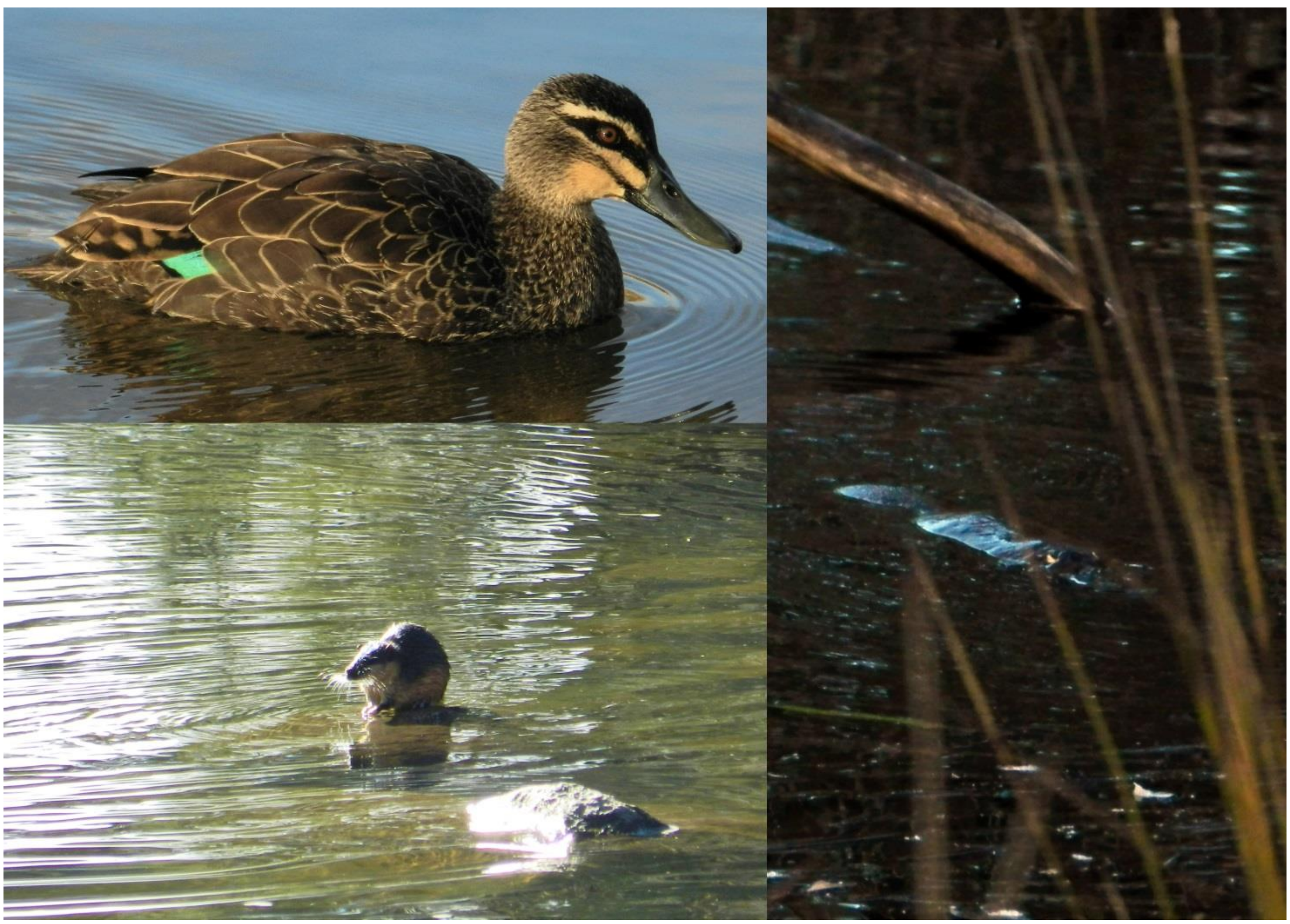
Fauna of the Upper Coxs River catchment:

An assessment of common freshwater species in a high-demand landscape.

S. M. Judge, University of Western Sydney.



Photos by S. Judge (2013)

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OLD MAN PLATYPUS

Banjo Paterson

Far from the trouble and toil of town,
Where the reed beds sweep and shiver,
Look at a fragment of velvet brown -
Old Man Platypus drifting down,
Drifting along the river.

And he plays and dives in the river bends
In a style that is most elusive;
With few relations and fewer friends,
For Old Man Platypus descends
From a family most exclusive.

He shares his burrow beneath the bank
With his wife and his son and daughter
At the roots of the reeds and the grasses rank;
And the bubbles show where our hero sank
To its entrance under water.

Safe in their burrow below the falls
They live in a world of wonder,
Where no one visits and no one calls,
They sleep like little brown billiard balls
With their beaks tucked neatly under.

And he talks in a deep unfriendly growl
As he goes on his journey lonely;
For he's no relation to fish nor fowl,
Nor to bird nor beast, nor to horned owl;
In fact, he's the one and only!

Contents

Fauna of the Upper Coxs River catchment:

An assessment of common freshwater species in a high-demand landscape.

Sara M. Judge, University of Western Sydney.

1. Summary

This study was conducted as a component of the Natural Science degree at the University of Western Sydney on behalf of Lithgow Environment Group. It was observed that semi-aquatic animals were more prevalent at Marrangaroo Creek than along the more degraded main freshwater system of the Upper Coxs River catchment, NSW. The aim of the study was to establish whether or not there was a relationship between river condition and species diversity by comparing ecologically similar sites within a high-demand landscape. To achieve this, three common freshwater macro-fauna species were selected – the platypus, eastern water rat, and a selection of waterfowl – and comparatively assessed, along with key habitat resources analogous to all target species. These habitat resources included macro-invertebrate assemblage, water quality, and riparian condition. Three test sites were selected along the main land-use stretch of the Upper Coxs River, along with two additional contextual sites at Lake Wallace and Lake Lyell, and compared to a relatively un-impacted reference site at Marrangaroo Creek.

It was predicted that if river condition was a limiting influence on common aquatic animals, then there would be a significant difference in species diversity between degraded and reference sites. It was also predicted that if environmental variables associated with species needs were not adequate, then there would be significantly lower species diversity. Random sampling of species abundance and presence/absence data was undertaken along with the relevant physical, chemical and biological indicators. Analysis of variance (ANOVA) tests and abundance indices showed high levels of significance between sites, with more freshwater fauna present in higher diversities at less impacted sites. The results suggested that there is a strong relationship between river condition and species diversity along the high-demand stretch of the Upper Coxs River catchment, with Marrangaroo Creek potentially representing an ecological stronghold in an otherwise degraded landscape. For this reason, it has been recommended that Marrangaroo Creek be considered for local protection and that further long-term studies be conducted to determine the extent of impact on freshwater animals in order to inform local conservation status and future management.

2. Introduction & Literature Review

2.1 FRESHWATER ECOSYSTEMS: Sharing a high-demand resource

When the immense human-importance placed on freshwater systems is considered, it is easy to undervalue the needs of species other than our own. We rely on the networks of rivers, creeks, lakes, and streams to provide water for an array of essential human activities; ranging from the basic necessities of drinking water, to the secondary production demands of the industries that provide food and power, among other services, to growing populations (Lake & Bond 2007; Lenzen & Foran 2001). At best estimate, 105,000 of the 413,000 gigalitres (Baron et al. 2002) of annually available fresh water in Australia can be diverted to human use (Chartres & Williams 2006). In 2010-11, the Australian Bureau of Statistics (2012) recorded 71,797 gigalitres of that threshold being extracted, with 64, 691 gigalitres allocated to water-using industries, mainly agriculture at a hefty 54% of total water consumption. Even industries with comparatively smaller annual water usages place significant pressure on freshwater resources. At 4% of total water consumption (Australian Bureau of Statistics 2012), the economically significant mining industry utilises significant quantities of water for coal preparation plants and dust management, in addition to various other uses, much of which translates to contaminated waste water that must then be managed. With an average of 200 litres of freshwater consumed for every tonne of coal produced, the management of this waste water generates a number of storage and discharge challenges (Schandl et al. 2008; Thiruvenkatachari, Younes & Su 2011). Additionally, the land and water requirements to facilitate the various industry activities that support human needs result in disturbances to the aquatic and riparian landscape, dramatically altering integral processes essential to freshwater ecosystem health, such as flow regimes, ecological community assemblages, and habitat resources (Lenzen & Foran 2001; Peters & Meybeck 2000; Schandl et al. 2008).

In the shadow of such high human demand, it is often difficult to make an argument for those freshwater fauna species that share a dependency on what is being increasingly recognised as a critically degrading resource (Dudgeon et al. 2006; Lake & Bond 2007; Peters & Meybeck 2000). Although freshwater ecosystems represent a comparatively small selection of total natural habitats (Innis, Naiman & Elliott 2000), they support a disproportionate richness of fauna biodiversity – from micro-organisms and macro-invertebrates, to higher order mammalian, avian and amphibian animals (Dudgeon et al. 2006). Freshwater fauna exist in a complex and delicate ecosystem where small changes in condition have the potential to cause dramatic effects not only within the immediate vicinity, but progressively along the downstream network as well (Baron et al. 2002; Dudgeon et al. 2006; Saunders, Meeuwig & Vincent 2002). Despite this, freshwater catchments continue to degrade and are counted among the most endangered of ecosystems, with associated declines in fauna species often surpassing that of heavily impacted terrestrial environments (Dudgeon et al. 2006). The study presented in this report is an assessment of common freshwater vertebrate species in a high-demand aquatic landscape.

2.2 COMMON FRESHWATER SPECIES: Platypus; eastern water rat; waterfowl

Three common taxonomic groups in particular are characteristic representatives of Australian freshwater ecosystems: the platypus (*Ornithorhynchus anatinus*), the native eastern water rat (*Hydromys chrysogaster),* and a wide variety of waterbirds including native ducks (*Anatidae*), grebes (*Podicipedidae*), and water hens (*Rallidae*). Occupying waterways throughout the eastern and south-eastern mainland, as well as Tasmania (Serena & Pettigrove 2009), the platypus (Fig. 1) feeds exclusively in-stream by foraging for benthic macro-invertebrates and constructs burrows within the bank or immediate riparian stretch (Grant 2007; Grant & Temple-Smith 1998). This unique monotreme is of considerable conservation value, representing the only living species of a significant fossil history (Grant & Temple-Smith 2003) and filling an integral ecological niche as a high-order predator in aquatic food webs (Bunn et al. 1999).

Fig. 1. Australia's two freshwater aquatic mammal species, the platypus (left) and the eastern water rat (right), as observed at sites along the Upper Coxs River catchment NSW. Photos by S. Judge (2013).

Australia's only other aquatic mammal, the eastern water rat (Fig. 1), is widespread throughout freshwater systems ranging from southern Queensland to Victoria, Tasmania, and western South Australia (Dehnhardt et al. 1999; Hinds et al. 2002; Scott & Grant 1997) . The species is highly adapted to aquatic environments, though not entirely dependent on them, and forms burrows with extensive runs in both the immediate bankside and riparian stretch (McNally 1960; Scott & Grant 1997). An opportunistic predator, the diet of the water rat consists of a variable mix that includes freshwater macro-invertebrates, fish, vegetation, amphibians & small reptiles, waterbirds and their eggs, and in extreme conditions such as long-term drought the species has even been known to prey on young platypuses (Fish & Baudinette 1999; McNally 1960; Woollard, Vestjens & MacLean 1978).

Waterbirds (Fig. 2) comprise perhaps the most readily observable fauna aspect of freshwater biological communities, given their far less secretive nature in comparison to the aquatic mammals (Kingsford 1999; Scott & Grant 1997). With a wide variety of species distributed across Australia, waterbirds – particularly ducks and native hens – are commonly found on all water body types, from lakes and rivers to farm dams and urban water ways. Australian waterbirds are generally considered under four main feeding types: herbivorous; invertebrate; piscivorous; and omnivorous (Kingsford & Norman 2002), and tend to fill a niche as primarily diurnal feeders

(Norman, Thomson & Hamilton 1979) as opposed to the crepuscular/nocturnal platypus and eastern water rat (Scott & Grant 1997). With all waterfowl being obligate nesters, dense riparian vegetation including adequate old-growth trees for hollow nesting species such as the Australian Wood Duck are essential for breeding (Kingsford & Norman 2002).

Fig. 2. Common Australian waterbird species found in freshwater environments, the Australian wood duck (left), Australasian grebe (centre), and Eurasian coot(right), as observed at sites along the Upper Coxs River catchment NSW. Photos by S. Judge (2013).

These semi-aquatic fauna representatives, although considered common in their distribution and abundance, illustrate in their ecology some specific needs that once impaired may result in serious secondary impacts that need to be considered when managing freshwater resources. Three main factors in particular have been identified as common critical criteria for the platypus, eastern water rat, and waterbirds. These factors are macro-invertebrate community assemblage, riparian habitat quality, and negative shifts in water chemistry parameters (Kingsford & Norman 2002; Scott & Grant 1997; Serena & Pettigrove 2009). Unfortunately, all of these factors are easily affected by freshwater system degradation associated with human activities (Lake & Bond 2007; Peters & Meybeck 2000), and the International Union for Conservation of Nature (IUCN) status listing as 'of least concern' common to the target species (IUCN 2013) puts them in a precarious and often overlooked position for responsible management.

2.3 SPECIES RESILIENCE: The winners, the losers, and the risk of complacency

It is an unfortunate consequence that the most facilitative regions of Australia for human occupation also tend to be those rich in localised and often unique biodiversity (Williams et al. 2011). Iconic species such as the platypus and the eastern water rat for example, are distributed exclusively along the freshwater systems of eastern Australia (Scott & Grant 1997), where the bulk of the human population are, and continue to be, settled (Australian Bureau of Statistics 2012). This places ever-increasing pressure on the species as competition for freshwater resources puts them at odds with anthropogenic needs (Williams et al. 2011). Yet remarkably, the resilience of some of our native species to the ever-encroaching human frontier has been something of a saving grace in the shadow of an otherwise devastating national record of species extinctions in modern times (Australian Bureau of Statistics 2010). Many species of native ducks and hens, for example, appear to thrive in highly polluted waterways by taking advantage of invertebrate food explosions associated with nutrient loading (Halse et al. 1993; Hamilton et al. 2005; White et al. 2005). Similarly, a number of waterbird species, as well as the eastern water rat (Scott & Grant 1997), have been seen to readily adapt to both modified and artificial waterways, continuing to be found in extensively exploited landscapes from the rural and peri-urban to big city centres (Halse et al. 1993; Kingsford & Norman 2002). Even the platypus appears to cope reasonably well in degraded environments, with animals often persisting despite the influence of human activities on their habitats (Grant & Temple-Smith 2003; Scott & Grant 1997; Serena & Pettigrove 2009).

Fig. 3. Lake Lyell, Upper Coxs River catchment NSW– despite a blue-green algal bloom outbreak during the study (left), waterbirds continued to use the lake freely with no observable change in numbers. Photos by S. Judge (2013).

Such resilience in the aquatic macro-fauna of eastern Australia is not, however, a standard response (Dudgeon et al. 2006). Though not included in this study, a number of amphibians and aquatic reptiles have declined dramatically in time with increasing human occupation and land-use pressures on freshwater habitats, with examples from within the vicinity of the current study site being numerous. The Blue Mountains water skink (*Eulamprus leuraensis*) is limited to less than 40 isolated alpine swamps in the Blue Mountains and Newnes Plateau, New South Wales (Dubey & Shine 2010). Not only is the skink itself listed as endangered, its entire distribution comprises habitat listed as 'threatened' under the Threatened Species Conservation Act (Dubey et al. 2013), circumstances attributed the substantial impacts of hydrological system disturbance and habitat degradation as a result of urbanisation, increased bushfire regimes, and long-wall mining (Dubey & Shine 2010; Dubey et al. 2013). Similarly, studies conducted adjacent to the Blue Mountains region on the Hawkesbury-Nepean River flood plain have found frog diversity and abundance to be negatively associated with habitat disturbance and urbanisation, where more degraded sites showed lower amphibian diversity (Ferraro & Burgin 1993; Schell & Burgin 2003). This is consistent with widespread declines in frog populations across Australia commonly attributed to the impacts of human activities on the freshwater environments they depend on (Lane & Burgin 2008). Hazell (2003) noted that of 41 species considered for IUCN listings of 'near threatened' or higher, 49% had declined primarily as a result of aquatic habitat degradation or loss. With a significant bulk of Australian frog diversity found to the fertile east, an alarming decline in species range and abundance has been seen, including in presumed minimally disturbed upper catchments with some species from these habitats now considered extinct (Lane & Burgin 2008). At least 25 New South Wales frog species are listed as threatened, with habitat disturbances from land-use activities cited as a common major threatening process to them all (Hazell 2003; Hazell, Osborne & Lindenmayer 2003).

The extent of resilience in common species is both poorly understood and largely unknown (Cucherousset et al. 2008; Lindenmayer et al. 2011; Roger, Laffan & Ramp 2007). There is much ambiguity surrounding the limiting factors of the platypus, for example, with some populations seeming remarkably resilient to negative shifts in environmental condition while others are impacted dramatically, making it extremely difficult to attribute specific threatening processes (Grant & Temple-Smith 2003). Scott and Grant (1997) identified the degradation of riparian habitat for burrowing sites and the impact of poor water quality on macro-invertebrate food availability as the key threatening processes of both the platypus and eastern water rat. There are concerns that salinity levels may interfere with the electrical receptors used by the platypus to locate food, though there are few studies to either substantiate or disprove this (Manger & Pettigrew 1995; Pettigrew, Manger & Fine 1998). High water turbidity is considered a concerning water quality factor for visual diving species such as the eastern water rat (and some waterbird species), as it may limit hunting visibility (Rutherfurd, Marsh & Jerie 2000; Scott & Grant 1997). Similarly, the resilience of water birds is a poorly understood phenomenon that is supported by few specific studies. While it is well established that waterbirds apparently thrive in some degraded habitats, there has not been nearly enough in the way of studies on secondary impacts to rule out long-term effects or resilience limits (Halse et al. 1993; Hamilton et al. 2005; Kingsford & Norman 2002). Little is known about how accumulations of pesticide chemicals or heavy metals effect water bird health and reproduction, for example, despite a prevalence of organo-chlorines at levels exceeding the recommended human consumption level found in the wings and feathers of waterfowl shot in eastern Australia (Kingsford & Norman 2002). Furthermore, water salinity levels may have a critical range, particularly where there is limited access to an alternative fresh drinking water source. On the one hand, unnaturally low levels of salinity can have negative impacts on macrophyte and invertebrate availability, limiting integral food sources (Hart et al. 1990; White et al. 2005). On the other hand, however, there is evidence of reduced breeding success in some waterbird species as a result of high salinity, and this is attributed to the inability of hatchlings to osmoregulate (Hart et al. 1990). Australian shelducks, for instance, do not begin to osmoregulate until they are six days old, before which they must have access to fresh water in order to survive (Goodsell 1990). Despite being listed as potential concerns, few studies have been conducted to provide any definitive evidence of such potential threatening factors. Furthermore, given the adaptability and resilience of these species, it is difficult to pinpoint a single observable pattern for threatening processes across the board as individual populations appear to differ between their localities in response to their own adaptive capabilities to a variety of contextual circumstances (Halse et al. 1993; Hamilton et al. 2005; Kingsford & Norman 2002; Scott & Grant 1997; Serena & Pettigrove 2009).

Such gaps in the understanding of freshwater fauna resilience make it increasingly necessary to consider species management and conservation on a case-by-case basis that is dependent on the local circumstances (Cucherousset et al. 2008; Roger, Laffan & Ramp 2007). For instance, critical limits for threatening processes may be different between alpine and lowland regions, low genetic diversity in one local population may render it more susceptible to limiting factors than other populations of the same species, or species apparently coping with impacts may only experience a sudden ‘crash’ in numbers once a certain limit is reached, at which point management efforts may be too late (Gomes, Ribeiro & Carretero 2011; Lindenmayer et al. 2011; Roger, Laffan & Ramp 2007). These are just some examples of how ‘local extinction’ can become a very real risk in an otherwise common, resilient species when management efforts do take into consideration the possibility that responses to threatening processes may not necessarily be identical, or even predictable, across contexts (Lindenmayer et al. 2011; Roger, Laffan & Ramp 2007). This study suggests that such may be the case with the common freshwater species populations of the Upper Coxs River catchment, NSW.

2.4 SIGNIFICANCE OF THE CATCHMENT: *Coxs River & Marrangaroo Creek*

The catchment region surrounding the upper reaches of the Coxs River has a long history of land-use, particularly forestry, agriculture and mining, and has consequently experienced a range of ecosystem modifications as a result (Birch, Siaka & Owens 2001; Young et al. 2000). Although reductions in forestry and agricultural ventures have lessened the pressure over time, leaving approximately 75% of the catchment area as either remnant or restored bush land, human influences on the freshwater system are significant (Fig. 4) as urbanisation and mining developments continue to exert considerable influence over the remainder of the landscape (Best 2004; Birch, Siaka & Owens 2001)

Fig. 4. Polluted site of the upper reaches of the Coxs river (left) just downstream of Angus Place Colliery (right). Photos by S. Judge (2013).

The townships of Lithgow and Wallerawang account for over 65% of the total catchment population (Lithgow City Council 2011) and are closely associated with the Coxs River, contributing urban runoff and sewage treatment plant effluent to the flow, particularly via Farmers Creek and stormwater channels (Birch, Siaka & Owens 2001; Bowmer et al. 2007; Young et al. 2000). Mining constitutes a major aspect of the local economy and sense of identity (Best 2004), providing 14.9% of local employment as the largest job-market contributor (Australian Bureau of Statistics 2011). Unfortunately, the industry also accounts for significant alterations to freshwater ecosystems as a result of their activities, particularly where waste water is discharged into the natural water ways. Similarly, flow regimes have been altered dramatically within the upper catchment. The Coxs River is impounded to form Lake Wallace and Lake Lyell (Fig. 5), both of which serve to provide cooling water, among other uses, to the coal-fired power stations at Wallerawang and Mt Piper (Bowmer et al. 2007; Young et al. 2000). These power stations contribute significantly to the total supply of approximately 12% of the national power needs generated by Delta Electricity (Delta Electricity 2013) and on their own account for approximately 25% of the New South Wales power supply (Young et al. 2000). Water discharge from the power stations into the Coxs River has previously been evidenced to contribute to heightened salinity and heavy metal deposits into the freshwater system. These are all important forms of land-use that represent a double edged sword, playing major roles in both the economy of the region and the environmental quality of the catchment (Birch, Siaka & Owens 2001). Unfortunately, as a result of both historic and continued extensive land-use along the Upper Coxs River catchment, the majority of the river reaches are highly degraded (Young et al. 2000).

Fig. 5. The Coxs river impoundments at Lake Wallace beside the Wallerawang power station (left) and at Lake Lyell (right). These human engineered lakes are significant modifications to the Upper Coxs River freshwater system. Photos by S. Judge (2013).

Despite having many sites impacted by human activities, the catchment remains environmentally significant, with high biodiversity values indicating considerable flora and fauna potential if provided adequate protection (Linke & Norris 2003). The current study site is one such example. Situated close to the heart of Wallerawang and surrounded by industrial activity, Marrangaroo Creek (Fig. 6) is a relatively un-impacted tributary that flows into the Coxs River in the upper catchment region and potentially represents a near-pristine benchmark by which to measure the health of the connecting freshwater system (Lithgow City Council 2011, 2012; Wright pers. comm.). The creek is particularly significant when considering freshwater animals given its history as an identified healthy platypus habitat (Hawkesbury-Nepean Catchment Management Authority 2008). The Atlas of NSW Wildlife (Dept. Environment & Heritage 2013) contains at least ten years of records consistently placing animals at considerable abundance and frequency at Marrangaroo Creek. Additionally, a number of landholders have identified not only platypuses, but also eastern water rats and a variety of water bird species using the creek over time in numbers that do not seem to be mirrored along the main stem of the Coxs River (Cutcliffe pers. comm.; Bastalic pers. comm.; Favell & Jonkers pers. comm.).

Fig. 6. Marrangaroo Creek, Upper Coxs River catchment NSW. Photos by S. Judge (2013).

2.5 STUDY AIMS & HYPOTHESES

The purpose of this study was to assess common species of semi-aquatic freshwater animals at Marrangaroo Creek and at a series of sites along the Upper Coxs River to determine whether or not there were any significant differences in their community composition. It was observed that the fauna diversity associated with the relatively undisturbed tributary of Marrangaroo Creek appeared to be greater than that of comparable sections of the more heavily exploited Coxs River. The particular target species were the platypus, the eastern water rat, and a variety of waterbird species, particularly ducks, grebes, and native hens. These species were specifically selected because they shared the attributes of occupying freshwater habitats; dependence on similar food sources and riparian habitat needs; being considered ‘common species’ able to cope with degraded conditions; and an IUCN listing as ‘of least concern’. Rare species were not included as the likelihood of detecting them in adequate numbers for robust data analysis given the time and seasonal constraints of the study were low (Lindenmayer & Burgman 2005).

The aim of the study was ultimately to establish whether or not there was a relationship between river condition and species diversity by comparing ecologically similar sites within a high-demand landscape. This was supplemented by the secondary aim of determining what factors appeared to favour or limit certain species where such relationships existed. It was predicted that if river condition was a limiting influence on common aquatic animals, then there would be a significant difference in species diversity between degraded and reference sites. It was also predicted that if environmental variables associated with species needs were not adequate, then there would be significantly lower species diversity at that site.

3. Methodology

3.1 SITE SELECTION & DESCRIPTION

The New South Wales Upper Coxs River catchment (Fig. 7) extends from Gardiners Gap in the Ben Bullen State Forest, down through Wallerawang and Lithgow, to the rural township of Hartley. It includes a range of networking streams, from Chain-of-Ponds to concrete lined urban water courses, that connect to the main stem of the Coxs River. One of the most significant of these connecting streams is Marrangaroo Creek, centrally located between Wallerawang and Lithgow (Hawkesbury-Nepean Catchment Management Authority, 2008).

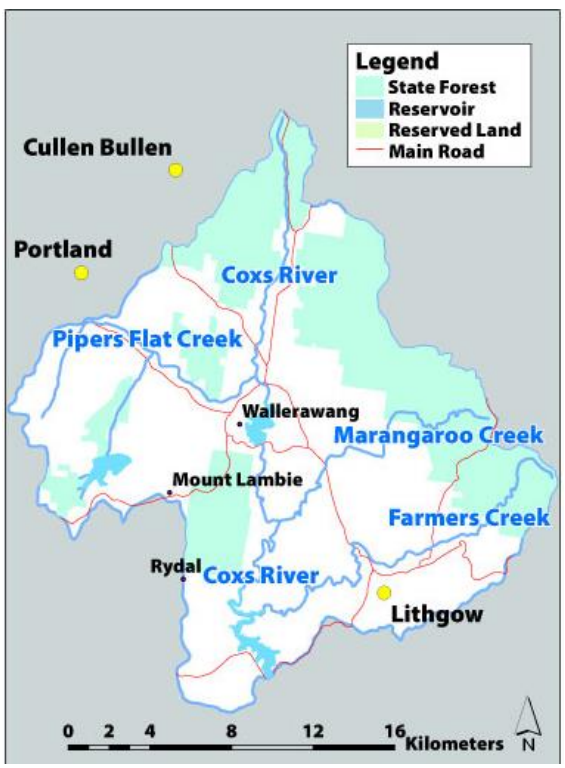

Fig. 7. The Upper Coxs River catchment (Hawkesbury-Nepean Catchment Management Authority 2008).

The selected Coxs River study sites extend from the upper reaches of Wallerawang to Little Hartley, and include three main land-use categories: urban development, industry, and agriculture. These anthropogenic eco-tones include a variety of point and non-point water pollution sources, as well as hydrologic disruption as a result of impoundment. While land-use types were not assessed for specific individual degree of impact on either the freshwater system or its fauna, it is important to acknowledge what is encompassed by the definition of a 'high-demand landscape' in the selection of sites for this study, as this provides context differentiation between the Coxs River sites and the comparatively un-impacted Marrangaroo Creek reference site.

Innis, Naiman and Elliott (2000) state that "the principle of place is an especially important scientific consideration in that every habitat has a relationship with the surrounding landscape and interpretation of site specific data needs to be conducted within the larger spatial and temporal perspective". This is generally achieved through BACI (before/after, control/impact) studies that utilise biologically ideal reference sites as comparative benchmarks against which to assess impacted sites (Innis, Naiman & Elliott 2000; Wright & Burgin 2009). In some circumstances, however, biologically ideal control sites are not always practical when applied to high-demand environments (Hughes, Larsen & Omernik 1986). In study sites that have been extensively modified by human activities over a long period of time, locating reference sites can be impractical, and even impossible, particularly where the altered conditions no longer resemble that of pristine regional conservation areas (Wright & Burgin 2009). This is particularly true of the current study site. It must be acknowledged that much of the Upper Coxs River catchment region has been extensively altered by anthropogenic processes over a long history (Birch, Siaka & Owens 2001; Young et al. 2000) and that a realistic approach to managing the fauna biodiversity along the high-demand freshwater stem may need to be considered according to the prevailing conditions rather than on pristine benchmarks. For this reason, the centrally located stretch of Marrangaroo Creek was selected as the main study site. While not exempt from all degrading impacts associated with close proximity to human land-use activities, the creek is under significantly less pressure than the Coxs River and hence provides an environmental 'snap-shot' of best-case contextual conditions upon which to potentially base management decisions (Fig. 8).

The aim of this study was not to specifically establish degraded and pristine freshwater systems, per se, but rather to assess fauna presence or absence in habitats across a landscape that is recognised to have been subject to long-term, extensive demand. It was therefore imperative that all sites along the Coxs River specifically represented human land-use eco-tones that could be assessed for target species' use of the aquatic habitat in comparison to Marrangaroo Creek. While this was not particularly difficult, there was, unfortunately, a distinct lack of local studies on any of the target species in or around the catchment region to indicate likely habitats, meaning 'best guess' approximations had to be made using historical species information (Innis, Naiman & Elliott 2000). Of the target species, it was determined that the platypus would be the most secretive and, consequently, the most difficult to confidently locate (Grant 2007; Grant & Temple-Smith 2003). Using historic data from the Atlas of NSW Wildlife (Dept. Environment & Heritage 2013) to identify points along the Coxs River known to have had platypus sightings within the past ten years (Fig. 9), four sites in total were selected for comparison: three impacted streams of the Coxs River, and one un-impacted stream at Marrangaroo Creek (Table.1), the latter of which is well documented by the Atlas as having regular platypus sightings spanning over twenty years in addition to eastern water rats and a variety of water bird species (Dept. Environment & Heritage 2013; Cutcliffe pers. comm.; Favell & Jonkers pers. comm.).

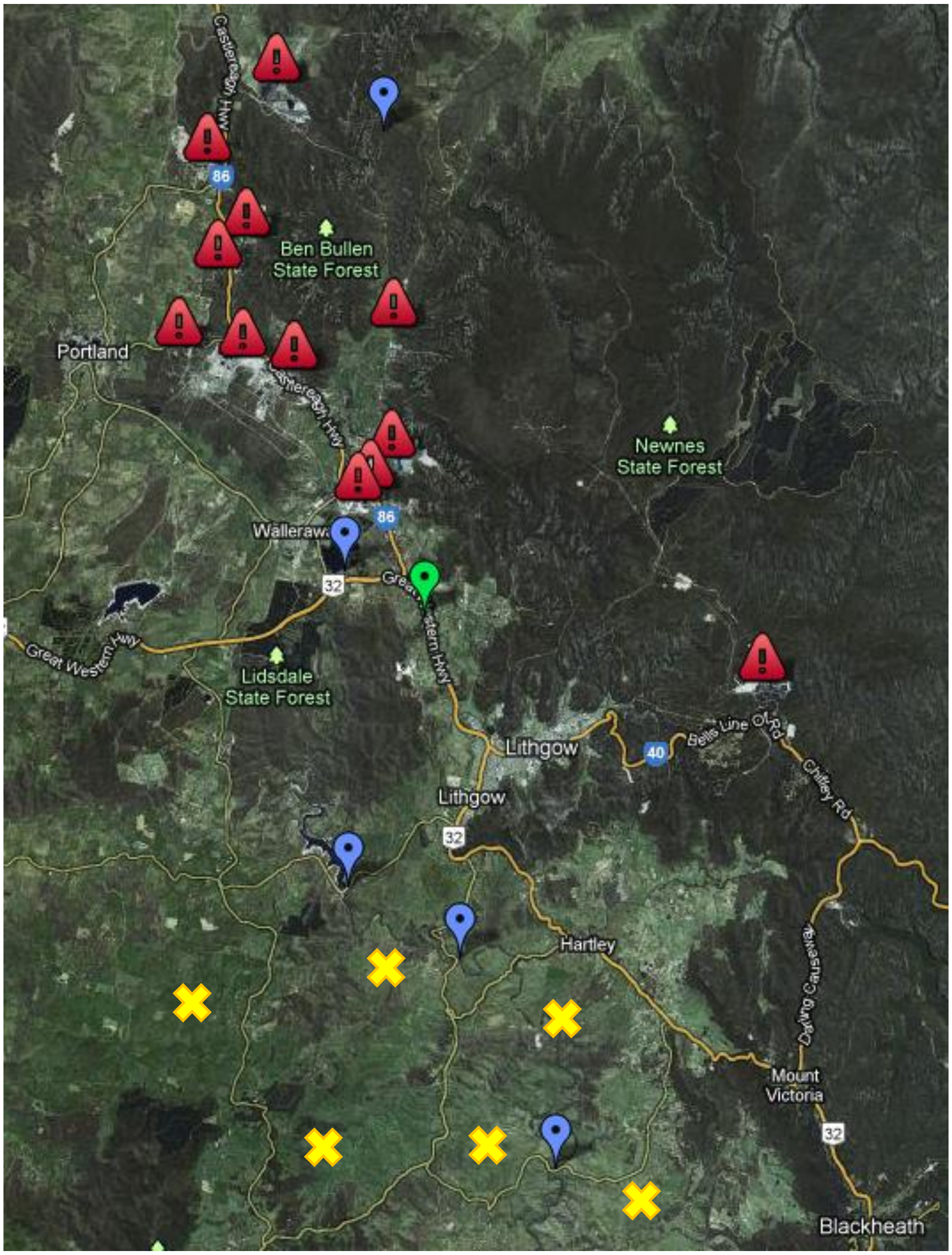

Fig. 8. Map showing study sites in relation to land-use concentrations. Study sites are indicated by blue markers, with the reference site at Marrangaroo Creek show in green. Mining collieries and the power stations are indicated by the red triangular markers. Extensively used rural and agricultural areas are indicated by yellow crosses (modified from Google Maps, 2013).

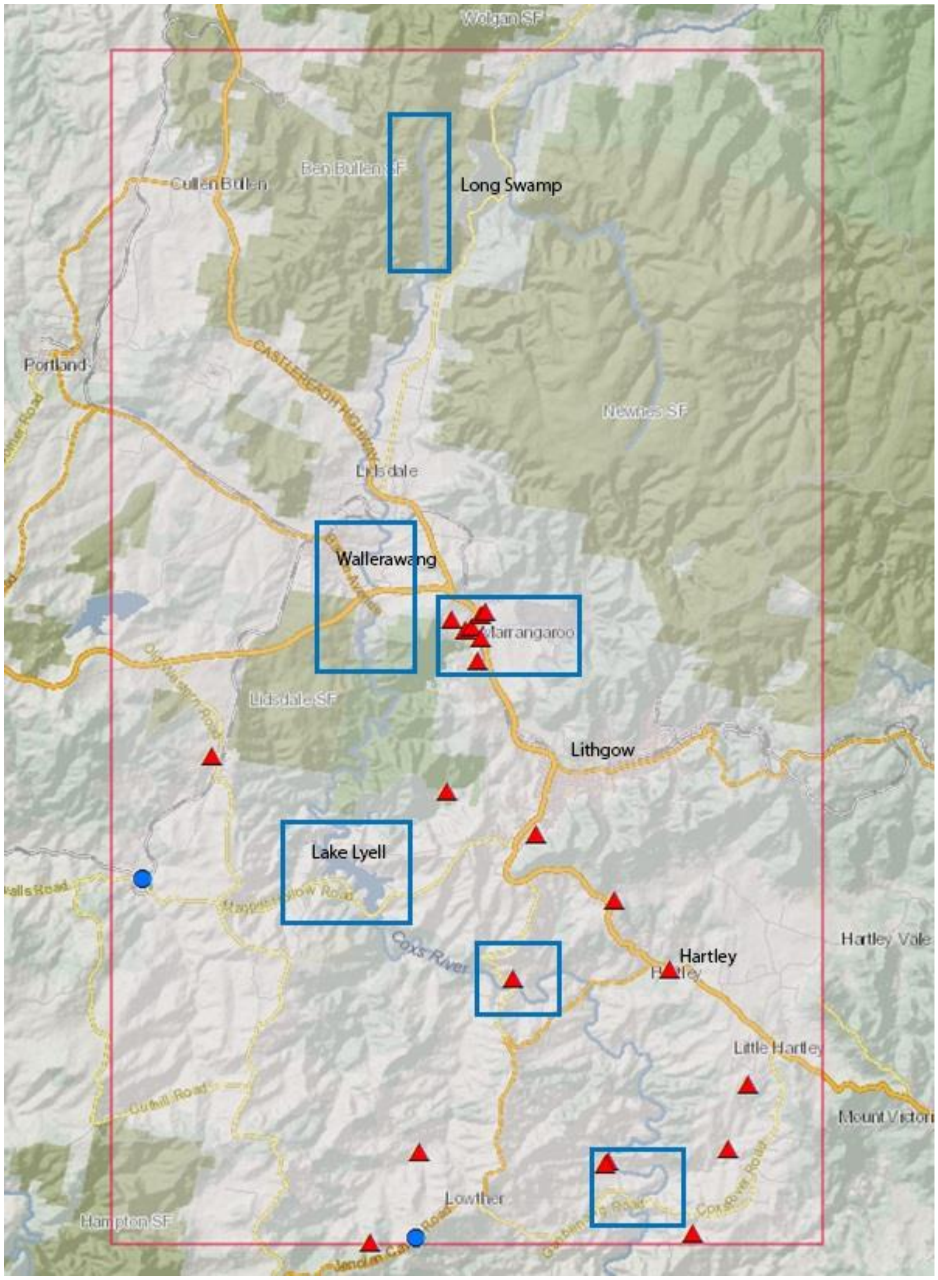

Fig. 9. Atlas of NSW Wildlife map indicating historic data records of platypus sightings within the past ten years in the study region. Platypus sightings are indicated by red triangles. Study sites for this project are indicated by blue boxes (modified from Dept. Environment & Heritage 2013).

A further two sites – impoundments of the Coxs River at Lake Wallace and Lake Lyell - were selected on separate criteria that excluded assessments of fauna presence/absence entirely. Both lakes, being human-developed impoundments of the Coxs River, were historically platypus habitat prior to construction (Short 2009) but due to the significant changes in flow regime are no longer considered viable habitat for this species, primarily as a result of increased depth (Grant 2007). Furthermore, despite reports of eastern water rats foraging around both lakes (Bastalic pers. comm.; Lake Lyell Recreation Park pers. comm.), poor accessibility and vastness of the sites made it highly unlikely that adequate data pertaining to this species could be collected within the time-frame of the study. Given the study aims, however, it was decided that the Lake Wallace and Lake Lyell sites were too important as representations of the current anthropogenic use of the freshwater system to be omitted entirely. The lakes occur both upstream and downstream of the Marrangaroo creek confluent point, effectively restricting the movements of animals entering the Coxs river from the creek. Furthermore, both lakes feed receiving waters into the lower reaches of the Coxs River (including two of the four stream sites selected for this project), making them a significant aspect of the total water system in the wider context of the study area (Bowmer et al. 2007; Young et al. 2000). However, due to the sheer water area of the lake sites providing a higher carrying capacity for waterbird species than even a pristine stream, regardless of environmental condition, these sites needed to be assessed independently and could not be compared with the stream habitats in terms of semi-aquatic fauna. As a result, the inclusion of the lakes in this study is limited to the provision of water chemistry and macro-invertebrate context data, with some reference to general waterbird monitoring data provided in Appendix 1.

Table. 1. Summary description of sites.

SITE (inc. GPS)	Habitat Type	Description
Marrangaroo Creek *-33.438729, 150.111845* (Fig. 10)	Tributary stream; flows into Coxs river near Wallerawang.	Situated between Wallerawang and Lithgow. Identified as a healthy platypus habitat, particularly alongside the Archvale Trout Farm (no longer operating). Land has been well managed, with mainly native vegetation planted on property site and surrounding remnant bushland further downstream and along opposite bankside. Two small family farms sit elevated above the site, though there has been no noticeable dramatic degradation to the site as a result. Extensive wildlife presence.
Long Swamp *-33.282037, 150.096073* (Fig. 11)	Wetland habitat broken by light stream of Coxs River.	Upper reaches of the Coxs river, close to headwaters. Situated in the Ben Bullen State Forest, the area was historically used for forestry and grazing, but has been extensively regenerated. High density riparian vegetation, mostly native with some invasive species (blackberry). Despite this, area is heavily utilised recreationally (dirt bikes in particular) and receives water from surrounding mines.
McKanes Bridge *-33.549653, 150.125089* (Fig. 12)	Coxs river; flows out of Lake Lyell.	Located on McKanes Falls Rd, Hartley. Extensive grazing land, downstream of mining activities. Waterway is at low situation to surrounding plains of variable elevation. Medium dense riparian vegetation cover, native and introduced. Close to traffic passage, medium usage. Mostly private property parallel to river course.

Duddawarra Bridge *-33.617478 ; 150.162163* (Fig. 13)	Coxs River; lower reaches of catchment.	Located on Coxs River Rd, Hartley. Extensive grazing land, downstream of mining & rural activities. Waterway is at low situation to surrounding plains of variable elevation. Sparse riparian vegetation cover, some native but mostly introduced weeds. Close to traffic passage, medium usage. Mostly private property parallel to river course.
Lake Wallace *-33.4246,* *150.080452* (Fig. 14)	Coxs River; impounded lake.	Coxs River impoundment associated with water usage by power plants. Surrounded by urban centre of Wallerawang & Lithgow, bankside used recreationally. Sparse riparian habitat, some native but mostly introduced. Close proximity to Wallerawang power station.
Lake Lyell *-33.526692, 150.082297* (Fig. 15)	Coxs River; impounded lake.	Coxs River impoundment associated with water usage by power stations & mines. Surrounded by elevated grazing land and some remnant bush habitat. Sparse riparian vegetation cover, medium-density near remnant habitat. Close to traffic passage, medium usage. Recreational facilities on lake opposite dam wall.

Fig. 10. Marrangaroo Creek, upper Cox's river catchment NSW – Bankside (left) and aerial (right). Photos by S. Judge (2013)

Fig. 11. Long Swamp, upper Cox's river catchment NSW. Photos by S. Judge (2013)

Fig. 12. McKanes Bridge, upper Cox's river catchment NSW. Photos by S. Judge (2013)

Fig. 13. Duddawarra Bridge, upper Cox's river catchment NSW. Photos by S. Judge (2013)

Fig. 14. Lake Wallace, upper Cox's river catchment NSW. Photos by S. Judge (2013)

Fig. 15. Lake Lyell, upper Cox's river catchment NSW. Photos by S. Judge (2013)

3.2 SAMPLING METHODS

Due to time and seasonal constraints, as well as differences in animal species ecology, full population abundance studies were considered impractical and unlikely to produce valid results. For example, while ducks and other waterbirds tend to exist in large colonies (Kingsford & Norman 2002), both platypuses and eastern water rats are less gregarious, more solitary species (Scott & Grant 1997), and therefore comparing counts of individuals as a measure of abundance would show ducks to be in greater abundance though this may not necessarily be the case given the differences in species ecology. For this reason, fauna surveys were based on a combination of presence-absence counts and a measurable percent-abundance index prescribed by the CSIRO for surveys where comparisons of individual counts across numerous species are needed, but are not necessarily accurate given differences in ecology (Mitchell & Balogh 2007). Surveys were taken at various times of day, chosen by random lot, to ensure that each site was sampled at least once in each major time category: pre-dawn, early-morning/dusk, late night. Again, this was to accommodate for differences in species ecology, with the platypus being nocturnally active (Grant 2007), waterbirds being diurnal (Norman, Thomson & Hamilton 1979), and water rats being predominantly crepuscular (Scott & Grant 1997). Fauna surveys were conducted according to prescription in presence-absence study literature (Royle & Nichols 2003; Strayer 1999; Vojta 2005). In addition, fauna surveys were also anecdotally conducted at Marrangaroo Creek using three types of remote sensing wildlife camera (infrared, LED night colour, and video footage) in order to qualitatively demonstrate wildlife activity, particularly of the platypus, to the relevant local environmental authorities. In order to establish environmental context that would indicate the degree of land-use impact on freshwater habitats, three main habitat condition variables were identified by previous, similar studies that could be measured individually in order to determine if and how the target fauna species are affected by waterway degradation. These condition variables are water quality, macro-invertebrate richness, and riparian habitat condition (Kingsford & Norman 2002; Scott & Grant 1997; Serena & Pettigrove 2009).

At each site, replicate samples were taken for each parameter to be measured over repeated sampling events. Time constraints limited the repeatability of this study, so only the minimum recommended sampling events were conducted for water chemistry and macro-invertebrate richness (Wright & Burgin 2009), and one sampling event for riparian habitat condition (Boggs & Weaver 1994; Moyo et al. 2010). Eight repeats of the fauna surveys were made however, as this data comprises the main aspect of the study. Sampling methods were as follows:

1. Fauna Surveys:

Three replicate sample areas of approximately 10 metres each along a 30-100 metre transect (depending on the accessible size of each site) were randomly selected and marked with field tape. Eight surveys were conducted at each site during the study, ensuring that each site was sampled at least twice at pre-dawn, early-morning/dusk, and late night. Surveys were conducted according to presence-absence studies, where each replicate was observed over five minute intervals and each species detected recorded on data sheets. Data was recorded in two ways: firstly, species were assigned one of two values depending on whether or not they were detected (1=detected; 0=not detected) at each replicate and secondly, individual counts of species were taken wherever possible in order to calculate specific abundance indices.

2. Water Chemistry:

Within each of the three replicates at each site, measures of water chemistry were taken after fauna surveys to ensure any disturbance to the animals would not interfere with survey results. A YSI-ProODO meter was used to calculate dissolved oxygen; an AQUA-CPA meter was used to measure electrical conductivity, pH, and total dissolved solids (TDS). A sample of water at each replicate within each site was taken and tested in the laboratory for further chemical parameters no more than 24 hours after collection. Water nutrients were calculated using a HACH Drel/2400 spectrophotometer and using the PhosVer3 ascorbic method for phosphorous and NitraVer5 Cadmium reduction method for nitrogen. Water turbidity was measured using a HACH 2100P turbidimeter. Three sampling events were conducted during the study period.

3. Macro-invertebrate Richness:

Within each of the three replicates at each site, macro-invertebrates were collected after water chemistry measurements to ensure river detritus and water disturbance would not interfere with results. Collection was by ‘kick sampling’, achieved by continuous disturbance of the river bed immediately upstream of a net for approximately 1 minute (Wright & Burgin 2009). All net contents were then placed in a sample jar and preserved in 70% ethanol. These samples were then taken back to the laboratory and sorted under a microscope. Two sampling events were conducted during the study period.

4. Riparian Condition Scores:

Using the same 10 metre replicates along 30-100 metre transects at each site as used for the fauna surveys, riparian condition scores were calculated using the step-point method. At the start point of the replicate, two steps of approximately 0.5 metres each was taken along the transect, at which point all vegetation within a 1.5 metre quadrat from the water's edge at the point where the step landed was assessed. A simple 'yes or no' indication point was made on data sheets for each vegetation category before moving along to the next step-point. In this way, approximately 10 metres were sampled, with all 'yes' indications added for each category to give a total score out of 10 for each replicate. Although it is normally advised to use 100 metres for step-point condition scoring, most of the sites for this project have less than 100 metres of accessible area. For this reason, the smallest site was used to determine the maximum possible transect size (30 metres) and all site replicates were hence divided into ten metre replicates in order to maintain sampling consistency across sites.

3.3 DATA ANALYSIS

Fauna survey data was organised into three categories: abundance; presence/absence; and species diversity counts. The data from all three categories was analysed using two way-analysis of variance with replication at 95% confidence to determine whether or not there was significance within and between samples across all data set categories. Presence/absence data was further analysed using a simplified percent-abundance index, using the equation %Abundance = (n / Total N) x 100, where n = number of replicates with confirmed sightings and N = total number of replicates over sampling period. Results were graphed by individual species for percent-abundance indices, and as total sample means for overall species diversity per site and overall species abundance per site.

Water chemistry parameters for each site were analysed by calculating the mean measurement of all replicates taken at each site over the sampling period, per parameter. Variance and standard error were also calculated from the data. In accordance with Australian and New Zealand Environment and Conservation Council (ANZECC) standards, the 20^{th} and 80^{th} percentiles for each parameter data set were also calculated for potential future use (ANZECC 2000). Because environmental conditions were measured as part of a secondary, contextual hypothesis, only significant means were graphed in relation to the ANZECC guidelines for upland rivers & streams. A complete summary of all water chemistry parameters is included in Appendix 2.

Macro-invertebrates were sorted from sample debris into corresponding preservation jars before being identified to taxonomic Order, and where possible to taxonomic Family. Once all sample specimens been identified, the SIGNAL2 analysis test was applied (Chessman 2003). This biological test is widely considered among the most robust and effective indices for indicator macro-invertebrates as a measurement of aquatic system health (Wright & Burgin 2009). The Australian SIGNAL2 biotic index measures the dominance of pollution-tolerant or pollution-sensitive macro-invertebrates based on taxonomic levels (Arnaiz et al. 2011; Chessman 2003), and accordingly two tests were carried out at the Order and Family levels. These results were individually graphed.

Riparian condition score results for each site were analysed by calculating the mean score of all three replicates at each site, per condition parameter. The means of each condition parameter were graphed and shown on a single graph with all sites represented in order to see the variations in habitat condition across sites.

Results

Table. 2. Two-way analysis of variance (ANOVA) output showing significance of species abundance & overall species diversity variation between sites (excluding lakes) along the Upper Coxs River catchment NSW, April – July 2013.

SPECIES	P-Value	F	Fcrit	Ho
Platypus	4.67E-05 (0.0000467)	9.0	2.75	P<0.05 ***; F>Fcrit.
E. Water Rat	0.04	3.0	2.75	P<0.05 *; F>Fcrit.
Pacific Black Duck	0.03	3.20	2.75	P<0.05 *; F>Fcrit.
Aust. Wood Duck	4.85E-07 (0.000000485)	13.79	2.75	P<0.001 ***; F>Fcrit.
Aust. Grebe	0.002	5.36	2.75	P<0.01 **; F>Fcrit.
Eurasian Coot	3.06E-05 (0.0000306)	9.26	2.75	P<0.001 ***; F>Fcrit.
Dusky Moorhen	0.09	2.29	2.75	P>0.05; F<Fcrit.
Overall Species Diversity	1.30E-07 (0.000000130)	15.30	2.75	P<0.001 ***; F>Fcrit.

*Moderate significance (P<0.05); **Intermediate significance (P<0.01); ***High significance (P<0.001).

Table. 3. Two-way analysis of variance (ANOVA) output showing significance of species presence/absence variation between sites (excluding lakes) along the Upper Coxs River catchment NSW, April – July 2013.

SPECIES	P-Value	F	Fcrit	Ho
Platypus	4.04E-05 (0.0000404)	9.14	2.75	P<0.001 ***; F>Fcrit.
E. Water Rat	0.02	3.67	2.75	P<0.05*; F>Fcrit.
Pacific Black Duck	0.13	1.92	2.75	P>0.05; F<Fcrit.
Aust. Wood Duck	2.75E-05 (0.0000275)	9.52	2.75	P<0.001 ***; F>Fcrit.
Aust. Grebe	0.0007	6.48	2.75	P<0.001 ***; F>Fcrit.
Eurasian Coot	4.04E-05 (0.0000404)	9.14	2.75	P<0.001 ***; F>Fcrit.
Dusky Moorhen	0.01	4.0	2.75	P<0.05*; F>Fcrit.

*Moderate significance (P<0.05); **Intermediate significance (P<0.01); ***High significance (P<0.001).

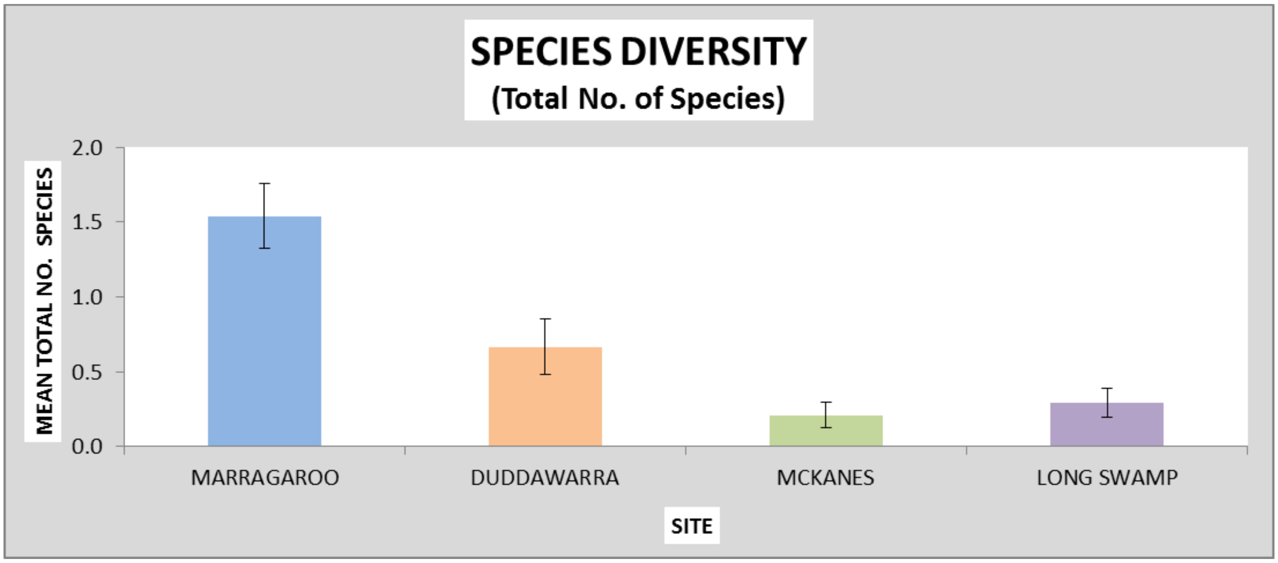

Fig. 15. Mean (average) number & standard error of total species per sample at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

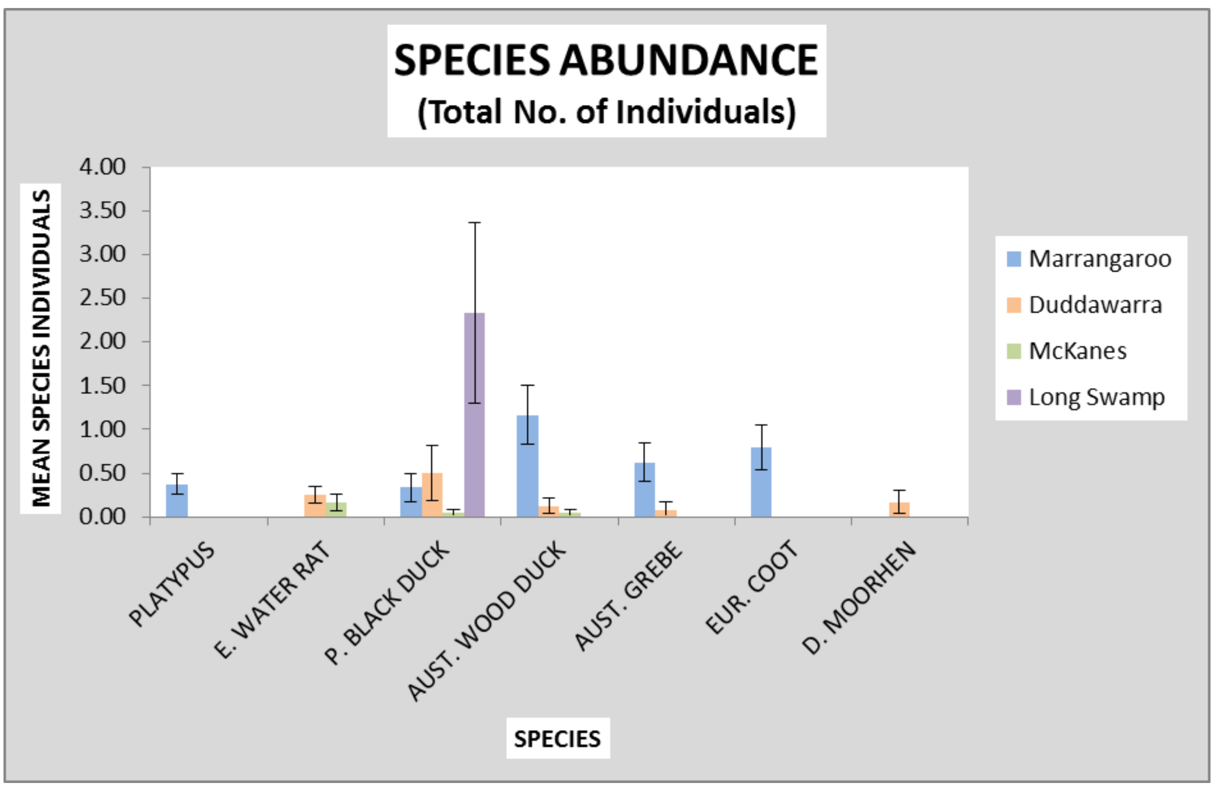

Fig. 16. Mean (average) number & standard error of individual species abundance per sample at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

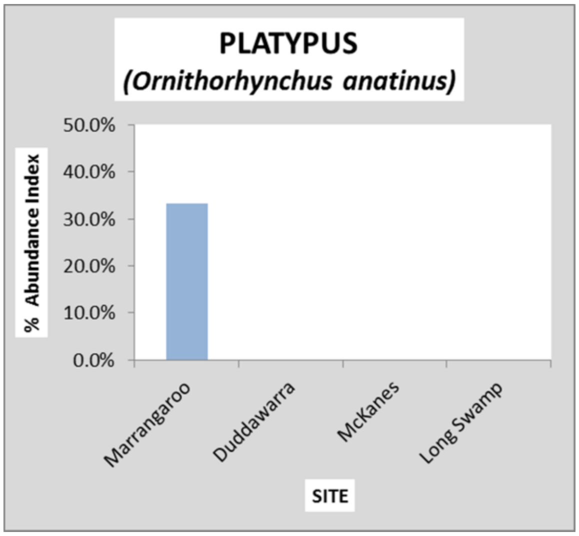

Fig. 17. %Abundance Index for the platypus (*Ornithorhynchus anatinus*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

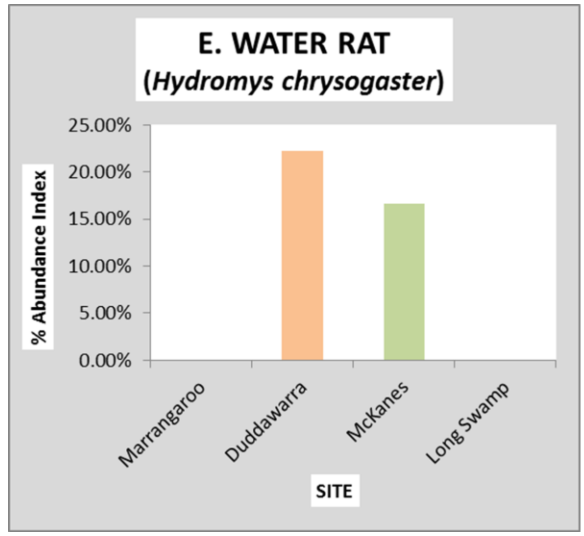

Fig. 18. %Abundance Index for the eastern water rat (*Hydromys chrysogaster*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

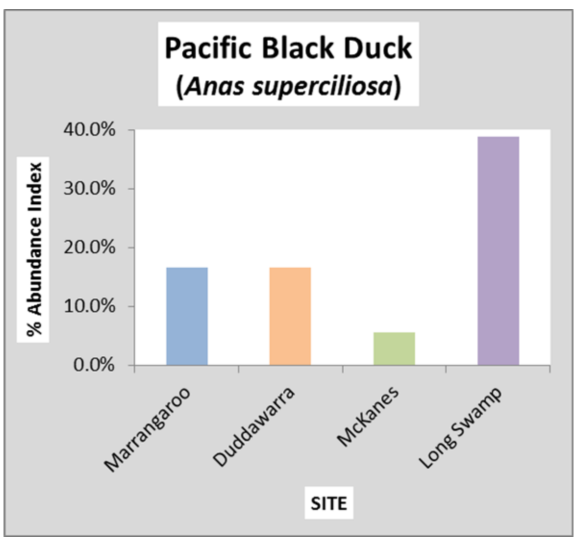

Fig. 19. %Abundance Index for the pacific black duck (*Anas superciliosa*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

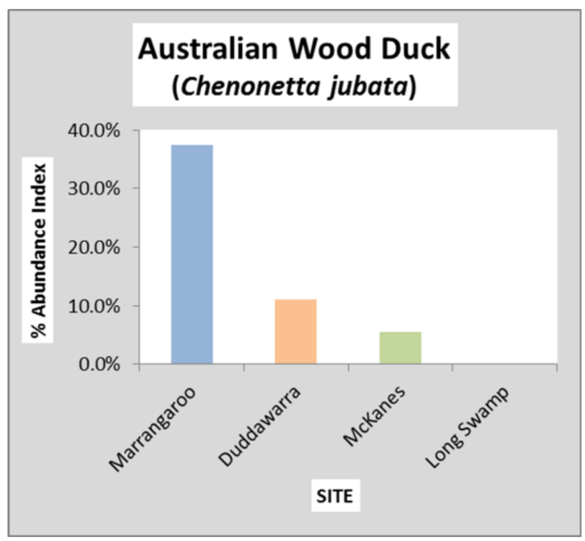

Fig. 20. %Abundance Index for the Australian wood duck (*Chenonetta jubata*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

Fig. 21. %Abundance Index for the Australasian grebe (*Tachybaptus novaehollandiae*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

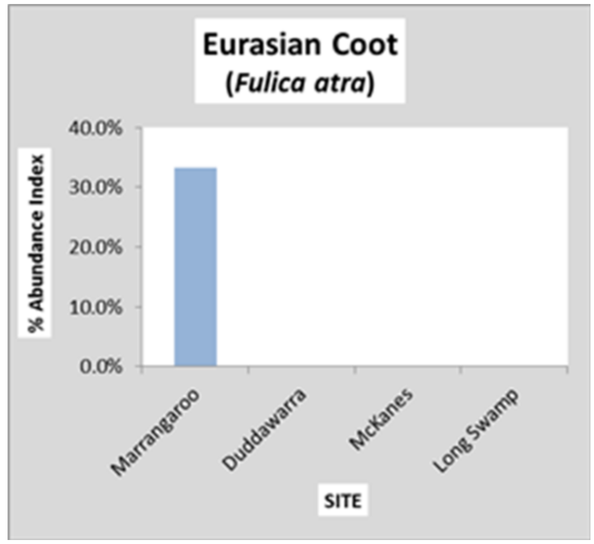

Fig. 22. %Abundance Index for the Eurasian coot (*Fulica atra*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

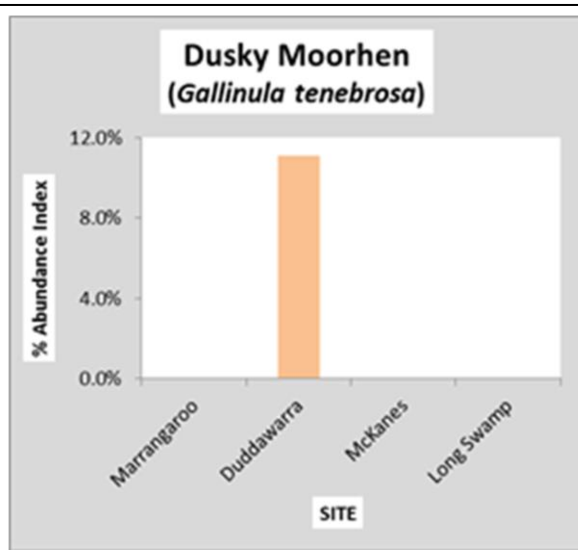

Fig. 23. %Abundance Index for the Australasian grebe (*Tachybaptus novaehollandiae*) at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

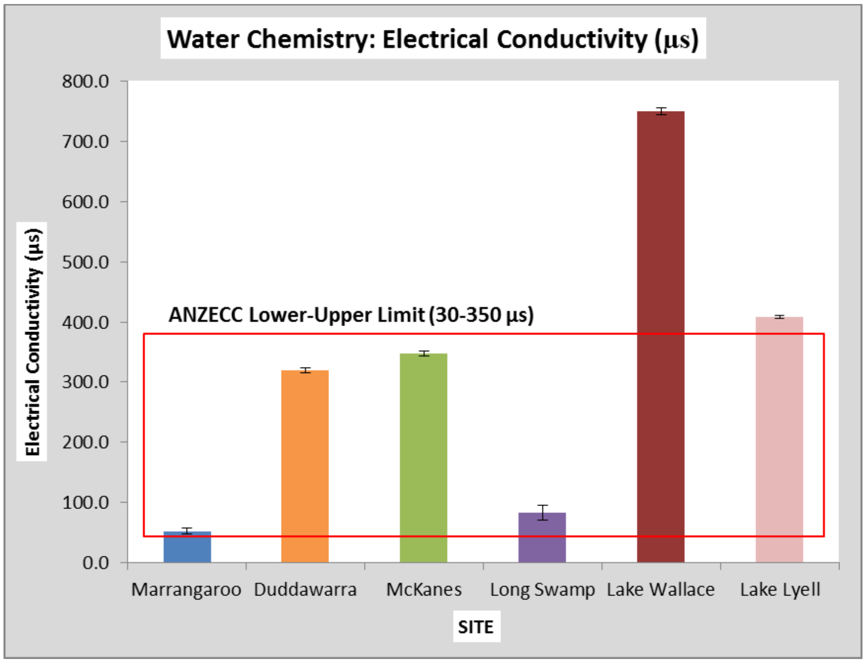

Fig. 24. Mean electrical conductivity levels at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013. ANZECC Lower-Upper limits indicated by red lines.

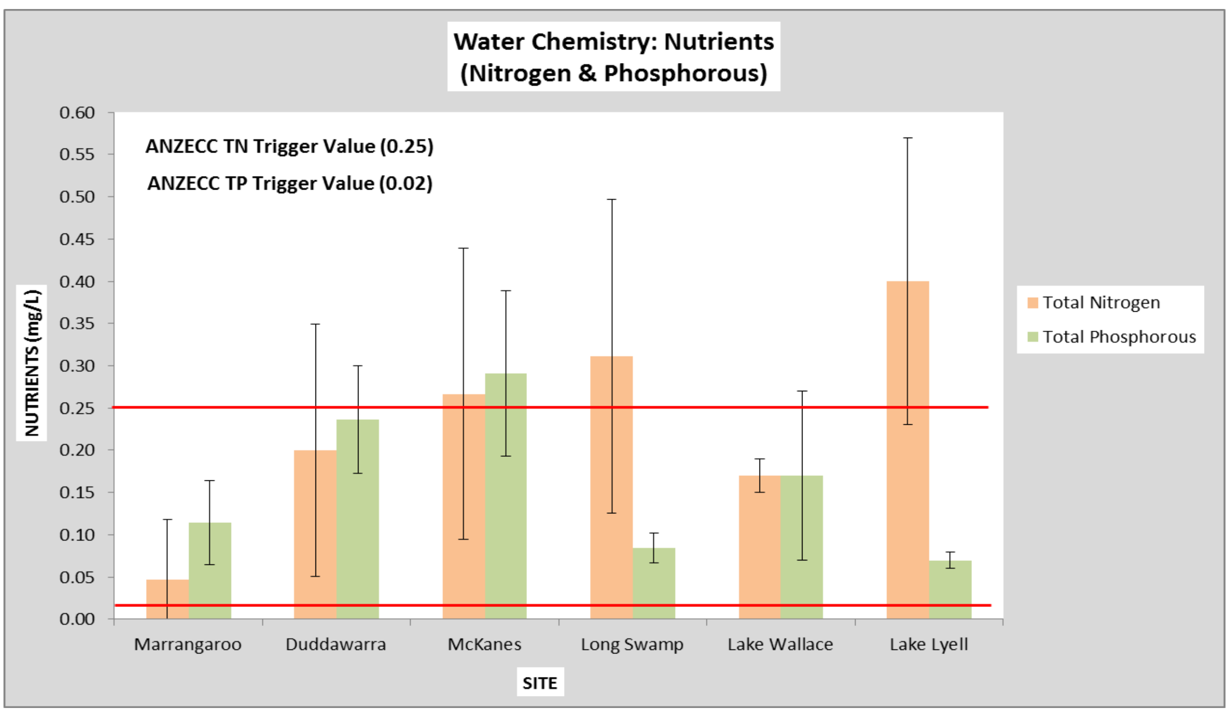

Fig. 25. Mean nutrient levels at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013. ANZECC trigger values indicated by red lines.

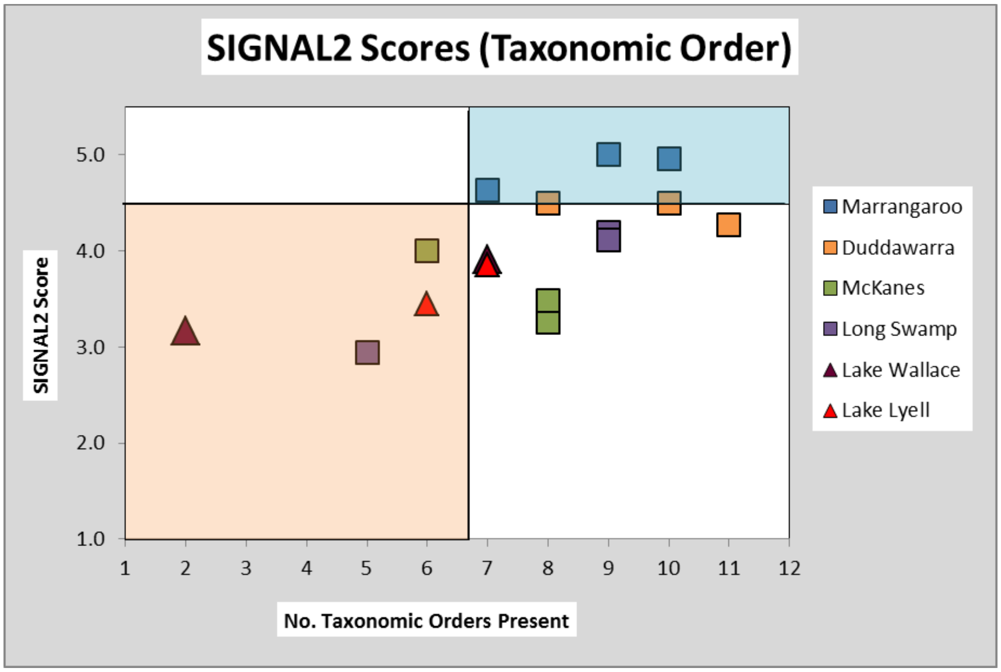

Fig. 26. SIGNAL2 scores according to taxonomic Order level at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013. Optimal quadrant 1 indicated in blue, high-impact quadrant 4 indicated in orange.

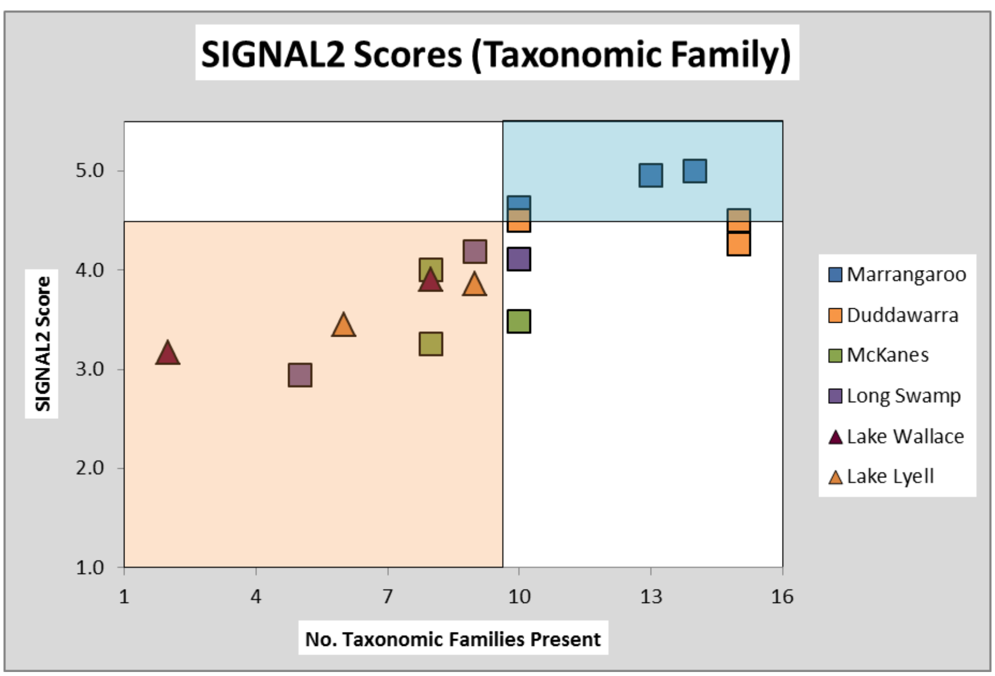

Fig. 27. SIGNAL2 scores according to taxonomic Family level at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013. Optimal quadrant 1 indicated in blue, high-impact quadrant 4 indicated in orange.

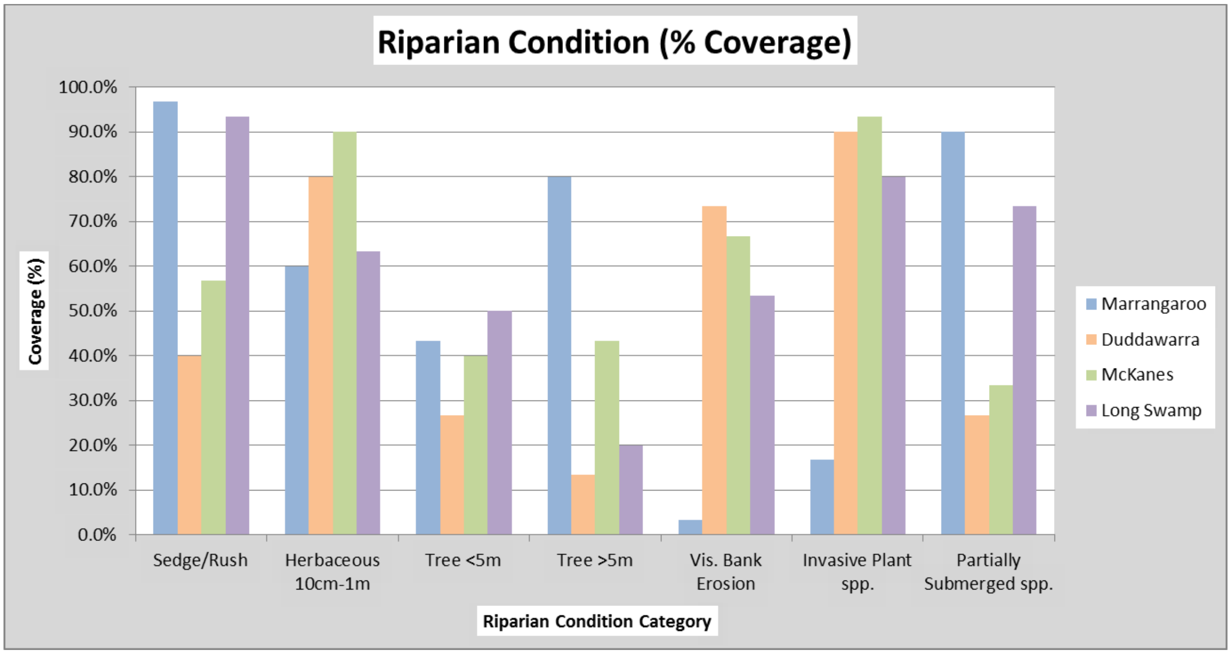

Fig. 28. Riparian condition according to percent-coverage score at each site along the Upper Coxs River catchment NSW compared to the reference site at Marrangaroo Creek, April – July 2013.

Overall, there was significant difference in species abundance and presence/absence between the Coxs River sites and Marrangaroo Creek, with a number of notable environmental factor correlations. Analysis of variance (ANOVA) showed significance in difference between sites for species abundance and diversity (Table. 2), as well as species presence/absence (Table. 3). This was supported by mean total number of species per site (Fig. 15) and mean total number of individuals per site (Fig. 16), both of which indicate a higher diversity and abundance at Marrangaroo Creek compared to the Coxs River sites. Individual species percent-abundance indices (Fig. 17-23) show a number of trends in species compositions across sites that support variations in site conditions, with higher abundances found at Marrangaroo Creek for most species. Environmental factor results consistently indicate better conditions at Marrangaroo Creek, with lower water salinity (Fig. 24) and nutrient loading (Fig. 25), and higher riparian condition (Fig. 28) and macro-invertebrate indicator scores (Fig. 26-27) compared to the Coxs River sites.

Discussion

A number of inferences can be derived from the results that ultimately suggest correlations between both environmental condition and species diversity across sites. ANOVA tests of species abundance (Table 2) and species presence/absence (Table 3) indicate significant differences between sites, with consistently high levels of variation in platypuses, Australian wood ducks, Eurasian coots, and Australasian grebes present in both tests. The eastern water rat showed a consistent moderate level of significance across both tests, while the Pacific Black Duck and Dusky Moorhen alternated in each test between moderate to no significant difference.

Species variation between sites is particularly detailed in total abundance per sample, per site measures (Fig. 16). Here it is indicated that the platypus was only found at Marrangaroo Creek (mean 0.38 per sample), along with a number of waterbird species surveyed at higher abundances than at any other site. Conversely, the eastern water rat was not found at Marrangaroo Creek during the study, but was counted at similar abundances along the Coxs River at Duddawarra Bridge (mean 0.25 per sample) and McKanes Bridge (mean 0.17 per sample). While water rats have been reported at Marrangaroo Creek previously (Cutcliffe, Favell & Jonkers pers. comm.), it may be that the strong platypus presence at this site potentially limits their numbers, particularly when the highly adaptive nature of the water rat is considered. It is possible that the combination of opportunistic habits and resilience to stream degradation (Scott & Grant 1997) has allowed for alternative site use by the water rat where competition from another high-order aquatic predator with a similar habitat and feeding niche, such as the platypus, is less abundant.

Similarly, the higher instance of Australian wood ducks (mean 1.17 per sample), Australasian grebes (mean 0.63 per sample), and Eurasian coots (mean 0.79 per sample) at Marrangaroo Creek is in strong contrast to their abundance at the Coxs River sites. Of these three species, only the Australian wood duck was found at both the Duddawarra Bridge (mean 0.13 per sample) and McKanes Bridge (mean 0.04 per sample) sites, while the Australasian grebe was present only at Duddawarra Bridge (mean 0.08 per sample). The Eurasian coot was not found at any of the Coxs River sites. Interestingly, the same prevalence in pacific black ducks and dusky moorhens was not seen at Marrangaroo Creek, despite these species sharing similar food and habitat requirements to the Australian wood duck, Australasian grebe, and Eurasian coot (Broome & Jarman 1982; Goodsell 1990; Halse et al. 1993; White et al. 2005). As with the platypus and eastern water rat, this may be the result of competition for resources on a relatively small waterway, a position supported by the results of abundance measurements and ANOVA tests. Firstly, abundance measurements show that at sites where the pacific black duck and dusky moorhen were prevalent, the Australian wood duck, Australasian grebe, and Eurasian coot were not (Fig. 16). There was a higher instance of pacific black ducks at Duddawarra Bridge (mean 0.50 per sample) than any other waterbird, as well as Dusky Moorhens (mean 0.17 per sample) which were not found at any other site. Similarly, the Long Swamp site of the Coxs River had the highest instance of pacific black ducks overall (mean 2.33 per sample), but recorded no other aquatic macro-fauna species during the study. McKanes Bridge was the only site to record pacific black ducks and Australian wood ducks in similar numbers (mean 0.04 per sample for both species), though abundance for both species was comparatively low and no other waterbird species were recorded at this site. Secondly, ANOVA analysis results of anecdotal waterbird surveys conducted at the much larger water bodies of Lake Wallace and Lake Lyell (Appendix 1) show no significant difference in abundance between these species, contextually suggesting that where waterway carrying capacity is high, these species are able to co-habitat as a result of higher resource availability.

ANOVA tests of species abundance (Table 2) showed high levels of significance in variation of overall species diversity between sites, supported by further measurements of total species per site (Fig. 15). The highest number of total species diversity was found at Marrangaroo Creek (mean 1.5 per sample), followed by Duddawarra

Bridge (mean 0.70 per sample), Long Swamp (mean 0.30 per sample), and finally McKanes Bridge (mean 0.20 per sample). Although a total of only one species was actually surveyed at Long Swamp compared to three total species at McKanes Bridge, it is important to note that the pacific black ducks found at Long Swamp were counted in high numbers, while the three species at McKanes Bridge occurred in very small numbers, meaning that the comparative measure of number of species to number of individuals (abundance) balanced overall diversity slightly in favour of Long Swamp. When considered in relation to percent-abundance indices for each species (Fig. 17-23), it can be seen that Marrangaroo Creek is significantly more fauna-diverse than the Coxs River sites, with almost all surveyed species found at highest abundance there. The complete absence of platypuses anywhere but Marrangaroo Creek is an unfortunate but expected result. Though all target species were considered resilient to environmental degradation, the platypus is likely to be the most susceptible to threatening processes as it is somewhat less adaptable in its ecology than the eastern water rat and waterbirds (Kingsford & Norman 2002; Scott & Grant 1997). It should also be noted that platypuses were found at Marrangaroo Creek at an abundance index of 33.3% (Fig. 17), which is closely comparable to site results for species considered highly common such as the Australian wood duck (abundance index 37.5%; Fig. 20), Australasian grebe (abundance index 29.2%; Fig. 21), and Eurasian coot (abundance index 33.3%; Fig. 22). This suggests that in an adequate habitat, the percent-abundance index for the platypus could be expected in comparable presence-absence ratios to these common waterfowl species. This study presents two supporting perspectives. Firstly, low percent-abundance indices for these species at the Coxs River sites coincided with low platypus abundance (Fig. 17, 20-22), in fact at each of these sites there were no platypuses recorded during the survey period. Secondly, in these circumstances it appeared that the eastern water rat filled the niche left by its monotreme counterpart (Fig. 18) in numbers not experienced at the healthy Marrangaroo Creek platypus habitat, evidenced by their abundance at the Duddawarra Bridge (abundance index 22.2%) and McKanes Bridge (abundance index 16.7%) sites. This suggests that within the local context, some common, specialist species such as the platypus are limited by environmental factors that may favour more opportunistic and degradation resistant species such as the eastern water rat. Additionally, the specialised aspects of platypus ecology may be a point of explanation as to the nil result at the Coxs River sites compared to the waterbird species that shared similar presence-absence abundance indices at Marrangaroo Creek. While waterbirds such as the Australian wood duck and Eurasian coot may be able to adapt to terrestrial feeding methods where aquatic systems are compromised, the platypus is essentially an obligate aquatic feeder despite having some capacity to move over land.

To determine patterns in species diversity with the impacts of a high-demand landscape, a number of environmental variables were tested. The results indicated that there were higher levels of water salinity at the Coxs River sites than at Marrangaroo Creek (Fig. 24). While all sites fell within the prescribed ANZECC trigger value range (ANZECC 2000), Marrangaroo Creek (52.5 µs) fell just above the lower-limit of 30µs, while the Coxs River sites were positioned closer to the upper limit of 350 µs. The McKanes Bridge (347.6 µs) site had the highest salinity, followed by the Duddawarra Bridge (319.9 µs) and Long swamp (82.3 µs) sites. Similarly, nutrient testing indicated Marrangaroo Creek to be generally less impacted by nitrogen and phosphorous loading than the other stream sites (Fig.25). While all sites were above the ANZECC (2000) trigger value of 0.02mg/L for total phosphorous, levels at Marrangaroo Creek (0.11 mg/L) and Long Swamp (0.08 mg/L) were much lower than at the

Duddawarra Bridge (0.24mg/L) and McKanes Bridge (029mg/L) sites. Only Marrangaroo Creek (0.05mg/L) and Duddawarra Bridge (0.20mg/L) were below the total nitrogen trigger value of 0.25mg/L, with Marrangaroo Creek being much lower than the Duddawarra Bridge site. Both Long Swamp (0.31 mg/L) and the McKanes Bridge (0.27mg/L) site exceeded the trigger value for total nitrogen. Water chemistry results reflect species diversity results closely. The Coxs River at the McKanes Bridge site has both the most impacted water quality of the stream sites as well as the lowest species diversity, followed by Long Swamp, Duddawarra Bridge, and finally Marrangaroo Creek with the least impacted water quality and highest species diversity results.

SIGNAL2 biological indicator results for macro-invertebrates (Fig. 26-27) indicated a similar pattern, with the optimal regional range (indicated by the blue quadrant) based on reference site data from Marrangaroo Creek. It can be seen that the Duddawarra Bridge site scores fall close to this optimal quadrant range across both taxonomic level tests, followed by Long Swamp and finally the McKanes Bridge site, a result consistent with water quality and species diversity outcomes. Both Long Swamp and the McKanes Bridge site had data points fall within the highest impact range (indicated by the orange quadrant) across both taxonomic level tests, suggesting a more impoverished macro-invertebrate assemblage and consequently a reduction in feeding resources at the Coxs River sites compared to Marrangaroo Creek. Again, this closely reflects a similar gradient as the species diversity and water chemistry results.

Water chemistry and SIGNAL2 results for Lake Wallace and Lake Lyell should be noted as further explanatory evidence for patterns in species diversity. Both lakes have a higher salinity level than any of the main study stream sites, with Lake Wallace (750.0 µs) dramatically exceeding the upper-limit of the ANZECC (2000) trigger value range of 350 µs, as does Lake Lyell (408.3 µs) to a lesser extent (Fig. 24). Nutrient loads at both lakes are comparable to the stream sites, with the highest total nitrogen levels of the entire study recorded at Lake Lyell (0.4mg/L) in contrast to the prescribed ANZECC trigger value of 0.25 mg/L (Fig. 25). Similarly, both lakes achieved low SIGNAL2 scores across both taxonomic levels, with data points among the worst recorded, particularly at Lake Wallace (Fig. 26-27). However, it is interesting to note that despite having the most impacted salinity and macro-invertebrate results overall the lakes appear to support large numbers of water birds with no significant variations in species diversity (Appendix 1) Though the results suggest that it is likely that high salinity levels are the main causative factor for macro-invertebrate limitations, it is important to consider that salinity can also benefit certain types of macrophytes and algal blooms, as can nutrient loading (Hart et al. 1990; White et al. 2005). Given that the lakes represent large water bodies with deep water and a vastly higher natural carrying capacity than a stream habitat (Broome & Jarman 1982; Halse et al. 1993), it is likely that the combination of high salinity and nutrients has favoured alternative food sources for resilient water birds at the detriment of more sensitive aquatic species, particularly fish (Lake & Bond 2007). While this is beyond the scope of this study, it does lend weight to the possibility that high salinity levels at the Coxs River stream sites may be a significant causative factor to reduced species diversity, particularly as water chemistry and SIGNAL2 results for these sites coincided with one another. The only apparent difference between the lake and stream sites in their response to these factors was species diversity, a factor which the independent consideration of lake habitats explains in terms of alternative food availability. Such alternative food sources are unlikely to benefit the eastern water rat and it would be expected that this species would either move on to another habitat or forage the banks of lake environments for opportunistic food sources, a behaviour that has been seen in water rats in the study region (Bastalic pers. comm.). A more specialised freshwater species with limitations on dive-depth capacity, the platypus is unlikely to derive benefits from such changes in food resource availability (Grant 2007). The important exception, however, are waterfowl with their specific adaptations and resilience for large water bodies rendering them well-equipped to take advantage of pollutant-induced boom and bust cycles in food resource type and availability (Kingsford & Norman 2002), as evidenced in this study.

Macro-invertebrate food availability is not the only environmental factor likely to be impacted by salinity and other human-induced processes (Goodsell 1990; Halse et al. 1993; Hart et al. 1990; White et al. 2005). Habitat quality is a critical consideration, and again the results of riparian condition scoring (Fig. 28) closely reflected species diversity. The most likely riparian features to play a limiting role is those related to bank stabilisation, particularly for burrow sites in the case of the platypus and eastern water rat (Scott & Grant 1997). The results of percent-coverage condition scoring (Fig. 28) indicated that Marrangaroo Creek was consistently higher in deep-rooted trees for bank stabilisation and lower in visible bank erosion than the Coxs River sites. Riparian factors influencing macro-invertebrate food composition include partially submerged vegetation and low instance of invasive plants species. Again, Marrangaroo Creek scored significantly better in both instances than any other site. Another factor potentially favouring platypuses at Marrangaroo Creek is the high instance of sedges and rushes. Although water quality and macro-invertebrate results indicate the Duddawarra Bridge site as the closest potential platypus habitat of the Coxs River sites studied, comparable differences in instance of deep-rooted trees, sedge and rushes, submerged vegetation, bank erosion, and invasive plants strongly suggest that riparian habitat condition plays a major determining role in habitat suitability that may serve as a major limiting factor when degraded.

Collaboratively, the results suggest that despite being common, the target species are significantly reduced along the high-demand aspects of the Coxs River compared to Marrangaroo Creek. Unfortunately, the IUCN listing as 'of least concern' assigned to these species along with the high human value invested in the land-use applications within the Upper Coxs River catchment mean that these species do not receive the management consideration they possibly should. A number of studies exist to suggest that common species can become suddenly locally extinct (Cucherousset et al. 2008; Gomes, Ribeiro & Carretero 2011; Lindenmayer et al. 2011; Roger, Laffan & Ramp 2007) and Lindenmayer et al. (2011) cite common species with specialised ecologies found in a wide range of environmental conditions as those particularly at risk. Of the target species, this criteria applies only to the platypus, which was the species most strongly affected by the impacts of the high-demand landscape in this study. Previous studies of other common Australian species highlight the risk of complacency towards local management of the catchment platypus population. Roger, Laffan and Ramp (2007) found that the common wombat (*Vombatus ursinus)* population in southern New South Wales had been significantly reduced despite the species being considered abundant throughout its distribution and areas of suitable habitat within the study area identified. A combination of limiting factors associated with habitat disturbance, particularly the isolation of pocketed populations reducing genetic diversity, were listed as the causation, and recommendations were given for further studies and ongoing monitoring of wombat populations at the local level to better inform specific species management decisions (Roger, Laffan & Ramp 2007). Lindenmayer et al. (2011) showed how suddenly common species can decline in a case study of the Greater Glider (*Petauroides volans)* in south-eastern Australia. Formerly common in two significant studies, the Greater Glider population crashed suddenly, with one population suffering a rapid extinction within a staggeringly short three year period, and the other declining at an annual rate of 8.8%. Such eye-opening studies highlight the urgency for a change in attitude towards the management of species considered common, particularly where IUCN conservation status listings are assigned despite experts citing a lack of sufficient population studies to confidently subscribe such listings to local and regional management levels (Kingsford & Norman 2002; Scott & Grant 1997).

Conclusion & Recommendations

The aim of this study was ultimately to establish whether or not there was a relationship between river condition and species diversity along the high-demand aspects of the upper Coxs River catchment, and to determine what factors appeared to favour or limit species where such relationships existed. The results suggested that significant differences in species diversity and abundances between the high-impact and reference sites were present, with a generally higher scope of freshwater fauna diversity found at Marrangaroo Creek. Furthermore, strong relationships between species diversity and the three environmental factors common to all target species strongly suggest that degradation of the aquatic system comprises a major causative factor. Differences in waterbird species diversity suggested that many of the Coxs River sites were too resource depleted to carry numerous species at any one time. This was further supported by results showing consistent species variation patterns between sites that can most likely be attributed to competition, along with contextual data from the two lake sites providing evidence that co-habitation between the target waterbird species does occur when resources are available. Shifts in environmental condition appear to favour some species more than others. The adaptive capacity of the eastern water rat to both utilise alternative feeding resources and tolerate more degraded environments appeared to support its presence in high-impact sites more predominantly than in the healthy but high-competition platypus habitat at Marrangaroo Creek. Though considered resilient, the platypus is likely to be the most susceptible to threatening processes due to a more specialised ecology than the eastern water rat and waterbirds. This was evidenced in the results with the complete absence of platypuses at all sites save Marrangaroo Creek being an unfortunate but expected result.

It is therefore the conclusion of this study that a number of common freshwater animal species have been adversely impacted by the high-demand of human land-use activities. In particular, the local platypus population that appears to be restricted to the relatively un-impacted tributary of Marrangaroo Creek is identified as potentially being at risk of population decline and sudden bottleneck events. These conclusions are made in recognition of a number of study limitations. First and foremost, this study was extremely time-constrained and further restricted by data sampling having to occur during the winter season, when the target species are both less active and possibly absent from the study site. Secondly, accessibility to the Coxs River was limited due to much of the waterway occurring on private property, and as a result surveying efforts were limited to site availability.

Despite these limitations, the findings of the study are relevant and deserving of further attention. It is therefore recommended that:

- Ongoing monitoring of the target species, particularly the platypus, and their habitats be undertaken over a long-term period that encompasses significant seasonal periods of species activity for a more robust survey of species abundance.

- Studies of platypus movements and population genetics be conducted in order to provide a much clearer picture of how the species is coping in terms of habitat fragmentation and altered hydrologic regimes impacting on gene flow. In particular, it is advised that the Marrangaroo Creek population be carefully assessed given the lake impoundments of the Coxs River upstream and downstream of the Marrangaroo Creek confluent potentially restricting dispersal movements and consequently, gene migration. Such studies should be considered an essential component of future research and management of the species within the catchment.

- The inclusion of tissue sampling from the target species, particularly waterbirds, in future assessments of local freshwater fauna and/or water quality to test for heavy metal accumulation and toxicity.

- Intensive land-care monitoring and bush regeneration activities be conducted around Marrangaroo Creek in order to ensure that this habitat remain as pristine as possible. Environmental management should also include regular macro-invertebrate surveys, riparian flora census and maintenance, water quality monitoring, and regulation of activities associated with the water way.

- Collaboration with scientists in association with the current Australian Platypus Conservancy (2013) aims to further research into the relationship between the platypus and eastern water rat. Preliminary studies have suggested that the highly opportunistic and degradation-tolerant ecology of the eastern water rat in combination with a shared habitat niche may place the native rodent as a potential indicator of shifting environmental conditions that could inform early intervention in platypus management strategies. Findings from this study did appear to indicate higher abundances of water rats in high-impact environments where the platypus was absent, but in lower abundances where it was present. Although the two species are known to share habitats, permanent increases in water rat population abundances could indicate that conditions are becoming less favourable to the platypus, reducing limiting competition on the water rat.

- It is further recommended that Marrangaroo Creek be genuinely and urgently considered for local protection as an evidenced healthy platypus habitat in an otherwise degraded freshwater system, as environmental pressures on this tributary may result in the loss of an ecologically significant resource for freshwater animals with significant consequences.

Although a number of local residents anecdotally claimed to have seen platypuses at various points along the Coxs River, no evidence of burrows or the animals were found during this study and when shown comparative images of the monotreme and the eastern water rat swimming, seasoned local fisherman freely admitted the ambiguity and potential misidentification of species on their part. Historically, Wallerawang and Lithgow have been well known platypus habitats with the animal holding both European and Indigenous cultural significance. Prior to impoundment, Charles Darwin recorded his first sighting of the unique Australian animal in the Coxs River at Wallerawang, while the local Indigenous community of the Wiradjuri people place the catchment river systems in the creation story of the platypus (Short 2009). The tale tells of an ill-fated union between the duck Gaygar and Bigun, the water rat. When their babies are born strange, neither duck nor water rat, they are banished from both tribes along with their mother, but eventually find refuge far from their home in the river systems surround Bathurst and Wallerawang. Here, the Biladurang, or platypus, tribe began, spreading downstream into the Blue Mountains, where they are now an internationally recognised feature of the freshwater systems (Ellis 1994, McKay 2001, Short 2009). With such a rich environmental and cultural significance surrounding this iconic species in the Upper Coxs River catchment, complacency towards their local conservation on the basis of their IUCN listing and consideration as common, resilient species cannot be afforded.

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Appendix 1 – Species Survey Data: Lake Wallace & Lake Lyell

PACIFIC BLACK DUCK ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	120.1429	1	120.1429	6.05036	0.027523	4.60011
Columns	108.4286	6	18.07143	0.910072	0.515471	2.847726
Interaction	86.85714	6	14.47619	0.729017	0.634119	2.847726
Within	278	14	19.85714			
Total	593.4286	27				

AUST. WOOD DUCK ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	2.892857	1	2.892857	3.857143	0.069708	4.60011
Columns	0.928571	6	0.154762	0.206349	0.96897	2.847726
Interaction	2.357143	6	0.392857	0.52381	0.781212	2.847726
Within	10.5	14	0.75			
Total	16.67857	27				

MUSK DUCK ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	4.321429	1	4.321429	8.066667	0.013101	4.60011
Columns	2.428571	6	0.404762	0.755556	0.615799	2.847726
Interaction	2.428571	6	0.404762	0.755556	0.615799	2.847726
Within	7.5	14	0.535714			
Total	16.67857	27				

HARDHEAD DUCK ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	1.75	1	1.75	0.731343	0.406846	4.60011
Columns	10.71429	6	1.785714	0.746269	0.622179	2.847726
Interaction	15	6	2.5	1.044776	0.438303	2.847726
Within	33.5	14	2.392857			
Total	60.96429	27				

EURASIAN COOT ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	3257.286	1	3257.286	3.759749	0.072927	4.60011
Columns	5568.929	6	928.1548	1.07133	0.424288	2.847726
Interaction	4169.214	6	694.869	0.802058	0.5844	2.847726
Within	12129	14	866.3571			
Total	25124.43	27				

DUSKY MOORHEN ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	22.32143	1	22.32143	2.853881	0.11329	4.60011
Columns	32.42857	6	5.404762	0.69102	0.660783	2.847726
Interaction	32.42857	6	5.404762	0.69102	0.660783	2.847726
Within	109.5	14	7.821429			
Total	196.6786	27				

PURPLE SWAMPHEN ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	1.75	1	1.75	4.454545	0.053279	4.60011
Columns	1	6	0.166667	0.424242	0.850824	2.847726
Interaction	1	6	0.166667	0.424242	0.850824	2.847726
Within	5.5	14	0.392857			
Total	9.25	27				

AUST. GREBE ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	456.0357	1	456.0357	2.27652	0.15358	4.60011
Columns	1166.929	6	194.4881	0.97088	0.479385	2.847726
Interaction	1327.214	6	221.2024	1.104237	0.407463	2.847726
Within	2804.5	14	200.3214			
Total	5754.679	27				

GT. CRESTED GREBE ABUNDANCE DATA

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	11.57143	1	11.57143	2.745763	0.119744	4.60011
Columns	14.71429	6	2.452381	0.581921	0.739221	2.847726
Interaction	15.42857	6	2.571429	0.610169	0.718758	2.847726
Within	59	14	4.214286			
Total	100.7143	27				

Appendix 1.a. ANOVA output results for individual species showing no significant difference between sites.

SPECIES DIVERSITY PER SITE

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	2.892857	1	2.892857	1.528302	0.236707	4.60011
Columns	17.71429	6	2.952381	1.559748	0.230573	2.847726
Interaction	7.857143	6	1.309524	0.691824	0.660214	2.847726
Within	26.5	14	1.892857			
Total	54.96429	27				

Appendix 1.b. ANOVA output results for overall species diversity showing no significant difference between sites.

Appendix 2 – Water Chemistry Data

Electrical Conductivity	MEAN	VARIANCE	ST. ERROR	20th Percentile	50th Percentile	80th Percentile
Marrangaroo	52.5	260.4	5.4	41.0	44.6	70.5
Duddawarra	319.9	142.6	4.0	307.2	321.0	332.4
McKanes	347.6	125.3	3.7	338.6	346.0	354.0
Long Swamp	82.3	1371.4	12.3	36.7	98.3	109.5
Lake Wallace	750.0	188.0	5.6	739.0	748.0	763.0
Lake Lyell	408.3	42.3	2.7	404.0	408.0	411.0

pH	MEAN	VARIANCE	ST. ERROR	20th Percentile	50th Percentile	80th Percentile
Marrangaroo	7.49	0.37	0.20	6.96	7.32	8.05
Duddawarra	7.79	0.60	0.26	7.07	8.17	8.23
McKanes	7.97	0.78	0.29	7.38	8.17	8.71
Long Swamp	6.30	0.17	0.14	5.91	6.49	6.58
Lake Wallace	8.77	0.07	0.11	8.70	8.89	8.91
Lake Lyell	8.35	0.40	0.26	8.33	8.49	8.68

Dissolved Oxygen	MEAN	VARIANCE	ST. ERROR	20th Percentile	50th Percentile	80th Percentile
Marrangaroo	85.8	216.5	4.9	73.9	75.4	100.4
Duddawarra	95.1	9.7	1.0	92.4	94.6	98.0
McKanes	94.7	137.6	3.9	87.1	90.1	104.9
Long Swamp	58.9	907.0	10.0	33.4	53.9	93.5
Lake Wallace	98.1	174.1	5.4	81.8	103.7	108.9
Lake Lyell	97.2	54.0	3.0	96.6	99.1	101.5

Turbidity (NTU)	MEAN	VARIANCE	ST. ERROR	20th Percentile	50th Percentile	80th Percentile
Marrangaroo	3.3	1.8	0.4	2.6	2.9	3.2
Duddawarra	4.1	3.7	0.6	2.5	4.4	5.1
McKanes	3.5	1.1	0.3	2.5	3.5	3.9
Long Swamp	23.2	453.3	7.1	9.1	16.5	35.1
Lake Wallace	3.2	4.6	0.9	1.8	2.4	4.0
Lake Lyell	3.9	7.0	1.1	2.2	2.7	4.7

Total Nitrogen	MEAN	VARIANCE	ST. ERROR	20th Percentile	50th Percentile	80th Percentile
Marrangaroo	0.05	0.00	0.02	0.00	0.01	0.10
Duddawarra	0.20	0.01	0.04	0.10	0.20	0.30
McKanes	0.27	0.02	0.04	0.16	0.30	0.40
Long Swamp	0.31	0.02	0.05	0.20	0.30	0.44
Lake Wallace	0.17	not calculated	not calculated	not calculated	not calculated	not calculated
Lake Lyell	0.4	not calculated	not calculated	not calculated	not calculated	not calculated

Total Phosphorus	MEAN	VARIANCE	ST. ERROR	20th Perc	50th Percentile	80th Percentile
Marrangaroo	0.11	0.02	0.05	0.04	0.06	0.12
Duddawarra	0.24	0.04	0.06	0.09	0.18	0.40
McKanes	0.29	0.09	0.10	0.06	0.18	0.51
Long Swamp	0.08	0.00	0.02	0.05	0.07	0.12
Lake Wallace	0.17	not calculated	not calculated	not calcul	not calculated	not calculated
Lake Lyell	0.07	not calculated	not calculated	not calcul	not calculated	not calculated

Appendix 3 – Macro-Invertebrates Data

SITE	SIGNAL 2 SCORE	NO. ORDERS	NO. FAMILIES
Marrangaroo A	5.0	10	13
Marrangaroo B	4.6	7	10
Marrangaroo C	5.0	9	14
Duddawarra A	4.5	8	10
Duddawarra B	4.5	10	15
Duddawarra C	4.3	11	15
McKanes A	3.3	8	8
McKanes B	3.5	8	10
McKanes C	4.0	6	8
Long Swamp A	2.9	5	5
Long Swamp B	4.2	9	9
Long Swamp C	4.1	9	10
Lake Wallace A	3.2	2	2
Lake Wallace B	3.9	7	8
Lake Lyell A	3.9	7	9
Lake Lyell B	3.5	6	6