the short flushing times in the lower estuary preventing eutrophication.
- Any sea level rise is likely to at least shift seagrass vegetation, given the colonising ability of *Zostera* and perhaps other taxa. Changed climatic conditions may have an influence (e. g. more prolonged drought may encourage greater seagrass extent through clearer water). Whether there will be net gain or loss is unclear, but it is important to aim to maintain the potential for shifts in distribution across shallow water habitats.

Ecological Processes – Mangroves and saltmarsh

Photo N. Wilson

Overview

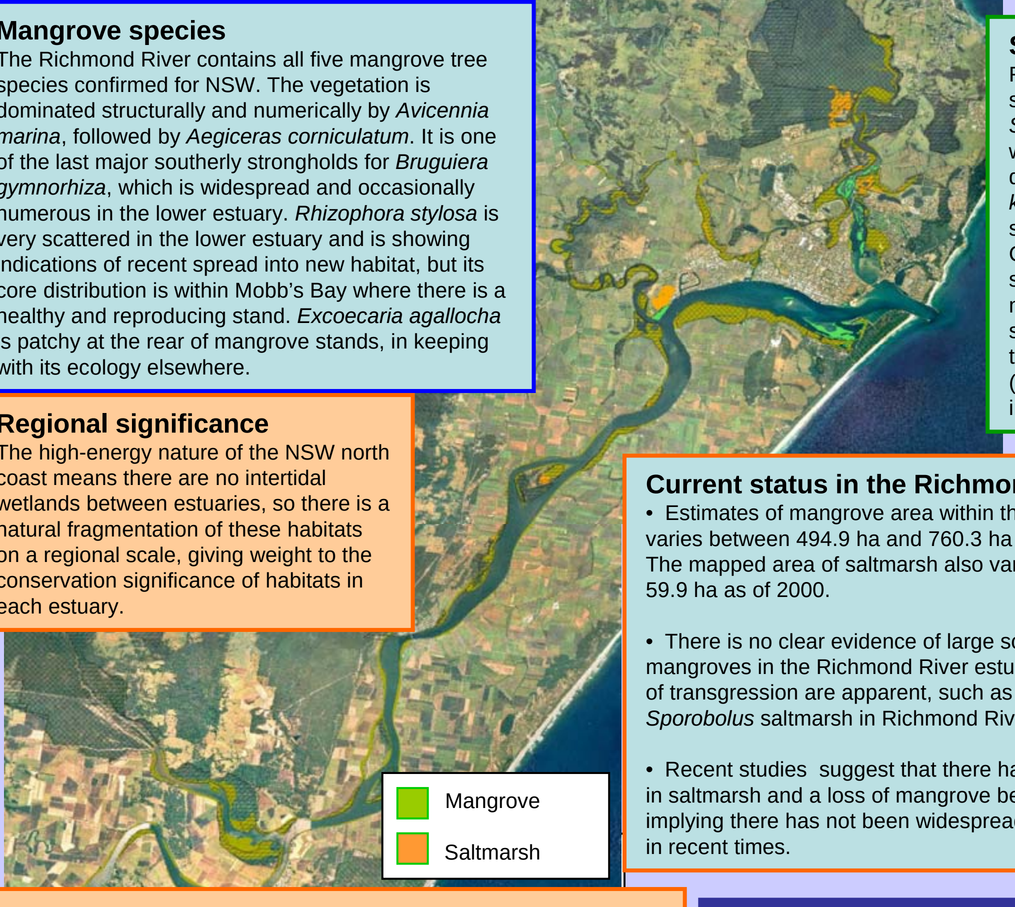
Mangroves are forested intertidal wetlands, whilst saltmarshes are intertidal wetlands made up of non-woody plants such as grasses, herbs, rushes and sedges. The major control on mangrove and saltmarsh distributions is the extent of the intertidal region, with saltmarshes dominating at higher elevations. The intertidal zone is relatively limited in mature barrier estuaries in micro-tidal regions. However, mangrove vegetation in the Richmond River estuary is widespread and of relatively large area for NSW estuaries as a result of the estuary's relative size, although the degree of infilling (maturity) restricts the area of mangroves on the main channel from the mid to upper estuary. The colonising ability of *Avicennia marina* and *Aegiceras corniculatum* in particular mean that even very limited areas of suitable habitat are occupied.

Mangrove species

The Richmond River contains all five mangrove tree species confirmed for NSW. The vegetation is dominated structurally and numerically by *Avicennia marina*, followed by *Aegiceras corniculatum*. It is one of the last major southerly strongholds for *Bruguiera gymnorhiza*, which is widespread and occasionally numerous in the lower estuary. *Rhizophora stylosa* is very scattered in the lower estuary and is showing indications of recent spread into new habitat, but its core distribution is within Mobb's Bay where there is a healthy and reproducing stand. *Excoecaria agallocha* is patchy at the rear of mangrove stands, in keeping with its ecology elsewhere.

Saltmarsh species

Relatively dry saltmarsh sites are dominated by *Sporobolus virginicus*, while wetter sites can have dense stands of *Juncus kraussii* on a more peaty sediment (e.g. North Creek). Rainfall is a significant contributor to moisture on *Juncus* saltmarshes and retaining this water is a critical factor (rather than more frequent inundation).



Regional significance

The high-energy nature of the NSW north coast means there are no intertidal wetlands between estuaries, so there is a natural fragmentation of these habitats on a regional scale, giving weight to the conservation significance of habitats in each estuary.

Current status in the Richmond

- Estimates of mangrove area within the Richmond River estuary varies between 494.9 ha and 760.3 ha depending on author. The mapped area of saltmarsh also varies between 9.9 ha and 59.9 ha as of 2000.
- There is no clear evidence of large scale transgression of mangroves in the Richmond River estuary, however small areas of transgression are apparent, such as onto well developed *Sporobolus* saltmarsh in Richmond River Nature Reserve.
- Recent studies suggest that there has been an overall net gain in saltmarsh and a loss of mangrove between 1986 and 2000, implying there has not been widespread mangrove transgression in recent times.

Mangrove significance

Mangrove is valued as a unique vegetation in itself, contributes to estuarine productivity (especially via detrital pathways), and provides habitat for biota. Recent investigations are revealing perhaps unpredictable details of the interactions and habitat use of mangroves, such as mammalian herbivory, including by possums and the local heavy herbivory on *Rhizophora stylosa* by Swamp Wallabies at Mobbs Bay.

Mangroves support a large number of insectivorous bird species and some nectivores. A large number of tree hollows in old *Avicennia marina* in the lower estuary appear to be utilised by birds and possibly micro-bats.

Threats to mangroves

- Clearing
- Altered hydrology via the construction of agricultural drains including the deposition of spoil affecting local flow patterns
- Permanent bunding holding water in mangrove areas,
- Stock browsing on *Avicennia marina*
- Die back, possibly related to factors such as Phytophthora invasion or agricultural chemical input
- Sea level rise or other symptoms of climate change that are beyond the capacity of the vegetation to adapt

Saltmarsh significance

Saltmarsh provides habitat for unique flora and other biota (including invertebrates, birds, itinerant fish, and mammals such as wallabies and kangaroos). Saltmarsh also contributes to estuarine productivity; for example, large exports of crab larvae have been observed on the ebb tide from a NSW temperate saltmarsh, with large numbers of larvae consumed by itinerant fish feeding on the saltmarsh at high tide.

Threats to saltmarsh

- Infilling ('reclamation')
- Structures that exclude tidal flow onto saltmarshes
- Mangrove transgression
- Increasing tidal flow onto saltmarsh areas
- weed invasion in drier saltmarsh areas
- Localised effect of stock trampling
- 4WD use across saltmarsh areas

Ecological Processes - Benthic invertebrates

Overview

Benthic invertebrates are organisms such as polychaete worms, yabbies and bivalves living within or on the surface of the sediments. Populations and diversity are highly dynamic both spatially and temporally, reflecting relatively short life cycles and the extremely variable nature of the estuarine environment.

Physical and biological controls - Salinity, water temperature, flow velocity and sediment properties all influence spatial variation in benthic species composition between estuarine zones, while flow velocity and frequency of high flow events are the primary influences on temporal variability. A large proportion of the variation in species composition is also likely due to factors such as biological interactions (recruitment, predation, mortality).

Diversity and abundance - The marine and fluvial deltas provide a wide diversity of habitats associated with complex micro-topographical and vegetation features, whereas the riverine channel has comparatively lower habitat diversity. As such, diversity declines along the Richmond River estuarine gradient, typical of trends observed in other estuaries of a similar type (i.e. non-barrier estuaries). Abundance does not follow this trend, with higher abundances generally recorded in the mid estuary compared to the lower estuary. The observed spatial trend for diversity is likely to relate to a combination of variation in physiological tolerances of benthic species to salinity, the extent to which hydrological processes and larval motility influence colonisation of benthic habitats in different parts of the estuary, and differences in drivers of trophic structure between estuarine reaches. Abundance is likely to be linked to factors affecting productivity rates, particularly the sources and supply rate of organic carbon.

Lower estuary

Assemblages in the lower Richmond estuary tend to have a more stable (or consistent) species composition. Reasons for this include the quicker recovery of habitat conditions after floods or black water events due to greater tidal exchange, the fact that sandy habitat fauna in the lower estuary are more well adapted to hydrological disturbance to their habitat compared to muddy sediment fauna and, the potential influence of habitat modification by keystone species on species composition. Important keystone species in this reach include the ghost shrimp (*Trypaea australiensis*), soldier crabs (see photo), and mangrove crabs. Bioturbation causes the rapid turnover of benthic microalgae production in sub- and inter-tidal shoals resulting in little accumulation of organic matter in these shoals.

Middle to upper estuary and tidal pools

Higher rates of organic matter supply in these reaches result in a higher abundance of polychaete species and lower overall diversity (although no information exists on benthic communities within the tidal pools). Bioturbation by benthic invertebrates in these reaches significantly influence the breakdown rates of organic matter and also reduce the accumulation of MBOs in sediments.

Tuckean Broadwater

The Tuckean Broadwater benthic assemblage is consistently more variable and distinct from those in the main channel. This may indicate chronic impacts of ASS runoff, or alternatively differences in the geomorphology, habitat conditions and ecological maintenance processes (in particular nutrient cycling process) in the Broadwater compared to that of benthic habitats in the main Richmond estuary. High organic matter supply from the Cape Lily can overwhelm benthic communities resulting in reduced diversity and the build-up of MBOs.

Ecological significance

Benthic invertebrates are an important link between benthic and pelagic environments along the estuary, influencing rates of organic matter mineralisation, biogeochemical cycling of nutrients, and promoting the flow of energy from benthic production and detrital pathways up the foodchain to fish and bird species. Benthic invertebrates can be regarded as a fisheries resource in their own right.

Photo A. Webb

Threats to benthic invertebrates

- **ASS runoff events** have been shown to influence benthic community structure in the Tuckean Broadwater.
- **Bait collection** of soldier crabs, ghost shrimps and worms (particularly the 'bloodworm') from intertidal areas in the lower estuary.
- **Impacts of water abstraction / regulation** on environmental flows in the Richmond River catchment causing modification of food sources and supply, and planktonic recruitment of larval benthic taxa in different parts of the estuary
- **Increased sedimentation** with potential loss of diversity in benthic fauna through depletion of suspension feeding species and of taxa susceptible to burial (sediment overburden)
- **Loss of seagrass and mangrove habitat**, leading to a reduction in overall ecosystem diversity due to loss of taxa associated with these habitats, and also a reduction in organic carbon food supply to foodchains in adjacent un-vegetated habitats. Resultant decreases in benthic productivity could have a cascading effect on higher order trophic levels and fisheries values in the estuary.
- **Bridge and road construction** in areas adjacent to the estuary.
- **Impacts of heated effluent discharge** from the Broadwater Sugar Mill on adjacent benthic communities.
- **Pesticide/herbicide** application to agricultural crops in the area.

Ecological Processes - Fisheries

Photo S. Schultz

Overview

Richmond River estuary has regionally important commercial and recreational fisheries. Commercial fishers target a wide range of species although four species represent approximately 87% of the total catch (1997-2004): Mullet (51% of catch), school prawn (27.5% of catch), Long-finned eel (4.8% of total catch), and Luderick (3.7% of total catch).

Fishery habitat in the Richmond estuary

The Richmond River estuary contains a suite of habitats that are utilised by species of direct fisheries value. The use of different habitat types can vary depending on the stage of the life-cycle. For example, juvenile mullet are commonly found in freshwater reaches of tidal creeks and around shoals, whereas adults are more common in river channel habitats. Other species only occupy estuaries during their juvenile phase, such as king prawns, snapper and tarwhine, whereas other species, such as Australian bass, migrate from their primary freshwater habitat into the estuary to spawn. Species such as school prawns, luderick, yellowfin bream, flathead and whiting spend most of their life-cycle in estuaries, only moving to nearshore areas to spawn.

Vegetated wetland habitats (i.e. mangroves, seagrass, saltmarsh) are utilised by many fish species of direct commercial and recreational fisheries value, particularly as juveniles. It is generally thought that intertidal vegetation provides a 'nursery' function, with the complex vegetative structures providing shelter from predators. In terms of these key harvested species, Dusky flathead is the only species that spawns in seagrass, although it is also known to spawn in a range of shallow water habitats. Other species such as garfish produce eggs with an adhesive filament that can adhere to seagrass.

Protection of fisheries habitat values

There are many factors that may influence the functional values of a particular habitat patch to fisheries, including spatial distribution and configuration of different habitats (e.g. distance between seagrass beds, mangroves and shoals), spatial characteristics of the habitat patch (i.e. location, shape, surface area or volume), and many other (frequently inter-correlated) environmental conditions.

Although large seagrass beds and mangrove forests are thought to represent important fisheries habitats, it is also apparent that most species spend part of their life-cycle in a wide range of habitats. Hence it is important to consider fisheries management at spatial scales greater than a habitat patch. There is a need to advance process-based approaches to better define important habitats in the estuary.

Threats to fisheries values

- **Habitat modifications**

Flood mitigation works (wetland draining, floodgate construction, de-snagging), catchment clearing, and seawall construction. The loss of large sections of the Tuckean wetlands has been cited as a major factor resulting in loss of fisheries productivity in the estuary, although no empirical studies have tested this.

- **Acid sulfate soil runoff (ASSR)**

Flood mitigation works have exacerbated ASSR resulting in acute impacts (e.g. mass mortality of fish and other gilled organisms following flood events) and chronic impacts (e.g. persistent acidification of key fisheries habitat such as the Tuckean Broadwater).

- **Blackwater runoff**

Drainage of anoxic floodwaters (blackwater) from inundated backswamps can cause mass fish kills

- **Barriers to fish passage**

Instream structures result in habitat isolation and fragmentation, by preventing movements between estuarine and freshwater environments (except in some cases during high flow events).

- **Flow modifications due to abstraction / regulation**

Freshwater inflows are important drivers affecting estuarine fish and invertebrate ecology

- **Fishing pressures**

Commercial and recreational fishing pressures in the broader Tweed/Richmond River region are relatively high. The impact of fishing pressures on fisheries resources is not well understood and requires further investigation. It is likely that pressures will increase in the future, in line with predicted regional growth in tourism and urban expansion.

Habitat usage during different stages of life cycle

Species	Estuary					Coastal / oceanic		
	mangrove	seagrass	shoals	channel	freshw.	inshore	offshore	reef
Dusky flathead	J	S J A	S J A	A		S		
Sand whiting	J	J	J A	J A		S		
Tailor		J A	J A	J A		S J A		
Yellowfin bream	J	J A	J A	A		S		A
Mulloway				J A		S		
Bully mullet			J	J A	J		S	
Luderick	J	J		A		S		A
Long-finned eel		A	A	A	J A		S	
Blue swimmer crab				J A				
Mud crab	J A		J				S	
King prawn		J	J	J			S A	
Greasyback prawn			J A	J A		S		
School prawn			J A	J A			S	

J = juvenile; A = adult, S = spawning

Regional significance

The Richmond River is the seventh largest (by surface area) estuary in NSW (19.73 km2), with the fifth largest finfish catch in the region. In general, large estuaries have higher abundances of fauna than smaller estuaries, however differences in evolutionary stage give rise to distinctly different habitat opportunities. Infilled barrier estuaries such as Richmond River which tend to have high mangrove cover but low seagrass extent, have different fish communities than immature (non-infilled) estuaries with a high extent of seagrass and but a lower extent of mangroves.

Changes since European settlement

Land clearing

70% of the land around the estuary has been cleared. There is currently little native forest remaining, with most large remnants restricted to steep slopes or heathlands. Very little remnant vegetation occurs on the floodplain areas adjacent to the estuary.

Impacts of clearing

- Loss of vegetation and associated fauna species has reduced the biodiversity values
- Fragmentation of habitats has compromised the long-term viability of remnants as vegetated “movement” corridors to fauna species
- Increase sediment / nutrient loads to the estuary
- Changes in morphological (erosion, accretion) processes within the estuary.

Flood mitigation and wetland drainage

The naturally swampy floodplain has been extensively drained via complex networks of drainage channels and floodgates. At present there are 391 floodgates in the Richmond River Community Flood Mitigation System and many more private gates

Impacts of drainage structures

- Lowering of water-tables and preventing the ingress of river waters
- Shifts from wetland vegetation species to vegetation intolerant of waterlogging
- Increase in blackwater runoff events
- Exposure of acid sulfate soils, and increase in chronic and acute impacts to aquatic biota
- Loss of swamp and estuarine wetland habitat
- Loss of connectivity between riverine and floodplain habitats
- Loss of agricultural land due to scalding by ASS.

Urbanisation

While urban areas account for only 2% of the land around the Richmond River estuary, the urban growth rate is rapidly increasing. The population of Lismore City, Ballina and Richmond Valley Shires now exceeds 100,000 and future urban expansion will be necessary to accommodate projected increases in population.

Impacts of urbanisation

- Removal of habitat for urban subdivisions
- Increase stormwater runoff and treated effluent discharges
- Increase demand for water supply, sewerage and road infrastructure
- Development and maintenance of canal estates has resulted in habitat losses and poor water quality in and adjacent to canals.
- Increased levels of waterway use and impacts associated with this use

Training walls

Much of the lower estuary, including the entrance, has been rock lined to stabilise shifting channels and maintain navigation. Most of the works were carried out in the late 1800s, when timber was transported by boat from the river to Sydney and other destinations. Refer to Sediment Processes (page 3) for details on the impacts of training walls.

Agriculture

Most of the cleared and drained lands are utilised for cattle grazing or sugar cane production.

Impacts of agriculture

- Loss of catchment soils via increased erosion results in larger loads of sediment and nutrients entering rivers and estuaries;
- Ongoing physical disturbance to catchment lands and riparian areas by stock, resulting in stream bank erosion and modifications to sedimentation processes
- Increasing pollutant levels (nutrients, sediments, pesticides) in catchment runoff and shallow groundwater aquifers.

Cultural values

Photo M. Wood

Wardell Bridge

Photo WBM Oceanics

European cultural values

The Richmond River estuary also contains a wide variety of European cultural heritage items owing to the rapid changes in key industries such as forestry and agriculture and the associated transportation networks development to support the industries, i.e. shipping and then rail. There are many listed heritage items, which occur around the urban centres, e.g. heritage buildings. Similarly as for Aboriginal heritage items, European heritage items are recorded in various registers and protected by various laws. Ongoing studies aim to improve the accuracy and quality of listed European heritage sites.

Aboriginal cultural values

The traditional owners and custodians of the study area are the Bundjalung and Widjabul peoples. There are currently four Native Title Claims covering approximately 90% of the study area currently being assessed.

The Richmond River estuary is very important to the local Aboriginal communities. Estuaries and other coastal lands were and are still of major economic, spiritual and cultural importance. Given the long period of Aboriginal use of the land there are numerous sites around the Richmond River estuary that are of Aboriginal heritage significance. All levels of Government maintain registers of important sites, which are then afforded varying levels of protection under current legislation. Ongoing studies aim to improve the Aboriginal heritage listings within the Richmond River catchment.

Key Issues - Cultural values

- Satisfactory resolution of Native Title and Land claims
- Incomplete cultural heritage studies
- Timely adoption of cultural heritage sites and artefacts into the appropriate registers to ensure their long-term preservation
- Protection of cultural and heritage items and sites from future activities (e.g. land clearing or foreshore works) occurring around the estuary.

Current human usage

Land Use

Most of the estuary, particularly the upper and middle reaches, has been degraded by past catchment clearing, poor land management and changes to natural flooding and drainage regimes as a result of physical works and structures. This has altered catchment inputs to the estuary and has resulted in dramatic changes to many estuarine processes. Based upon 1996 land use mapping data the study area consisted of the following primary land uses:

Grazing or grasslands – 54%
Forested lands – 26%
Cropping – 11.2%
Waterbodies – 5.3%
Urban – 1.8%

Current land use planning as dictated by the Local Environmental Plans (LEPs) of the local Council's is typically supportive of these current land uses with the vast majority of the study area being zoned for various forms of agricultural use (approximately 75%).

Key Issues - Landuse

- Agricultural land uses and management practices (i.e. cropping, grazing and horticulture) in the study area are impacting significantly on key estuarine processes via elevated concentrations of sediment, pathogens, nitrogen and phosphorus in catchment runoff.
- Drainage management practices are having significant impacts on estuarine water quality and ecological processes due to the drainage and oxidation of ASS, alteration of wetland hydrology, alteration of fish passage, and the exacerbation of "blackwater" runoff.
- Existing urban developments (and associated infrastructure) are impacting on key estuarine processes primarily due to high pathogen and nutrient concentrations in treated effluent and stormwater discharges.
- Limited coverage and poor condition of a significant portion of the estuary's riparian zone. Livestock have unlimited access to the waters edge in some areas, and the absence of riparian vegetation in certain locations is thought to be contributing to active bank erosion.
- Land use mapping data is 10 years old and there are reported to have been significant changes in key landuses such as cropping and horticulture in recent years
- Ensuring the soon to be updated Local Environmental Plans contain sufficient provisions and planning to provide an adequate level of protection to the estuary.

Waterway Use

Most boating carried out in the Richmond River estuary is for recreation, and numbers of recreational boats have increased in recent years. Commercial usage of the estuary also occurs, mainly for the purposes of oyster farming, commercial fishing and tourism.

Bow waves (wake) from boats can result in erosion of riverbanks, although there are many other factors that can cause bank erosion. Some speed-limited areas have been established in areas of significant bank erosion, however, compliance with such restrictions is an issue to be addressed. Areas of sensitive foreshore vegetation are generally unprotected from boat wake.

There is limited boat usage in the upper estuary. Bank erosion in these upper sections is likely to be caused by high velocity flood flows and exacerbated by a lack of riparian vegetation and cattle grazing of the riverbanks. Most historic bank erosion up to Wardell has been stabilized by rock protection.

Key Issues - Waterway use

- Lack of adequate boating facilities and associated facilities, e.g. parking, mooring, marina berths, etc in the lower estuary
- Lack of a holistic Richmond River Estuary Recreational Boating Plan that extends over the entire estuary (compilation of such a plan may require the collection of usage data)
- Potential concentration of boating activities in the lower estuary
- Lack of facilities for small recreational vessels such as kayaks
- Lack of knowledge in relation to existing the location (and types) of usage conflicts (on water and on land)
- Limited protection of sensitive ecological communities in the estuary, e.g. seagrass and saltmarsh communities
- Lack of information in relation to appropriate boat speeds in various sections of the estuary (appropriate boat speeds will not produce a wash that exceeds wave energy criteria specific for the banks of the Richmond and consequently will not erode the banks).

Foreshore Land Use

In addition to agricultural land uses described above, many licences and leases have been granted for the purposes of cattle grazing and access on foreshore Crown Land, particularly adjacent to the mid to upper reaches of the estuary. Unless fenced and setback from the riverbanks, cattle access to foreshores can have significant impacts on riparian vegetation, bank stability and water quality.

Although some 188 foreshore structures (including jetties, wharves, boatsheds, boat ramps, pontoons and slipways) are currently licenced, there is an unknown number of unlicenced foreshore access points to the estuary. Informal access can degrade foreshore habitats and destabilise riverbanks.

Key Issues - Foreshore use

- Review the conditions and appropriateness of existing Crown licences and leases for cattle grazing within the riparian zone along the estuary
- Review the licensing status of existing foreshore structures

Economic drivers

Overview

Economic drivers are important considerations as they influence land use decision-making and other factors affecting estuarine use.

Photo WBM Oceanics

Fisheries

Restricted commercial fishing is carried out in the Richmond River estuary. The effort and commercial catch of fish from the river has reduced in recent years, partly due to the impacts of the 2001 fish kill and also the buyout of a number of existing commercial licences. Despite this, the industry has significant local economic and social importance.

Recreational fishing is also a significant social and economic driver in the estuary. There is a relatively large percentage of fishers who maintain high participation rates, compared to Statewide averages. Recreational fishers mostly target flathead, bream, whiting, tailor and luderick. The total recreational fish catch in NSW is about 30% of the commercial catch (by weight), however, for six prominent recreational species, greater numbers are taken by recreational fishers than commercial fishers.

Declining fish stocks can result from numerous factors, including:

- Habitat destruction over broad regional scales;
- Habitat destruction at local (within estuary) scales;
- Direct loss of fish stocks due to both commercial and recreational fishing
- Declines in estuary condition or ecosystem processes

Key Issues - Fisheries

- Incomplete understanding of the potential impacts of waterway obstructions on fish migration patterns and habitats
- Incomplete understanding of factors contributing to declining fish stocks within the estuary
- Poor understanding within the recreational fishing sector of the Estuary General Fishery EIS and Fisheries Management Strategy and the controls it places on commercial fishing
- Poor understanding of the potential impacts of the recreational sector on populations of key estuarine species

Agriculture

Agriculture is a major driver of the local economy, employing approximately 10% of the working population in the North Coast Region (includes Byron, Ballina, Richmond Valley, Lismore City and Kyogle Shires). Local forms of agriculture include cattle grazing, sugar cane cropping, and horticulture. The farm gate value of agricultural production in the North Coast Region was estimated in excess of $650 million (for the year 2000). In addition to this, the “add-on” value of agricultural-based industries contributed a further $1 billion to the regional economy. Current agricultural practices in the study area do not interact with the estuary as much as they did in bygone times, e.g. shipping of timber and sugarcane, etc. However, the freshwater sections of the estuary (i.e. the tidal pool) are a valuable source of water to the agricultural industry.

Key Issues - Agriculture

- Promotion and support of economically and environmentally sustainable agricultural industries (and practices) within the region and study area.
- Development and adoption of best-practice management for ASS, floodplain grazing, floodplain drainage and floodgate structures.
- Development and adoption of best-practice management for native remnant vegetation on agricultural land

Oyster Aquaculture

The Sydney rock oyster is grown and harvested within the Richmond River. Commercial production records for the Richmond River extend back to the 1930’s. Currently there are ten commercial oyster leases that occupy approximately 20ha of waterway area. The farm gate oyster sales of the Richmond River estuary oyster industry are estimated to be around $200,000/year (which is about 0.5% of the State industry income).

The Richmond River estuary is presently being classified by the NSW Food Authority as part of the Shellfish Quality Assurance Program (SQAP). Water quality concerns in North Creek are likely to prevent harvesting from this area in the future. QX disease is present and active within the estuary and was cited for causing a 70% oyster mortality rate from a recent harvest.

Key Issues - Oyster industry

- Presence of QX disease, and general lack of understanding of triggers for QX and how it may be controlled
- Loss of the North Creek harvest areas and its effect on the viability of the Richmond River oyster industry
- Poor water quality (particularly faecal coliform levels) in oyster harvest areas resulting in extended harvest closure periods (typically around 9 months of the year).

Tourism

Tourism and recreation are also major economic drivers for the North Coast Region. Outdoor recreation and sports (e.g. swimming, fishing, boating, etc) are popular activities, particularly in the lower estuary near Ballina. The value of tourism to the North Coast Region is estimated at $646 million, and supports some 6000 jobs. Tourism has been identified as a priority industry for the North Coast Region.

Key Issues - Tourism

- Promotion and support of economically and environmentally sustainable tourism industries (and practices) within the region and study area.
- Actively support fisheries habitat protection and rehabilitation

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References

Ferguson, A. and Eyre, B. (1995) Local and Regional impacts of acid sulphate soil runoff in the lower Richmond River catchment. Report to Department of Land and Water Conservation. Southern Cross University.

Hashimoto, T. R., Saintilan, N. and Haberle, S. G. (2006) Mid-Holocene Development of MangroveCommunities Featuring Rhizophoraceae and Geomorphic Change in the Richmond River Estuary, New South Wales, Australia. *Geographical Research* **44**(1): 63-76.

Glossary

Acid sulfate soils (ASS) – Holocene soils occurring in low lying floodplain areas with high concentrations of iron pyrite, formed as the by-product of sulfate reduction. ASS formed approximately 7000-3000 years before present when post-glacial sea levels reached their current level creating vast intertidal mangrove swamps.
Algal bloom – the rapid growth of phytoplankton resulting in a high biomass in the water column.
Ammonium – inorganic nitrogen compound ($NH4^+$) readily available to marine plants for growth.
Anoxic – an oxygen-free environment.
Antecedent – preceding the present
Anthropogenic – any phenomenon caused by human activities.
Autotrophic – refers to organisms that are able to fix carbon dioxide to form organic matter (e.g. plants and algae). May also refer benthic community metabolism (see also Benthic community metabolism).
Benthic – belonging to the bottom, or sediments, of the estuary.
Benthic community metabolism – refers to the sum of metabolism by all benthic plants and animals over 24 hours, e.g. benthic community metabolism may be net autotrophic (production of organic matter by algae exceeds breakdown by bacteria), or alternatively net heterotrophic (breakdown of organic matter by bacteria exceeds production by algae).
Benthic fluxes – exchange of nutrients and gases between the sediments and water column.
Benthic microalgae (BMA) – microscopic algae living in the surface sediments.
Biochemical oxygen demand (BOD) – a measure of the amount of oxygen that will be consumed by biological and chemical processes over a given time period (usually 5 days).
Bio-available – Nutrient forms (usually inorganic) available for plant growth
Biomass – The living weight of plant or animal material (organic matter).
Blackwater – A collective term used to describe low oxygen floodwaters emanating from backswamp areas.
Chlorophyll-a – The green pigment in plants used to capture and use energy from sunlight to form organic matter (see photosynthesis). Concentrations of chlorophyll-*a* are used as an indicator for phytoplankton and benthic algae biomass.
Denitrification – the reduction of bio-available nitrate ($NO3^-$) to unavailable nitrogen gas (N_2) by bacteria.
Detrital – Foodchain based on organic carbon deposited from outside the system
Dissolved inorganic nitrogen (DIN) – the total of all inorganic nitrogen compounds; ammonium ($NH4^+$) + nitrite ($NO2^-$) + nitrate ($NO3^-$). DIN is recognised as the most bio-available form of nitrogen used by plants for growth.
Dissolved inorganic phosphorus (DIP) – the most bio-available form of phosphorus. Also known as phosphate (PO4+), reactive phosphorus, or dissolved reactive phosphorus (DRP).
Ecosystem – refers to all the biological and physical parts of a biological unit (e.g. an estuary, forest, or planet) and their interconnections.
Eutrophication – the process of nutrient enrichment of a water body resulting in the increase in plant biomass (algal blooms) and bacterial decay (heterotrophic activity). Often results in a reduction in species diversity, visual amenity, and the prevalence of toxic algal species.
Foodchain – the predator / prey interactions of an ecosystem component
Foodweb – foodchain interactions of the whole ecosystem.
Freshwater flushing time – the time (in days) that freshwater stays within an estuary before being transported to the sea by advection and tidal mixing.
Grazing – the eating of plants (e.g. phytoplankton) by animals (e.g. zooplankton).
Heterotrophic - refers to organisms that source their energy from the breakdown of organic carbon (e.g. bacteria, humans). May also refer benthic community metabolism (see also Benthic community metabolism).
Hypoxic – critically low concentrations of dissolved oxygen
Light attenuation – the absorbance of sunlight by dissolved and particulate matter in a water body.
Monosulfidic Black Ooze (MBO) – An iron sulfide compound formed as a by-product of sulfate reduction. MBOs commonly form in environments with high organic matter supply and have a high chemical oxygen demand.
Nitrate – an inorganic nitrogen compound ($NO3^-$).
Nitrification – the oxidation of ammonium to nitrate by bacteria.
Nutrient budget – a simple model quantifying nutrient loadings (by weight) to a waterway from different sources over a given time period (e.g. one year).
Nutrient limitation – the restriction of phytoplankton growth by the low concentration (availability) of a nutrient.
Oxygen saturation – the maximum concentration of oxygen that can be dissolved in water at a given temperature and salinity.
Pelagic – belonging to the water column.
Phosphate – see dissolved inorganic phosphorus.
Physico-chemical – basic water quality parameters
Phytoplankton – microscopic single-cell plants growing in the water column.
Primary production – the formation of organic matter by autotrophs (e.g. phytoplankton).
Pristine – undisturbed by human activities such as urban and agricultural development, pollution, erosion, weed infestations etc.
Redfield ratio – the relative proportions of nitrogen and phosphorus required by phytoplankton for growth.
Secondary production – biomass production of all orders of life higher than plants (i.e. bacteria through to sharks)
Stratification – where there is a distinct difference in salinity (or dissolved oxygen) between the surface and bottom water in the water column of an estuary.
Sulphate reduction – the bacterial breakdown of organic matter in anoxic sediments using sulphate instead of oxygen. Produces hydrogen sulphide, the 'rotten egg gas' smell common in muddy sediments.
Total nitrogen – the total of all inorganic and organic forms of particulate and dissolved nitrogen.
Total phosphorus - the total of all inorganic and organic forms of particulate and dissolved phosphorus.
Turbidity – a measure of the amount of light-attenuating particles in a water body.
Well mixed - where there is a little difference in salinity (or dissolved oxygen) between the surface and bottom water in the water column of an estuary.