Macleay River Estuary & Floodplain Ecology Study

Report to Kempsey Shire Council

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Aquatic Science and Management In association with GeoLINK

DISCLAIMER

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1 Introduction

1.1 Forward

The Macleay Estuary Management Plan is currently under preparation. The plan is a culmination of a number of steps, including a Data Compilation Study (Telfer 2005), an Estuary Processes Study (WMA Water 2009) and an Estuary Management Study (GeoLINK 2010). Prior to the preparation of the Estuary Management Study, a review of the understanding of the Macleay River estuary ecology was undertaken (GeoLINK 2010) that identified a number of areas where improved information would support the preparation of a more targeted and efficient Estuary Management Plan. Kempsey Shire Council, with support of the NSW Estuary Management Program, then commissioned an ecological study which has resulted in the following report.

1.2 The Study Area

The study area is located in the Kempsey Shire Local Government Area located on the mid north coast of NSW approximately 400km north of Sydney. The study area includes the Macleay River estuary and its coastal floodplain. This includes the waterways and all tributaries up to the tidal limit, the entrance, foreshores, floodplain and adjacent land including towns, and the coastline. The study area also includes Back Creek (South West Rocks Creek). The extent of the Macleay River estuary study area is shown in **Figure 1.1** along with the major catchment features.

1.3 Aims

The key aims of this study are to review the state of understanding and provide improved information with respect to the ecology of the Macleay River estuary and its catchment. The following aspects are to be considered;

- *Productivity* – The productivity of the estuary with particular emphasis on the associated floodplain wetlands and the riparian zone and how improved management of these ecosystems may improve the overall estuary health and productivity;
- *Fisheries Resources* – This includes a detailed analysis of the Macleay River estuary general fishery, oyster aquaculture industry and recreational fisheries;
- *Estuarine Habitats* – An analysis of the temporal and spatial dynamics of seagrass, mangrove and saltmarsh habitats and an assessment of aquatic species and habitat associations;
- *Key Threatening Processes* – An assessment of threatening processes that impact upon estuarine ecology and an assessment of key threatening processes operating on the floodplain;
- *High Conservation Value Flora and Fauna Communities* – A review and update of existing information with respect to the floodplain;
- *Habitat Corridors* – Identification of habitat corridors on the floodplain and an assessment of the relevant land use planning controls;

Study area including estuarine waters, major tributaries and key catchment features

- *Sea Level Rise and Climate Change* – Assess the potential effects of current projections for sea level rise and climate change on the estuary and its floodplain;
- *Rehabilitation and Monitoring Efforts* – The aim of this part of the study is to provide an update of rehabilitation and monitoring programs that have taken place since the last review (Telfer 2005). Another key part of the study is to design an appropriate monitoring program to assess the health of the estuary; and
- *GIS resources* – Identify the existing GIS resources and any others that may prove useful for the future management of the Macleay River estuary.

The secondary aim of this study is to consider the management implications of the collected information and to present them in a format that will readily translate into the preparation of the Macleay Estuary Management Plan.

1.4 Summary of Management Options Arising from this Study

The management options developed during the finalisation of this study can be broken up into two broad classes; those that have a direct impact on the management of the estuary and those that relate more to broader floodplain management. A few of the options relate to both.

1.4.1 Management Options Relating to the Macleay River Estuary

Option 2.1: Improve the cover of riparian vegetation on all public foreshore lands

Option 2.2: Continue to encourage private landholders to actively manage the riparian strip by fencing, revegetation and stock access management using education and initiatives

Option 2.3: Improve fish passage and reinstate some tidal flow through the Clybucca, Belmore and Kinchela floodgates through changes to floodgate infrastructure

Option 2.4: Alter the drainage management of the lower Clybucca wetlands to increase the number of landholders with individual control of water levels

Option 2.5: Continue to encourage wetter management of pastures in the Belmore, West Kinchela and Clybucca/Collombatti wetland areas as a means of increasing water retention times and habitat value of floodplain wetlands

Option 2.6: Continue to improve the management of east Kinchela wetland for ecological values

Option 3.1: Reduce sediment inputs from erosion and runoff into the Macleay River

Option 3.2: Aim to improve the quality of floodwater discharges

Option 3.3: Improve the connectivity of aquatic habitats

Option 3.4: Incorporate commercial fishing requirements into the planning approvals process for wharves, jetties and pontoons

Option 3.5: Identify and clean up derelict oyster leases

Option 3.6: Define clear protocols for the reporting of and response to oyster mortality events

Option 4.1: Maintain or improve biodiversity values of local EECs

Option 4.3: Collect information relating to shorebirds

Option 4.5: Further investigate the possibility of establishing a sanctuary zone on the Macleay River estuary

Option 5.1: Continue to monitor the estuarine macrophytes to assess long term trends in habitat availability

Option 5.2: Undertake a control program for *Juncus acutus*

Option 5.3: Continue to monitor the spread of egeria

Option 5.4: Manage listed key threatening processes

Option 7.1: Continue to monitor the distribution and extent of seagrass, saltmarsh and mangrove habitats as a measure of estuary health

Option 8.1: Design and implement monitoring programs for key ecosystems

Option 8.4: Adjust the local planning framework to incorporate sea level rise predictions

Option 9.1: Develop or acquire additional GIS datasets as required

Option 10.1: Design and implement a comprehensive estuary health monitoring program

Option 10.2: Improve the documentation of existing monitoring and rehabilitation programs

Option 10.3: Develop comprehensive plans for the future rehabilitation of riparian and floodplain wetland areas

Option 10.4: Develop and implement a shorebirds study

1.4.2 Management Options that Relate to the Broader Macleay Floodplain

Option 4.1: Maintain or improve biodiversity values of local EECs

Option 4.2: Where possible implement DECCW Priority Action Statements

Option 4.4: Develop a comprehensive conservation plan for the floodplain

Option 5.4: Manage listed key threatening processes

Option 5.5: Manage Landuse Threats

Option 5.6: Manage Wildfire

Option 5.7: Manage Roadkills

Option 5.8: Manage Fencing

Option 5.9: Manage Pest Flora and Fauna

Option 6.1: Maintain and improve habitat connectivity on the floodplain

Option 8.1: Design and implement monitoring programs for key ecosystems

Option 8.2: Design and implement programs to protect and enhance ecosystems and biodiversity

Option 8.3: Identify, protect and enhance wildlife corridors

Option 9.1: Develop or acquire additional GIS datasets as required

Option 10.2: Improve the documentation of existing monitoring and rehabilitation programs

Option 10.5: Develop plans for the management of other high conservation value habitat areas on the floodplain

2 Estuarine Productivity

2.1 Introduction

The productivity of an estuary is a key indicator of its health and ability to support human uses. There are a number of measures of productivity, but in recent years the focus of study has been on the sources of carbon that support the complex food webs that occur within an estuary. The basic primary production of carbon that enters the food chain is either *autochthonous*, ie occurring within the estuarine system via photosynthesis of seagrass, benthic microalgae or phytoplankton, or *allochthonous*, occurring outside the estuary system by upstream macrophytes, riparian vegetation or floodplain wetlands and then imported into the system.

The productivity of the Macleay River system has been greatly reduced as a result of the intensified development and habitation that have occurred within the catchment over the 20th century. Whilst this is an acceptable statement evidence of this reduction is limited and often anecdotal. Some of the evidence that demonstrates the changes is as follows;

- The 14km long midden that follows Clybucca Creek, though formed over thousands of years, indicates the enormous productivity of the system prior to white settlement.
- The reduction in oyster productivity and overall fisheries productivity since the 1970s, despite technological and methodological advances, indicates a system under stress.

The obvious stresses that have caused a reduction in overall productivity are those that have reduced primary productivity in the estuary and in connected ecosystems. Additional causes are those that have affected habitat availability and direct pressures on biota such as pollution and fishing effort. Unfortunately, the aforementioned paucity of evidence for the reduced productivity of the system is accompanied by a lack of information about changes in habitat connectivity, ecological production in general, the role of habitat diversity in the life cycles of individual species and the role of nutrient transformation in providing available and appropriate primary food sources for the biological webs that occur in the estuary.

Massive reductions in the extent and quality of riparian vegetation and the integrity and function of floodplain wetlands have characterized the evolution of the Macleay River system. These changes have occurred for two primary reasons, to secure the people, towns and industry of the lower Macleay Valley against damage from floodwaters and to increase the area of land available to grazing stock. An understanding of how these changes affect the estuary has emerged in terms of acid and black water events, habitat availability, banks stability and hydrodynamics (see WMA Water 2009). It is likely that changes in the dynamics and supply of carbon to the food chains supporting estuarine biota have also occurred as a result but this has received little attention, either on the Macleay River or in similarly affected systems on the north and mid north coast of NSW. Now, as the quality of some of the agricultural land has reduced and the drainage and flood mitigation infrastructure begins to degrade, a pressing question is whether the impacts on the estuary are justified by the benefits of the drainage and flood mitigation system as it currently functions. In answering this question it is important that the relationship between the estuary, its riparian zone and associated wetlands is as well defined as possible. A literature review and summary of the dynamics and supply of carbon to estuarine waters from the riparian zone follows. The information gathered has been used to develop conceptual models, which are also presented.

2.2 Available Information

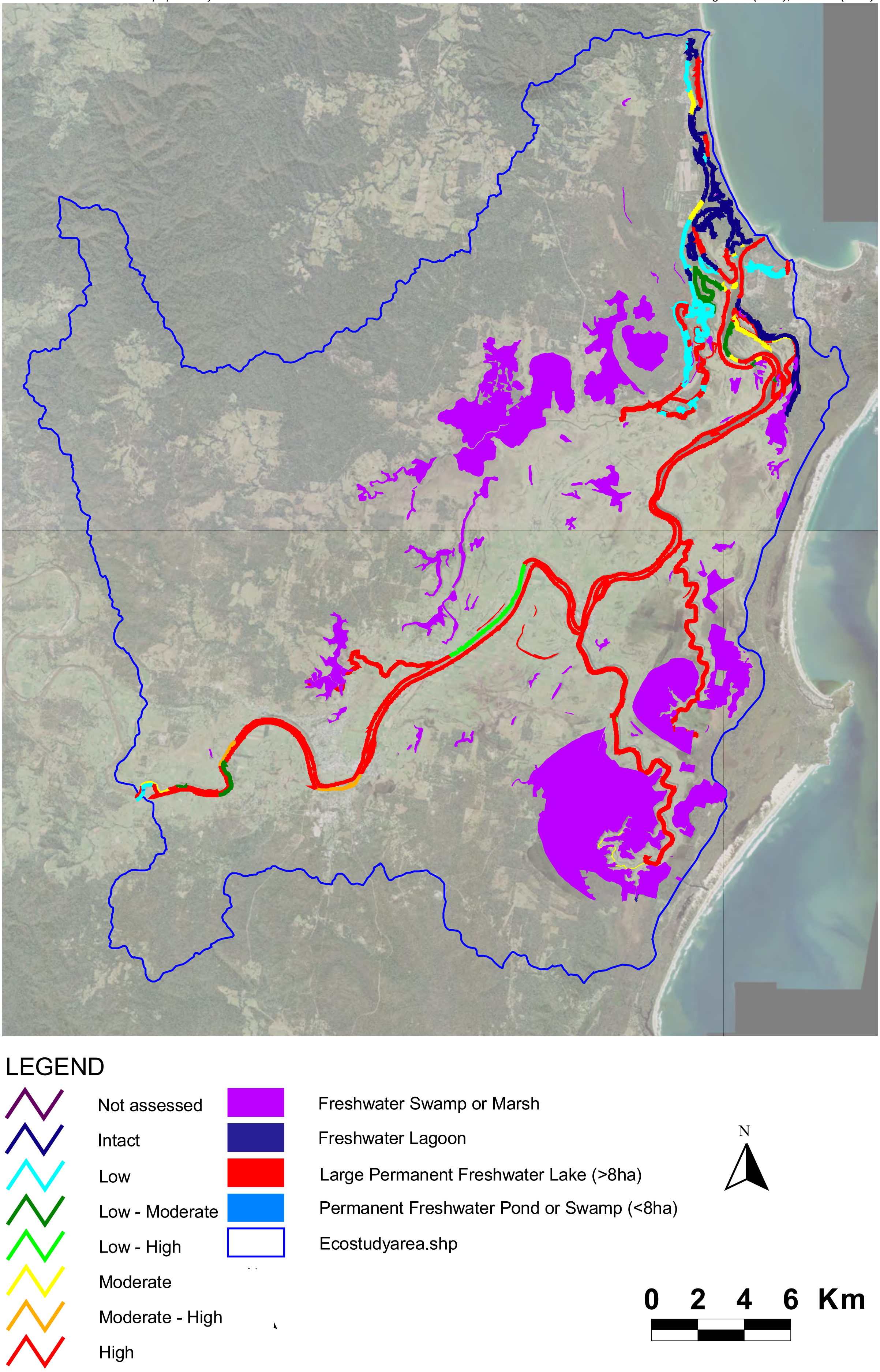
Carbon production was considered in the nutrient budget prepared during the Macleay Processes Study (page 82). The study focussed on production within the estuarine waters (autochthonous production), including production of benthic sediments, phytoplankton production, seagrass production, mangrove production, and the production of macrophyte beds in the upper estuary. The study found that total carbon production of these contributors was 20787 tonnes with benthic microalgae contributing the highest proportion (7792 tonnes) and seagrass contributing the second highest proportion (4888 tonnes including benthic microalgae associated with seagrass beds).

With respect to the contribution of the riparian zone to the total estuary productivity no information specific to the Macleay River exists. In general, most studies dealing with the carbon contribution of riparian zones focus on lower order freshwater streams (eg. Deegan & Ganf 2008), though some international studies have begun to focus in on large estuaries (eg. Sobczak *et al*. 2005, He *et al*. 2010 etc.).

With respect to the contribution of floodplain wetlands to the total estuary productivity no information specific to the Macleay River, to similar large wave dominated barrier estuaries in NSW or even to NSW estuaries in general was encountered during extensive literature searches undertaken for this study. The only information relevant to these fields was contained in reviews of the relatively pristine tropical rivers of northern Queensland (Davis *et al*. 2007) and Western Australia (Douglas *et al* 2005). The applicability of the information collected in studies from the tropics to the Macleay River is questionable, due to the different biological and physical processes governing their ecology. Despite this, many of the underlying ecological principles, such as wetland productivity, species migration and wet and dry cycles apply in both regions.

The current condition and extent of the riparian zone and the floodplain wetlands on the Macleay River floodplain are well described. ID Management (in Telfer 2005) mapped the riparian vegetation along the entire estuary and described it according to vegetation community, native vegetation status, weeds status, disturbance level, vulnerability class, flora and fauna significance and habitat value. The floodplain wetlands have been mapped and classified (Burns *et al*. 2006) and ranked with respect to conservation priority. The maps produced are conspicuous for having overlooked the Frogmore and Kinchella Swamps. Both datasets are depicted in **Figure 2.1**.

The original, pre settlement, condition of both the riparian zone and the floodplain wetlands is described in the diaries of explorer Clement Hodgkinson who travelled up the Macleay River in the 1830s and 1840s.



Condition of riparian vegetation and wetland type and distibution

2.3 Productivity of the Riparian Zone

The riparian zone can be loosely defined as the land that adjoins a waterway. This means different things in different parts of an estuary. On the lower Macleay River estuary, in the mangrove zone, it can be defined as the area of mangroves and saltmarsh and the vegetation immediately landward of them. In the upper estuary it can be defined for the purposes of this study as corresponding with the extent of the alluvial levee, although it would normally also include floodplain wetlands and their margin.

A vegetated riparian zone contributes to a healthy waterway in a number of ways. The benefits of intact riparian vegetation include (Lovett *et al*. 2004);

- *Shading* - this is particularly important in controlling the temperature of upstream waters. In a wide, open estuary like the lower Macleay River, shading would be most important in providing cover for prey species and reducing the cover of light dependent weed species;
- *Erosion control* - well vegetated riparian zones are known to stabilize banks;
- *Provision of Woody debris* – this provides food and habitat for native fish and invertebrate species as well as controlling flows and protecting banks from erosion; and
- *Buffering* - controlling the concentration of nutrients and sediment in catchment runoff.

The extent to which these services are provided depends upon a number of factors, including the width, diversity, integrity and structure of the vegetation present.

In addition to the above ecosystem services, a vegetated riparian zone is also a source of carbon to the estuary in the form of leaf litter, fruit, flowers and stems that find their way into the stream. This input of organic material from outside of the system is referred to as an allochthonous input. An assessment of this productivity contribution forms the basis of this section of the report. For the purposes of this study, the productivity of mangrove and saltmarsh habitats have not been considered, despite their obvious location in the riparian zone and the well understood contribution they make to the overall productivity of the estuary. The productivity contribution of these ecosystems was included in the carbon budget prepared for the Macleay River Estuary Processes Study (WMA Water 2009).

2.3.1 Current State of the Macleay Estuary Riparian Zone

With the exception of the lower estuary, where extensive intact mangrove forests are found, the riparian zone of the Macleay River estuary is generally highly degraded. Native vegetation tends to be patchy and in poor condition, the majority of the river banks have some form of rock stabilisation and most banks are pastured. ID Management (in Telfer 2005) described 17 types of riparian vegetation zone but found that 59.7% of the mapped area was under improved pasture and cropland. The next most common vegetation zone described was mangrove forest, which made up 23.4% of the mapped area. ID Management also mapped the degree of disturbance to the riparian zone a summary of their results is displayed in **Table 2.1**. The results show that the clear majority (63.64%) of the riparian zone of the Macleay River were recently mapped as highly disturbed.

Table 2.1 Results of ID Management riparian vegetation mapping - degree of disturbance.

Degree of disturbance	***Length of riparian zone (m)***	***% total length***
Intact	48094.964	13.91
Low	35074.548	10.15
Low - Moderate	12936.201	3.74
Low - High	5857.21	1.69
Moderate	9043.28	2.62
Moderate - High	3793.038	1.10
High	219975.677	63.64
not assessed	9034.657	2.61
Break Wall	1846.171	0.53
Total	**345655.746**	**100**

A closer look at the distribution of these areas across the Macleay estuary system (see **Figure 2.1**) shows that the riparian zones mapped as 'intact' correspond almost exclusively with the mangrove zone in the Macleay Arm, Clybucca Creek and Spencers Creek and that the majority of the riparian area mapped as 'low' or 'low-moderate' disturbance are found on Clybucca Creek. The main channel of the Macleay River has very little riparian zone that is not mapped as 'high' disturbance category.

2.3.2 Natural State of the Macleay Estuary Riparian Zone

Clement Hodgkinson, during his travels on the Macleay in the 1830s and 1840s described the riparian zone upstream of the mangroves as '*dense alluvial brushes, rising like gigantic green walls on both sides of the river*' and also noted that '*The reaches of the river are long and straight, averaging about a quarter of a mile in width, flanked on both sides by huge walls of the dense brush I have just described*.'. He describes the species composition as '*Red Cedar, White Cedar, Mahogany, Tulipwood, Rosewood, Ironwood, Lightwood, Sassafras, Corkwood the Australian Tamarind, Box, numerous and elegant varieties of the Myrtle genus, the Australian Palms, and the Brush Fig……..But the peculiar appearance of the brush is principally caused by the countless species of creepers, wild vines and parasitical plants of singular conformation, which interlaced and intertwined in inextricable confusion, bind and weave together the trees almost to their summits, and hang in rich and elegant flowering festoons from the highest branches*'. Hodgkinson also hinted at the future of the riparian zone, suggesting that '*When this brush land is cleared, and cultivated, its fertility seems inexhaustible*'.

All of the aforementioned ecosystem services provided by a riparian zone are affected by the change from a densely forested area to a degraded, cleared area comprised chiefly of pasture. From the point of view of productivity, the changes in the nature of the riparian areas of the Macleay River will have resulted in vastly reduced direct and indirect inputs of leaf litter material.

2.3.3 Riparian Inputs to the Estuary System

Natural streamside vegetation is a vital source of leaf litter, flowers, insects and other organic debris which drop into the water and as they break down add to the 'pool' of detritus. Detritus comprises all non living organic matter, including waste products and the remains of dead organisms, together with the associated microbial community. Detritus is essential food for many aquatic animals, including crabs, benthic invertebrates and some fish such as sea mullet and provides the basic source for a complex web of life that, in turn, supports larger animals, such as fish. This means that there is a close connection between in-stream health and the health of adjacent land-based ecosystems. In addition, the riparian inputs that enter streams in the *upper tributaries* of a river system may be gradually processed to become an essential food source in the lower reaches of the river. This results in a strong connection between the health of the upper reaches of a river system and important fisheries and other species in its estuary and in-shore regions.

Riparian vegetation can contribute organic material directly to the stream via overhanging branches or indirectly via transport of collected leaf litter in overland flows. The dynamics of direct contributions depend on the specifics of the riparian vegetation including species makeup, diversity and the density of vegetation. In the case of indirect contributions, the effect of the delivery depends on the size of the flow and the time between flows. Once in the waterway, the organic material can follow a number of pathways. It can be either;

- washed out to sea in heavy flows whereby it becomes lost to the system;
- leached from the litter into the waterway, or washed in as pre-leached matter. It is then known as dissolved organic matter and subsequently processed via successively higher order consumers;
- processed by detrital feeders, thereby entering the detrital food chain and/or broken down into successively smaller pieces, some of which will enter the water column as particulate organic matter; or
- any combination of the above paths.

Under high flow conditions the majority of detritus is carried out to sea (Ferguson 2004) and with it, most of the dissolved carbon and nutrients. The typical post flood pattern of carbon dynamics is that autotrophic organisms are quick to utilise available nutrients as light penetration improves (WMA Water 2009) and dominate overall carbon production as detrital inputs are slow to build up. Under low flow conditions detritus is allowed to break down and can be the major source of organic carbon to the estuary (Smith & Hollibaugh 1997).

Dissolved organic matter (DOM), usually in the form of carbohydrates, sugars, fatty acids etc, usually enters the food chain via direct or indirect assimilation by heterotrophic organisms such as bacteria (Findlay & Sinsabaugh 1999). The delivery and assimilation of DOM varies over the length of a river and over time, depending on factors such as water salinity, light availability, leachable organic content of detritus, etc (Findlay & Sinsabaugh 1999).

In relatively natural settings, detritus can be a major source of particulate organic matter (POM) to a stream. Where riparian vegetation shades the stream, limiting light availability for autochthonous production by phytoplankton and benthic microalgae, this is likely to but may not always be so (Deegan & Ganf 2008). On large systems, such as open embayments and wide lowland rivers (such as the Macleay River estuary), riparian vegetation is unlikely to reduce light availability to phytoplankton but may still be a major contributor of POM. Without identifying the specific sources of detritus, a study of a large embayed estuary in North America used a nutrient budgeting approach to demonstrate that the estuary imported approximately 10% of its carbon (ie respired 10% more carbon than it produced) and that detritus contributed approximately 50% of the allochthonous particulate carbon, the other 50% coming from marine waters (Smith & Hollibaugh 1997). The study also found that the turnover of particulate carbon from marine waters was very fast, and was a key driver of variations in net ecosystem productivity but that detritus inputs from terrestrial systems, eg riparian zones, were slow to turnover and thus less likely to explain short term variations (Smith & Hollibaugh 1997). Another US study showed that detritus was the major contributor of organic material to a tidal upper estuarine delta system and that it helped explain metabolism (pathways of carbon production and loss) but that detrital sources of carbon did not support the upper level pelagic food webs when compared with phytoplankton sources even though .pelagic sources of carbon contributed far less particulate and dissolved organic carbon (Sobczak *et al*. 2005). The study did not assess the pathways of detrital carbon sources through the benthic food webs. Another study, in a Chinese estuarine embayment, found that terrestrial sources of carbon contributed around 50% of the total particulate organic carbon in the upper estuary but also demonstrated that this proportion became markedly lower as salinity became higher and also, logically that the terrestrially derived organic matter was replaced with a greater proportion of marine derived matter at the seaward end of the estuary (He *et al*. 2010).

Not all carbon delivery has a positive effect on estuarine ecology. The types of changes to catchment landuse characterised by deforestation and removal of riparian vegetation have resulted in net loads of carbon (and nutrients) to rivers much greater (3-5 times) than those in relatively pristine systems (Hopkinson & Vallino 1995). However, the labile (easily processed) portion of the carbon delivered under these circumstances is much lower, estimated at around 20% (Hopkinson & Vallino 1995), meaning that a greater proportion of it ends up as buried sediments as opposed to increased food web activity.

The majority of the studies into the nature of riparian zone productivity export are from the northern hemisphere. This bias in the available information creates some problems. The fact that the majority of native Australian tree species are evergreen would lead to a reduction in the overall leaf litter fall into systems and also the timing of litter fall. Riparian areas made up of primarily deciduous trees would contribute the majority of organic material in annual pulses.

2.3.4 Model of Riparian Inputs to the Macleay System

The above information has been used to generate two conceptual models of how the riparian zone contributes to estuarine productivity under a vegetated state and under a non-vegetated state. The majority of the information used as a support for the model has been derived from studies of systems in the northern hemisphere. For this reason, no effort has been made to quantify the inputs, only to understand the pathways by which riparian inputs may enter estuarine food webs. The conceptual models are displayed as **Figure 2.2** and **Figure 2.3**.

The conceptual models are generalisations of complex and highly variable processes intended to be used as a resource to improve the understanding of the relationship between the riparian zone and the productivity of the estuary and also how revegetation of the severely degraded riparian zone might improve the productivity of the estuary overall. As a generalisation, the models apply to the Macleay estuary in general, despite quantitative and qualitative changes in the nature of the relationship described over a saline gradient. However, they were designed primarily with the transitional and alluvial reaches of the estuary in mind (see Cohen 2005, in Telfer 2005). This is because the riparian zone of the marine tidal deltaic process zone is largely intact and made up mostly of mangrove forests which have been considered in previous productivity assessments (WMA 2009).

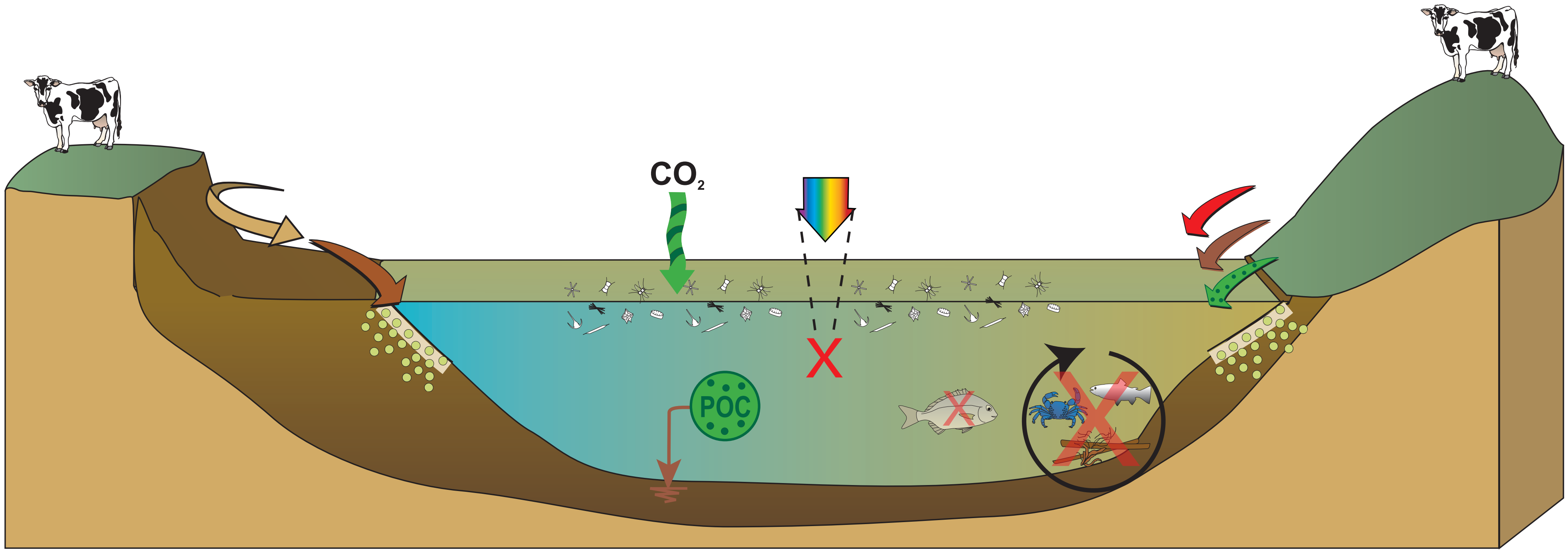
In reality, the relationship between the riparian zone and the estuary is far more complex than could be demonstrated in a series of diagrams. Most of the riparian-estuarine dynamics are well described and understood including the shading, buffering and bank stabilisation effects of vegetation. The models are intended only to describe the relationship with respect to estuarine productivity.

The key differences demonstrated by the conceptual models between a vegetated riparian zone and a cleared riparian zone are;

- increased autochthonous production due to improved light availability. This is a result of reduced sediment loads and dependent on riparian vegetation throughout the whole river catchment;
- increased variation in the sources of carbon for food chains. It is proposed that this would improve the resilience of the system; and
- increased productivity in general.

Information shown is for illustrative purposes only

Conceptual Diagram Created by Aquatic Science and Managment, June 2010
Source Files: IAN libraries, Macleay Ecology Study (ASM 2010)



Productivity Effects of a Cleared Riparian Zone

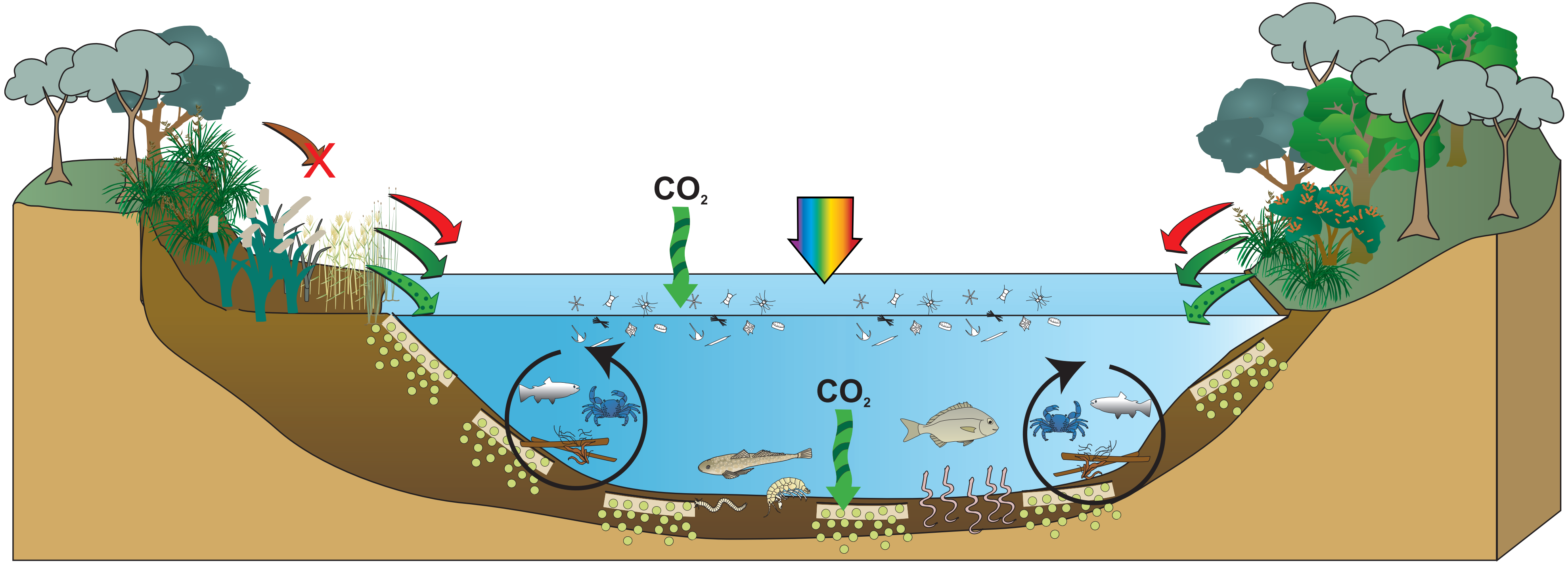
Riparian vegetation has been cleared for agriculture. Lack of vegetation leads to increased erosion and increased inputs of sediments, nutrients and particulate organic matter. Lability of POM in overland flows is relatively low leading to increased burial of POM. Increased sediment loads lead to turbid waters diminishing the penetration of light and resulting in limited productivity associated with benthic microalgae. Clearing riparian vegetation impacts detrital foodwebs with follow on effects to higher trophic levels. Primary productivity CO_2 is constrained and dominated by phytoplankton production.

Conceptual model demonstrating the productivity effects of a cleared riparian zone

Figure 2.2

Information shown is for illustrative purposes only

Conceptual Diagram Created by Aquatic Science and Managment, June 2010
Source Files: IAN libraries, Macleay Ecology Study (ASM 2010)



Productivity Effects of a Vegetated Riparian Zone

Healthy riparian vegetation reduces sediment input resulting in clearer water and improved light penetration. This results in increased primary productivity CO_2 by benthic microalgae and phytoplankton. Overland flows deliver leached nutrients, dissolved organic matter, particulate organic matter and detritus supporting detrital foodwebs and heterotrophic microorganisms. Overhanging and fallen vegetation delivers detritus directly. Grazers and lower order predators consume benthic microalgae, detritus and particulate organic matter. Upper trophic levels are supported via numerous pathways, adding resilience to the system.

Conceptual model demonstrating the productivity effects of a vegetated riparian zone

2.4 Productivity of Backswamp Wetlands

Backswamp wetlands on the Macleay floodplain are intrinsically connected to the Macleay River estuary because they drain through it. The primary source of water for the floodplain wetlands on the Macleay is floodwaters carried by the river, though the Clybucca/Collombatti wetlands have a substantial catchment of their own. In their natural state, the wetlands were connected to the estuary via a series of meandering natural drains and floodwaters took up to 100 days to recede (NCEC 1999). This meant that floodwaters were processed in a number of ways during their time in the wetlands and that the vegetation that persisted in wetland areas was tolerant of, or adapted to, regular and long term inundation. Due to the effects of drainage and flood mitigation, floodwaters are drained quickly from the backswamps with the following effects:

- The volume of floodwaters that reach the floodplain wetlands is reduced due to levee construction;
- the time for floodwaters to be processed (*ie*. nutrient uptake and sediment settlement) is less;
- the productivity of wetland species is reduced due to limited availability of water;
- the inundation of non-water tolerant dryland pasture species results in large volumes of rotting vegetable matter that deoxygenates the water prior to its release into the estuary; and
- export water is often acidic due to the activation of acid sulfate soils.

The purpose of this section of the report is to explore the relationship between the floodplain wetlands of the Macleay River system and the estuary in terms of the productivity connections. Where possible, it will explore the current status of this relationship and contrast it with the natural (pre-flood mitigation and drainage) state and/or the state of a rehabilitated system. As there are a wide variety of individual wetlands on the Macleay that all differ in their structure and function this study will focus on the three major floodplain wetland complexes of the Macleay, namely the Kinchela, Clybucca/Collombatti and Belmore backswamps.

2.4.1 Types of Wetlands on the Macleay Floodplain

Wetlands can be loosely defined as areas that are permanently, intermittently or regularly inundated with water. Obviously, this definition includes a range of habitats and ecosystems that vary greatly in their function and nature. Different wetland types require different management tools and wetland classification is an important first step in the management of wetland areas. For this reason a number of systems of wetland classification have been developed. In Australia, these systems are mostly based upon the system used by the Directory of Important Wetlands of Australia (DIWA) or the system proposed by Cowardin *et al*. (1979). After a review of existing classification methods, an additional system was proposed for the management of NSW wetlands by Green (1997).

The wetland classification system used by DIWA (itself based upon the RAMSAR system) divides wetlands up into three basic groups (eg. Marine and coastal zone, inland and human made). Within these basic groups are 42 individual classes which define wetlands based upon their hydrology, salinity and ecology. The Macleay floodplain wetlands described in this report all fit into two of the DIWA classes, ‘freshwater lagoons and marshes in the coastal zone’ or ‘non-tidal freshwater forested wetlands’. This system will be applied in the current study. The ‘freshwater lagoons and marshes in the coastal zone’ class is very broad and includes varieties of wetlands that differ greatly in their functions (ie both lacustrine and palustrine, as defined by Cowardin *et al*. 1979, wetland types are included). It is important to note that the various types of wetlands are mostly found contiguously as part of greater wetland complexes on the Macleay floodplain and therefore need to be managed together.

The classification system used by Cowardin *et al*. (1979) describes 5 basic wetland types (marine, estuarine, riverine, lacustrine and palustrine). Within these five basic wetland types they describe 56 wetland classes which are divided up based upon the present hydrologic regime, benthic structure and vegetation. Each of these classes is further modified by factors such as water regime, water chemistry, soil type and anthropogenic factors. The Cowardin method results in a very fine wetland definition for scientific purposes though experience with this method in Australia has shown that it may not be suitable in terms of generating management strategies (Green 1997).

The classification system for NSW wetlands proposed by Green (1997) divided wetlands into three broad geographical areas (coastal, tableland, inland) and defined 14 classes within these 3 areas by broad hydrological, morphological and vegetation characteristics. Of these classes the floodplain wetlands on the Macleay fit into either ‘coastal floodplain swamps and lagoons or ‘coastal floodplain forest’. These classes are considered equivalent to the aforementioned classes used in the DIWA classification system.

On the Macleay the floodplain wetlands are primarily freshwater marshes (coastal floodplain swamps and lagoons) in their current state as most of the forested areas have been cleared for grazing (Pressey 1989). The other major historical change has been in the reduction of lagoonal, or lacustrine, type wetlands encountered. Although large areas of open water persisted in areas of the floodplain prior to drainage (eg. the Swanpool/East Kinchela) most of the wetland areas are now characterised by marsh type vegetation including rushes and water couch, adapted to less frequent and less persistent inundation. These types of wetlands, referred to as palustrine, are considered among the least well understood (Davis *et al*. 2007). In general, the Macleay floodplain is now characterised by infrequent and irregular short periods of inundation interspersed with dry periods where the aquatic environment is limited to small isolated shallow pools and the water that remains in the drainage system.

2.4.2 Current Understanding of Floodplain Wetland Productivity

Wetlands in general are widely considered to be highly productive systems (Davis *et al*. 2007). Robertson *et al*. (1999) found floodplain wetland systems to be one to three orders of magnitude more productive than their downstream systems with respect to the concentrations of dissolved and particulate carbon and the biomass of the microalgal, microbial and microfaunal communities. Lagoonal wetland systems are thought to be particularly productive in addition to providing refugia for fish and invertebrates. This productivity is largely a result of the regular inputs of available nutrients during flood pulses. Also, the large and diverse microfauna give these systems the ability to support substantial food webs. An understanding of what factors contribute to the productivity of wetlands has been gained through research, though in

Australia most of this has been focussed on the largely unregulated rivers and floodplains of the Tropics. The productivity of marsh type wetlands is not well understood, whilst the productivity of forested wetlands, primarily *Melaleuca* swamps, has been the focus of some research. Forested swamps are known to be carbon sinks, but also as major carbon contributors through leaf fall. They are believed to export productivity during floods as well as providing excellent habitat and refuge values (Davis *et al*. 2007). Both nutrients and carbon tend to aggregate in floodplain wetland ecosystems. As a result of this they are generally referred to as sinks, though this does not mean that no productivity is exported to downstream systems.

Nutrient Cycles

When attached to sediment particles or suspended or dissolved in the water column, nutrients can enter floodplain backswamps directly as part of a flood pulse when riverbanks overtop. The deposition of flood borne sediment can be a significant source of nutrients that drives floodplain wetland food webs (Douglas *et al*. 2005). In the tropics, where the flood pulse is predictable aquatic faunal lifecycles tend to be synchronised with the wet/dry seasonal cycles. On the Macleay floods regularly occur out of season and the effects on wetland productivity and food webs is likely to be less predictable. Submerged and emergent vegetation within the wetland along with resident and visiting fauna can also contribute nutrients and organic matter to the food web. The release of nutrients from dying plant matter happens quickly at first, as they leach from tissue matter and then more slowly as microbes complete the decomposition. Decay is variable between plant species but also between environments, possibly mediated by water quality factors or the availability of sunlight (Shilla *et al*. 2006).

Nitrogen is cycled throughout the food web within the wetland, with bacterially mediated nitrification and denitrification (nitrogen absorption from and loss to the atmosphere) further regulating the supply. Phosphorus is understood to be cycled within the food web once it enters the wetland from sources such as catchment erosion, land use practices and detritus. The pathways of nutrients out of the wetland are transport with flow events and/or via the migration of fauna.

Carbon Cycles

Wetlands are generally considered to be carbon sinks as production tends to be greater than respiration though carbon can also enter the wetland in overland flows or exported downstream via a number of mechanisms (Davis *et al*. 2007). The primary source of carbon in wetlands tends to depend on the availability of light. Where the water quality permits light penetration (ie where turbidity is low), photosynthesis can be the major source of carbon. Photosynthetic production in floodplain wetlands has been shown to be dominated by microalgal production (Douglas *et al*. 2005, Bunn & Boon 1993). This does not diminish the importance of macrophytes though, which, aside from providing important habitat and a source of carbon, also provide increased surface area for microalgal growth and production. Where water is turbid, the carbon to drive the food chain may come from allochthonous sources and the food web will rely on the breakdown of detritus, or it may be dissolved in the water column in the form of tannins (for example). Wetlands are considered carbon sinks, particularly in the case of forested wetlands where the carbon is sequestered into the growth of plants. Carbon leaves the wetland in the form of respired CO2, or when dissolved or suspended in exported water or as fauna that migrate. Carbon release from the wetland into the estuary can only occur when the two ecosystems are connected.

2.4.3 Backswamp Inputs to the Estuary System

The export of productivity from wetlands into connected ecosystems is gaining acknowledgment as a common phenomenon (Davis *et al*. 2007). Some of the productivity of floodplain wetlands is thought to support the food webs of downstream estuaries. Despite this view, very little detailed information about the nature, frequency or magnitude of the productivity export from backswamp wetlands has been collected.

In general, the types of factors that are likely to determine the export of productivity out of floodplain wetlands into downstream systems include (modified from Cappo *et al*. 1998);

- The rate of primary and secondary production;
- The timing, extent, duration, variability and depth of freshwater flows into and out of wetlands;
- The ratio of wetland to catchment area;
- Total wetland area;
- Frequency of storms and rainfall; and
- Total water exchange.

The specific combination of these factors makes each wetland area unique in its specific relationship to the estuary and generalisations about the nature of the relationship difficult.

Under natural Conditions

Clement Hodgkinson described the Macleay floodplain wetlands in their original state, commenting that, '*These borders of alluvial brush land on the banks of the river, are generally half a mile, or a mile wide, and are then backed by extensive swamps of many thousand acres in extent, whose verdant sea, of high waving reeds and sedge, stretches away to the base of the distant forest ranges. There are several lagoons in these swamps, and the stagnant water is very generally diffused over their surface*.'

Plate 2.1 Freshwater swamps in the Belmore area being cleared of rushes. The image provides an indication of the 'high waving reeds and sedge' described by Hodgkinson. (Image source, DECCW Kempsey)

Whilst this does not give an indication of the precise distribution and makeup of the floodplain wetlands it is clear that they have been extensively altered from their natural state and that the current state of the floodplain wetlands has little in common with the original state. The areas of both open waters (or lagoons) and rushes have reduced as a result of drainage.

Aside from Hodgkinson's descriptions and a few photos taken of the early drainage works in progress (see Telfer 2005) little information exists about the state of the Macleay floodplain wetlands or their relationship with the estuary prior to the effects of drainage and flood mitigation. The natural state of these systems can only be inferred from information about other similar systems. As all of the nearby subtropical wave dominated delta systems (Clarence River, Hastings River, Richmond River, Manning River) have been modified in similar ways to the Macleay, this means collecting information from the River systems of tropical Australia, the only natural systems to have been studied in any detail (Sheaves *et al*. 2006, Douglas *et al*. 2005).

Most floodplain wetland areas are not permanently connected to their downstream estuaries. Connections tend to occur during times of heavy rainfall, king tides and/or storm surges. The timing and frequency of this connection has been shown to determine the nature and direction of the biological connection (Sheaves *et al*. 2006). In short, the timing of the connection will determine what species of fish and invertebrates migrate to and from the wetland areas depending upon the specific stage of their life cycle they are in. The frequency and timing of previous physical connections will also have an effect, with pools that are most often connected to the estuary commonly found to be the most diverse with respect to fish (Sheaves *et al*. 2006). The availability of fish to predatory birds is also variable depending on the depth and clarity of the water, with deeper pools offering improved hiding opportunities for fish and invertebrates and pools that are shallow or dry out faster offering improved opportunities for birds to feed. All of these factors make floodplain wetlands highly dynamic, complex and difficult to characterise. In dry times, each individual pool will have a specific faunal makeup depending on the frequency and timing of previous connections, and the persistence, depth and clarity of the standing water.

When connected, there are three pathways through which the productivity of backswamp wetlands can be exported into the estuaries that they are connected to (Johnstone *et al*. 1995). The first is via dissolved nutrients and carbon in bioavailable forms. The productivity, rates of decay and leachable carbon content of many Australian wetland species has been measured (reviewed by Robertson *et al* 1999) meaning that this *process* is relatively well understood, despite the difficulties in measuring the *magnitude* of the contribution. The second pathway for carbon export is as bioavailable nutrients and carbon bound to exported sediments. The third is in the export of biota either in the form of upper trophic level consumers or lower order consumers that can enter the estuarine food web. Available information suggests that food chains in floodplain wetlands are generally very short (Sheaves *et al*. 2006). The effect of this is that a large proportion of primary energy production makes its way to the top of the food chain, providing the opportunity for high levels of export to other ecosystems as these organisms tend to be more mobile. Most fish species that move upstream out of estuarine areas to utilise freshwater habitats as feeding or nursery areas (eg. mullet, bass, eels), move downstream again having fed or grown, indicating a net movement of productivity out of the floodplain wetlands into the estuary.

Figure 2.4 shows a conceptual diagram of the pathways of carbon through the floodplain wetland food web, culminating in the export of mobile biota.

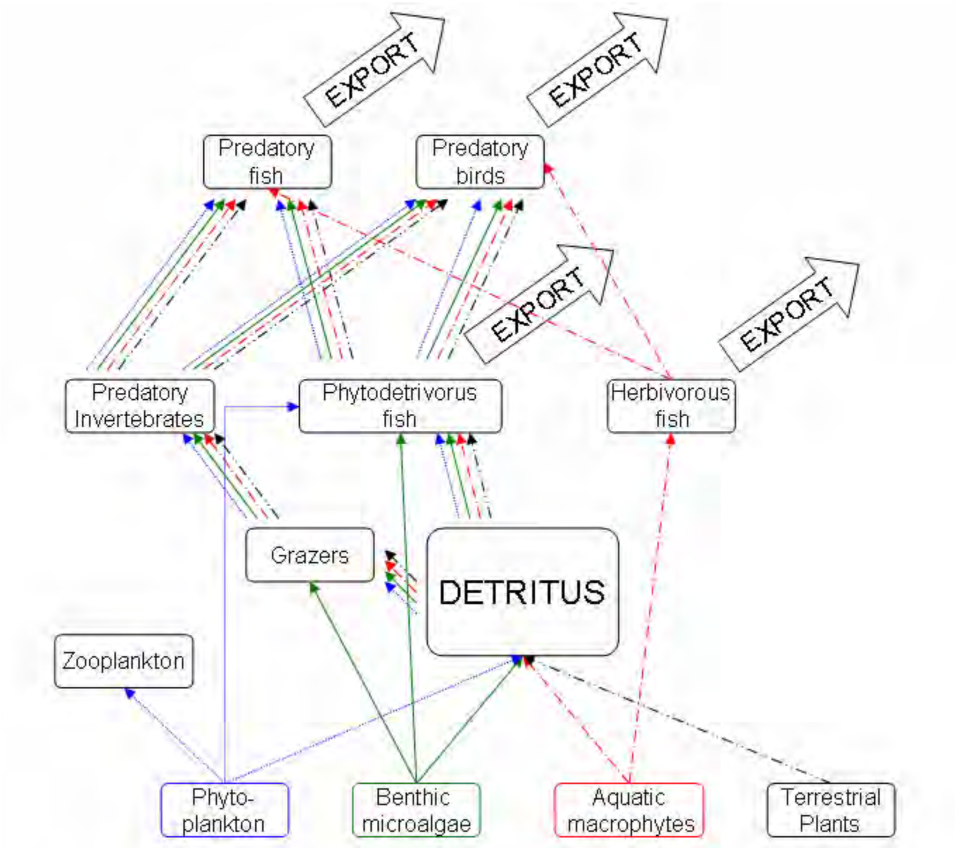


Figure 2.4 Simplified floodplain wetland food web showing export pathways (modified from Sheaves *et al.* (2006))

Under Current Conditions

The drainage of the Macleay floodplain wetlands has a number of effects on the productivity, food webs and the nature of exported materials from the wetland areas.

The most obvious effect is upon the persistence and extent of wetland pools on the floodplain. Floodwaters are now removed from the floodplain in a very efficient manner, leaving very few shallow pools that, with the combined effect of evaporation, are not able to persist for long periods. Large areas of persistent standing water and some permanent pools have been replaced with dryland pasture species in some areas and ecosystems dominated by emergent macrophytes and rushes in others. Another effect of the current management of the floodplain is an overall change of vegetation from tall emergent macrophytes (such as Cumbungi (*Typha orientalis*) and twig rush (*Baumea articulata*)) that require frequent medium to long term inundation, to rushes and herbaceous species (*eg*. spike rush (*Eleocharis spp*.) and knotweed species/smartweed (*Polygonum spp*.)) which are more commonly associated with the edges of wetland areas.

The effect that this has upon aquatic productivity is unknown, though most of the carbon on the floodplain would now go into agricultural productivity rather than aquatic systems as the vast majority is now grazed. The nutrient and sediment cycles in the floodplain are also affected, in the sense that the floodwaters have less time to be processed and therefore runoff contains higher concentrations of sediment and nutrients.

The effects of increased coverage of dryland pasture species is that when inundated, these species rapidly decompose, in the process reducing the concentration of dissolved oxygen in the water. Inundation of dryland species lasting up to a week is more a feature of the Belmore and Kinchela areas as they have a specific use as flood storages. The poor quality of floodwater exported post storage from Belmore and Kinchela Swamps is reflected in the relatively large numbers of severe fish kills reported from the Belmore River and Kinchela Creek. Additional impacts occur in many areas due to a history of acid sulfate soil disturbance. These two factors, combined with the fact that floodwaters are transported rapidly into the estuary, mean that the uptake of exported dissolved and particulate organic matter by estuarine food webs is compromised due to the impacts of poor water quality on estuarine biota. In addition, the poor water quality conditions in degraded wetlands during times of inundation means that any aquatic fauna that reside there may not survive inundation, reducing the likelihood of carbon export to the estuary through migration.

To better describe the relationship of the Macleay River floodplain and estuary it would be a desirable outcome of this study to understand:

- to what extent the area of wetland pools has been reduced;
- to what extent the areas of the various wetland types or vegetation types have changed on the floodplain as result of land clearing and drainage;
- to what extent the delivery of water to the floodplain has been reduced as a result of flood mitigation measures;
- what proportion of the wetlands are used primarily for grazing; and
- to what extent the productivity contributions of floodplain wetlands to the estuary have been reduced.

Unfortunately, at this stage, with the available information it is not possible to accurately quantify the above for the following reasons:

- There is no available information that clearly demonstrates or infers what proportion of the floodplain was made up of open waters, rushlands, sedgelands and/or wetland forests under natural conditions.
- The available landuse and vegetation mapping is of insufficient accuracy to clearly describe the current distribution of open waters, rushlands, sedgelands, wetland forests and dryland species;
- The vegetation regimes in the most low lying areas of the floodplain are subject to significant variation over time periods as short as a year due to variations in water supply and land management; and
- The relationship between the estuary and the floodplain depends on a number of variables, as described earlier in this section of the report, many of which cannot themselves be accurately described.

Of the available information describing distribution of vegetation across the Macleay floodplain wetlands, the most descriptive is the East Kempsey vegetation mapping (Telfer & Kendall 2006). The East Kempsey vegetation mapping, when overlayed with the Belmore, Kinchela and Clybucca swamps as mapped by WMA (2006), reveals the breakdown of vegetation types in those areas listed in **Table 2.2**.

Table 2.2 Breakdown of vegetation types across Belmore, Clybucca and Kinchela wetland areas.

Vegetation Type	*Area (ha)*	*Percent total*
Sedgeland	2414.886	46.73436
Cleared	1020.275	19.74499
Paperbark	766.447	14.78201
Swamp	452.288	8.752956
Spike rush-water couch	443.932	8.591246
Swamp Oak	51.63	0.999176
Paperbark-Swamp Oak	14.358	0.277865
Water surfaces	2.394	0.04633
Rainforest	0.956	0.018501
Dry Grassy Blackbutt-Tallowwood	0.094	0.001819
Total	**5167.26**	**100**

The numbers reported in **Table 2.2** cannot be considered very accurate because the GIS datasets used to generate them both suffer from a number of inaccuracies and because the dynamic, changing nature of wetland vegetation means that there would be variation in the cover of each vegetation type over time. However, the large proportions of the wetland areas mapped as ‘sedgeland’, ‘cleared’ or ‘spike rush-water couch’ and the relatively low proportion mapped as ‘swamp’ or ‘open water’ are indicative of the significant changes that have occurred since the early observations of Clement Hodgkinson.

A final factor influencing the current relationship between the estuary and the floodplain is the presence of blockages to fish passage. Of the major floodplain wetland complexes on the Macleay only the design of the East Kinchela drainage system makes allowances for fish passage. Unfortunately, the function of that structure, an auto tidal floodgate on the Lock, is regularly compromised due to reoccurring vandalism.

2.4.4 Model of Backswamp Wetland Inputs to the Macleay System

The above summary of relevant available information has led to the preparation of two conceptual diagrams, one demonstrating the relationship between the estuary and floodplain under natural conditions and the other demonstrating the relationship under disturbed conditions. The models are generalisations based on information mostly gathered from other systems. They are intended as a resource for educational purposes regarding the potential effects of different management strategies for floodplain wetlands.

The key differences demonstrated by the conceptual models between floodplain wetlands in their current state and floodplain wetlands in a degraded state are;

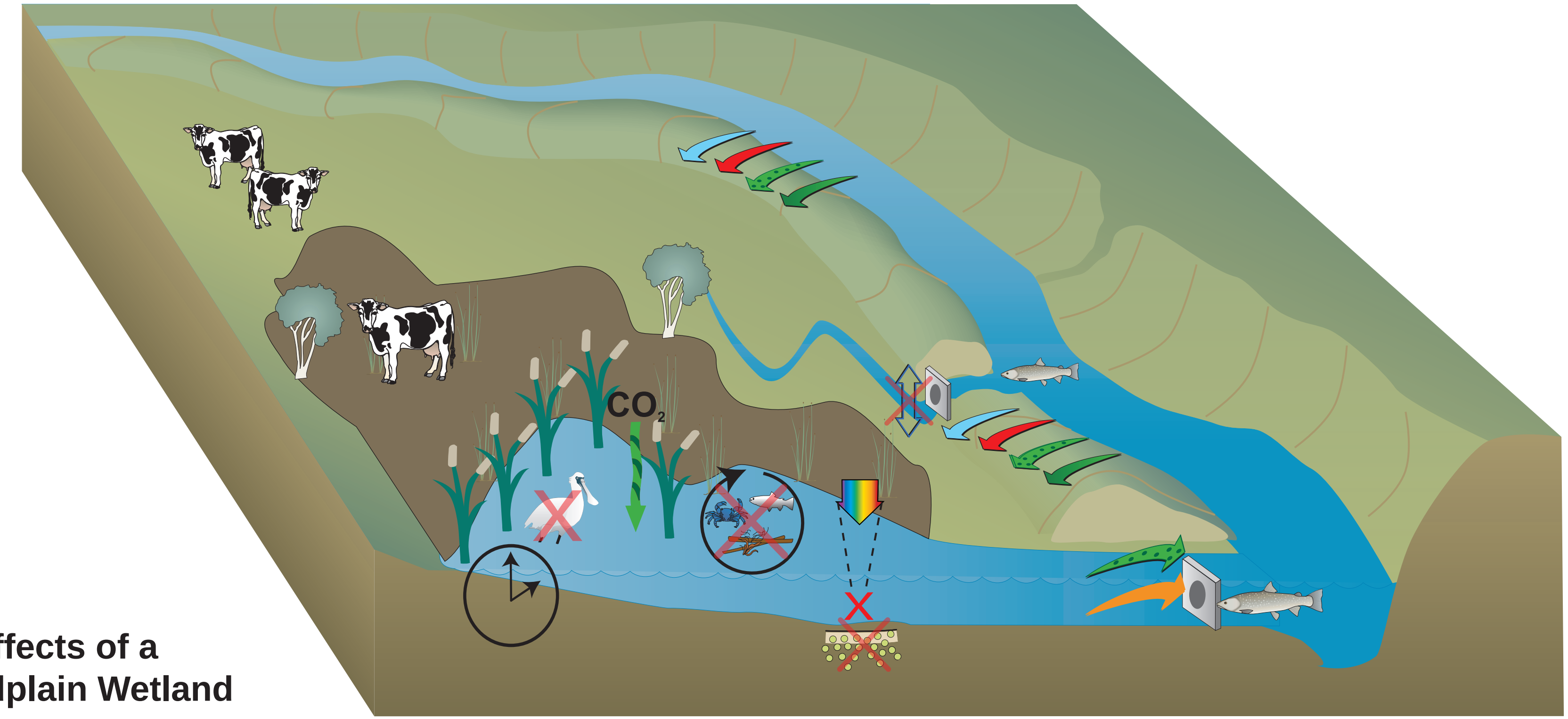
- Increased residence time for water in natural systems with knock-on effects for benthic microalgal production, waterbirds and export water quality.

- Improved support for detrital food webs in natural systems and more varied pathways for carbon production in general;
- Increased migration of fish into and out of the estuary. A potential result of this is increased fish production via increased fish habitat availability and increased ‘access’ to the food chains of the floodplain wetlands; and
- A greater proportion of carbon export to the estuary in the form of dissolved organic matter, and biota, as opposed to particulate organic matter.

Aside from productivity contributions, wetlands perform a variety of ‘ecosystem services’. These include, but are not limited to, floodwater storage and processing, refugia for threatened and protected species, recreational values and provision of drought refuges for stock. As the focus of this study is the relationship between the estuary and the floodplain wetlands from a productivity perspective these have not been considered in the preparation of the conceptual models.

Information shown is for illustrative purposes only

Conceptual Diagram Created by Aquatic Science and Managment, June 2010
Source Files: IAN libraries, Macleay Ecology Study (ASM 2010)

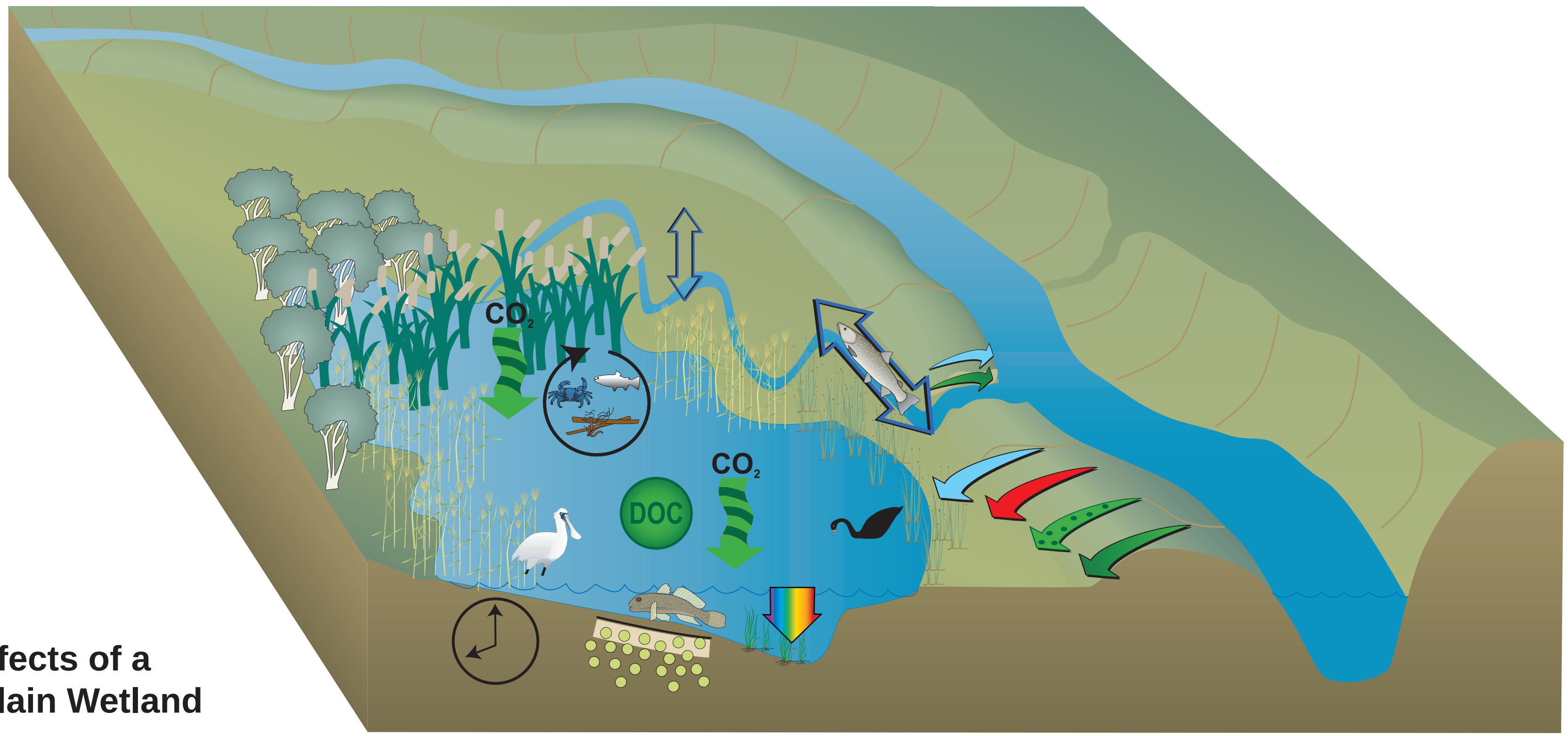


Productivity Effects of a Modified Floodplain Wetland

Reduced inputs during flood pulse of water, nutrients and dissolved and particulate organic matter. Tidal action and fish migration reduced as a result of floodgates. Vegetative cover and diversity reduced, wetland forests fragmented . Resultant reduction in detrial inputs and impacts upon detrital food webs. Water residence time and area of water cover greatly reduced, sediments remain in water column and reduce light pentration. Benthic microalgal production reduced as a result. Also leads to reduced use by waterbirds and that pathway for carbon export. Increased proportion of carbon export as particulate matter. Export of poor quality water has direct impacts on downstream productivity, causing fish kills etc.

Conceptual model demonstrating the productivity effects of a modified floodplain wetland

Conceptual Diagram Created by Aquatic Science and Managment, June 2010
Source Files: IAN libraries, Macleay Ecology Study (ASM 2010)



Productivity Effects of a Natural Floodplain Wetland

Flood pulse delivers water, nutrients and dissolved and particulate organic matter. Tidal action and limited drainage pathways result in long residence times for water. Sediment is deposited and post flood waters are clear, supporting benthic microalgal production in turn supporting upper level consumers. Habitat availability for water birds is good, a pathway for carbon export. Regular and long term connection with estuary creates opportunities for fish migration. Primary productivity (CO_2) by submerged, emergent and swamp forest plants results in high dissolved organic matter (DOC) concentrations and detritus supply to detrital food webs. Export water is of good quality and a much of the carbon export is in the form of dissolved organic matter.

Conceptual model demonstrating the productivity effects of a natural floodplain wetland

Figure 2.6

2.5 *Management Issues Associated with Estuary Productivity*

Issue 2.1: Reduced estuarine productivity due to a degraded riparian zone

Whilst at this point in time it is not possible to quantify the reduction in estuary productivity due to changes in the nature of the riparian zone nor quantify the potential gains in productivity from riparian restoration works it is a conclusion of this study that overall estuary productivity has been reduced and the overall resilience of estuary food webs has been reduced by changes to the riparian zone.

Issue 2.2: Reduced estuarine productivity due to degraded floodplain wetlands

Again it is not possible at this point in time to quantify the productivity contributions of healthy vs degraded floodplain wetlands. However, it is concluded that, in addition to direct impacts such as reduced water quality and fish kills after flood events, overall estuary productivity has been reduced due to changes brought by clearing, flood mitigation and drainage on floodplain wetlands.

Issue 2.3: Lack of quantifiable information about the floodplain-estuary and riparian vegetation-estuary relationship

The aforementioned difficulties in quantifying the productivity contributions to the estuary of floodplain wetlands and the riparian zone are an issue because they reduce the ability of planners to make an accurate cost/benefit analysis of changes to the management of the estuary and its floodplain and riparian zone that may improve the current situation.

Upgrades and maintenance of flood mitigation and drainage infrastructure will be vastly more expensive than they were when the systems were designed and constructed. In addition to this the objectives of floodplain management have changed over this timeframe. Under the principals of ecologically sustainable development and total catchment management it is desirable for the floodplain to be managed and developed in a way that minimises the impacts on the health of the estuary and the industries and activities that rely upon it. There is also relatively new information available with respect to climate change and sea level rise to be considered. For these reasons it is desirable to describe the relationship between the floodplain and the estuary in as much detail as possible so that planning decisions are well informed. Improved valuation of the costs and benefits (environmental, financial and social) of all of the available management options would benefit the planning process.

2.6 Management Options Associated with Estuary Productivity

Option 2.1: Improve the cover of riparian vegetation on all public foreshore lands

A plan for improved riparian management is being developed as part of the MREMP.

Option 2.2: Continue to encourage private landholders to actively manage the riparian strip by fencing, revegetation and stock access management using education and initiatives

A plan for improved riparian management is being developed as part of the MREMP.

Option 2.3: Improve fish passage and reinstate some tidal flow through the Clybucca, Belmore and Kinchela floodgates through changes to floodgate infrastructure

This could include the installation of tidally operated windows on existing floodgates or regular active management.

Option 2.4 Alter the drainage management of the lower Clybucca wetlands to increase the number of landholders with individual control of water levels

On many properties there has already been a shift to micro management of water levels. Ideally, this option would involve the installation of sills that either fix a desirable water level in the lowest areas or sills that can be managed to adjust water levels along drainage pathways that enter the main drains in the wetland such as the Seven Oaks, Clybucca East and Clybucca West drains. The second step would be the alteration of the Clybucca floodgates to allow improved fish passage and some tidal exchange.

Option 2.5: Continue to encourage wetter management of pastures in the Belmore, West Kinchela and Clybucca/Collombatti wetland areas as a means of increasing water retention times and habitat value of floodplain wetlands

The key mechanisms to achieve this are education and incentives for landholders.

Option 2.6: Continue to improve the management of east Kinchela wetland for ecological values

This would ideally involve increasing water retention times to simulate a more ‘natural’ pattern of wetting and drying, reinstating the connectivity of the wetlands with the river by modifying the existing floodgates and managing the growth of introduced aquatic weeds.