Cardno Ecology Lab

Shaping the Future

Marine and Freshwater Studies

NRE No 1 Mine

Assessment of Mine Subsidence Impacts on Aquatic Habitat and Biota

Job Number: EL0910036

Prepared for Gujarat NRE Coking Coal Limited

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Cover Image: Cataract Creek, November 2009. Photographer Doug Hazell, Cardno Ecology Lab

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Executive Summary

Background

Gujarat NRE Coking Coal Limited (Gujarat NRE) proposes to use longwall mining methods to extract coal from the base of the Wongawilli Seam within the Wongawilli East and Wongawilli West areas of NRE No. 1 Mine at Russell Vale, in the NSW Southern Coalfield. Cardno Ecology Lab has assessed the likelihood and significance of potential impacts on aquatic habitats and biota arising from the extraction of coal within these areas and made recommendations about ongoing aquatic ecology monitoring. The assessment has been prepared on the basis of the latest mine layout proposed by Gujarat NRE, the results of baseline studies on aquatic habitats and biota in significant watercourses above the two areas of the proposed mine conducted by Cardno, and on predictions of mine subsidence and the effects of this subsidence on stream flow, bank stability and water quality made by other specialists. The major watercourses of interest within the mine areas are the 'third order' streams, Lizard Creek and Wallandoola Creek, and the lower 'fourth order' reaches of Cataract Creek and Lizard Creek, all of which contain substantial amounts of permanent aquatic habitat. Baseline data has also been collected from sites in the Upper Cataract River, Loddon Creek, Allen Creek and Cascade Creek, which are situated outside the mine area and serve as controls.

Physical Setting

The proposed longwalls in the Wongawilli West Mine would be divided into two areas to reduce the risk of subsidence along Wallandoola and Lizard Creeks. The longwalls would be situated below watersheds and ephemeral tributaries, but not the main channel of these creeks. The longwalls in the Wongawilli East Mine would also be divided into two areas, one of which would be situated below ephemeral tributaries that flow into the main channel of Cataract Creek downstream of Mount Ousley Road and the other would be below 1st and 2nd order tributaries and the main channel of Cataract Creek. These longwalls would be positioned in a north-east to south-west direction to reduce the risk of vertical subsidence under Cataract Creek.

Existing Environment

Wallandoola Creek and Lizard Creek are deeply-incised streams that flow into the Cataract River between Cataract Dam and Broughton's Pass Weir. Both creeks are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath. They contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. The cascades and waterfalls that occur on the downstream reaches of these creeks are significant barriers to fish passage. Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc all being evident.

Cataract Creek is bordered by temperate rainforest. This creek is shallow and is characterised by alternating series of long pools interspersed with shorter bars and riffles. It also contains submerged snags and dams of large woody debris. The water in Lake Cataract backs up into Cataract Creek with the extent of the incursion depending on the storage level of the dam. There are no barriers that would prevent fish in this lake moving into this section of the creek.

The most recent water quality monitoring programme indicates the water in all three creeks is fairly acidic. The pH values were generally outside the ANZECC/ARMCANZ guidelines for slightly disturbed rivers in south-east Australia, but are typical for Hawkesbury Sandstone watercourses of the Southern Highlands and Illawarra. Salinity was within the guideline range. On some occasions, the filtered zinc, copper and aluminium and total nitrogen and phosphorus levels in the creeks were above the 95% species protection level for freshwater aquatic ecosystem guidelines.

The baseline aquatic ecology monitoring program indicated the dissolved oxygen levels in all three creeks were generally below the lower default trigger value (DTV). The pH and turbidity levels in Wallandoola Creek and electrical conductivity, pH and turbidity levels in Lizard Creek and Cataract Creek deviated from the DTVs occasionally.

Substantial variations in the number of aquatic macroinvertebrate taxa found in these creeks were evident across spring and autumn baseline surveys. The "health" of the macroinvertebrate fauna in Wallandoola Creek varied from more diverse than the AUSRIVAS reference condition to severely impaired, while that in Lizard Creek varied from equivalent to AUSRIVAS reference condition to impoverished. The 'health" of the fauna in Cataract Creek varied from equivalent to AUSRIVAS reference condition to severely impaired. SIGNAL2 scores indicated that the fauna at monitoring sites on Wallandoola Creek and Lizard Creek were subject to moderate to severe degradation, but those on Cataract Creek were subject to mild degradation.

Two species of fish (Climbing Galaxias and Australian Smelt) were observed in Lizard Creek, but no fish were found in Wallandoola Creek. Macquarie Perch, Silver Perch, Short-finned and Long-finned Eels, Goldfish, Climbing Galaxias and Mountain Galaxias, Eastern Gambusia, Freshwater Catfish and an unidentified Freshwater Cod of the genus *Maccullochella* have been recorded in Cataract Creek. Freshwater crayfish were present in all three creeks.

Risk of Subsidence

Gujarat NRE has indicated an adaptive management plan would be implemented to reduce the risk of major subsidence. At Wongawilli West, extraction of longwalls would not occur under the main or named channels of third or fourth order streams and longwalls would be set back at least 200 m from the centreline of Lizard Creek. At Wongawilli East, the risk of major subsidence would be reduced by using narrow longwall blocks with wide chain pillars, setting the start lines for the longwalls at least 110 m back from the maximum stored water level of Cataract Dam, monitoring the subsidence that occurs as longwalls are extracted and modifying their length and position to ensure subsidence does not exceed a pre-determined trigger level. The proponent has provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact.

Assessment of Impacts on Aquatic Habitats and Biota

The physical subsidence resulting from extraction of the Wongawilli East longwalls is not expected to have any detectable effects on stream flow, pond drainage or stream gradient of Cataract Creek, provided the adaptive management plan is adhered to. Changes in these attributes are not expected to have any observable effects on the aquatic habitats or biota within the creek. Minor bank and bed erosion may occur above the longwall panels and could lead to minor, transient increases in sediment mobility and turbidity within and downstream of the subsidence area. These would have minimal impact on aquatic habitats and biota, as the sediment loads and turbidity would be smaller than that experienced naturally during heavy rainfall events.

The extraction of the majority of the Wongawilli West longwalls is not expected to have any observable physical, chemical or biological impacts on Wallandoola Creek. Subsidence resulting from extraction of Longwalls 3 and 4, however, could fracture a sandstone rock shelf in the creek and cause the pool immediately upstream to drain. This could result in loss of aquatic habitat and associated biota and prevent fish from accessing potential upstream feeding and spawning areas. This habitat would be re-established as soon as inflows exceed diversionary flows. The diversion of water through the underlying substrata may elevate iron, zinc, copper and aluminium levels and increase iron staining in Wallandoola Creek. Precipitation of iron hydroxide could facilitate growth of bacterially-mediated iron flocs and mats which, in turn, could smother the substratum and reduce the amount and variety of habitats available to aquatic organisms. The water that re-emerges may have different qualities such as lower oxygen levels and elevated metal concentrations. The impacts of the above on diversity and abundance of aquatic organisms are expected to be localised, minor in extent and transient in nature and therefore of no significance.

Mining is not expected to have any detectable effects on stream flow or pools in the reach of Lizard Creek above the Wongawilli West longwalls. Consequently, no flow-on effects are expected on water quality, aquatic habitats or their biota. There is a possibility that additional fracturing of the creek bed, loss of water at rock bars, diversion of flows to underlying substrata and greater pool drainage could occur in a section of Lizard Creek to the north of proposed Longwall 2 that has already been impacted by previous mining. The impacts on water quality, aquatic habitats and biota of the diversion of flow through the underlying substrata would be similar to those described for Wallandoola Creek.

Threatened Species and Assessments of Significance

Two aquatic invertebrate species, Adam's Emerald Dragonfly (*Archaeophya adamsi*), Sydney Hawk Dragonfly (*Austrocordulia leonardi*), listed as threatened under state legislation, could potentially occur within the NRE No.1 Mine Area. There are no records of these species occurring within Cataract, Wallandoola or Lizard Creeks or the greater Cataract River catchment. There is suitable habitat for Adam's Emerald Dragonfly within all three creeks, but not for Sydney Hawk Dragonfly. The latter dragonfly is consequently highly unlikely to be present within the mine areas, so potential impacts on this species have not been considered. The Assessment of Significance indicated that the proposed mining operation is highly unlikely to have a significant impact on any Adam's Emerald Dragonfly that may be present, provided the adaptive management plan is implemented.

Four species of fish, Macquarie Perch (*Macquaria australasica*), Trout Cod (*Maccullochella macquariensis*), Silver Perch (*Bidyanus bidyanus*) and Murray Cod (*Maccullochella peelii peelii*), listed as threatened under state and/or federal legislation are known to have been translocated to Cataract Dam. Targeted fish surveys indicate that Macquarie Perch, Silver Perch and an unidentified Freshwater Cod, that may be either Trout Cod, Murray Cod or a hybrid of these species, occur in the reach of Cataract Creek that traverses the proposed Wongawilli East Mine Area. The Assessments of Significance indicate that the proposed mining operation is highly unlikely to have a significant impact on any Macquarie Perch, Silver Perch, Trout Cod or Murray Cod accessing this mine area, provided the adaptive management plan is implemented.

Conclusions

The assessment of potential impacts on aquatic ecology generally, and threatened species in particular, is consistent with the performance measures specified in the Bulli Seam Operations Approval. Subsidence resulting form the extraction of the proposed longwalls would have negligible environmental consequences for aquatic flora and fauna, including threatened species.

Recommendations

1. The condition of aquatic habitats and biota should be monitored during and following the extraction of the longwalls using the same survey sites, methods and seasons as in the baseline study. The objective of this monitoring would be to validate the predictions about the flow-on effects of subsidence-related disturbances on aquatic habitats and biota and assess any unexpected impacts on these that may occur.
2. If fractures of the stream bed and associated loss of water or significant changes in pH, dissolved oxygen, turbidity or metal concentrations are detected during routine surface monitoring, additional surveys of aquatic habitats and biota should be undertaken to determine whether these have had any flow-on effects on aquatic ecology.

3. If fish or yabby kills are noted during routine surface monitoring, further studies should be undertaken to determine the extent of impact on aquatic ecology and whether there is a need to implement management and/or mitigation measures.
4. If significant effects on aquatic habitats and/or biota are detected during monitoring, consideration should be given to reducing further impacts by modifying the dimensions of future longwalls, increasing their setback from the affected watercourse or remediation of fractured rock bars.

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1 Introduction

1.1 Background and Aims

Gujarat NRE Coking Coal Limited (Gujarat NRE) proposes to extract coal from the base of the Wongawilli Seam within the Wongawilli East and Wongawilli West areas of the NRE No. 1 Mine at Russell Vale, in the NSW Southern Coalfield. The extraction of coal from these areas, using longwall mining methods, has the potential to result in physical subsidence impacts, which could, in turn, have direct effects on stream flow and water quality and indirect effects on aquatic habitats and biota in the surface watercourses located within and downstream of the mine areas.

Cardno Ecology Lab was commissioned by Gujarat NRE to assess the likelihood and significance of potential impacts on aquatic habitat and biota arising from mining of longwalls within the Wongawilli East and Wongawilli West areas and make recommendations for ongoing monitoring. This assessment is to be included in the Environmental Assessment that is being prepared for submission to the Department of Planning as part of the Part 3A approvals process for NRE No. 1 Mine. The Study Area encompasses the predicted 20 mm subsidence zone above the proposed workings, the defined 400 m Risk Management Zones and the 600 m zone from the edge of secondary extraction for assessment of significant natural features (NSW Planning Assessment Commission 2009).

1.2 Study Areas

1.2.1 Wongawilli West

The proposed Wongawilli West longwalls are located within the Cataract River catchment. The Study Area includes two tributaries of the Cataract River: Wallandoola Creek and Lizard Creek that flow into the reach of the Cataract River downstream of Cataract Dam and upstream of Broughtons Pass Weir within the Sydney Water supply system. These are the only watercourses in this area that contain significant areas of permanent aquatic habitat. The reach of Wallandoola Creek that flows through the mine area is classified as a ‘third order’ stream under the Strahler Stream Classification System, but becomes a ‘fourth order’ stream approximately 1.8 km downstream of the proposed longwall panels. Lizard Creek is a ‘third order’ stream upstream of its confluence with LCT1, but a ‘fourth order’ stream downstream of this point.

1.2.2 Wongawilli East

The proposed Wongawilli East longwalls are located within the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir. Cataract Creek, the only significant watercourse located within this Study Area flows directly into Lake Cataract. The reach of the creek within the Study Area is classified as a ‘fourth order’ stream.

1.3 Aquatic Ecology Monitoring Program

The baseline aquatic ecology monitoring program for the Wongawilli East and Wongawilli West mine areas was designed to satisfy the recommendations made by the NSW Department of Planning’s ‘Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield’ (NSW Department of Planning 2008). Specific recommendations within the review that are relevant to environmental investigations for project applications lodged under Part 3A include:

- Assessments should focus on Risk Management Zones (RMZs), which in the case of watercourses should include streams within the mine subsidence area classified as 3rd order or above under the Strahler Stream Classification System;

- A minimum of 2 years of baseline data should be collected at an appropriate frequency and scale for significant natural features located within an RMZ or not.
- Before, After, Control, Impact (BACI) designed ecological studies should be used to monitor mine subsidence impacts.

Within each of the significant watercourses identified within the Study Areas, two 'potential impact' sites that may be subjected to mine subsidence impacts during and after longwall extraction were selected for monitoring. Ecologically comparable 'control' watercourses in the Cataract catchment that are not expected to be undermined were also identified, and within each of these, two sites were selected for monitoring. The control watercourses used in this study were Upper Cataract River, Loddon Creek, Allen Creek and Cascade Creek. These 'control' sites provide measures of the natural background environmental variability within the greater Cataract catchment as distinct from any mine subsidence impacts. The position of the 'potential impact' and 'control' sites relative to the proposed Wongawilli West and Wongawilli East Longwalls is shown in Figure 1.

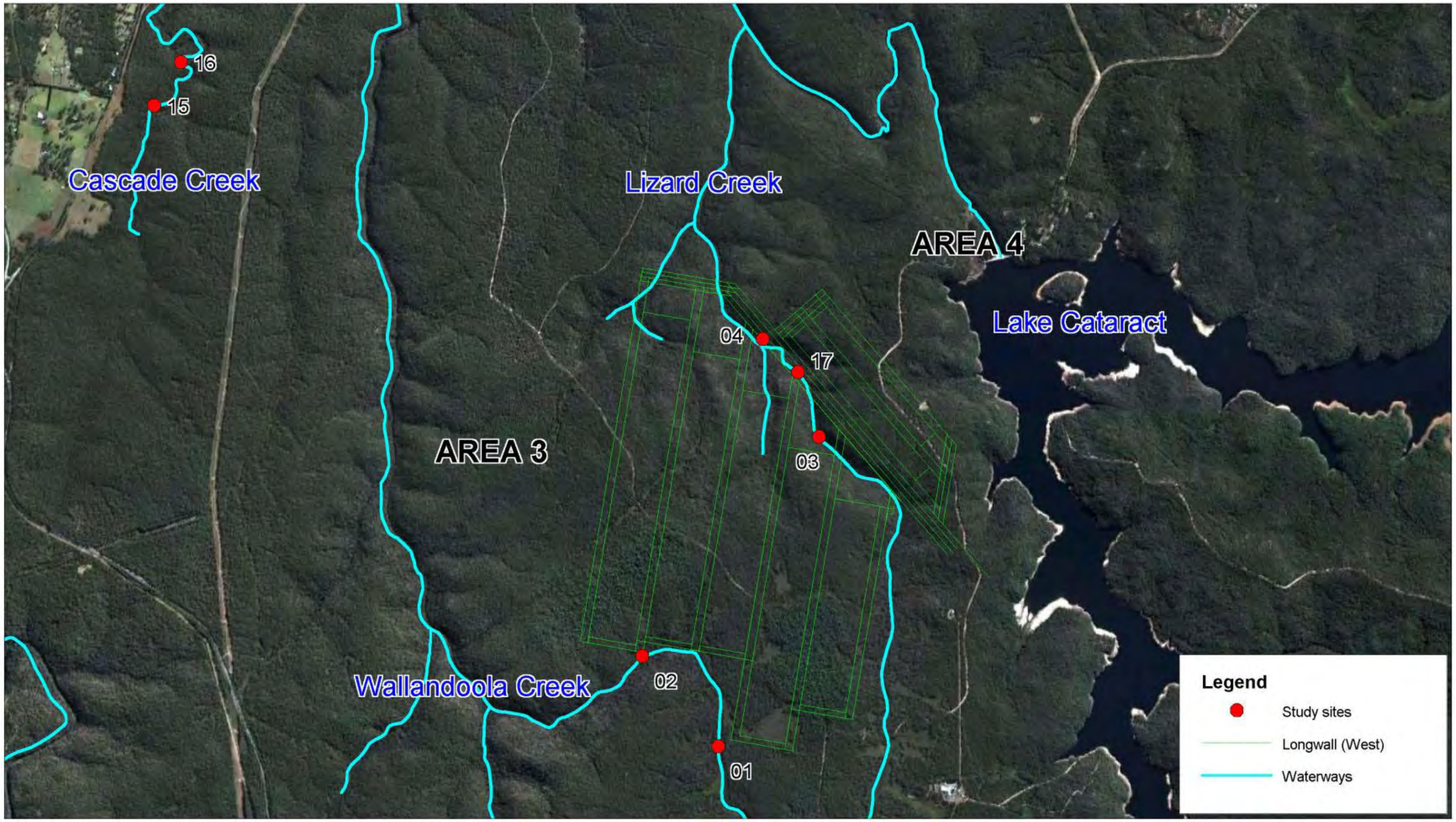
The sampling design chosen for the baseline monitoring program will enable Beyond BACI analyses to be used to assess any potential impacts of mining subsidence on aquatic ecology, provided that similar assessments are made during and after mining. The Beyond BACI technique is a modification to the BACI approach that has been developed specifically to distinguish environmental impacts from natural changes (Underwood 1991, 1992, 1994).

At each monitoring site, the following aquatic ecological indicators were surveyed in spring and autumn:

- Aquatic habitat
- Aquatic macroinvertebrate fauna
- Fish fauna
- Water quality.

Baseline monitoring commenced in spring (October) 2008 and was completed in spring (September) 2011. A summary of the results of the baseline monitoring program is presented in the Review of Existing Information (see Section 2.0). A detailed description of the ecological indicators sampled, methods and the results of the baseline monitoring undertaken at 'control' and 'potential impact' sites is presented in Cardno Ecology Lab (2011) (see Annexure 1).

The initial site inspection undertaken prior to the selection of monitoring sites indicated that the aquatic habitat within Cataract Creek was suitable for occupation by Macquarie Perch, a threatened species listed under both State and federal legislation (Cardno Ecology Lab 2009). A preliminary survey of fish occurring within these habitats was undertaken between 25 and 26 November 2008 and targeted backpack electrofishing surveys for this and other threatened fish species were undertaken during the summers of 2009/2010, 2010/2011 and 2011/2012. A description of the sampling methods and results of these surveys are presented in Cardno Ecology Lab (2011 and 2012) (see Annexure 1).



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Kilometres

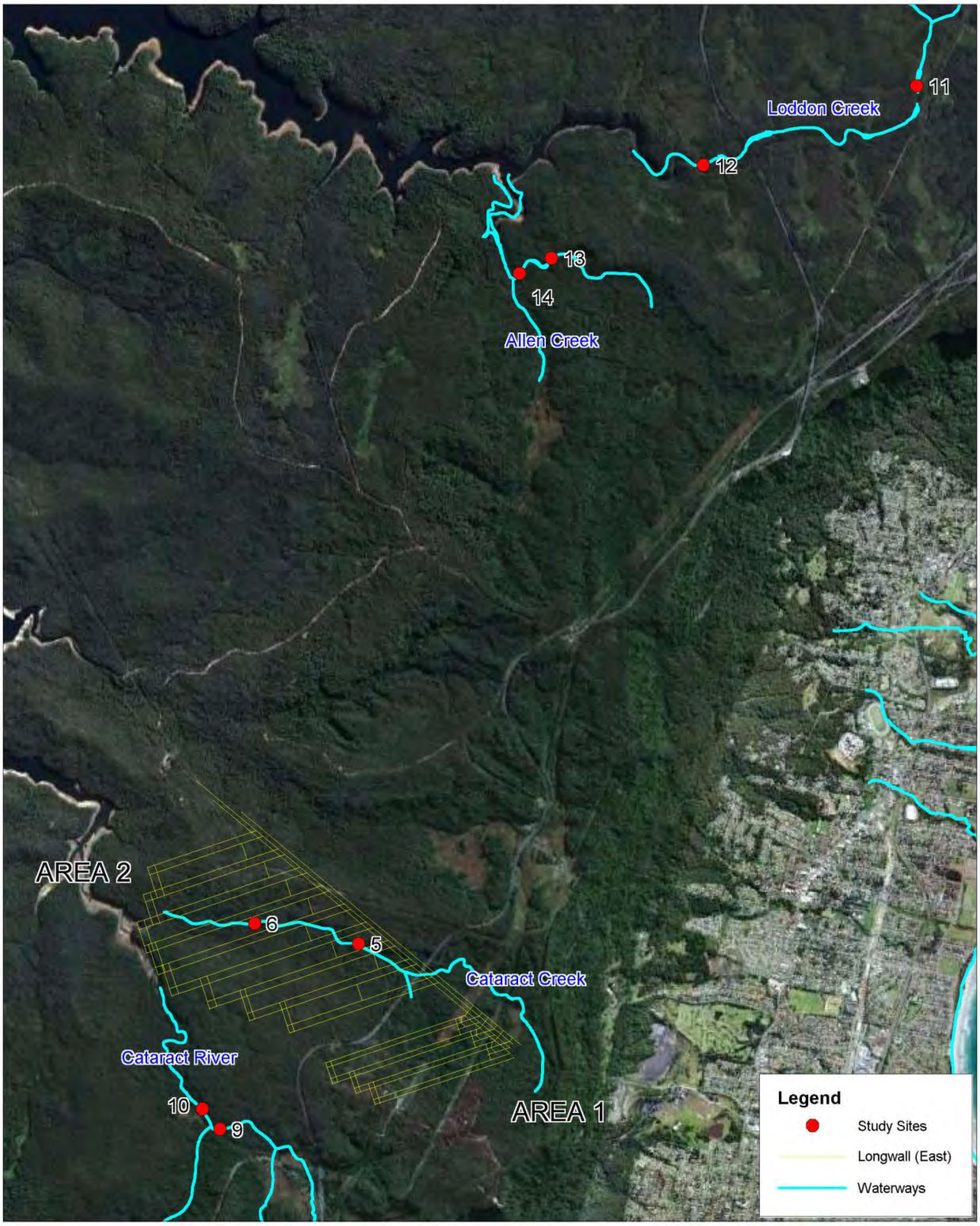
Study Sites in Wongawilli West

NRE No 1 MINE - EFFECTS OF MINE SUBSIDENCE ON AQUATIC HABITAT AND BIOTA
PREPARED FOR GUJARAT NRE COKING COAL LIMITED

Figure 1a

Cardno Ecology Lab

Map Produced by Cardno Ecology Lab
Date: 22 October 2012
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: Google Images
EL0910036_WongawilliWest_Figure_1



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Study Sites at Wongawilli East

NRE No 1 MINE -
EFFECTS OF MINE SUBSIDENCE ON AQUATIC HABITAT AND BIOTA
PREPARED FOR GUJARAT NRE COKING COAL LIMITED

Figure 1b

Cardno Ecology Lab

Map Produced by Cardno Ecology Lab
Date: 22 Oct 2012
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF: Google Images
EL0910036_WongawilliEast_Figure_2

2 Review of Existing Information

2.1 Introduction

The natural environment in the two Study Areas is relatively undisturbed due to the restrictions on access and development arising from the inclusion of the greater Cataract River catchment within the Metropolitan Special Area administered by Sydney Catchment Authority (SCA). The flow within the three significant streams traversing the Study Areas is unregulated.

Information on the aquatic ecology of the significant watercourses traversing the proposed mine areas is fairly limited. The results of previous investigations of water quality, aquatic habitats and biota within the reaches of these watercourses, including that from the baseline monitoring program undertaken by Cardno Ecology Lab (2011 and 2012), are summarised in Sections 2.1.1 and 2.1.2. The likely occurrence of threatened species listed under State and Federal legislation is addressed in Section 2.1.3.

2.1.1 Wongawilli West

2.1.1.1 Aquatic Habitat

Wallandoola Creek and Lizard Creek are deeply-incised streams cut into Hawkesbury Sandstone that flow into the Cataract River between Cataract Dam and Broughton's Pass Weir (The Ecology Lab 2007 and 2008). The streams are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath (Cardno Ecology Lab 2011). The reaches of the creeks within the Study Area contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. Some sections of Lizard Creek dry out after lengthy dry periods. The reaches of Wallandoola and Lizard Creek immediately upstream of the Study Area are characterised by headwater swamps, with relatively low gradients (The Ecology Lab 2008). There are numerous cascades and waterfalls on both creeks between the proposed mining area and their confluence with the Cataract River that would pose significant barriers to fish passage.

Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc all being evident. Iron staining has been observed in the reach of Wallandoola Creek to the south of proposed LW's 3 and 4 and the reach of Lizard Creek to the north of proposed LW 1 within Area 3 (Cardno Ecology Lab 2011).

2.1.1.2 Water Quality

The quality of water in Wallandoola Creek and Lizard Creek has been assessed on several occasions (Australian Water Technologies 2001; Seedsman Geotechnics 2001; Geoterra 2002 and 2012; Ecoengineers Pty Ltd, 2008; The Ecology Lab 2008; Cardno Ecology Lab 2011). Only the results of the most recent monitoring programmes are reported below.

The water in Lizard Creek and Wallandoola Creek was generally within the acceptable range for potable water (Geoterra 2012). The water in both creeks was fairly acidic, with median pH levels ranging from 4.6 to 6.5 in Lizard Creek and from 5.5.to 6.2 in Wallandoola Creek. The pH of the water in Lizard Creek was thus occasionally equivalent to the ANZECC/ARMCANZ lower default trigger value (DTV), whereas that in Wallandoola creek was invariably below the lower DTV. Slightly acid streams are quite common in the Hawkesbury Sandstone watercourses of the Southern Highlands and Illawarra. Salinity was within the DTV range, varying from 19 – 290 µS/cm in Lizard Creek and 53 - 199 µS/cm in Wallandoola Creek. In Lizard Creek, both salinity and pH increased with distance downstream. On some occasions, the filtered zinc, copper and aluminium and total nitrogen and phosphorus levels in both creeks were above the 95% species protection level for freshwater aquatic ecosystem guidelines.

The Ecology Lab (2008) noted that turbidity levels in both creeks were generally below the lower DTV and that the dissolved oxygen concentration in Lizard Creek was also below the lower DTV. During the baseline aquatic ecology surveys, the dissolved oxygen levels in both creeks were generally below the lower DTV, suggesting that conditions may not be optimal for aquatic life (Cardno Ecology Lab 2011). The pH and turbidity levels in Wallandoola Creek and electrical conductivity, pH and turbidity levels in Lizard Creek deviated from the DTVs on some occasions.

2.1.1.3 Aquatic Macrophytes

No published information is available on the distribution of aquatic macrophytes within or in the vicinity of the watercourses in the Study Area. The ribbonweed, *Vallisneria* sp., has been recorded in the in-stream section of both creeks, while native plants, such as rushes (*Juncus* sp.), sawsedge (*Gahnia* sp.), and numerous small ferns occur along the stream banks (The Ecology Lab 2008). The report of *Vallisneria* sp. is likely to be a misidentification of the water ribbon, *Triglochin procerum,* a species that is relatively common in the Cataract River catchment (Bioanalysis 2009).

2.1.1.4 Aquatic Macroinvertebrates

Growns *et al.* (1997) found that slightly fewer aquatic macroinvertebrate fauna were associated with riffles (18) than the pool edge habitat (21) at a site within Wallandoola Creek. The Stream Invertebrate Grade Number Average Level (SIGNAL) scores derived from their data indicate that the water at this study site was unpolluted.

The macroinvertebrates associated with the edge habitat at a site in Lizard Creek adjacent to Fire Road 8 were sampled in spring 2004 as part of Sydney Catchment Authority‘s Macroinvertebrate Monitoring Program: 2004 (Ecowise 2005). The AUSRIVAS bands and SIGNAL2 scores for this site indicate respectively that the fauna was significantly impaired and the water was moderately polluted.

The spring baseline surveys for the NRE No1 Mine indicated there was considerable variation in the aquatic macroinvertebrate associated with the edge habitat, with the number of taxa collected per survey ranging from 7-22 and from 10-26 at the sites in Wallandoola Creek and from 9-25, 9-28 and 12-15 at the sampling sites on Lizard Creek (Cardno Ecology Lab 2011). The ‘health” of the fauna at Site 1 on Wallandoola Creek varied from equivalent to AUSRIVAS reference condition to severely impaired, whereas that Site 2 varied from more diverse than the reference condition to significantly impaired. The “health” of the fauna at Sites 3 and 4 on Lizard Creek varied from equivalent to AUSRIVAS reference condition to severely impaired, whereas that at Site 17 was assessed as either significantly impaired or severely impaired. The SIGNAL2 scores indicated that the five sites were subject to moderate to severe degradation.

The baseline surveys conducted in autumn suggested there was less variation in the number of aquatic macroinvertebrate fauna, with the number of taxa collected per survey ranging from 16-25 and from 16-21 at the sites in Wallandoola Creek and from 7-8, 14-21 and 10-20 at the sampling sites on Lizard Creek. The “health” of the fauna at Sites 1 and 2 on Wallandoola Creek varying from more diverse than the reference condition to severely impaired and from equivalent to AUSRIVAS reference condition to significantly impaired, respectively. The fauna at Site 3 on Lizard Creek was rated as significantly impaired, whereas that at Sites 4 and 17 varied from equivalent to AUSRIVAS reference condition to severely impaired and impoverished, respectively. The SIGNAL2 scores derived from the data collected in autumn also indicated that the five sites were subject to moderate to severe degradation.

2.1.1.5 Fish

The Ecology Lab (2003 and 2005) caught three native species, Macquarie Perch, Flathead Gudgeon (*Philypnodon grandiceps*), and Australian Smelt (*Retropinna semoni*) and one introduced species, the Mosquito Fish (*Gambusia holbrooki*) in the Cataract River between Cataract Dam and Broughtons Pass Weir. They also noted that native freshwater crayfish (*Euastacus* sp.) were present throughout this reach of the river.

The “Audit of Sydney Drinking Water Catchment 2007” indicates three endemic fish species were present within Wallandoola Creek, but does not specify their identity (DECC 2007).

Climbing galaxias (*Galaxias olidus*) are known to occur in the reach of this creek overlying Appin Area 3 extended (Bioanalysis 2009).

During the baseline surveys for the NRE No1 Mine, Climbing Galaxias (*Galaxias brevipinnis*) and Australian Smelt (*Retropinna semoni*) were observed in Lizard Creek, but no fish were caught in Wallandoola Creek (Cardno Ecology Lab 2011). The freshwater crayfish, *Euastacus* sp. was present in both creeks.

2.1.2 Wongawilli East

2.1.2.1 Aquatic Habitat

Cataract Creek is bordered by temperate rainforest. The creek is mostly shallow with alternating series of long pools, some of which are deep, interspersed with shorter bars and riffles composed of bedrock, boulders, cobble, pebble and gravel. Dams of large woody debris are fairly. There are also submerged snags in pools. There is no evidence of impacts associated with previous mining. Lake Cataract backs up into the creek, with the extent of the incursion depending on the storage level of the dam. There are no waterfalls or highly-stepped zones in this creek and hence no barrier to the upstream passage of fish from Lake Cataract.

2.1.2.2 Water Quality

The Sydney Catchment Authority (2008) monitored water quality at Cataract Lake 30 meters from the dam wall and found that it generally had a very good aquatic environmental value. Between 68 and 100 percent of samples met the ANZECC guideline levels for all indicators, except for oxidised nitrogen, which met the guideline levels for 36 percent of samples, and ammonia nitrogen, which met the guidelines for 18 percent of samples.

The water in Cataract Creek was also generally within the acceptable range for potable water (Geoterra 2012). The median pH of the water within the creek was below the ANZECC/ARMCANZ (2000) lower DTV, with values ranging from 5.7 to 6.3 (Geoterra 2012). Salinity was within the DTV limits, with median values ranging from 130 – 145 µS/cm. In areas of the creek where there were ferruginous deposits, filtered zinc, copper and aluminium and total nitrogen and phosphorus levels occasionally exceeded the ANZECC/ARMCANZ (2000) guidelines.

During the baseline aquatic ecology surveys, the dissolved oxygen levels in Cataract Creek were generally below the lower DTV, but electrical conductivity, pH and turbidity levels only deviated from the guidelines occasionally (Cardno Ecology Lab 2011).

2.1.2.3 Aquatic Macrophytes

No information was found.

2.1.2.4 Aquatic Macroinvertebrates

The baseline surveys for the NRE No1 Mine indicated there was also considerable variation in the aquatic macroinvertebrate associated with the edge habitat at the sites in Cataract Creek, with the number of taxa collected per spring and autumn survey ranging from 12-23 and from 13-20 at Site 5 and from 9-19 and 16-22 at Site 6, respectively (Cardno Ecology Lab 2011). The ‘health” of the fauna at Site 5 varied from equivalent to AUSRIVAS reference condition to significantly impaired during the spring surveys, but was either significantly impaired or severely impaired in autumn. The “health” of the fauna at Site 6 varied from equivalent to AUSRIVAS reference condition to severely impaired during the spring and autumn surveys. The SIGNAL2 scores indicated that, in general, the two sites were subject to mild degradation.

2.1.2.5 Fish

Gehrke and Harris (1996) caught Trout Cod and Murray Cod (*Maccullochella peelii* x *M. macquariensis*) hybrids and Macquarie Perch in Cataract Dam and recorded climbing galaxias

(*Galaxias brevipinnis*) in the Bellambi Creek tributary of the dam. A NSW Fish Survey conducted in August 2006 found multiple juvenile cod that could have been either Trout Cod, Murray Cod or hybrids of these species (A. Bruce, personal communication, 3 December 2008).

The "Audit of Sydney Drinking Water Catchment 2007" indicated that two endemic, two translocated, and one introduced fish species were present within Cataract Dam (DECC 2007). The only information given about the identity of the fish caught in this location was that Macquarie Perch was present.

During the baseline surveys for the NRE No1 Mine, Climbing Galaxias (*Galaxias brevipinnis*), Eastern Gambusia (*Gambusia holbrooki*) and freshwater crayfish, *Euastacus* sp. were observed in Cataract Creek (Cardno Ecology Lab 2011). The targeted backpack electrofishing surveys that were undertaken in Cataract Creek during the summers of 2009/2010, 2010/2011 and 2011/2012, indicated an additional seven species of fish, Macquarie Perch (*Macquaria australasica*), Silver Perch (*Bidyanus bidyanus*), Short-finned Eel (*Anguilla australis*), Freshwater (Eel-tailed) Catfish (*Tandanus tandanus*), Mountain Galaxias (*Galaxias olidus*), Goldfish (*Carassius auratus*) and an unidentified Freshwater Cod of the genus *Maccullochella* (potentially Murray Cod, Trout Cod or a hybrid of these species) frequent this reach (Cardno Ecology Lab 2011 and 2012). A Long-finned Eel (*Anguillla reinhardtii)* was caught in this reach during a preliminary fish survey undertaken in November 2008.

The Australian Museum tentatively identified a juvenile specimen of the Freshwater Cod caught in Cataract Creek as Eastern Freshwater Cod on the basis of its external morphology (Mark McGrouther pers. comm.). DPI NSW has subsequently suggested that this fish may have been a hybrid of Trout Cod and Murray Cod that are known to occur in this impoundment (Andrew Bruce, pers. comm.).

2.2 Threatened Species

A review of the information that is available on the geographic distribution of aquatic organisms listed as threatened under state and federal legislation indicates that six species could potentially occur within the Study Area. These are:

- Sydney Hawk Dragonfly (*Austrocordulia leonardi*), listed as endangered under the FM Act;
- Adam's Emerald Dragonfly (*Archaeophya adamsi*), listed as endangered under the FM Act;
- Macquarie Perch (*Macquaria australasica*), listed as endanagered under the FM Act and EPBC Act;
- Trout Cod (*Maccullochella macquariensis*), listed as endangered under the FM Act and EPBC Act.
- Murray Cod (*Maccullochella peelii peelii*) listed as vulnerable under the EPBC Act.
- Silver Perch (*Bidyanus bidyanus*) listed as vulnerable under the FM Act

Macquarie Perch, Silver Perch and an unidentified Freshwater Cod (potentially Murray Cod, Trout Cod or a hybrid of these species) have been recorded in the reach of Cataract Creek upstream of Lake Cataract that flows through the Wongawilli East Study Area. Adams Emerald Dragonfly has not been recorded in any of the significant watercourses that flow through the two Study Areas, but suitable habitat for them has been identified in these creeks. Further details of the distribution of these five species and Assessments of Significance for them are presented in Appendices 1-5.

Sydney Hawk Dragonfly is an extremely rare species, having been collected in small numbers at only a few locations to the south of Sydney, between Audley to Picton (NSW DPI, 2005b). There are no records for this species within the Wallandoola or Lizard Creek catchments or within the greater Cataract River catchment. Most of the lifecycle of this species is spent as an aquatic larva, while adults are present for only a few weeks. The larvae of Sydney Hawk Dragonfly appear to have specific habitat requirements, including deep, cool, slow-flowing water in rocky rivers with steep sides (NSW DPI, 2005b). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae (G. Theischinger, pers. comm.). The nearest watercourse to the proposed mine area containing suitable habitat for the Sydney Hawk Dragonfly is likely to be the Cataract River, which is beyond the influence of significant subsidence impacts. An Assessment of Significance has consequently not been prepared for this species.

3 Assessment of Impacts

This assessment of impacts on aquatic habitat and biota as a result of physical subsidence from extraction of the proposed Wongawilli East and Wongawilli West mine areas is based on:

- the most recent mine layout provided by Gujarat NRE;
- predictions of mine subsidence (Seedsman Geotechnics 2012);
- assessment of the effects of subsidence on surface water and groundwater quality (Geoterra 2012); and
- data from the baseline aquatic ecology monitoring program (Cardno Ecology Lab 2011 and 2012).

3.1 Proposed Mine Layout

Gujarat NRE intends to reduce the risk of major subsidence by:

- Not extracting longwalls under the main or named channels of third or fourth order streams in the Wongawilli West mine area;
- Undertaking mining in Area 4 that will not have any impact on Cataract Dam and in accordance with consent of the NSW Dam Safety Committee);
- Setting each of the nominally 380 m wide longwall panels in the Wongawilli West mine area 200 m back from the centreline of Lizard Creek;
- Using narrow (nominally 150 m wide) longwall blocks with wide (60 m) chain pillars in the Wongawilli East mine area to access coal in the Cataract Reservoir Notification Area and under Cataract Creek;
- Setting the start lines for the panels in the Wongawilli East mine area at least 110 m back from the maximum stored water level of Cataract Dam;
- Monitoring the subsidence that arises as longwalls in the Wongawilli East mine area are extracted and changing the start and finish lines of panels, if necessary (Seedsman Geotechnics 2012).

The proponent has also provided an undertaking that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact.

Further details of the layouts of the two mines and their relationship to the overlying watercourses are presented below. Note that use of narrow longwall panels would not be economic in the Wongawilli West mine area.

3.1.1 Wongawilli East

The Wongawilli East workings would be divided into two areas to reduce the risk of subsidence along Mount Ousley Road, with Areas 1 and 2 being situated to the east and west of this road, respectively (Figure 1a). The longwalls would also be positioned in a north-east to south-west direction, in order to restrict vertical subsidence under significant watercourses. The three longwalls below Area 1 would be situated beneath ephemeral 1st order and intermittent 2nd order tributaries that flow into the main channel of Cataract Creek downstream of Mount Ousley Road. The eight longwalls below Area 2 would be located beneath 1st and 2nd order tributaries of Cataract Creek, but the main channel of the creek would only be undermined by Longwalls 7, 8 and 9. The depth to the floor of the Wongawilli Seam varies from 280 m below Cataract Creek to 340m to the south (Seedsman Geotechnics 2012). The section of the Seam that would be extracted is likely to vary from 2.7 -3.2 m.

3.1.2 Wongawilli West

The Wongawilli West workings would be divided into two areas to reduce the risk of subsidence along Wallandoola and Lizard Creeks, with Area 3 and 4 being located to the west and east of Lizard Creek, respectively. The five longwalls within Area 3 would be positioned in a north-south direction and would terminate immediately to the north of Wallandoola Creek. The two longwalls within Area 4 would be oriented from north-west to south-east. The longwalls within Areas 3 and 4 would not be situated below the main channel of Lizard Creek or Wallandoola Creek, but would undermine several watersheds and 1st to 3rd order tributaries that drain into these creeks. The depth to the floor of the Wongawilli Seam varies from 440-500 m (Seedsman Geotechnics 2012).

3.2 Subsidence Predictions

The Bulli Seam, and some parts of the Balgownie Seam, within the Wongawilli East and Wongawilli West areas have been extracted previously using either longwall, pillar or bord and pillar extraction techniques (Seedsman Geotechnics 2012). Previous mining operations have resulted in subsidence within both the Wongawilli East and Wongawilli West areas (Seedsman Geotechnics 2012). Mining has already occurred under Cataract, Lizard and Wallandoola Creeks, but only the creeks within the Wongawilli West Study Area appear to have been impacted, with fractured bedrock, iron staining and iron floc being common in both. Localised loss of surface water flows is also evident in Lizard Creek (Cardno Ecology Lab 2011; Geoterra 2012).

Subsidence within the Wongawilli East and Wongawilli West mine areas is expected to be non-conventional, because of the extraction of multiple coal seams, lack of isolation between longwalls in previously mined seams and proposed longwalls, the Bulgo Sandstone overlying the Bulli Seam and irregular topographic surface (Seedsman Geotechnics 2012). The extent of the subsidence deformations will depend on whether or not the Balgownie longwalls have disrupted the spanning capacity of the Bulgo Sandstone above large Bulli Seam pillars. As this is not yet known, subsidence can not be accurately predicted. Seedsman Geotechnics (2012) have consequently provided subsidence, strain and tilt predictions for extraction of the Wongawilli Seam only for both the Wongawilli and Bulli Seams. The predictions provided for each of the mine areas and the reaches of Cataract Creek crossing Longwalls 8-10 in Wongawilli East are summarised in Table1. Note that the worse case predicted subsidence (1.2 m) is only expected to occur above Longwalls 5 and 6 if the Bulli pillars collapse.

Table 1: Predicted subsidence, tilt and strain parameters for Wongawilli East and Wongawilli West (additional values inside brackets represent extraction of the Wongawilli + Bulli Seams).

Mine Area	Location	Subsidence (m)	Tilt (mm/m)	Strain (mm/m)
Wongawilli East		0.0-1.2	0.0-25.0	-10.0-6.0
	Area 1	0.02-0.6		
	Area 2	0.02-1.2		
	Cataract Creek above Longwall 8	0.02-1.0 (0.02-1.2)		
	Cataract Creek above Longwall 9	0.02-0.04 (0.02-0.2)		
	Cataract Creek above Longwall 10	0.02-0.2		
Wongawilli West		0.0-3.6	0.0-16.0	
	Area 3	0.0-2.0 (0.0-2.5)		
	Area 4	0.0-2.5 (0.02-3.0)		

3.3 Impacts on Creeks

3.3.1 Alterations to Flow and Ponding

Mining-induced subsidence has the potential to alter flow in the creeks by:

- Diverting surface water flows through fractures and joints in the bedrock into subterranean flows;
- Draining water in pools and ponds through fractures and joints in rock bars;
- Reducing inflow into pools as a result of upstream diversion of surface flows into the near surface groundwater system; and
- Creating inter-connected cracks between the seam and surface which lead to loss of surface water into the mine.

The predictions made by Geoterra (2012) about the likelihood of alterations to flows and drainage of pools in significant creeks as a result of extraction of the proposed Wongawilli West and Wongawilli East longwalls are summarised in the following sections. In the case of the Wongawilli East mine area, this assessment assumes that an adaptive management plan that prevents subsidence-induced fracturing of the Cataract Creek bed would be implemented. Such a plan would require the subsidence that develops as the longwalls are progressively extracted to be monitored closely and, if a certain threshold that could lead to fracturing is exceeded, the layout of the longwalls would need to be revised.

Extraction of the longwalls will also lead to depressurisation of the Hawkesbury Sandstone which, in turn, will reduce the gradient of the water table draining to the watercourses and the overall height of the water table. This will lead to a reduction in baseflow recharge to the streams (Geoterra 2012).

3.3.1.1 Wongawilli East

The physical subsidence arising as a result of extraction of the Wongawilli East longwalls is unlikely to have any detectable effects on stream flow or ponding or stream gradient of Cataract Creek, provided that the adaptive management plan is adhered to (Geoterra 2012). The reduction in baseflow recharge to the Cataract Creek due to changes in the water table resulting from depressurisation of the Hawkesbury sandstone would be negligible (0.07 ML/d), so it is highly unlikely that it would have any detectable effects on the availability of aquatic habitat in this creek.

3.3.1.2 Wongawilli West

The predicted 20 mm total subsidence is not expected to have any detectable effects on the pools up to the main bend in Wallandoola Creek, which is situated to the south of proposed LW 3 within Area 3. The predicted strains (< 3 mm/m) for this section of the creek are also not expected to have any detectable effects on stream flow or pool drainage. The northern part of the main bend is likely to experience greater subsidence (0.25-0.5 m), but this is still not expected to have any detectable effects on flow or ponding. The predicted strains (~ 6 mm/m) in the stream bed to the south of proposed LW's 3 and 4 could fracture the sandstone rock shelf and lead to drainage of the pool situated upstream of this shelf. The flow into the cracks is expected to reappear downstream. There is a possibility of stream bed fractures migrating progressively downstream as proposed LW's 2 to 4 are extracted within Area 3. In this case, fracturing of the creek bed could lead to loss of water to the voids. The predicted subsidence (0.02-0.25 m) and strains (1-3 mm/m) of the rock shelf constrained pool situated close to the southern end of proposed LW 5 and upstream of the waterfall on Wallandoola Creek are not expected to alter stream flow or ponding. The channel of Wallandoola Creek is not expected to experience any significant detectable uplift.

The predicted subsidence (20 mm to 0.25 m) and strains (< 3 mm/m) are not expected to have any adverse detectable effects on stream flow or pools in the reach of Lizard Creek situated within Wongawilli West. In the area to the north of proposed LW 2, maximum strains of between 3 mm/m and 7 mm/m could occur over a 300 m long stretch of the creek. This could lead to further fracturing of the creek bed and associated loss of water at rock bars, diversion of flows to underlying substrata and greater pool drainage.

Reductions in baseflow recharge to Wallandoola and Lizard Creek due to changes in the water table are expected to negligible (0.25 and 0.10 ML/d, respectively) (Geoterra 2012), so this is unlikely to have any detectable effects on the availability of aquatic habitat in this creek.

3.3.2 Surface Water Quality

Fracturing of bedrock and diversion of flows has the potential to alter water quality by:

- Increasing groundwater discharge to streams;
- Reducing dissolved oxygen and pH levels;
- Elevating concentrations of dissolved iron, nickel, aluminium, zinc and manganese, sulphate and salinity through weathering of newly-exposed rock faces;
- Increasing rainfall recharge through cracked Wianamatta Shale and discharge out of the interface between shale and Hawkesbury sandstone;
- Elevating salinity and decreasing oxygen concentrations in pools through reduction in their depth, enhanced evaporation and stagnation; and
- Facilitating periodic emission of gases, such as methane, into watercourses.

The most obvious change in water quality is the orange-brown iron hydroxide staining, resulting from the dissolution of iron sulphide or iron carbonate exposed when sandstone fractures. The dissolution of these minerals leads to localised changes in water quality such as reduced pH and elevated concentrations of iron, manganese, aluminium, nickel and zinc. It is important to note that precipitation of iron hydroxide also occurs within streams that are not affected by mining. Emission of gases at the surface is not expected given the pre-existing fractures in the stream beds.

The predictions made by Geoterra (2012) about the likelihood of changes in surface water quality arising as a result of extraction of the Wongawilli West and Wongawilli East longwalls are summarised below.

3.3.2.1 Wongawilli East

As extraction of the longwalls is not expected to result in fracturing of bedrock or diversion of flows in Cataract Creek and Cataract River, these are not expected to have any adverse effects on surface water quality. Emission of gases is not expected to have any adverse effects on water quality because of the pre-existing subsidence and fracturing. Minor bank and bed erosion may occur over the longwall panels, particularly at the ends of the subsidence troughs and over chain pillars. This could lead to minor, transient increases in sediment mobility within and downstream of the subsidence area and minor, transient increases in turbidity of the water. These impacts are likely to be much smaller than those that occur naturally during heavy rainfall and are therefore considered to be of no significance.

3.3.2.2 Wongawilli West

If mining results in fracturing of the creek bed to the south of proposed Longwall 3 and 4 and diversion of flows through the underlying sandstone, the amount of iron staining and concentrations of iron, aluminium, copper and zinc could increase in Wallandoola Creek. The water at the point where flow re-emerges could exhibit localised changes in quality such as slightly lower pH and slightly elevated salinity. The quality of the emerging water would depend on whether the fractures in the bedrock are new or old and the extent to which it is diluted by surface flows, with effects being greater if the bedrock has not been weathered previously.

There are not expected to be any adverse effects on water quality in the other sections of Wallandoola Creek or Lizard Creek, because the predicted subsidence and strain parameters indicate fracturing of bedrock and flow diversion is unlikely to occur.

3.3.3 Aquatic Habitats and Biota

The aquatic habitats within some sections of Wallandoola Creek and Lizard Creek overlying the proposed Wongawilli West workings have already been degraded by previous mining operations.

3.3.3.1 Wongawilli East

Extraction of the proposed longwalls is not expected to result in any detectable effects on stream flow, pond drainage or water quality within Cataract Creek or Cataract River. The changes in these factors, in turn, are unlikely to have any observable effects on aquatic habitats, flora or fauna within these watercourses. The reduction in baseflow recharge of the creek due to depressurisation of the Hawkesbury sandstone is expected to be negligible, so this is also unlikely to have any detectable effect on the availability of aquatic habitat. Minor, transient increases in sediment mobility and turbidity of the water that occur within and downstream of the subsidence area are likely to have only a minimal impact on aquatic habitats and biota, because of their periodic exposure to such conditions during heavy rainfall events.

3.3.3.2 Wongawilli West

If extraction fractures the sandstone rock shelf in the bed of Wallandoola Creek to the south of proposed LW’s 3 and 4 and causes the pool upstream of the shelf to drain, there would be loss of aquatic habitat and associated biota within this pool. Organisms that are left stranded in air or that are unable to move to areas that are damp or submerged would suffer the greatest losses. The ability of organisms to cope with pool drainage varies, depending on their tolerance, response to desiccation and rapid changes in water level, ability to move, weather conditions at the time, the underlying substratum and duration of exposure. The drainage of this pool would also reduce longitudinal connectivity along the creek and prevent mobile aquatic fauna, particularly fish, from accessing upstream habitat for feeding or spawning purposes. The extent and duration of these losses would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established once inflows exceed diversionary flows. Losses would be greater and more prolonged during periods of low rainfall. Downstream transfer of fine sediments, nutrients, organic materials, seeds, spores, vegetative fragments of aquatic plants and drift of macroinvertebrates is unlikely to be adversely affected, because the water lost is expected to re-emerge further downstream.

The diversion of the water lost from the pool through the underlying sandstone substratum could lead to iron staining and elevated dissolved metal concentrations in the water where the flows re-emerges on the surface. The precipitation of iron hydroxide may be followed by the growth of bacterially-mediated iron flocs and mats in pools which can, in turn, cause a reduction in dissolved oxygen levels. High levels of iron floc within a watercourse can also smother the surface of aquatic macrophytes, snags, boulders and bank edge and reduce the amount and variety of habitats suitable for occupation by aquatic organisms. The varying water quality along with reduced oxygen concentrations and elevated metal concentrations in the re-emerging water may also affect the diversity and abundance of aquatic organisms. These changes would be restricted to the area immediately downstream of rock fractures, where the flow re-emerges. The duration of these impacts would depend on the dilution, flushing and re-aeration effects of surface flows. Impacts would be more protracted during periods of low flows. It should be noted that the quality of the water within Wallandoola and Lizard Creeks is already highly variable and that pH and filtered zinc levels often exceed the ANZECC/ARMCANZ (2000) criteria (Geoterra 2012).

These impacts would be localised, minor in extent and transient in nature and therefore unlikely to be significant. There are not expected to be any adverse effects on the aquatic habitats, flora and fauna in the other sections of Wallandoola Creek and Lizard Creek.

3.4 Threatened Species

The Assessments of Significance presented in Appendices 1-5 indicate that the proposed mining operation is highly unlikely to have a significant impact on any viable populations of Adams Emerald Dragonfly, Macquarie Perch, Silver Perch, Trout Cod or Murray Cod that may be present in the Study Areas, provided the adaptive management plan is implemented.

3.5 Sensitive Aquatic Habitats

None of the aquatic reserves declared under the FM Act, proclaimed Ramsar or nationally important wetlands occur within or proximal to the proposed Application Area, hence there is no need to assess the effects of the proposed mine area on sensitive aquatic habitats.

3.6 Conclusions

The Bulli Seam Operations Approval specifies subsidence impact performance measures for natural features that must not be exceeded by underground mining operations. The following are relevant to aquatic ecology:

- Watercourses must not be subject to greater subsidence impact or environmental consequences than predicted in the Environmental Assessment;
- Subsidence must have negligible environmental consequences for threatened species, threatened populations, or endangered ecological communities.

The term negligible is defined in the BSO Project Approval as small and unimportant, such as to be not worth considering.

The assessment of potential impacts on aquatic ecology generally, and threatened species in particular, is consistent with these performance measures. The assessment indicates that changes in stream flow, ponding, stream gradient of Cataract Creek resulting from extraction of the Wongawilli East longwalls would not have any observable effects on the aquatic habitats or biota within Cataract Creek. Minor bank and bed erosion may occur above these longwalls and could lead to minor, transient increases in sediment mobility and turbidity within and downstream of the subsidence area. These would have a minimal impact on aquatic habitats and biota, because of their periodic exposure to such conditions during heavy rainfall events. Subsidence resulting from extraction of the proposed longwalls within the Wongawilli West Study Area is expected to have some impact on the aquatic habitats and biota within part of Wallandoola Creek. These impacts would be localised, minor in extent and transient in nature and therefore unlikely to be significant. They are not expected to be any observable effects on the aquatic habitats, flora and fauna in the other sections of Wallandoola Creek or in Lizard Creek.

4 Recommendations

4.1 Aquatic Environmental Monitoring

The monitoring of the ecological impacts of longwall mining is expected to be done in accordance with the recommendations made in the "Strategic Review of Impacts of Coal Mining on Natural Features in the Southern Coalfields" (NSW Planning 2008). The pertinent recommendations in that report are:

- Collection of a minimum of two years of baseline data (including threatened species monitoring);
- Use of Before, After, Control, Impact (BACI) designs for monitoring (current best practice); and
- Monitoring of third order or higher streams in the vicinity of predicted subsidence footprints.

Cardno Ecology Lab has now collected three years of baseline data from 'potential impact' sites on the significant creeks (Cataract, Wallandoola and Lizard) that traverse the proposed Wongawilli East and Wongawilli West Mine Areas and 'control' sites on nearby streams (Allen, Loddon and Cascade Creeks and the Upper Cataract River) (See Figure1). These data constitute the "before" component of the BACI ("Before, After, Control, Impact") study design. The following components have been monitored using the methods specified:

- Physico-chemical water quality parameters measured with a portable multi-probe meter;
- Condition of aquatic habitat based on standard scoring for variables listed within the AUSRIVAS protocol;
- Macroinvertebrates in pool edge habitats collected using (i) the standard AUSRIVAS rapid assessment methodology and SIGNAL2 scores and (ii) artificial collectors, a sampling method that provides a standardised habitat unit for macroinvertebrates to colonise and results in quantitative estimates of abundance and diversity that are independent of the quality or quantity of habitat present within the creeks;
- Fish sampled using dip nets.

The above have generally been monitored during spring and autumn. Targeted surveys of Macquarie Perch and other threatened fish species within the reach of Cataract Creek overlying the Wongawilli East Mine Area have been undertaken in the summer of 2009/2010, 2010/2011 and 2011/2012.

It is recommended that further monitoring of all of these components be undertaken during and following the extraction of these longwalls using the same survey sites and methods and during the same seasons as used for the baseline study. This will provide best practice environmental monitoring of aquatic ecology and allow statistically powerful analysis of the nature and extent of mine subsidence impacts, if any. The objective of this monitoring is to validate the predictions about the flow-on effects of subsidence-related disturbances on aquatic habitats and biota and assess any unexpected impacts on these that may occur.

Additional surveys of aquatic habitats and biota should be undertaken as soon as possible if fractures of the stream bed and associated loss of water from pools or significant changes in water quality are detected during routine surface monitoring of the potential impact creeks. The objective of these surveys would be to determine whether there have been any flow-effects on aquatic ecology. If fish or yabby kills are noted during routine surface monitoring, further studies should be undertaken to determine the extent of impact on aquatic ecology and whether there is a need for management/mitigation measures.

4.2 Management/Mitigation Measures

If significant effects on aquatic habitats and/or biota are detected during monitoring it may be necessary to reduce further impacts by adopting one of the following strategies:

- The commitment by the proponent that it will terminate mining beneath Cataract Creek if subsidence and ground movements exceed 250 mm and the creek experience greater than minimal impact;
- Modifying mine layout to further reduce potential subsidence impacts;
- Increasing the setback of the longwall being extracted and future longwalls from the affected watercourse;
- Implementing remediation measures to reduce the extent of fracturing of the stream bed (e.g. grouting of rock bars);
- Using standard erosion and sediment control measures to prevent mobilised sediments entering watercourses.

5 References

ANZECC/ARMCANZ (2000*). Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*

Bioanalysis (2009*). Illawarra Coal - Bulli Seam Operations - Aquatic Ecology Assessment.* Prepared for Ilawarra Coal Holdings Pty Ltd.

Cadwallader, P.L. & Douglas, J. (1986). Changing food habits of Macquarie Perch Macquaria australasica Cuvier (Pisces: Percichthyidae), during the initial filling phase of Lake Dartmouth, Victoria. *Australian Journal of Marine and Freshwater Research* 37: pp. 647-657.

Cadwallader, P.L. & Eden, A.K. (1979). Observations of the food of the Macquarie Perch *Macquaria australasica* (Pisces: Percichthyidae), in Victoria*. Australian Journal of Marine and Freshwater Research* 30: pp.401-9.

Cadwallader, P.L. & Rogan, P.L. (1977). The Macquarie Perch, *Macquaria australasica* (Pisces: Percichthyidae) of Lake Eildon, Victoria. *Australian Journal of Ecology* 2: pp 409-418.

Cardno Ecology Lab (2009). *Aquatic Ecology Monitoring for Gujarat NRE No 1 Mine: Spring 2008 Progress Report.* Prepared for ERM (Australia) Pty Ltd February 2009.

Cardno Ecology Lab (2011). *NRE No. 1 Mine, Russellvale Baseline Aquatic Ecology Monitoring.* Prepared for Gujarat NRE Coking Coal Limited.

Cardno Ecology Lab (2012). *NRE No. 1 Mine, Aquatic Ecology Monitoring 2011-2012.* Prepared for Gujarat NRE Coking Coal Limited.

Clunie, P.E. & Koehn, J.D. (2001). *Silver Perch: A Resource Docum*ent. Final report for project R8002 to Murray-Darling Basin Commission: Canberra. Department of Natural Resources and Environment, Victoria.

Ecoengineers (2009). Water Quality, Catchment and Water Course Monitoring T & W Mains Pillar Extraction Area, October 2008 to May 2009.

Fisheries Scientific Committee (2008). Final determination *Archaeophya adamsi* –Adam's Emerald Dragonfly.

Gehrke, P.C, and Harris, J.H. (1996). *Fish and fisheries of the Hawkesbury-Nepean river system: Final report to the Sydney Water Corporation*. Prepared by NSW Fisheries Research Institute and cooperative Research Centre for Freshwater Ecology.

Geoterra (2002). Lizard Creek and Wallandoola Creek Baseline Assessment.

Geoterra (2012). NRE No.1 Colliery. Major Expansion. Stream Assessment, NSW. Draft report prepared for Gujarat NRE Coking Coal Limited.

Ingram, B.A., Barlow, C.G., Burchmore, J.J., Gooley, G.J., Rowland, S.J. & Sanger. A.C. (1990). Threatened native freshwater fishes in Australia - some case histories. Journal of Fish Biology 37: pp 175-182.

Kearney, R.E & Kildea, M.A. (2001). The Status of the Murray Cod in the Murray-Darling Basin. http://www.environment.gov.au/water/publications/mdb/pubs/murray-cod.pdf

Lake, J.S. (1971). Freshwater Fishes and Rivers of Australia. Page(s) 61. Melbourne: Thomas Nelson.

Lintermans, M. (2006). Threatened fish in mountain streams: out of sight, out of mind. In: Proceedings of the NPA ACT Symposium: Caring for Namadgi: Science and People: Canberra, 5-7 May 2006. Woden: National Parks Association of the ACT Inc.

Mallen-Cooper, M. Stuart, I.G., Hides-Pearson, F. & Harris. J. (1995). *Fish Migration in the Murray River and Assessment of the Torrumbarry Fishway.* Final report for Natural Resource Management Strategy Project N002. NSW Fisheries Research Institute and the Cooperative Research Centre for Freshwater Ecology.

McDowall, R.M. (1996). *Freshwater Fishes of South-Eastern Australia* 2nd edn. Chatswood, NSW: Reed Books.

Merrick, J.R. (1996). Freshwater grunters or perches, Family Terapontidae. Chapter 26. Silver perch. Pp. 164-166 in: Freshwater fishes of south-eastern Australia. [Ed. McDowall R.]. Reed Books, NSW.

National Murray Cod Recovery Team (2010). National Recovery Plan for the Murray Cod *Maccullochella peelii peelii.* Department of Sustainability and Environment, Melbourne.

NSW Department of Environment and Climate Change (2007). Audit of the Sydney Drinking Water Catchment 2007. Department of Environment and Climate Change NSW.

NSW Department of Planning (2008). Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review. July 2001.

NSW DPI (2005a). Profile for species, populations and ecological communities. Sydney Hawk Dragonfly. http://pas.dpi.nsw.gov.au/Species/Species_Profile.aspx?SpeciesListingID=9.

NSW DPI (2005b). Profile for species, populations and ecological communities. Adam's Emerald Dragonfly. http://pas.dpi.nsw.gov.au/Species/Species_Profile.aspx?SpeciesListingID=10.

NSW DPI (2005c). Priority recovery strategies. Macquarie Perch. http://pas.dpi.nsw.gov.au/Recovery_ThreatAbatement/RecoveryStrategies_bySpecies.aspx?SpeciesListingID=16

NSW DPI (2005e). Priority recovery strategies. Trout Cod. http://pas.dpi.nsw.gov.au/Recovery_ThreatAbatement/RecoveryStrategies_bySpecies.aspx?SpeciesListingID=4

NSW DPI (2006a). Silver Perch *Bidyanus bidyanus* NSW Recovery Plan.

NSW DPI (2006b). Trout cod (*Maccullochella macquariensis*) Recovery Plan.

NSW Planning Assessment Commission (2009). The Metropolitan Coal Project Review Report.

Rowland, S.J. (1995). The silver perch and its potential for aquaculture. In: *Proceedings of Silver Perch Aquaculture Workshops, Grafton and Narrandera, April 1994. NSW Fisheries*, pp. 9-11.

Rowland, S.J., Dirou, J.F. & Selosse, P.M. (1983). Production and stocking of golden perch and silver perch in New South Wales. *Australian Fisheries* 42: pp. 24-28.

Seedsman Geotechnics Pty Ltd (2012). Gujarat NRE No.1 Colliery, Management of Subsidence Risks Associated with Wongawilli Seam Extraction. Report prepared for Gujarat NRE Minerals.

The Ecology Lab (2003). Upper Nepean Bulk Water Transfers, Environmental Assessment of Aquatic Ecology. Report prepared for Sydney Catchment Authority.

The Ecology Lab (2005). Appin Area 3 – Effects of Mine Subsidence on Aquatic Habitat and Biota. Report prepared for BHP Billiton Illawarra Coal.

The Ecology Lab (2008). NRE No 1 Mine V Mains Area. Effects of Mine Subsidence on Aquatic Habitats and Biota. Report prepared for ERM (Australia) Pty Ltd.

Threatened Species Scientific Committee (TSSC) (2003i). Commonwealth Listing Advice on Maccullochella peelii peelii (Murray Cod, Cod, Goodoo). [Online]. Available from: http://www.environment.gov.au/biodiversity/threatened/species/m-peelii-peelii.html.

Trout Cod Recovery Team (2008). National Recovery Plan for the Trout Cod *Maccullochella macquariensis*. Department of Sustainability and Environment, Melbourne.

Wharton, J.C.F. (1973). Spawning, induction, artificial fertilization and pond culture of the Macquarie perch (*Macquaria australasica*)[Cuvier 1830]). *Australian Society of Limnology Bulletin* 5:pp. 43-65.

6 Appendices

6.1 Appendix 1: Adam's Emerald Dragonfly

6.1.1 Background Information

Adam's Emerald Dragonfly is extremely rare, having been collected in small numbers from only a few locations in the greater Sydney region (NSW DPI 2005b). There are no records of Adam's Emerald Dragonfly occurring south of Sydney despite active collecting in the Hawkesbury-Nepean River catchment (Fisheries Scientific Committee 2008). This species was not sampled during the baseline surveys of aquatic macroinvertebrates in Wallandoola, Lizard and Cataract creeks, but aquatic habitat suitable for this species was identified within these watercourses (Cardno Ecology Lab 2011).

Although the current distribution records suggest that this species is unlikely to occur within the Study Area, an Assessment of Significance has been prepared as a precautionary measure (see below).

6.1.2 Assessment of Significance

(a) Is the proposed mining likely to have an adverse effect on the life cycle of Adam's Emerald Dragonfly that would result in a risk of extinction of a viable local population of the species?

The Adam's Emerald Dragonfly has a predominantly aquatic life cycle, with larvae living for approximately seven years before metamorphosing into adults, which fly away from water to mature (NSW DPI 2005b). The adults are believed to live for only a few months. They return to water to breed, with males congregating at breeding sites and guarding a territory and females laying their eggs into the water. Larval Adam's Emerald Dragonfly have been found in small creeks with gravel or sandy bottoms and narrow shaded riffle zones with moss and extensive riparian vegetation. This species appears to have a low natural rate of recruitment and limited dispersal abilities.

Disturbances that result in significant degradation or loss of habitat, water quality pollution and siltation could potentially have an adverse effect on the life cycle of this dragonfly (NSW DPI 2005b).

Mine subsidence is not predicted to result in significant adverse impacts on aquatic habitat or water quality within Cataract Creek or Lizard Creek (Section 2.2), so it is highly unlikely that there would be any adverse effects on the life cycle of Adam's Emerald Dragonfly, if a viable population exists within these watercourses.

There is a possibility that mining subsidence could fracture the sandstone rock shelf in the bed of Wallandoola Creek to the south of Longwalls 3 and 4 in Wongawilli West Area 3. This could lead to drainage of the pool upstream of the shelf and loss of aquatic habitat and associated biota, including any larval Adam's Emerald Dragonfly, present within the pool. Changes in water quality, including iron staining, could occur where the diverted flows re-emerge downstream. The increase in iron concentration could lead to the formation of iron-mediated bacterial flocs and smothering of aquatic habitats occupied by larvae or used for breeding by adults. The changes in availability of aquatic habitat and water quality that would occur as a result of mining, however, would be temporary, localised and minor in nature and would therefore not be significant relative to the total amount of potential habitat within Area 3. The duration of such impacts on any larval Adam's Emerald Dragonfly present in the area would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established and water quality improving once inflows exceed diversionary flows. If a population of this species were to exist within Wongawilli West Area 3, it is highly unlikely that the proposed mining would disrupt the lifecycle of this species to such an extent that it would threaten the viability of a local population of Adam's Emerald Dragonfly.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

There are no threatened populations of Adam's Emerald Dragonfly listed on the Threatened Species Schedules of the *FM Act*.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Adam's Emerald Dragonfly is not part of an endangered ecological community listed on the Threatened Species Schedules of the *FM Act*.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed, and

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Larval Adam's Emerald Dragonfly are aquatic and inhabit small creeks with gravel or sandy bottoms and narrow shaded riffle zones with moss and extensive riparian vegetation (NSW DPI 2005b). The adults are terrestrial, but return to water to breed. Some of the aquatic habitat within the reaches of Cataract, Wallandoola and Lizard Creeks that traverse the proposed mine areas is suitable for the larvae (Cardno Ecology Lab 2011).

Mine subsidence is not expected to result in removal, fragmentation or modification of the aquatic habitat within Cataract Creek and Lizard Creek that is suitable for larval Adam's Emerald Dragonfly. If mining subsidence fractures the sandstone rock shelf in the bed of Wallandoola Creek to the south of Longwalls 3 and 4 in Wongawilli West Area 3, this could result in temporary drainage of the pool upstream of the shelf and loss of aquatic habitat for any larval Adam's Emerald Dragonfly that may exist within the pool. If iron staining occurs, where the diverted flows re-emerge downstream, the increase in iron concentration could lead to the formation of iron-mediated bacterial flocs and smothering of aquatic habitats that are occupied by larvae and used for breeding by adults. The changes in availability and quality of aquatic habitat that could occur would be temporary, localised and minor in nature and therefore not significant relative to the total amount of potential habitat within Area 3. The extent and duration of these impacts would depend on the degree of drainage, rainfall and inflows from further upstream, with pool habitat being re-established and water quality improving once inflows exceed diversionary flows. If a population of this species were to exist within Wongawilli West Area 3, it is highly unlikely that the proposed mining would have a significant effect on the overall amount or connectivity of habitat within this locality.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There are no areas of critical habitat for Adam's Emerald Dragonfly listed on the NSW Register of Critical Habitat.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

At present there is no recovery or threat abatement plan for Adam's Emerald Dragonfly.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the FM Act 1994, under which Adam's Emerald Dragonfly is listed.

Conclusion

If a viable population of this species is present within Cataract Creek or Lizard Creek, it is highly unlikely that the proposed mining operations would have any significant impact on the species, because no alteration of habitat is expected. If a viable population of the species exists in Wallandoola Creek, it may be subject to temporary, localised, minor impacts.

6.2 Appendix 2: Macquarie Perch

6.2.1 Background Information

Macquarie Perch are found in the Murray-Darling Basin, particularly the upstream reaches of the Lachlan, Murrumbidgee and Murray rivers, and parts of south-eastern coastal NSW, including the Hawkesbury and Shoalhaven catchments (NSW Fisheries 2005c). There has been a marked decline in their distribution and abundance in NSW. Macquarie Perch are now considered to be restricted to the upper reaches of the Lachlan and Murrumbidgee Rivers in southern NSW (Ingram *et al.* 1990). This species has also been translocated to numerous sites within and outside its natural range, including Lake Cataract, with the population at this locality having been translocated from the Murray River (Lintermans 2006).

The baseline aquatic ecology studies undertaken for NRE No. 1 Mine have established that Macquarie Perch are present in the Cataract Creek arm of Lake Cataract and that they extend into the proposed Wongawilli East Mine Area (Cardno Ecology Lab 2011). There is also a viable population of Macquarie Perch in the reach of the Cataract River between the Cataract Dam and Broughtons Pass Weir (Gehrke and Harris 1996; The Ecology Lab 2003 and 2005). This species is unlikely to be present in the Wongawilli West Study Area, because a number of waterfalls between Wallandoola Creek and Lizard Creek and the Cataract River would prevent their upstream passage.

An Assessment of Significance has therefore been prepared for this species within the Wongawilli East Mine Area, but not that at Wongawilli West (see Appendix 2).

6.2.2 Assessment of Significance

(a) *In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.*

Macquarie Perch is known to migrate from impoundments into rivers to spawn in areas with small boulders, pebbles and gravel. Spawning generally occurs during spring and early summer in shallow, fast-flowing water over gravel beds. The eggs are adhesive and stick to gravel (Lake 1971; Wharton 1973). Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11–18 °C (Wharton 1973). Newly-hatched larvae shelter amongst pebbles (Cadwallader & Rogan 1977). In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites (Cadwallader & Douglas 1986).

The absence of any significant barriers to fish passage means that individuals of the translocated Macquarie Perch populations within Lake Cataract could potentially migrate up the reach of Cataract Creek that traverses the proposed Wongawilli East Mine Area. The baseline aquatic ecology surveys undertaken for NRE No. 1 Mine indicate that greater numbers of Macquarie Perch occur within these reach as summer progresses and that their distribution extends from the confluence with Cataract River as far up as the rock bar below Site 6, which would overlies proposed Longwalls 7 and 8 (Cardno Ecology Lab 2011). The fish caught ranged in size from 80 -370 mm, so it is possible that some of the fish may have been migrating upstream to spawn.

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Macquarie Perch would be placed at risk of extinction.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Macquarie Perch have been listed on the Schedules of the *FM Act*.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Macquarie Perch is not part of a listed endangered ecological community.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Macquarie Perch is a schooling species that prefers clear water and deep, rocky holes with lots of cover in the form of aquatic vegetation, large boulders, debris and overhanging banks (Cadwallader & Eden 1979). This species is known to migrate from impoundments into rivers to spawn in areas with small boulders, pebbles and gravel. Newly-hatched larvae shelter amongst pebbles, but move back downstream to lake habitat (Cadwallader & Rogan 1977Cadwallader & Douglas 1986).

The subsidence predictions indicate that there are not likely to be any physical impacts on the aquatic habitat that Macquarie Perch periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. Nor are any flow-on effects on water quality expected. The potential Macquarie Perch habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Macquarie Perch within the Study Area.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

At present, there is no recovery or threat abatement plan for Macquarie Perch.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

Longwall mining is not classed as a Key Threatening Process under the *FM Act or EPBC Act*, under which Macquarie Perch are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to local Macquarie Perch populations within the Cataract River catchment.

6.3 Appendix 3: Silver Perch

6.3.1 Background Information

Historical records show that Silver Perch occurred throughout most of the Murray-Darling drainage (NSW DPI 2006). This species has undergone a dramatic decline in abundance and distribution over the last few decades and is now absent from most of its natural range. Silver perch have been stocked at numerous sites within the Murray-Darling Basin. This fish has also been translocated into many areas outside their natural range, including some catchments along the east coast of NSW and Lake Cataract (NSW DPI 2006). The population in Lake Cataract was translocated in the early part of the 20th century and is secure and self-sustaining. I&I NSW research surveys indicate that Silver Perch were still present in this dam in 1994 and 2006.

6.3.2 Assessment of Significance

(a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Adult Silver Perch migrate upstream from November to February and juveniles over one year old do so from October to April (Mallen-Cooper *et al.* 1995). These movements appear to be stimulated by increases in water temperature above 20ºC and water level. The reasons for this movement are not well understood, but there is evidence that adults move upstream prior to spawning (Mallen-Cooper *et al.* 1995). Females release non-adhesive, floating eggs (Merrick 1996), which hatch within 36 hours. The larvae commence feeding after about 5 days and develop into juvenile fish measuring approximately 11 mm after 18 days (Rowland *et al.* 1983).

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Silver Perch, if one exists, would be placed at risk of extinction.

(b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Silver Perch have been listed on the Schedules of the FM Act.

(c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

The Silver Perch is not part of a listed endangered ecological community.

(d) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Silver perch are found in a variety of habitats and climates across the Murray-Darling Basin, including the cool, clear, gravel-bed streams of the upper reaches and the lower, slow flowing, turbid rivers of the west and north (Rowland 1995, Clunie & Koehn 2001). They also occur in lakes and reservoirs. Little is known about their specific habitat requirements or the extent to which they depend on structural habitat components (Clunie & Koehn 2001). NSW DPI sampling records indicate that this species was generally caught near snags, however, in impoundments they have been observed in open waters.

The subsidence predictions indicate that there are not likely to be any physical or chemical impacts on the aquatic habitat that Silver Perch may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Silver Perch habitat in the Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Silver Perch within the Wongawilli East Study Area.

(f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is a Recovery Plan for Silver Perch in NSW (NSW DPI 2006a). The primary objective of the plan is to prevent the extinction and ensure the recovery of silver perch populations, while the specific objectives are to:

- Increase awareness of the species current status throughout its range;
- Increase scientific knowledge of its current distribution, ecological and habitat requirements and population genetics;
- Protect and enhance the remaining natural populations;
- Minimise the impacts of known major threats, including fishing impacts on natural populations;
- Improve management of aquaculture and stocking programs.
- Encourage and support the involvement of indigenous communities in the implementation of recovery actions.
- Establish a program to monitor the status of silver perch and evaluate the effectiveness of recovery actions.

The recovery actions identified in the plan focus on:

- Research and information needs – e.g. current distribution and abundance, genetic variation within natural and stocked populations, identification of habitat requirements, ecology and key threats to wild populations
- Habitat protection and restoration, particularly reducing the impacts of altered river flows, improving fish passage in the Murray-Darling Basin, investigating the impacts of cold water pollution, minimisation of impacts on habitat, protection and rehabilitation of river reaches known to support important silver perch populations.
- Introduced species and diseases - by investigating their potential impact on natural populations, preventing the transfer of disease agents from stocked to natural populations
- Fishing – by improving awareness of the status of silver perch and compliance with fishing regulations, the cultural importance of the species to indigenous communities, and reviewing existing regulations

- Aquaculture and stocking – minimising the risk of genetic impacts from hatchery-bred fish on wild populations, encouraging hatcheries to comply with regulations and guidelines, preventing stocked fish impacting on natural populations.

The proposed mining will not affect the objectives or actions of the Silver Perch Recovery Plan.

(g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not a listed Key Threatening Process under the *FM Act 1994.*

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the populations of Silver Perch within the Cataract River catchment.

6.4 Appendix 4: Trout Cod

6.4.1 Background Information

The Trout Cod is endemic to the southern Murray-Darling river system, including the Murrumbidgee and Murray Rivers, and the Macquarie River in central NSW (NSW DPI 2005c). This species has undergone dramatic declines in its distributional range and abundance over the past century. Hatchery-bred Trout Cod have been released into sites in its former distribution range. Trout Cod have also been translocated into areas outside their natural range, including Lake Cataract, with that introduction taking place before 1915 (Rimmer 1988; Douglas *et al.* 1994). The survival rate of translocated Trout Cod is poor, with few records of fish surviving past three years of age. I&I NSW research surveys indicate that Trout Cod were still present in this dam in 1994. The Trout Cod Recovery Team (2010) indicates that the cod population within this lake is composed largely of hybrids of Trout Cod and Murray Cod.

The absence of any significant barriers to fish passage within this reach of the creek, means that any surviving individuals present in Lake Cataract could potentially migrate upstream and utilise habitats overlying the proposed longwalls. Juvenile and adult specimens of an unidentified species within this genus, that could potentially be Trout Cod, were found in the reach of Cataract Creek upstream of Lake Cataract that traverses the Wongawilli East Study Area (Cardno Ecology Lab 2011). In view of the uncertainty as to the identification of these fish, Assessments of Significance have been prepared for both Trout Cod and Murray Cod.

6.4.2 Assessment of Significance

(h) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Little is known about the biology and ecology of Trout Cod in the wild. This species was originally thought to undertake significant upstream migrations, possibly for spawning (Brown *et al.* 1998), however, recent radio tracking studies in the Murray River suggest it does not move beyond a small home range (Brown & Nicol 1998). Trout Cod spawn in late October to early November when water temperatures reach about 16°C (Ingram & Rimmer 1992; ACT Government 1999). Spawning does not appear to be dependent on flow conditions (Gilligan & Schiller 2003. The adhesive eggs are probably deposited on hard surfaces on or near the stream bottom. Hatching begins 5-10 days after fertilisation at a temperature of 20 °C and larvae live off the yolk sac for about 17 days. Larvae begin feeding on zooplankton at 6-9 mm and disperse downstream in the flow for a short distance. Larval dispersal reaches a peak in November (Gilligan & Schiller 2003). The environmental conditions favouring successful recruitment are not known.

The subsidence predictions indicate that extraction of the proposed longwalls within this area is unlikely to alter stream flow, ponding or water quality in this reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Trout Cod, if one exists, would be placed at risk of extinction.

(i) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Trout Cod have been listed on the Schedules of the FM Act.

(j) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

The Trout Cod is not part of a listed endangered ecological community.

(k) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Trout Cod utilise several types of aquatic habitat. The existing self-sustaining populations occur in deep, flowing rivers with sand, silt or clay substrata and numerous snags and in relatively narrow streams with rock, gravel and sand substrata, and shallow pools (generally <2m deep) interspersed with rapids and cascades up to 4 m high (Brown *et al.* 1998).

The subsidence predictions indicate that there are not likely to be any physical or chemical impacts on the aquatic habitat that Trout Cod may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Trout Cod habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(l) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

The critical habitat requirements of Trout Cod appear to be sites with large woody debris, or snags, particularly those located away from the stream bank (Nicol *et al.* 2002). There is no listed critical habitat for Trout Cod within the Wongawilli East Study Area.

(m) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is both a National and NSW Recovery Plan for Trout Cod (Trout Cod Recovery Team 2008; NSW DPI 2006b). The overall objective of the NSW Plan is to ensure the recovery and natural viability of this species throughout its former range within the state. The specific objectives of the plan are to:

- Ensure the security of the existing trout cod population in the Murray River by maintaining and improving aquatic habitat;
- Establish and protect additional stocked populations of Trout Cod at selected locations throughout the species former range;
- Reduce fishing related mortality of Trout Cod by setting appropriate regulatory controls and maximising angler compliance;
- Improve our understanding of the population size, distribution, ecological requirements, and genetic status of Trout Cod;
- Improve our understanding of the threats to the survival of this species and identify management actions to minimise these;
- Increasing awareness about the status of Trout Cod.

The recovery actions specified in the plan include:

- Habitat protection and restoration – minimising habitat degradation, improved protection and rehabilitation of key habitat;
- Reducing the impact of Illegal fishing and incidental capture;

- Minimising risks from inter-specific competition with stocked, translocated and introduced species;
- Establishing new self-sustaining populations through stocking;
- Research and monitoring of Trout Cod populations;
- Community awareness, involvement and support.

The proposed mining will not affect the objectives or actions of the Trout Cod Recovery Plan.

(n) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the *FM Act 1994,* under which Trout Cod are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the local populations of Trout Cod within the Cataract River catchment.

6.5 Appendix 5: Murray Cod

6.5.1 Background Information

The historic distribution of Murray Cod included the entire Murray Darling Basin in the south-eastern region of Australia, except for the upper reaches of some tributaries. This fish still occurs throughout most of the Basin. Translocated populations have also been established in impoundments and waterways in NSW and Victoria outside the natural distribution, including Lake Cataract (TSSC 2003). Translocated populations are maintained by the release of hatchery-bred fish and often persist for several years, but few have established self-sustaining populations. I &I NSW research surveys indicate that Murray Cod were present in this lake in 1994, 2002, 2006 and 2007. The Trout Cod Recovery Team (2010) indicates that the cod population within this lake is composed largely of hybrids of Trout Cod and Murray Cod.

6.5.2 Assessment of Significance

(o) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

During late summer, autumn and winter Murray Cod remain within a "territory", consisting of a specific hole, snag or area of a river or lake (Kearney & Kildea 2001). In late spring and early summer, when the water reaches a temperature of between 16-21°C, the adults migrate upstream to spawn (Kearney & Kildea 2001). In upland streams, spawning occurs in the vicinity of submerged rocks. Murray Cod may also lay their eggs in depressions excavated in clay banks. The eggs are adhesive and are deposited as a large mat on the spawning surface. After spawning, the adults move back downstream to their territory (Koehn 1997). The eggs hatch occurs 5-7 days after fertilisation, with a batch of eggs taking several days to hatch (Kearney & Kildea 2001). The larvae drift downstream and the fry settle out in suitable protected habitat (TSSC 2003).

The subsidence predictions indicate that extraction of the proposed longwalls within the Wongawilli East area is unlikely to alter stream flow, ponding or water quality in the overlying reach of Cataract Creek. It is consequently highly unlikely that there would be any adverse effects on the life cycle of this species or that a viable local population of Murray Cod, if one exists, would be placed at risk of extinction.

(p) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.

No endangered populations of Murray Cod have been listed on the Schedules of the *FM Act.*

(q) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:

(i) have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.

Murray Cod is not part of a listed endangered ecological community.

(r) In relation to the habitat of a threatened species, population or ecological community:

(i) the extent to which habitat is likely to be removed or modified as a result of the action proposed;

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.

Murray Cod occur in a variety of habitats, including clear rocky streams, slow flowing, turbid rivers, and billabongs (McDowall 1996). This fish is usually found in sheltered areas, where there is extensive cover in the form of large rocks, snags, overhanging vegetation or other woody structures (Kearney and Kildea 2001). Juveniles are usually found in the main river channel.

The subsidence predictions indicate that there are not likely to be any physico-chemical impacts on the aquatic habitat that Murray Cod may periodically occupy in the reach of Cataract Creek that traverses the Wongawilli East area. The existing Murray Cod habitat in Lake Cataract catchment is well outside of the predicted subsidence impact area, so no fragmentation or isolation of habitat is anticipated.

(s) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).

There is no listed critical habitat for Murray Cod within the Wongawilli East Study Area.

(t) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.

There is a National Recovery Plan for Murray Cod (National Murray Cod Recovery Team 2010). The overall objective of this plan is to have self-sustaining Murray Cod populations managed for conservation, fishing and culture. The specific objectives of the plan include:

- Assessing the distribution, structure and dynamics of populations across the Murray Darling Basin;
- Managing river flows to enhance recruitment;
- Evaluating the risks of threats and benefits of recovery options on populations for each management unit;
- Determining the habitat requirements of life stages and populations; and
- Management of a sustainable recreational fishery.

The plan identifies seventy-one actions to address the range of threats and management issues, with priority actions including:

- Determining the distribution, structure and dynamics of populations across the Murray Darling Basin;
- Identifying and quantifying the environmental parameters that control recruitment and population growth;
- Identifying, protecting and repairing key aquatic and riparian habitats in each Spatial Management Unit; and
- Managing the recreational fishery in a sustainable manner.

The proposed mining will not affect the objectives or actions of the Murray Cod Recovery Plan.

(u) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

Longwall mining is not classed as a Key Threatening Process under the *EPBC Act 1994,* under which Murray Cod are listed.

Conclusion

The proposed mining of Wongawilli East does not pose a significant threat to the local populations of Murray Cod within the Cataract River catchment.

Annexures

1. Cardno Ecology Lab (2011). NRE No. 1 Mine, Russell Vale – Baseline Aquatic Ecology Monitoring.

Cardno Ecology Lab

Shaping the Future

Marine and Freshwater Studies

NRE No. 1 Mine, Russellvale Baseline Aquatic Ecology Monitoring

Job Number: EL0910036

Prepared for Gujarat NRE Coking Coal Limited

November 2011

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Cover Image: Cataract Creek, 17 December 2008. Photographer Bob Hunt, Cardno Ecology Lab

Document Control

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EL0910036D	Draft	16 November 2011	Dr Theresa Dye	TAD	Dr Arthur Dye	AHD

Executive Summary

Gujarat NRE Coking Coal Limited (NRE) proposes to extract coal from the Wongawilli West and Wongawilli East areas of the NRE No. 1 Mine at Russellvale, in the New South Wales Southern Coalfield. The submission to the NSW government for approval to mine these areas under the Part 3A (NSW EP&A Act) process is being co-ordinated by Environmental Resources Management (Australia) Pty Ltd (ERM). Cardno Ecology Lab was commissioned by ERM, and subsequently NRE, to undertake the aquatic ecology component of the environmental monitoring for the Wongawilli West and Wongawilli East mine areas, which are located within the Cataract River catchment and the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir, respectively.

This report summarises the results of the baseline aquatic ecology monitoring undertaken over a three year period between spring 2008 and spring 2011. The monitoring program was designed in accordance with the recommendations made by the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield'. The Wongawilli West Study Area includes two 'potential impact' sites each on Wallandoola Creek and Lizard Creek and two 'control' sites with comparable aquatic habitat and surroundings each on Loddon Creek and Cascade River. The Wongawilli East Study Area comprises two 'potential impact' sites on Cataract Creek and two 'control' sites each on Cataract River and Allens Creek. This sampling design will enable Beyond BACI (Before/After, Control/Impact) analyses to be used to distinguish any impacts on aquatic ecology associated with mining subsidence from natural variability. The baseline monitoring program involves repeated spring and autumn sampling of the following indicators:

- Aquatic habitat
- Water quality
- Aquatic macroinvertebrates
- Fish.

The results of a preliminary survey of fish occurring within aquatic habitats identified as being suitable for occupation by Macquarie Perch and of a more intensive targeted survey designed to assess the distribution of the population of this species within Cataract Creek are also described. The latter is based on backpack electrofishing undertaken on four occasions during the summers of 2009-2010 and 2010/2011.

Results

Wongawilli West

The 'potential impact' and 'control' sites are surrounded by relatively natural, undisturbed, dry sclerophyll woodland and heath. Wallandoola Creek and Lizard Creek contain a variety of aquatic habitats, including deep, permanent pools, shallow areas over bedrock bars, submerged woody debris and aquatic macrophytes. Both creeks have been impacted by previous mining activity, with fractured bedrock, iron staining and iron floc being common features. There are substantial waterfalls on Lizard Creek and between the Study Area and the Cataract River that pose significant barriers to fish passage.

The overall water quality at the 'potential impact' sites was either similar to or better than that at the 'control' sites. The electrical conductivity in Cascade Creek, one of the 'control' streams, generally exceeded the appropriate ANZECC/ARMCANZ (2000) guidelines. The pH levels at the 'control' sites were often below guidelines. The dissolved oxygen levels at both the 'potential impact' and 'control' sites were generally below that considered favourable for aquatic life.

AUSRIVAS analyses indicated the "health" of the aquatic macroinvertebrate fauna varied across spring and autumn surveys, with changes generally being greater at 'potential impact'

sites than at 'control' sites. Large changes in "health" were common at the majority of monitoring sites, indicating the composition of the fauna is naturally variable. The SIGNAL2 score, an indicator of sensitivity to pollution, suggested the 'potential impact' sites were more degraded than 'control' sites, but only those in one creek. The SIGNAL2 scores were less variable than the AUSRIVAS indices and could consequently be a more useful indicator of effects associated with mining.

Artificial collectors, in the form of bundles of chopsticks, were also used to examine spatial and temporal differences in the aquatic macroinvertebrate fauna. The collectors yielded fewer taxa than the AUSRIVAS samples, however, it should be noted that only one deployment was totally successful. Statistical analyses based on these data showed that the fauna varied more between sites than among creeks.

The fish fauna at 'potential impact' and 'control' sites appeared to be depauperate, with number of species varying from zero in Wallandoola Creek to three in Loddon Creek. Freshwater crayfish, *Euastacus* sp. were present in three creeks, but not Cascade Creek. It should, however, be noted that only limited sampling of fish was undertaken at these sites.

Wongawilli East

The terrestrial habitat surrounding the monitoring sites on the major watercourses in the Wongawilli East Study Area consists of undisturbed, temperate rainforest. The aquatic habitats at the 'potential impact' sites within Cataract Creek comprise long pools with sandy substrata interspersed with bars and riffles composed of bedrock, boulders, pebbles and gravel. Large woody debris is common. The channel forms and substrata at the 'control' sites on Cataract River and Allens Creek are similar.

The overall water quality at this set of 'potential impact' sites was also either similar to or better than that at the 'control' sites. Most water quality parameters showed only occasional deviations from the accepted guidelines. The dissolved oxygen levels at both the 'potential impact' and 'control' sites, however, were generally below that considered favourable for aquatic life.

The "health" of the aquatic macroinvertebrate fauna varied across spring and autumn surveys, with changes generally being similar or smaller at 'potential impact' sites than at 'control' sites in spring and larger at two sites than at others in autumn. At most sites, the "health" of the macroinvertebrate fauna was less variable than in the other Study Area. The SIGNAL2 scores indicated the fauna was generally in a similar condition at the 'potential impact' and 'control' sites. The SIGNAL2 scores were less variable than the AUSRIVAS indices, as was the case in the Wongawilli West Study Area.

The deployment of artificial collectors was more successful in this Study Area, but they still yielded fewer taxa than the AUSRIVAS samples. Statistical analyses based on these data also showed that differences in the fauna between sites were more common than among creeks.

The observations during the baseline monitoring suggested that the fish fauna at this set of 'potential impact' and 'control' sites was also depauperate, with number of species varying from zero in Allens Creek to two in Cataract Creek and Cataract River. Freshwater crayfish, however, were present in all three creeks. Targeted fish surveys, however, indicated that at least seven species, three of which are subject to protection under State and/or Federal Legislation, were present in Cataract Creek. One of the threatened species, Macquarie Perch, occurs naturally in this part of NSW but is known to have been translocated from the Murray River into Lake Cataract. This species appears to migrate upstream as the summer progresses, with individuals occurring as far up as the rock bar at Site 6, which would be above two of the proposed longwalls. The other two threatened species, Freshwater Cod (identity not yet confirmed and possibly a hybrid) and Silver Perch, have been translocated into Lake Cataract, although this is outside their natural range.

Issues Identified

The baseline monitoring has identified three major issues relating to aquatic ecology that require consideration as part of the Part 3A approval process for the Wongawilli East and Wongawilli West mining areas. These are:

- The occurrence of threatened fish species, particularly Macquarie Perch, within the Wongawilli East mine area;
- The existence of prior mine subsidence related impacts in the form of rockbar fractures and iron staining within the watercourses overlying the Wongawilli West mine area;
- The variability in the "health' of the aquatic macroinvertebrate fauna suggests that AUSRIVAS indices may not be an effective indicator of impacts associated with mining.

Recommendations

1. Further aquatic ecology monitoring should be conducted during and after the extraction of the longwalls within Wongawilli West and Wongawilli East using the same survey sites and methods as in this study. This will provide best practice environmental monitoring of aquatic ecology and will allow statistically powerful tests of the effects of any impacts on aquatic habitats and biota arising from mine subsidence.
2. In view of the apparent variability in the 'health" of the aquatic macroinvertebrate fauna, it is recommended that SIGNAL2 scores continue to be calculated in future in addition to AUSRIVAS indices.
3. Further attempts should be made to identify the Freshwater Cod caught during the 2011/2012 summer season.
4. The position and extent of existing rockbar fractures within the watercourses overlying the proposed mine area should be recorded prior to the extraction of coal, so that fractures resulting from extraction of the proposed longwalls can be distinguished from past fractures and the consequences of any additional fracturing for aquatic ecology can be assessed.
5. The occurrence and extent of iron staining and flocs should be monitored regularly in areas expected to undergo subsidence. This should be done before, during and after mining of the longwalls. A sudden marked increase in the extent of iron staining should trigger an assessment of its impacts on aquatic habitats and biota.

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1 Introduction

1.1 Background and Aims

The NRE No. 1 Colliery (formerly known as South Bulli Colliery) extends across 6421 hectares and is estimated to have reserves of around 300 million tonnes of coking coal spread across the Bulli, Balgownie and Wongawilli Seams (Gujarat NRE Minerals 2005). Gujarat NRE Coking Coal Limited (NRE) proposes to extract coal from the Wongawilli East and Wongawilli West areas of the NRE No. 1 Mine at Russellvale, in the New South Wales Southern Coalfield. The application to the NSW government for approval to mine these areas under the Part 3A (NSW EP&A Act) process is being co-ordinated by Environmental Resources Management (Australia) Pty Ltd (ERM). Cardno (NSW/ACT) Pty Ltd trading as Cardno Ecology Lab (formally The Ecology Lab Pty Ltd) was commissioned by ERM to undertake the aquatic ecology component of the environmental monitoring for the two mine areas.

The baseline aquatic ecology monitoring program focuses on two separate areas of the NRE No. 1 Mine at Russellvale: Wongawilli West and Wongawilli East, which are located within the Cataract River catchment and the Lake Cataract catchment, to the north-east of the Cataract River arm of the reservoir, respectively. Baseline monitoring commenced in spring 2008 and focuses on the following components:

- Aquatic habitat
- Water quality
- Aquatic plants
- Aquatic macroinvertebrates
- Fish
- Threatened species of freshwater fish and aquatic macroinvertebrates.

This report comprises:

- A description of the sampling design, methodologies used and results of the baseline monitoring undertaken between September 2008 and September 2011;
- Identification of issues relevant to environmental assessment of aquatic ecology for this project;
- Recommendations for ongoing monitoring.

1.2 Baseline Monitoring Program

The baseline monitoring program was designed in accordance with relevant recommendations in the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield' (NSW DoP, 2008). The specific recommendations of relevance to aquatic ecological investigations were:

- Streams within mine subsidence areas classified as 3rd order or above under the Strahler stream classification scheme should be considered Risk Management Zones (RMZs);
- A minimum of 18-24 months of baseline data should be collected at an appropriate frequency and scale for significant natural features;
- A Before, After, Control, Impact (BACI) sampling design should be used for monitoring mine subsidence impacts on flora and fauna, so that advanced statistical techniques can be used to detect impacts.

The baseline monitoring program designed by Cardno Ecology Lab is based on the results of an initial site inspection undertaken on 22-23 October 2008 (Cardno Ecology Lab 2009). The monitoring program involves repeated spring and autumn surveys of key aquatic ecological indicators at two 'potential impact' sites located on each of the significant watercourses (third order or higher) overlying the Wongawilli West and Wongawilli East areas and two 'control' sites on four ecologically comparable watercourses located nearby that will not be affected by mining. The 'control' sites provide a measure of the background variability in aquatic ecology within the greater Cataract catchment as distinct from any mine subsidence impacts. This sampling design will enable Beyond BACI (Before/After, Control/Impact) analyses to be used to assess the potential impacts of mining subsidence on aquatic ecology in the Wongawilli West and Wongawilli East areas of NRE No.1 Mine, provided that similar assessments are made during or after mining. The Beyond BACI technique is a modification to the BACI approach that has been developed specifically to distinguish environmental impacts from natural changes (Underwood 1991, 1992 and 1994). The surveys undertaken to date provide three years (four sampling events, two seasons) of aquatic ecological baseline data for "control" and "potential impact" locations. This constitutes the "before" component of the Beyond BACI study design.

During each baseline survey, the state of the following key indicators was assessed:

- Aquatic habitat
- Water quality
- Aquatic macroinvertebrate fauna
- Fish fauna

The monitoring sites and methodologies used to assess each key indicator are described in Section 4.

1.3 Targeted Fish Surveys

A preliminary survey of fish occurring within the aquatic habitats identified as being suitable for occupation by Macquarie Perch during the initial site inspection was undertaken in Cataract Creek between 25 and 26 November 2008. The distribution of the Macquarie Perch population within Cataract Creek has been assessed during the summers of 2009/2010 and 2010/2011. The sampling program involves backpack electrofishing surveys on four occasions each summer.

2 Study Methods

2.1 Study Areas

The positions of the monitoring sites established on the 'potential impact' and 'control' creeks with the Wongawilli West and Wongawilli East Study Areas are shown in Figure 1. The GPS co-ordinates of the monitoring sites and dates of each survey are listed in Appendix 1.

1.2.1 Wongawilli West

During the initial site inspection in September 2008, two 'potential impact' sites were identified on the reaches of Wallandoola Creek and Lizard Creek that flow through the mine area (The Ecology Lab 2009).

The two 'potential impact' sites (Sites 1 and 2) on Wallandoola Creek are located downstream of the headwater swamp, in an area where there is a well-defined, permanent creek channel, but upstream of a series of waterfalls that pose significant barriers to fish passage. This reach of the Cataract River is highly regulated as it is used as a conduit for the Sydney water supply and is managed by the Sydney Catchment Authority (SCA). The upstream 'potential impact' site (Site 3) on Lizard Creek is located within a chain of deep pools upstream and downstream of sections of the creek where the bedrock has been fractured by previous mining activity. Site 3 drained completely during the initial phases of the monitoring, so in autumn 2009 an alternative upstream 'potential impact' site (Site 17) was established in Lizard Creek approximately 0.5km downstream. The other 'potential impact' site (Site 4) on Lizard Creek is situated over 1 km downstream of Site 3. Site 4 is separated from the two upstream 'potential impact' sites by a significant waterfall. Both creeks flow into the Cataract River downstream of Cataract Dam and upstream of Broughtons Pass Weir (Figure 1).

The riparian vegetation in Loddon Creek is dominated by heath with some sections of open dry sclerophyll woodland. The channel is characterised by long pool sections with infrequent riffles. Swamp habitat is present above the upstream monitoring site (Site 11) and there is a large waterfall below the downstream site (Site 12). The bed in the shallower sections of Loddon Creek, particularly at Site 12, is characterised by bedrock.

1.2.2 Wongawilli East

The 'potential impact' sites within the Wongawilli East area are located on Cataract Creek (Figure 1). The Upper Cataract River is very similar to Cataract Creek, in terms of channel forms and bed composition. The riparian vegetation surrounding both watercourses consists of dense temperate rainforest.

The mine layout provided by NRE indicates that Lake Cataract will not be undermined by the proposed longwalls and there will be sufficient distance between the edge of the longwalls and the lake that direct mine subsidence impacts will not occur in the lake. The aquatic habitat within Lake Cataract is therefore not considered part of the Study Area. No other significant areas of aquatic habitat have been identified in this area.

2.2 Baseline Monitoring Methodology

2.2.1 Aquatic Habitat Condition

During the first survey, a standardised description of the adjacent land and the condition of riverbanks, channel and bed at each site was prepared using a modified version of the Riparian, Channel and Environmental Inventory (RCE) (Chessman *et al.* 1997). This assessment gives an overall score for each site based on the natural characteristics and to a lesser extent degree of disturbance evident. Any changes to the initial scores were recorded in subsequent surveys.

The habitat descriptors used included:

- geomorphological characteristics of the waterways (e.g. gully, intermittent stream, major river; deep pools or gravel beds; waterways interconnecting with other waterways or wetlands upstream or downstream);
- flow regime of the waterways (e.g. intermittent or permanently flowing, flow velocity);
- types of land use along the waterway (e.g. industries associated with the river, recreational uses);
- riparian vegetation and instream vegetation (e.g. presence/absence, native or exotic, condition);
- presence of instream or offstream wetlands;
- substratum type (e.g. rock, sand, gravel, alluvial substrates);
- presence of refuge areas (e.g. wetlands nearby could be interlinked by the waterway during flow, pools of water above/below the licensed discharge point could be fish habitat);
- presence of spawning areas (e.g. gravel beds, riparian vegetation, snags) and nests; and
- presence of natural or artificial barriers to fish passage both upstream and downstream (e.g. weirs, dams, waterfalls, causeways).

A qualitative description of the aquatic habitats at the study sites in each watercourse was also undertaken based on the following attributes:

- surrounding landform;
- instream features such as sequence of pools, runs and riffles (shallow areas with broken water);
- presence, extent and type of aquatic vegetation;
- stream substratum;

- potential refuge areas during periods of low flow (e.g. large deep pools);
- presence of fish habitat including snags, bank undercuts and aquatic plants; and
- presence of barriers to fish passage into and beyond the study area.

A comprehensive photo record was also assembled for each site during each survey. Standardized photos were taken (with a 2 m tall x 1 m wide T-bar) at the top of the site looking downstream, at the middle of the site looking upstream, at the middle of the site looking downstream, and at the bottom of the site looking upstream to gain an understanding of environmental variation within the watercourses.

2.2.2 Water Quality

Surface water quality was measured in situ using a Yeokal 611 water quality probe. Two readings of the following parameters were recorded at each site:

- Temperature (˚C);
- Electrical Conductivity (µS/cm);
- pH;
- Oxidation – Reduction Potential (ORP) (mV);
- Dissolved Oxygen (% saturation); and
- Turbidity (ntu).

The electrical conductivity pH, dissolved oxygen and turbidity measurements were compared with the ANZECC (2000) default trigger values for physical and chemical stressors for protection of slightly disturbed upland aquatic ecosystems in south-eastern Australia.

2.2.3 Aquatic Macroinvertebrate Sampling

Aquatic macroinvertebrates were collected using two methods: the AUSRIVAS protocol for NSW streams (Turak et al. 2004), and aquatic macroinvertebrate collectors, a quantitative method developed by Cardno Ecology Lab for freshwater environmental impact assessment.

2.2.3.1 AUSRIVAS Sampling

AUSRIVAS surveys were undertaken twice in spring 2008 and autumn 2009, but only once each in the subsequent spring and autumn survey periods. During each survey, the aquatic macroinvertebrates associated with pool edge habitats at each site were sampled using dip nets (250 µm mesh) in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak et al. 2004). The dip net was used to agitate and scoop up material from vegetated river edges (Plate 1a). Each RAM sample was collected over a period of 3-5 minutes from a 10 m length of representative edge habitat along the reach of the site. If the required habitat was discontinuous, patches of habitats with a total length of 10 m were sampled.

Each RAM sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten minute intervals for either a total of one hour or until no new specimens were found. Care was taken to collect cryptic and fast moving animals in addition to those that were conspicuous or slow. The animals collected at each site were placed into a labelled jar containing 70% alcohol.

Chemical and physical variables such as alkalinity of the water, modal water depth and river width, percentage of bedrock, boulder or cobble on the substratum, latitude and longitude that are required for running the AUSRIVAS predictive model were also recorded at each site. The other variables required for the predictive mode (i.e. distance from source, altitude, land-slope and rainfall) were determined in the lab.

In the laboratory, RAM samples were sorted under a binocular microscope (at 40 X magnification), identified to family level and up to ten animals of each taxon counted, in accordance with the AUSRIVAS protocol (Turak *et al.* 2004). A randomly chosen 10% of the RAM sample identifications were checked by a second experienced scientist to validate macroinvertebrate identifications.

2.2.3.2 Artificial Collectors

The macroinvertebrate collectors were deployed in spring 2008 and autumn 2009 at the Wongawilli West monitoring sites and in spring 2008, autumn 2009, spring 2009 and autumn 2010.

During each of these surveys, eight replicate artificial collector units providing habitat structure for aquatic macroinvertebrates were deployed at each site. The collectors consisted of 24 cm long x 3 cm diameter bundles of 18 wooden chopsticks held together with plastic cable ties (Plate 1b-c). The collectors were attached to vegetation with nylon twine and submerged 1 meter apart at the edge of pools in 30-60 cm of water (Plate 1d). The collectors were retrieved during the second and fourth surveys, approximately six weeks after being deployed. During retrieval the collectors were carefully cut away from their anchors, placed individually into plastic bags, labelled and preserved in 70% ethanol for subsequent laboratory identification and analysis.

The aquatic macroinvertebrates that had colonised each bundle of chopsticks were rinsed onto a 0.5 mm mesh sieve and examined in the laboratory using a binocular microscope. The macroinvertebrates were sorted, identified to family (most invertebrate taxa), sub-family (chironomids) or class (flatworms and leeches) level and then counted.

Artificial collectors have been used in a wide range of studies involving freshwater macroinvertebrates (Rosenberg and Resh 1982, Cairns and Pratt 1993, Czerniawska Kusza, 2004). They provide a standard habitat for macroinvertebrates to colonise and result in data that exhibit less variability between samples (greater precision) and sites than fauna associated with natural substrata. They are also quicker and easier to sample and hence a more cost-effective sampling methodology (Hellawell 1978; Rosenburg and Resh 1982). The disadvantage is that they are artificial and cannot simulate all the conditions that may prevail in all habitats. Thus, the assemblages that might develop within or on the collectors are unlikely to be identical to those that occur in natural habitats at the same location. Provided that the collectors resemble some elements of the local habitat, it is not necessary for the assemblages on the collectors to be the same as those on natural substrata; what is important is how the sites differ. The artificial collectors and therefore provide quantitative data that are independent of the quality or quantity of habitat present within the creeks.

2.2.4 Fish Sampling

During each survey, fish sampling was conducted at all sites using dip nets (250 μm mesh) in conjunction with the AUSRIVAS macroinvertebrate collection. A 10 m length of representative edge habitat at each site was selected and thoroughly agitated and scooped for a period of 3–5 minutes. All captured fish and large crustaceans were immediately transferred to a fish box, filled with stream water, for identification and released as quickly as practicably possible. Additional fish observed in-stream along the length of each site over an approximately 30 minute period were also recorded.

2.3 Targeted Fish Surveys

A preliminary fish survey was undertaken in watercourses in the vicinity of the Wongawilli East investigation area identified as potential habitat for Macquarie Perch and Trout Cod. This survey was undertaken on the 25th and 26th of November 2008 in Cataract Creek, and the uppermost inundation of Lake Cataract within these drainages. Fish and large mobile invertebrates, such as freshwater crayfish, occurring at the sites were sampled using a back-pack electrofisher (Model Smith-Root LR24). The operator of the electrofisher discharged an electric pulse into the water which stunned the fish, allowing them to be easily netted, counted, identified and released. Electrofishing was done in riffles, pools, beds of aquatic macrophytes and beneath overhanging banks, snags and vegetation. One staff member used the electrofisher, whilst a second handled a dip net and was primarily responsible for capture of stunned fish. Captured fish were placed into a fish box, filled with stream water, which was handled by a third person on the bank. The third person acted as a safety officer for the other two. Electrofishing "shots" of approximately 30 seconds of continuous fishing time were done at locations within the creeks with potential fish habitat. Exhaustive fishing techniques were conducted in an attempt to record all fish present in the targeted areas. The reaches of Cataract Creek surveyed are shown in Figure 2.

Native fish caught were identified and released as quickly as practicably possible. Fish that could not be identified in the field were brought back to be examined under a binocular microscope. Individuals whose identity still remained in doubt were sent to an expert at The Australian Museum for further investigation. Exotic fish were not returned to the water in accordance with Cardno Ecology Lab's scientific research permit.

As Macquarie Perch are known to migrate upstream to spawn in riffles in late Spring/Summer, and there are no significant existing barriers to this migration in Cataract Creek, additional targeted surveys for Macquarie Perch surveys were undertaken on four separate occasions during the summers of 2009/2010 and 2010/2011. The survey area extended from the confluence of Cataract Creek and Cataract River or the most upstream extent of the current supply level within the Cataract Creek arm of Lake Cataract if this had inundated this confluence, upstream as far as a rockbar identified as a likely barrier to further upstream migration. The GPS coordinates of the study area and dates of surveys are presented in Appendix 1. Sampling was timed so that it coincided with high water temperatures and was conducted after heavy rainfall and high levels of runoff to maximise the potential for observing the upstream and downstream movement of this species. Electrofishing was undertaken using a Smith-Root LR24 backpack electrofisher throughout the entire reach of the watercourse within the survey area to achieve as close as possible to 100% coverage. The water depth was generally within the limitation of backpack electrofishing (wading depth) and as such, all habitats were accessible. The habitat surveyed and the backpack electrofishing technique is illustrated in Plate 2.

The GPS position of any Macquarie Perch caught were recorded. All specimens were measured (Caudal Fork Length), photographed, and fin clip samples were taken and preserved in alcohol for genetic analysis (beyond the scope of this study). All captured fish were handled with care to minimise stress, and released as soon as possible. All other species caught were identified and counted. Introduced pest species were not returned to the water in accordance with our NSW Fisheries research permit.

During each of these targeted surveys, the quality of water at the upstream and downstream extent of the survey area was recorded with a hand held probe (Yeo Kal 611), as described in Section 3.2. The supply level of Lake Cataract at the time of each survey, as indicated in the SCA records, is presented in Appendix 1.

2.4 Data Analysis

2.4.1 AUSRIVAS Samples

Macroinvertebrate data from the dip netting were analysed using the AUSRIVAS predictive spring and autumn models for NSW pool edge habitats (Coysh *et al.* 2000). The following indices generated by the AUSRIVAS model were examined:

- OE50Taxa Score - This is the ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50 % probability of occurrence. OE50 taxa values range from 0 to 1 and provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.
- Overall Bands derived from OE50Taxa scores which indicate the level of impairment of the assemblage. These bands are graded as follows:

  Band X = Richer invertebrate assemblage than reference condition.

  Band A = Equivalent to reference condition.

  Band B = Sites below reference condition (i.e. significantly impaired).

  Band C = Sites well below reference condition (i.e. severely impaired).

  Band D = Impoverished (i.e. extremely impaired).

The revised SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (1995; 2003) was also used to determine the “environmental quality” of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers to each macroinvertebrate family or taxa found, based largely on their responses to chemical pollutants. Grade values range from 1 to 10, with a value of 1 indicating a family tolerant to chemical pollution and a value of 10 indicating a sensitive family. The sum of all grade numbers for that habitat is then divided by the total number of families recorded in each habitat to calculate the SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values greater than 6, between 5 and 6, 4 and 5 and less than 4 indicate that the quality of the water is clean, mildly, moderately or severely degraded, respectively.

2.4.2 Artificial Collectors

Differences in the types and relative abundance of the macroinvertebrate taxa found in each pair of collectors were estimated by calculating their respective Bray-Curtis similarity coefficients. Spatial patterns in the composition of the assemblages were examined by means of non-metric Multi

Dimensional Scaling (MDS) (Clarke 1993). MDS provides a graphical representation of assemblages based on their similarity within and among places or times sampled. In MDS plots, samples which have similar sets of organisms are grouped closer together than ones containing different sets of organisms. The upstream location in Lizard Creek (Site 3) completely dried up during the spring 2008 season, which left the collectors at this site with significantly less macroinvertebrate colonisation. Due to this result, this outlying point was removed from the spring 2008 MDS analysis. MDS ordinations were done with the software package Primer 6 (Plymouth Routines in Multivariate Ecological Research 6 2008) (Clarke and Gorley 2006). PERMANOVA, a non-parametric permutation test, was used to examine differences in the structure of assemblages among Sites and Creeks (Anderson 2001; Anderson *et al.* 2008).

3 Results

3.1 Aquatic Habitats

3.1.1 Wongawilli West

Wallandoola, Lizard and Cascade Creeks are surrounded by open dry sclerophyll woodland and heath (Plate 3a-b). The creeks are generally unshaded. The substratum is dominated by bedrock and boulders with sand and fine sediment accumulations in some of the deeper pools and channel sections. A variety of habitat features are present within the creeks, including relatively deep, permanent pools, sections of shallow flow over bedrock bars. There are also soft sediment banks with overhanging vegetation and instream features such as submerged woody debris and aquatic macrophytes. The upper reach of Wallandoola Creek comprises a headwater swamp and lacks a clearly defined channel. In the downstream reach there is a series of waterfalls as the creek drops from the plateau before eventually entering Cataract River downstream of Cataract Dam. These waterfalls pose significant barriers to fish passage. Fractured bedrock bars are evident throughout the downstream reach of the creek (Plate 4a). Iron staining and associated iron flocculant is also common (Plate 4b). There are also extensive areas of fractured bedrock in the upstream reaches of Lizard Creek and considerable amounts of iron floc throughout the reach that flows through the Study Area (Plate 4c-d). The cracking of the bedrock observed Site 3 in Lizard Creek appears to have resulted in drainage of water. There is a significant waterfall between Site 4 and the two upstream sites and other significant waterfalls between the Study Area and the Cataract River. These waterfalls are barriers to fish passage.

The riparian vegetation in Loddon Creek is dominated by heath with some sections of open dry sclerophyll woodland. The channel is characterised by long pool sections with infrequent riffles. The reach above the upstream site (Site 11) contains swamp habitat. There is a large waterfall below the downstream site (Site 12). The bed in the shallower sections of Loddon Creek, particularly at Site 12, is characterized by bedrock.

3.1.2 Wongawilli East

Allen Creek and Cataract Creek are bordered by temperate rainforest riparian vegetation. The canopy is closed and the creek is shaded (Plate 3c-d). The channel morphology is characterised by alternating series of long pools and shorter bars and riffles (Plates 1a – 1d). The creek is generally shallow, but there are occasional deep holes. The beds of the pools are sandy. The bars and riffles are composed of various combinations of bedrock, boulders, cobble, pebble and gravel. Large woody debris is relatively common, forming dams and submerged snags in pools. Cataract Creek contains aquatic habitats suitable for Macquarie Perch, a threatened fish species. The current supply level of Cataract Lake extends upstream into Cataract Creek and contains suitable habitat for

Macquarie Perch (Plate 2b). Occasional riffles and bars further upstream in the creek may be barriers to fish passage during low to moderate flows.

The riparian vegetation in the Upper Cataract River also consists of dense temperate rainforest. The channel forms and bed composition of the river are similar to that found in Cataract Creek.

3.2 Water Quality

3.2.1 Wongawilli West

The mean (± S.E.) water quality measurements recorded per survey at the monitoring sites in the Wongawilli West Study Area are presented in Appendix 2. In Table 1 the water quality measurements taken within the Wongawilli West Study Area are compared with the ANZECC/ARMCANZ guidelines for slightly disturbed upland rivers in south-east Australia. Deviations from the default trigger values (DTV) are indicated below.

Electrical conductivity

- Below the lower DTV at Sites 3 and 4 on Lizard Creek in September 2010 and Sites 11 and 12 on Loddon Creek in March 2009;
- Above the upper DTV at Site16 on Cascade Creek during all surveys and at Site 15 on 5 out of 7 surveys.

pH

- Below the lower DTV at Sites 15 and 16 on Cascade Creek during all surveys, at Sites 11 and 12 on Loddon Creek during most surveys, at Sites 1 and 2 on Wallandoola Creek and Sites 3, 4 and 17 on Lizard Creek in September 2010, April 2011 and September 2011, but at only some of these sites during the earlier surveys.

DO (% saturation)

- Below the lower DTV at Sites 15 and 16 on Cascade Creek during all surveys and at Sites 1 and 2 on Wallandoola Creek, Sites 3, 4 and 17 on Lizard Creek on most sampling occasions and at Sites 11 and 12 on Loddon Creek during at least half the surveys
- Above the upper DTV on occasion at Sites 1 and 2 on Wallandoola Creek, Site 17 on Lizard Creek and Sites 11 and 12 on Loddon Creek.

Turbidity

- Below the lower DTV during a few surveys undertaken at Sites 1 and 2 on Wallandoola Creek, Sites 3,4 and 17 on Lizard Creek, Sites 11 and 12 on Loddon Creek and on one or two occasions at Sites 15 and 16 on Cascade Creek.

- Above the upper DTV on one or two occasions at Sites 4 and17 on Lizard Creek.

3.2.2 Wongawilli East

The mean (± S.E.) water quality measurements recorded per survey at the monitoring sites in the Wongawilli East Study Area are presented in Appendix 3. Table 2 compares the water quality measurements taken within the Wongawilli East Study Area with the ANZECC/ARMCANZ guidelines for slightly disturbed upland rivers in south-east Australia. Deviations from the default trigger values (DTV) are indicated below.

Electrical conductivity

- Below the lower DTV on one occasion at Site 5 on Cataract Creek and Site 10 on Cataract River.

pH

- Below the lower DTV on two occasions at Site 6 on Cataract Creek and Site 14 on Allens Creek and three occasions at Site 13 on Allens Creek.

DO (% saturation)

- Below the lower DTV during most surveys undertaken at Sites 5 and 6 on Cataract Creek and Sites 9 and 10 on Cataract River and during four of the seven surveys of Sites 13 and 14 in Allens Creek.
- Above the upper DTV on occasion at Site 6 on Cataract Creek and Site 14 on Allens Creek.

Turbidity

- Below the lower DTV on one or two surveys undertaken at Sites 5 and 6 on Cataract Creek and Sites 9 and 10 on Cataract River and on two to three of the surveys of Sites 13 and 14 in Allens Creek.
- Above the upper DTV on one or two occasions at Sites 5 and 6 on Cataract Creek, Site 9 on Cataract River and Site 14 on Allens creek.

3.3 Aquatic Macroinvertebrates

3.3.1 AUSRIVAS Samples

3.3.1.1 Wongawilli West

3.3.1.1.1 Spring

The numbers of each macroinvertebrate taxon found in each AUSRIVAS sample collected from the monitoring sites in the Wongawilli West Study Area are presented in Appendix 4. The number of taxa collected per site varied 7 (Site 1 in spring 2011) to 28 (Site 4 in December

2008) (Figure 3a). At Site 1 in Wallandoola Creek, the number of taxa declined from 22 in October and December 2008 to 7 in spring 2011. Marked declines in the number of taxa were also found at Site 2 on Wallandoola Creek, Site 4 on Lizard Creek, Site 11 on Loddon Creek and Site 15 on Cascade Creek, but only during the last three surveys. There was also a marked difference in the number of taxa found at Site 3, with this site having the most diverse fauna in October 2008 but the least diverse in December 2008. No particular trend was evident at the other sites.

The "health" of the macroinvertebrate fauna at all the study sites bar one (site 11 in Loddon Creek) varied across the spring surveys (Figure 4a). The fauna at Site 1 on Wallandoola Creek declined from equivalent to AUSRIVAS reference condition (band A) in spring 2008, to significantly impaired (band B) in 2009 and 2010 and severely impaired (band C) in 2011. The fauna at Site 2 on this creek did not show any particular trend, being equivalent to reference condition on two occasions, more diverse on one occasion and significantly impaired on two occasions. The fauna at two of the sites on Lizard Creek also declined, with that at Site 3 changing from equivalent to reference condition at the beginning of spring 2008 to severely impaired in the second 2008 survey and 2011 and that at Site 4 changing from equivalent to reference condition at the beginning of spring 2008 to significantly impaired from the second survey in 2008 until spring 2010 and to significantly impaired in 2011. The fauna at Site 17 on Lizard creek was more impaired in spring 2009 than in the two subsequent surveys. The fauna in Lizard Creek was thus in a poorer overall condition than that in Wallandoola Creek.

The fauna at Site 11 on Loddon Creek was significantly impaired during all five spring surveys, but that at Site 12 did not show any particular trend, fluctuating between equivalent to reference condition and significantly impaired during the first four surveys, but being severely impaired in spring 2011. The health of the fauna at the sites on Cascade Creek was significantly impaired in spring 2009 and 2011, but equivalent to the reference condition in spring 2010. It should be noted that monitoring of these sites did not commenced until spring 2009.

The OE50 taxa scores for the six sites with severely impaired fauna show that between 50% and 75 % of macroinvertebrate taxa with a 50% probability of occurrence were missing (Figure 4b).

The SIGNAL2 scores indicated the sites on Wallandoola Creek and Lizard Creek were subject to moderate pollution on some occasions, but to severe pollution on others (Figure 4c). A decline in SIGNAL2 scores over the last three surveys was evident at Sites 1 and 2 on Wallandoola Creek and Sites 4 and 17 in Lizard Creek, but at none of the 'control' sites on Loddon Creek or Cascade Creek. The scores for Site 11 on Loddon Creek were indicative of either moderate or mild pollution, as were those for Site 12, except in Spring 2011 when the score was indicative of severe pollution. The scores for the sites on Cascade Creek were indicative of either moderate or severe pollution, with an improvement over time being evident at Site 16.

3.3.1.1.2 Autumn

The number of taxa collected per site varied from 7 (Site 3 in May 2009) to 29 (Site 15 in March 2009) (Figure 3b). The changes in numbers of taxa at most sites were not consistent over time. However, at Site 1 in Wallandoola Creek there was an increase in numbers from 16 in March 2009 to 25 in autumn 2011 and at Sites 11 and 12 in Loddon Creek more taxa were collected in autumn 2009 than in the two subsequent surveys.

The health of the aquatic macroinvertebrate fauna at the majority of study sites also varied across the autumn surveys (Figure 5a). The fauna at Site 1 on Wallandoola Creek declined from equivalent to AUSRIVAS reference condition during the two autumn 2009 surveys to severely impaired (band C) in autumn 2010, but was more diverse than the reference condition (band X) in autumn 2011. The fauna at Site 2 on this creek was equivalent to reference condition on three occasions, but significantly impaired during the other survey. The fauna at Site 3 on Lizard Creek was significantly impaired during all three surveys undertaken at this site. The fauna at Site 4 on Lizard Creek was either equivalent to reference condition or significantly impaired. The condition of the fauna at Site 17 on Lizard Creek was more variable, being equivalent to reference condition in March 2009 and autumn 2011, but significantly impaired in May 2009 and impoverished (band D) in autumn 2010. The fauna at Sites 11 and 12 on Loddon Creek was also variable, changing from equivalent to reference condition to severely impaired. The trends in fauna at Sites 15 and 16 on Cascade Creek were similar, ranging on condition from more diverse than the reference condition to significantly impaired.

The OE50 taxa scores for the four sites with severely impaired fauna show they lacked between 63% and 91 % of the expected macroinvertebrate taxa with a 50% probability of occurrence (Figure 5b).

The SIGNAL2 scores indicated the sites on Wallandoola Creek were generally subject to moderate pollution, except at Site 1 in May 2009 when the score was indicative of severe pollution (Figure 5c). Site 3 on Lizard Creek was subject to severe pollution on both of the occasions it was surveyed, but the other sites on this creek were generally subject to moderate pollution, except for Sites 4 which was assessed as severely polluted in May 2009 and Site 17 which was mild polluted in autumn 2010. The scores for Site 11 on Loddon Creek were indicative of moderate pollution, except in survey 2, whereas those for Site 12 were indicative of either mild or moderate pollution. The sites on Cascade Creek were generally severely polluted, but moderately polluted on one occasion.

3.3.1.2 Wongawilli East

3.3.1.2.1 Spring

The numbers of each macroinvertebrate taxon found in each AUSRIVAS sample collected from the monitoring sites in the Wongawilli East Study Area are presented in Appendix 5. The number of taxa collected per site varied from 9 (Site 6 in spring 2011) to 30 (Site 10 in spring 2010) (Figure 6a). The samples collected at Sites 5 and 6 on Cataract Creek were generally less diverse than those collected at Sites 9 and 10 on Cataract River and Sites 13 and 14 in Allens Creek. The changes in numbers of taxa over time at the sites on Cataract Creek and Cataract River and Site 13 on Allens Creek were not consistent over time, however, there does appear to have been a gradual decrease in numbers at Site 14 over the last three spring surveys. The fauna at all the study sites was less diverse in spring 2011 than during the other spring surveys.

The health of the aquatic macroinvertebrate fauna at all the study sites varied across the spring surveys, with no particular trends evident, except possibly at one of the sites on Allens Creek (Site 14) (Figure 7a). In Cataract Creek, the fauna at Site 5 was either equivalent to AUSRIVAS reference condition or significantly impaired, whereas that at Site 6 was significantly impaired during the first three surveys, equivalent to reference condition in spring 2010, but severely impaired during the most recent survey. The fauna at Site 9 on the Cataract River fluctuated between equivalent to reference condition and significantly impaired during the first four spring surveys, but was severely impaired in spring 2011. The fauna at Site 10 on the Cataract River also fluctuated between equivalent to reference condition and significantly impaired, except in spring 2010 when it was more diverse than the reference condition. The fauna at the sites on Allens Creek was assessed only during the last three surveys springs. At these sites, the fauna was either equivalent to reference condition or significantly impaired.

The OE50 taxa scores for the two sites with severely impaired fauna show they lacked 63% and 67 % of macroinvertebrate taxa with a 50% probability of occurrence, respectively (Figure 7b).

The SIGNAL2 scores indicated that both the ‘potential impact’ and ‘control’ sites were generally subject to moderate pollution (Figure 7c). In spring 2011, SIGNAL2 scores indicative of severe pollution were recorded at one of the sites on each watercourse. SIGNAL2 scores indicative of mild pollution were also recorded on occasion, but only at Sites 9 and 10 on the Cataract River and Site 14 on Allens Creek.

3.3.1.2.2 Autumn

The number of taxa collected per site varied 13 (Site 5 in autumn 2010) to 33 (Site 9 in March 2009) (Figure 6b). The samples collected at Sites 5 and 6 on Cataract Creek were also less diverse during these surveys than those collected at Sites 9 and 10 on Cataract River and Sites 13 and 14 in Allens Creek. The pattern of changes in numbers of taxa over time was similar at the sites on Cataract River and Allens Creek and Site 5 on Cascade Creek, with a decline being evident between March 2009 and autumn 2010 followed by an increase in numbers. At Site 6 on Cascade Creek there was a gradual decline in number of taxa collected over time.

The health of the aquatic macroinvertebrate fauna at all the study sites also varied across the autumn surveys (Figure 8a). The fauna at Site 5 on Cataract Creek was significantly impaired, except in autumn 2010 when it was rated severely impaired. The fauna at Site 6 was equivalent to reference condition during the first two survey, severely impaired in autumn 2010, but significantly impaired in autumn 2011. The fauna at Site 10 on the Cataract River and Sites 13 and 14 on Allens Creek was generally equivalent to reference condition, except in autumn 2010 when it was significantly impaired. The fauna at Site 9 on Cataract River was more variable, being either equivalent to reference condition, significantly impaired or severely impaired.

The OE50 taxa scores show that the severely impaired fauna lacked between 62% and 72 % of the expected macroinvertebrate taxa with a 50% probability of occurrence (Figure 8b).

The SIGNAL2 scores for the autumn surveys indicated that the ‘potential impact’ and ‘control’ sites were generally subject to moderate pollution (Figure 8c). SIGNAL2 scores indicative of severe pollution, however, were recorded on one occasion at the sites on Allens Creek. SIGNAL2 scores indicative of mild pollution were recorded on one occasion at each ‘control site’ but at only one ‘potential impact’ site (Site 5 on Cataract Creek).

3.3.2 Collectors

3.3.2.1 Wongawilli West

The total numbers of each macroinvertebrate taxon found on the collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009 are presented in Appendix 6. In spring 2008, the average number of macroinvertebrate taxa colonising the collectors varied from 1.2 at Site 3 on Lizard Creek to 7.4 at Site 12 on Loddon Creek, while average number of macroinvertebrate animals varied from 3 at Site 3 to 94 at Site 4 on Lizard Creek (Figure 9). Chironomidae (non-biting midges) and Leptoceridae (stick caddisflies) were two most abundant taxa found on the collectors retrieved at Sites 1 and 2 on Wallandoola Creek (Figure10). The collectors at the Sites in Lizard Creek were dominated by different taxa, with Entomobryidae followed by Chironomidae being the most abundant taxa at Site 3 and Chironomidae and Oligochaete the two numerically dominant taxa at Site 4. Chironomidae and Leptophlebiidae (leptofleb mayflies) were the dominant taxa at Site 12 on Loddon Creek. Some of the aquatic macroinvertebrates found on the collectors are depicted on Plates 5a-e. It should be noted that collectors deployed at some sites were not processed because they had been stranded on dry land and that none were deployed at the study sites on Cascade River. As the data from this deployment of collectors is incomplete it has not been subject to statistical comparison.

In autumn 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 2 at Site 16 on Cascade Creek to 7 at Sites 11 and 12 on Loddon Creek, while average number of macroinvertebrate animals varied from 16 at Site 1 on Wallandoola Creek to 273 at Site 12 on Loddon Creek (Figure 11). Chironomidae and Oligochaeta were the two most abundant taxa on the collectors retrieved from Site 2 on Wallandoola Creek, Sites 4 and 17 on Lizard Creek and Site 15 in Cascade Creek. The collectors retrieved from Sites 11 and 12 on Loddon Creek and Site 16 in Cascade Creek were dominated by Chironomidae followed by Leptophlebiidae, while those at Site 1 on Wallandoola Creek were dominated by Anclylidae (freshwater limpets) and Chironomidae (Figure 10). The MDS plot indicates the assemblages at Sites 1 and 2 on Wallandoola Creek were distinct from each other, as were those at Sites 4 and 17 on Lizard Creek (Figure 12). The differences in the structure of the macroinvertebrate assemblage, total numbers of taxa and macroinvertebrates within location were statistically significant but not those among locations (Table 3; Appendix 8).

3.3.2.2 Wongawilli East

The total numbers of each macroinvertebrate taxon found per survey on the collectors retrieved from the monitoring sites in the Wongawilli East Study Area are presented in Appendix 7. In spring 2008, the average number of macroinvertebrate taxa colonising the collectors varied from 4 at Site 6 on Cataract Creek to 9 at Site 10 on Cataract River, while average number of macroinvertebrate animals varied from 35 at Site 6 on Cataract Creek to 149 at Site 9 on Cataract River (Figure 13). Chironomidae and Oligochaete were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek and Site 10 on Cataract River (Figure 14). Chironomidae followed by Ancylidae were the numerically dominant taxa on the collectors from Site 9 on Cataract River. It should be noted that on this occasion no collectors were deployed at the study sites on Allens Creek. As the data from this deployment of collectors is incomplete it has not been subject to statistical comparison.

In autumn 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 9 at Site 13 on Allens Creek to 11 at Site 9 on Cataract River, while average number of macroinvertebrate animals varied from 83 at Site 14 on Allens Creek to 377 at Site 10 on Cataract River (Figure 15). Chironomidae and Oligochaeta were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek, Site 10 on Cataract River and Site13 on Allens Creek (Figure 16). Ancylidae followed by Oligochaeta were the numerically dominant taxa on the collectors from Site 9 on Cataract River. The collectors from Site 14 on Allens Creek were dominated by Chironomidae followed by Leptophlebiidae. The MDS plot indicates the assemblages at the paired sites on the three watercourses were more or less distinct from each other (Figure 17). There were significant differences in the structure of the macroinvertebrate assemblage and total numbers of macroinvertebrates within but not among locations (Table 3; Appendix 9). The total number of taxa, however, differed among but not within locations.

In spring 2009, the average number of macroinvertebrate taxa colonising the collectors varied from 4.6 at Site 5 on Cataract Creek to 9.3 at Site 10 on Cataract River, while average number of macroinvertebrate animals varied from 68 at Site 13 on Allens Creek to 86 at Site 9 on Cataract River (Figure 18). Oligochaeta followed by Chironomidae were the two most abundant taxa found on the collectors retrieved from Sites 5 and 6 on Cataract Creek and Site 14 on Allens Creek (Figure 14). The collectors from Sites 10 and 13 were dominated by Chironomidae followed by Leptophlebiidae, while that at Site 9 was dominated by Chironomidae followed by Oligochaeta. The MDS plot indicates the assemblages at the paired sites on Cataract River and Allens Creek were more or less distinct from each other (Figure 19). In spring 2009, the only statistically significant differences detected were in assemblages within locations and total numbers of taxa among locations (Table 3; Appendix 10).

In autumn 2010, the average number of macroinvertebrate taxa colonising the collectors varied from 8 at Site 6 on Cataract Creek to 15 at Site 9 on Cataract River, while average number of macroinvertebrate animals varied from 85 at Site 13 on Allens Creek to 452 at Site 5 on Cataract Creek (Figure 20). In autumn 2010, Chironomidae followed by Leptophlebiidae were the most abundant taxa on the collectors retrieved from the sites in Cataract River and Allens Creek. The collectors from the Cataract Creek sites were dominated by Oligochaeta and Chironomidae. The MDS plot indicates the assemblages at the paired sites on the three watercourses were more or less distinct from each other (Figure 21). In autumn 2010, statistically significant differences in all three indicators were found within locations (Table 3: Appendix 11). The structure of the assemblages also differed among locations.

3.4 Fish

3.4.1 Targeted Fish Surveys

3.4.1.1 Preliminary Survey of Wongawilli East

The species and numbers of fish collected in Cataract Creek in November 2008 are shown in Table 4. Two specimens of Macquarie Perch, a species listed as threatened under both State and Federal legislation, were caught within the current supply level and another specimen was caught at the inflow of the creek (Plate 6a). Numerous juvenile cod that may have been Murray cod (*Maccullochella peelii*), Trout Cod (*Maccullochella macquariensis*) or a hybrid of these species (Andrew Bruce of DPI, pers. comm.) were also caught (Plate 6b). A specimen sent to The Australian Museum for further analysis could not be positively identified. A native long-finned eel and a number of climbing galaxias were caught in the riffle/pool sequences upstream of the dam storage level.

3.4.1.2 Summer 2009/2010

Six species of fish were caught (Table 5a).

The number of Macquarie Perch caught per survey increased from 3 in December 2009, to 6 in the January surveys and 15 in February 2010. The geographic location and length of each Macquarie Perch caught is presented in Appendix 12. The fish caught ranged in length from 80 mm to 230 mm. Macquarie Perch were caught further upstream during each successive survey, with the most upstream records being up to the rock bar at the upstream extent of the survey area in Survey 4.

Juvenile Freshwater Ccod were recorded in all four surveys. Silver Perch (*Bidyanus bidyanus)* were recorded in Survey 4 (Plate 6c). All three species are known to have been stocked in Lake Cataract, although it is outside their natural distribution range. A small endemic species, Mountain galaxias (*Galaxias olidus*), was caught in all four surveys (Plate 6d). Two introduced pest species, Eastern gambusia (*Gambusia holbrooki)* and goldfish (*Carassius auratus*) (Plate 6e) were also caught in all four surveys. Gambusia was the most abundant species of fish caught.

Freshwater crayfish (*Euastacus* sp.) were found throughout the study area (Plate 5f), but their numbers were not recorded.

The water quality parameters recorded during the targeted fish survey are presented in Appendix 14a. During the December 2009 survey, the water temperature at the confluence of the Cataract River was 21.7°C but it was only 17°C at Site 6, which is below the spawning trigger temperature (18°C) for this species. A distinct temperature gradient was also evident during the other surveys, with temperatures at these sites being 21°C and 18°C respectively, at the beginning of January, but rising to 19°C and 22.3°C towards the end of January. During the February survey, the temperature at the confluence was 19.9°C, whereas that at site 6 was 16.5°C.

3.4.1.3 Summer 2010/2011

Seven species of fish were caught during the summer 2010-2011 surveys (Table 5b).

Macquarie Perch were found within Cataract Creek from the confluence with Cataract River, to upstream well above the full supply level, and as far as the rock bar located at Site 6. This is approximately 100 m further upstream than this species was recorded in the final survey of summer 2009-2010. The individuals recorded furthest upstream were caught on 21 February 2011. This species was found much further upstream during the first survey of 2010/2011 than that of the 2009/2010 monitoring period. As in the previous year, individual Macquarie Perch were found further upstream as the season progressed. However, significantly more Macquarie Perch were caught in 2010/2011, with numbers increasing from 11 in December 2010 to 37 in

January 2011 and 28 in February 2011. The geographic location and length of each Macquarie Perch caught are presented in Appendix 13. The Macquarie Perch fish caught ranged in length from 90 mm to 370 mm. The geographic co-ordinates of each Freshwater Cod and Silver Perch caught are listed in Appendix 15.

Freshwater cod were recorded in all four surveys, with numbers also increasing as the season progressed (i.e. 5 in December 2010 to 22 in February 2011). Silver Perch (*Bidyanus bidyanus)* were recorded only in late January and February 2011. Eastern Gambusia and Mountain Galaxias were also caught during all four surveys, with the former again being the most abundant species caught. Goldfish were only caught in December 2010 and February 2011 and were less abundant than during the previous season. The seventh species caught, the short-finned eel (*Anguilla australis*) was caught only in January.

Freshwater crayfish (*Euastacus* sp.) were again found throughout the survey area.

The water quality parameters recorded during the targeted fish survey are presented in Appendix 14b. During the December 2010 survey, the water temperature at the confluence of the Cataract River was 24.9°C but it was only 17.4°C at Site 6, which is below the spawning trigger temperature (18°C) for this species. A distinct temperature gradient was also evident during the other surveys, with temperatures at these sites being 21.7°C and 16.6°C respectively, at the beginning of January, but rising to 19°C and 22.3°C towards the end of January. During the February survey, the temperature at the confluence was 19.9°C, whereas that at site 6 was 16.5°C.

3.4.2 Baseline Monitoring

Three species of fish, eastern gambusia (*Gambusia holbrooki*), climbing galaxias (*Galaxias brevipinnis*) and Australian smelt (*Retropinna semoni*) and one crustacean, the freshwater crayfish (*Euastacus* sp.) were either caught in dip nets or observed at the study sites (Table 6). All four species were present within the Wongawilli West and Wongawilli East Study Areas, but not at all sites. Eastern gambusia was recorded only at Sites 5 (Cataract Creek) and 12 (Loddon Creek). Climbing galaxias and Australian smelt (Plate 6f) had an intermediate distribution, with both being recorded at five sites. Freshwater crayfish had the widest distribution range, being found at 11 study sites. No fish were observed or caught at the Wallandoola Creek sites, but freshwater crayfish (*Euastacus* sp.) were present.

4 Discussion

4.1 Wongawilli West

4.1.1 Aquatic Habitat

The reaches of Wallandoola Creek and Lizard Creek within the Wongawilli West Study Area have clearly been degraded by previous underground mining operations. Numerous fractures are evident in the sandstone rock bars within these creeks. In Lizard Creek, the fractures appear to have led to sub-surface flow diversion and drainage of pools. There are also high levels of iron staining and associated bacterially-mediated iron flocculant and matting within these creeks. This is most likely due to dissolution into the surface water of iron sulphides and iron oxy-hydroxides exposed by fracturing of the bedrock. The iron floc is likely to have smothered the surfaces of aquatic macrophytes, snags, boulders and bank edge and in so doing reduced the amount of aquatic habitat suitable for occupation by aquatic organisms. Despite this, a variety of different aquatic habitats, including pools, overhanging vegetation, boulders, bedrock, sediment accumulations, submerged woody debris, aquatic macrophytes are still present. The occupation of these habitats by fish is limited by waterfalls in the downstream reaches of both creeks that are significant barriers to fish passage.

4.1.2 Water Quality

Although the water quality parameters measured during the surveys often deviated from the ANZECC/ARMCANZ (2000) guidelines, there was no evidence to suggest that the overall quality of the water at the ‘potential impact’ sites in Wallandoola and Lizard Creek was poorer than that at the ‘control’ sites. Table 1, in fact, shows that on some occasions (e.g. May 2009) the number of water quality parameters outside the accepted guidelines was similar at the ‘control’ and ‘potential impact’ sites, but on others (e.g. September 2010 and September 2011) the water quality was better at the ‘potential impact’ sites. The deviations in some of the individual water quality parameters were consistent, with dissolved oxygen, a major factor influencing aquatic biota, generally being below the lower DTV in all four watercourses. pH levels were more frequently below the lower DTV at the ‘control sites’ than at the ‘potential impact’ sites. The electrical conductivity of the water in one of the ‘control’ creeks (Cascade) also differed from that in the other watercourses in generally being in excess rather than within the accepted guidelines.

4.1.3 Aquatic Macroinvertebrates

The “health” of the macroinvertebrate fauna at the majority of monitoring sites was not consistent across either the spring or autumn surveys. During the spring surveys, the changes in condition of the fauna, as indicated by differences in AUSRIVAS banding, was generally greater at the 'potential impact' sites than at the 'control' sites. During the autumn surveys, two of the 'potential impact' sites on Lizard Creek showed smaller changes in "health" than the other 'potential impact' and 'control sites'. The amount of change in AUSRIVAS bands observed at some of the monitoring sites is of concern (e.g. X to B or A to C or D), because it indicates the composition of the macroinvertebrate fauna is naturally highly variable. This implies that AUSRIVAS bands, and the OE50 taxa scores from which they are derived, may not be effective indicators of any impacts on aquatic macroinvertebrates associated with the proposed mining activities. The variability in these indicators may be due to differences in reproduction and development of the aquatic macroinvertebrate fauna towards the beginning, middle or end of the spring survey period (September to December) and the lack of a temporally consistent sampling regime. This potential source of variability could be reduced by restricting the timing of monitoring (e.g. to a three week period in the middle of the AUSRIVAS sampling periods). It should, of course, be noted that some flexibility in the monitoring program is needed to cope with the variability in rainfall and flows.

The SIGNAL2 scores from the spring surveys indicated the fauna at the 'potential impact' sites on Wallandoola Creek and Lizard Creek was more degraded than that at the 'control sites' in Loddon Creek, but not necessarily those in Cascade Creek. A similar trend was evident in the SIGNAL2 scores from the autumn surveys. The SIGNAL2 scores were less variable than the AUSRIVAS bands, particularly in autumn, and could therefore be a better indicator of changes in the macroinvertebrate fauna associated with mine-induced subsidence. However, as these scores are based primarily on the sensitivity of individual taxa to pollution, it is not clear whether they will respond to changes in aquatic habitats arising from the impact of subsidence on physical features.

4.1.4 Fish

The limited sampling and observations made during the baseline monitoring program suggest that the fish fauna in the watercourses above the proposed longwalls is depauperate. No fish species were observed at the 'potential impact' sites in Wallandoola Creek and only two species were found at those in Lizard Creek. The 'control sites' also appeared to be depauperate with only one and three species being recorded in Cascade Creek and Loddon Creek, respectively. The paucity of fish species is most likely due to the presence of barriers to fish passage in the form of waterfalls downstream of the study sites. The difference in results from the baseline monitoring and backpack electrofishing surveys in Wongawilli East suggest that use of a more effective sampling technique may result in the capture of other species.

4.2 Wongawilli East

4.2.1 Aquatic Habitat

There is also evidence of habitat degradation within the Wongawilli East Study Area, with iron staining and floc being present in both Cataract Creek and Cataract River.

4.2.2 Water Quality

There was no evidence to suggest that the overall quality of the water at the 'potential impact' sites on Cataract Creek was poorer than that at the 'control' sites. Table 2, in fact, shows that on some occasions (e.g. May 2009) the number of water quality parameters outside the accepted guidelines was similar at the 'control' and 'potential impact' sites, but on others (e.g. March 2009, November 20009 and September 2010) the water quality was better at the 'potential impact' sites. Dissolved oxygen was the parameter that showed the most frequent deviation from the accepted guidelines, with values generally being below the lower DTV at the 'potential impact' sites on Cataract Creek and the 'control' sites on Cataract River and also frequently at the 'control' sites in Allens Creek. The overall water quality was generally better than in the Wongawilli East Study Area.

4.2.3 Aquatic Macroinvertebrates

The "health" of the macroinvertebrate fauna at the monitoring sites was not consistent across either the spring or autumn surveys. During the spring surveys, the changes in condition of the fauna, as indicated by differences in AUSRIVAS banding, was generally greater at the 'control' sites on Cataract River than at the 'potential impact sites on Cataract Creek and 'control' sites on Allens Creek. During the autumn surveys, one of the 'potential impact' sites on Cataract Creek and one of the 'control sites' on Cataract River showed larger changes in "health" than the other monitoring sites. The amount of change in AUSRIVAS bands observed at the more variable sites was in the same order as that observed in the Wongawilli West Study Area (i.e. X to B or A to C). The less variable nature of the monitoring sites in this Study Area suggests that AUSRIVAS bands, and the OE50 taxa scores from which they are derived, may be more effective indicators of impacts on aquatic macroinvertebrates associated with extraction of the Wongawilli East longwalls.

The SIGNAL2 scores from both the spring and autumn surveys indicated the fauna at the 'potential impact' sites on Cataract Creek was generally in a similar state to that at the 'control sites' on Cataract River and Allens Creek. The SIGNAL2 scores were less variable than the AUSRIVAS bands, as was the case in the Wongawilli West Study Area, suggesting that it might potentially be a better indicator of changes in the macroinvertebrate fauna associated with mine-induced subsidence.

One of the supposed advantages associated with the use of artificial collectors is that they provide a standard habitat for macroinvertebrates to colonise and result in data that exhibit less variability between samples (greater precision) and sites than fauna associated with natural substrata. The current study, however, has shown that statistically significant differences in the structure of the assemblages, total numbers of taxa and macroinvertebrates were more common between paired sites than among watercourses in Wongawilli East. This small-scale spatial variability is likely to hinder our ability to detect any impacts associated with extraction of the proposed longwalls.

4.2.4 Fish

The limited sampling and observations made during the baseline monitoring program suggest that the fish fauna in the watercourses in the Wongawilli East Study Area is also depauperate. No fish species were observed at the ‘control’ sites in Allens Creek and only two species were found in Cataract Creek and Cataract River.

The backpack electrofishing survey undertaken on Cataract Creek between its confluence with Cataract River and Site 6, however, indicates that at least seven species are present. Three of the species caught, Macquarie Perch, Freshwater Cod (identification not confirmed could be Trout Cod, Murray Cod or a hybrid between the two species) (Gehrke & Harris 1996, Douglas *et al.* 1994) and Silver Perch are threatened species listed under State and/or Federal legislation. It should be noted that the Study Area is outside the natural distribution range of the latter species and that their presence is most likely due to upstream migration of individuals that have been translocated to Cataract Dam. The translocated populations of Trout Cod that exist in NSW are generally maintained by the release of hatchery-bred fish, however, that in Cataract Dam is known to be self-sustaining (NSW DPI 2006). Stocking of impoundments with hatchery-reared silver perch has generally not resulted in self-reproducing populations, so this species is still considered under threat in the wild. The translocated population that is present, in Cataract Dam, however, is known to be self-sustaining (Fisheries Scientific Committee 1999). Macquarie Perch are known to occur within the Cataract River between Broughtons Pass Weir and the Cataract Dam, but have also been translocated from the Murray River to Cataract Dam (Lintermans 2006). It is therefore not known whether the fish caught are part of a natural or translocated population. The targeted surveys indicate this species moves upstream as the summer season progresses, with individuals extending as far up as the rock bar below Site 6, which is situated above proposed Longwalls 7 and 8. The larger numbers of Macquarie Perch caught during the 2010/2011 summer may be related to the supply level extending further up the creek than the previous year (Appendix1). Freshwater Cod and Silver Perch were also present throughout the reach of the creek electro-fished.

Assessments of the impact of the proposed mining on the threatened species will need to be prepared and included within the Subsidence Management Plan (SMP). If there is evidence that the proposed mining work is likely to have a significant impact on this species or scientific uncertainty about the potential for impacts, a referral will need to be submitted to the Federal Department of Environment and Heritage for a decision as to whether assessment and approval is needed under the *EPBC Act.*

4.3 Conclusion

During the baseline monitoring, three major issues relating to aquatic ecology that require consideration as part of the Part 3A approval process for the Wongawilli East and Wongawilli West mining areas have been identified. These are:

1. The occurrence of threatened fish species, particularly Macquarie Perch, within or adjacent to the Wongawilli East mine area;
2. The existence of prior mine subsidence related impacts in the form of rockbar fractures and iron staining within the watercourses overlying the Wongawilli West mine area;
3. The variability in the “health’ of the aquatic macroinvertebrate fauna which suggests that AUSRIVAS indices may not be an effective indicator of impacts associated with mining.

5 Recommendations

1. Further aquatic ecology monitoring should be conducted during and after the extraction of the longwalls within Wongawilli West and Wongawilli East using the same survey sites and methods as in this study. This will provide best practice environmental monitoring of aquatic ecology and will allow statistically powerful tests of the effects of any impacts on aquatic habitats and biota arising from mine subsidence. This monitoring plan conforms to the recommendations made by the NSW Department of Planning's 'Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield' (NSW DoP, 2008).

2. In view of the apparent variability in the 'health" of the aquatic macroinvertebrate fauna, it is recommended that SIGNAL2 scores continue to be calculated in addition to AUSRIVAS indices.

3. Further attempt should be made to identify the freshwater cod caught during the 2011/2012 summer season. The retention of some specimens for screening of otoliths for hatchery chemical batch marks could facilitate this process.

4. The position and extent (i.e. length and width) of existing rockbar fractures within the watercourses overlying the proposed mine area should be recorded prior to the extraction of coal from the Wongawilli East and Wongawilli West Longwalls. This will enable future fractures in the bedrock due to subsidence resulting from extraction of the proposed longwalls, if any, to be distinguished from past fractures and the effects of additional mining on existing fractures and their consequences for aquatic ecology to be assessed.

5. Iron staining can lead to the proliferation of iron-oxidising bacteria that can smother the surface of aquatic macrophytes, snags, boulders and bank edge and thereby reduce the amount of habitat suitable for occupation by aquatic organisms. In view of this, it is recommended that the occurrence and extent of iron stains be monitored regularly in areas expected to undergo subsidence. This should be done before, during and after mining of the longwalls. The observation of a sudden marked increase in the extent of iron staining should trigger an assessment of impacts on aquatic habitats and biota.

6 Acknowledgements

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7 References

Anderson, M.J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology* **26**, 32-46.

Anderson, M.J., Gorley, R.N. and Clarke, K.R. (2008). PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. Primer-E, Plymouth.

ANZECC (2000). *Australian and New Zealand Guidelines for Fresh and Marine Waters.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Australian Water Technologies (2001). *Investigation of dirty water at Broughtons Pass*.

Bioanalysis (2009). *Illawarra Coal – Bulli Seam Operations – Aquatic Ecology Assessment*. Report prepared for Illawarra Coal Holdings Pty Ltd.

Cairns, J. Jr. and Pratt. J. R. (1993). *Freshwater Biomonitoring and Benthic Macroinvertebrates.* Chapman and Hall: New York, pp. 10-27.

Chessman, B. C. (1995). Rapid assessment of rivers using macroinvertebrates: A procedure based on habit-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology*, 20: pp. 122-129.

Chessman, B. C., Growns, J. E. and Kotlash, A. R. (1997). Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL biotic index: Application to the Hunter River system, New South Wales. *Marine & Freshwater Research* 48, pp. 159-172.

Chessman, B.C. 2003, New sensitivity grades for Australian river macroinvertebrates. *Marine and Freshwater Research*, 54, pp. 95-103.

Clarke K. R. (1993). Non-parametric multivariate analyses of changes in assemblage structure. *Australian Journal of Ecology,* 18: pp. 117-143.

Clarke K.R. and Gorley R.N. (2006). *Primer V6: User Manual/Tutorial.* Primer-E, Plymouth.

Coysh, J., Nichols, S. Ransom, G., Simpson, J., Norris, R., Barmuta, L. and Chessman, B. (2000). *AUSRIVAS Macroinvertebrate Bioassessment Predictive Modelling Manual.*

Czerniawska-Kusza, I. (2004). Use of Artificial Substrates for Sampling Benthic Macroinvertebrates in the Assessment of Water Quality of Large Lowland Rivers. *Polish Journal of Environmental Studies* **13**, 579-584.

DECC (2007) *Audit of the Sydney Drinking Water Catchment 2007*. Department of Environment and Climate Change NSW.

Douglas, J. W., Gooley, G. J. & Ingram, B. A., (1994). Trout Cod, *Maccullochella macquariensis* (Cuvier) (Pisces: Percichthyidae), Resource Handbook and Research and Recovery Plan. DCNR, Victoria.

ECOWISE (2005). *SCA Macroinvertebrate Monitoring Program 2004: Final Report.* Prepared for Sydney Catchment Authority.

ERM (2008). *V Mains Surface Water Monitoring Baseline Data.*

Fisheries Scientific Committee (1999). Ref. No. FR8 File No. FSC 99/21. Recommendation *Bidyanus bidyanus* – Silver perch. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/208251/FR8-silver-perch.pdf

Gehrke, P.C. and Harris, J.H. (1996). Fish *and fisheries of the Hawkesbury-Nepean river system: Final report to the Sydney Water Corporation.* Prepared by NSW Fisheries Research Institute and cooperative Research Centre for Freshwater Ecology.

Geoterra (2002). *Lizard Creek and Wallandoola Creek Baseline Assessment*.

Geoterra (2009). *Gujarat NRE No.1 Colliery. V-Mains Surface Water and Groundwater Assessment, Bellambi, NSW.* Draft report prepared for Gujarat NRE No. 1 Colliery.

Growns, J.E., Chessman, B.C., Jackson, J.E. and Ross, D.G. (1997). Rapid assessment of Australian rivers using macroinvertebrates: cost and efficiency of 6 methods of sample processing. *Journal of the North American Benthological Society* 16: pp.682-693.

Hellawell, J. (1978). *Macroinvertebrates methods, in Biological surveillance of Rivers. A Biological Monitoring Handbook*, J. Hellawell, Editor. Dorset Press: Dorchester, England. pp. 35-90.

Lintermans, M. (2006). Threatened fish in mountain streams: out of sight, out of mind. In: *Proceedings of the NPA ACT Symposium: Caring for Namadgi: Science and People: Canberra, 5-7 May 2006.* Woden: National Parks Association of the ACT Inc.

NSW Department of Planning (2008). *Impacts of underground coal mining on natural features in the Southern Coalfield: strategic review.* http://www.planning.nsw.gov.au/planningsystem/pdf/report_southern_coalfields_final_jul08.pdf Accessed 30 June 2009.

NSW DPI (2005a). Profile for species, populations and ecological communities. Adam's Emerald Dragonfly. http://pas.dpi.nsw.gov.au/Species/Species_Profile.aspx?SpeciesListingID=10

NSW DPI (2005b). Profile for species, populations and ecological communities. Sydney Hawk Dragonfly. http://pas.dpi.nsw.gov.au/Species/Species_Profile.aspx?SpeciesListingID=9

NSW DPI (2006). Trout cod (*Maccullochella macquariensis*) recovery plan.

Rosenberg, D. M. and Resh, V. H. (1982). The use of artificial substrates in the study of freshwater benthic macroinvertebrates. In Cairns J. Jr. (ed) *Artificial Substrates*, Ann Arbor Science Publishers. pp175-236.

Seedsman Geotechnics Pty Ltd (2001). *300s Panels Impact on Surface Features.*

Sydney Catchment Authority (2008). *Sydney Catchment Authority Annual Water Quality Monitoring Report 2007-2008.*

The Ecology Lab (2003). *Upper Nepean Bulk Water Transfers, Environmental Assessment of Aquatic Ecology.* Report prepared for Sydney Catchment Authority.

The Ecology Lab (2005). *Appin Area 3 – Effects of Mine Subsidence on Aquatic Habitat and Biota.* Report prepared for BHP Billiton Illawarra Coal.

The Ecology Lab (2007). *NRE No. 1 Mine – V Mains Aquatic Ecology Baseline Monitoring Program June-August 2007 Survey Baseline Progress Report 1.* Prepared for ERM Australia.

The Ecology Lab (2008). *NRE No. 1 Mine – V Mains Aquatic Ecology Baseline Monitoring Program Baseline Report. Report* prepared for ERM Australia.

Turak, E., Waddell, N. and Johnstone, G. (2004). *New South Wales (NSW) Australian River Assessment System (AusRivAS) Sampling and Processing Manual.* Department of Environment and Conservation (NSW).

Underwood, A. J. (1991). Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine & Freshwater Research* 42, pp. 569-587.

Underwood, A. J. (1992). Beyond BACI - the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology* 161, pp. 145-178.

Underwood, A. J. (1994). On beyond BACI - sampling designs that might reliably detect environmental disturbances. *Ecological Applications* 4, pp. 3-15.

8 Tables

Table 1: Comparison of water quality data from the monitoring sites in the Wongawilli West Study Area in relation to ANZECC guidelines for slightly distrubed upland streams in south-east Australia. (= within guidelines; > above; < below; ND = no data. See Appendix 2 for complete data.

		Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
Survey/Parameter		1	2	3	4	17	11	12	15	16
Oct-08										
Conductivity	30-350 uS/cm	=	=	=	=	ND	=	=	ND	ND
pH	6.5-8.0	=	=	=	=	ND	<	<	ND	ND
DO saturation	90-110%	<	<	<	<	ND	<	<	ND	ND
Turbidity	2-25 NTU	=	=	=	=	ND	=	=	ND	ND
Dec-08										
Conductivity		ND	ND	ND	ND	ND	ND	ND	ND	ND
pH		=	=	<	=	ND	<	<	ND	ND
DO sat.		<	<	<	<	ND	<	<	ND	ND
Turbidity		<	=	<	=	ND	<	<	ND	ND
Mar-09										
Conductivity		=	=	ND	=	=	<	<	>	>
pH		ND	ND	ND	ND	ND	<	<	ND	ND
DO sat.		<	=	ND	<	<	<	<	<	<
Turbidity		ND	ND	ND	>	>	ND	ND	=	=
May-09										
Conductivity		=	=	=	=	=	=	=	>	>
pH		<	=	<	=	=	<	<	<	<
DO sat.		>	>	<	=	>	>	>	<	<
Turbidity		<	ND	=	=	ND	ND	ND	=	=
Nov-09										
Conductivity		=	=	ND	=	=	=	=	>	>
pH		<	<	ND	<	=	<	=	<	<
DO sat.		=	<	ND	<	<	=	<	<	<
Turbidity		=	<	ND	=	>	<	<	<	<
Mar-10										
Conductivity		=	=	ND	=	=	=	=	>	>
pH		<	=	ND	<	=	<	<	<	<
DO sat.		<	<	ND	<	<	<	<	<	<
Turbidity		=	<	ND	<	<	=	<	=	<
Sep-10										
Conductivity		=	=	<	<	=	=	=	>	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	<	<	<	<	>	=	<	<
Turbidity		=	=	=	=	=	<	<	=	=
Apr-11										
Conductivity		=	=	=	=	=	=	=	=	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	=	<	<	<	<	=	<	<
Turbidity		=	=	<	=	<	=	<	=	=
Sep-11										
Conductivity		=	=	=	=	=	=	=	=	>
pH		<	<	<	<	<	<	<	<	<
DO sat.		<	<	<	<	<	<	<	<	<
Turbidity		<	=	<	=	=	<	=	=	=

Table 2: Summary of water quality data for Wongawilli East and Control sites in relation to ANZECC guidelines for upland streams in NSW. = within guidelines; > above; < below; ND = no data. See Appendix 3 for complete data.

		Wongawilli East		Controls			
Survey/Parameter		5	6	9	10	13	14
Oct-08							
Conductivity	30-350 uS/cm	=	=	=	=	ND	ND
pH	6.5-8.0	=	=	=	=	ND	ND
DO saturation	90-110%	<	<	<	<	ND	ND
Turbidity	2-25 NTU	=	=	=	=	ND	ND
Dec-08							
Conductivity		ND	ND	ND	ND	ND	ND
pH		=	=	=	=	ND	ND
DO sat.		<	<	<	<	ND	ND
Turbidity		=	=	=	=	ND	ND
Mar-09							
Conductivity		<	=	=	<	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	<	<	<
Turbidity		=	=	=	=	<	<
May-09							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	<	<	<
Turbidity		<	<	<	<	<	<
Nov-09							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		=	>	<	<	<	>
Turbidity		=	>	<	<	<	>
Mar-10							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	=	=
DO sat.		<	<	<	=	<	=
Turbidity		=	=	>	=	=	=
Sep-10							
Conductivity		=	=	=	=	=	=
pH		=	<	=	=	<	<
DO sat.		<	<	<	<	=	<
Turbidity		=	=	=	=	<	=
Apr-11							
Conductivity		=	=	=	=	=	=
pH		=	<	=	=	<	=
DO sat.		=	<	<	<	=	=
Turbidity		>	=	=	=	=	=
Sep-11							
Conductivity		=	=	=	=	=	=
pH		=	=	=	=	<	<
DO sat.		<	<	<	<	<	<
Turbidity		<	=	=	=	=	=

Table 3: Summary of the results of PERMANOVA tests based on aquatic macroinvertebrate assemblages, total number of taxa and macroinvertebrates found on collectors retrieved from monitoring sites in (a) Wongawilli West and (b) Wongawilli East Study Areas.

(a) Wongawilli West

Survey	Indicator	Source of Variation	
		Location	Sites(location)
Autumn 2009	Assemblage	ns	**
	No. of taxa	ns	***
	No. of macroinvertebrates	ns	***

b) Wongawilli East

Survey	Indicator	Source of Variation	
		Location	Sites(location)
Autumn 2009	Assemblage	ns	***
	No. of taxa	*	ns
	No. of macroinvertebrates	ns	*
Spring 2009	Assemblage	ns	***
	No. of taxa	*	ns
	No. of macroinvertebrates	ns	ns
Autumn 2010	Assemblage	**	**
	No. of taxa	ns	**
	No. of macroinvertebrates	ns	***

Table 4: Fish sampled with a backpack electrofishing unit in Cataract Creek from 25-26 November, 2008. * indicates exotic species (introduced from outside Australia).

Location	Murray/Trout Cod *(Maccullochella peelii peelii / macquariensis)*	Macquarie Perch *(Macquaria australasica)*	Climbing Galaxias *(Galaxias brevipinnis)*	Longfinned Eel *(Anguilla reinhardtii)*	Mosquito Fish* *(Gambusia holbrooki)*	Goldfish* *(Carassius auratus)*
Cataract Creek						
Within current supply level	4	2	-	-	> 1000	>500
Inflow of creek	-	3	1	-	-	20
Upstream of inflow	1	-	19	-	-	-
Upstream of maximum supply level	-	-	13	1	-	-

Table 5: Numbers of each species of fish caught during the targeted surveys for Macquarie Perch undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.

A. Summer 2009/2010

Common Name	Scientific Name	Survey Date			
		15/12/2009	8/01/2010	29/01/2010	25/02/2010
Macquarie Perch	*Macquaria australasica*	3	6	6	15
Freshwater Cod	*Maccullochella* sp.	5	2	5	53
Silver Perch	*Bidyanus bidyanus*	0	0	0	9
Goldfish	*Carrassius auratus*	93	27	11	8
Eastern Gambusia	*Gambusia holbrooki*	>1000	>1000	>1000	>1000
Mountain Galaxias	*Galaxias olidus*	49	19	4	56

B. Summer 2010/2011

Common Name	Scientific Name	Survey Date			
		8/12/2010	7/01/2011	25/01/2011	21/02/2011
Macquarie Perch	*Macquaria australasica*	11	14	37	28
Freshwater Cod	*Maccullochella* sp.	5	8	18	22
Silver Perch	*Bidyanus bidyanus*	0	0	5	4
Goldfish	*Carrassius auratus*	1	0	0	12
Gambusia	*Gambusia holbrooki*	193	42	189	>500
Mountain Galaxias	*Galaxias olidus*	249	34	82	57
Short-finned Eel	*Anguilla australis*	0	2	1	0

Table 6: Species of fish and large crustaceans observed at the monitoring sites in the Wonga West and Wonga East Study Areas (* = introduced species, X = present)

Common name	Scientific name	Creek	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck		Cataract Ck		Cataract River		Allens Ck	
		Site	1	2	3	4	17	11	12	15	16	5	6	9	10	13	14
FISH																	
Mosquito fish*	*Gambusia holbrooki*								X			X					
Climbing galaxias	*Galaxias brevipinnis*					X		X	X			X		X			
Smelt	*Retropinna semoni*					X	X		X	X					X		
CRUSTACEANS																	
Freshwater crayfish	*Euastacus* sp.		X	X		X		X	X			X	X	X	X	X	X

9 Figures

Figure 1: Map showing the position of aquatic ecology monitoring sites in relation to the proposed Wongawilli East and Wongawilli West Mine Areas.
Figure 2: Map showing the reach of Cataract Creek (blue dotted line) in which targeted Macquarie Perch surveys were undertaken.
Figure 3: Wongawilli West Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Wallandoola, Lizard, Loddon and Cascade Creeks in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.
Figure 4: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.
Figure 5: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.
Figure 6: Wongawilli East Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Cataract Creek, Cataract River and Allens Creek in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.
Figure 7: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.
Figure 8: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.
Figure 9: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from monitoring sites in the Wongawilli West Study Area in spring 2008.
Figure 10: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009.
Figure 11: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in autumn 2009.
Figure 12: MDS of macroinvertebrates assemblages found on collectors at the study sites on Wallandoola Creek, Lizard Creek, Loddon Creek and Cascade Creek in autumn 2009.
Figure 13: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008.
Figure 14: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008 and 2009.
Figure 15: Mean number of taxa and mean numbers of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009.
Figure 16: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009 and 2010.
Figure 17: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2009.
Figure 18: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2009.
Figure 19: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in spring 2009.
Figure 20: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2010.
Figure 21: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2010.

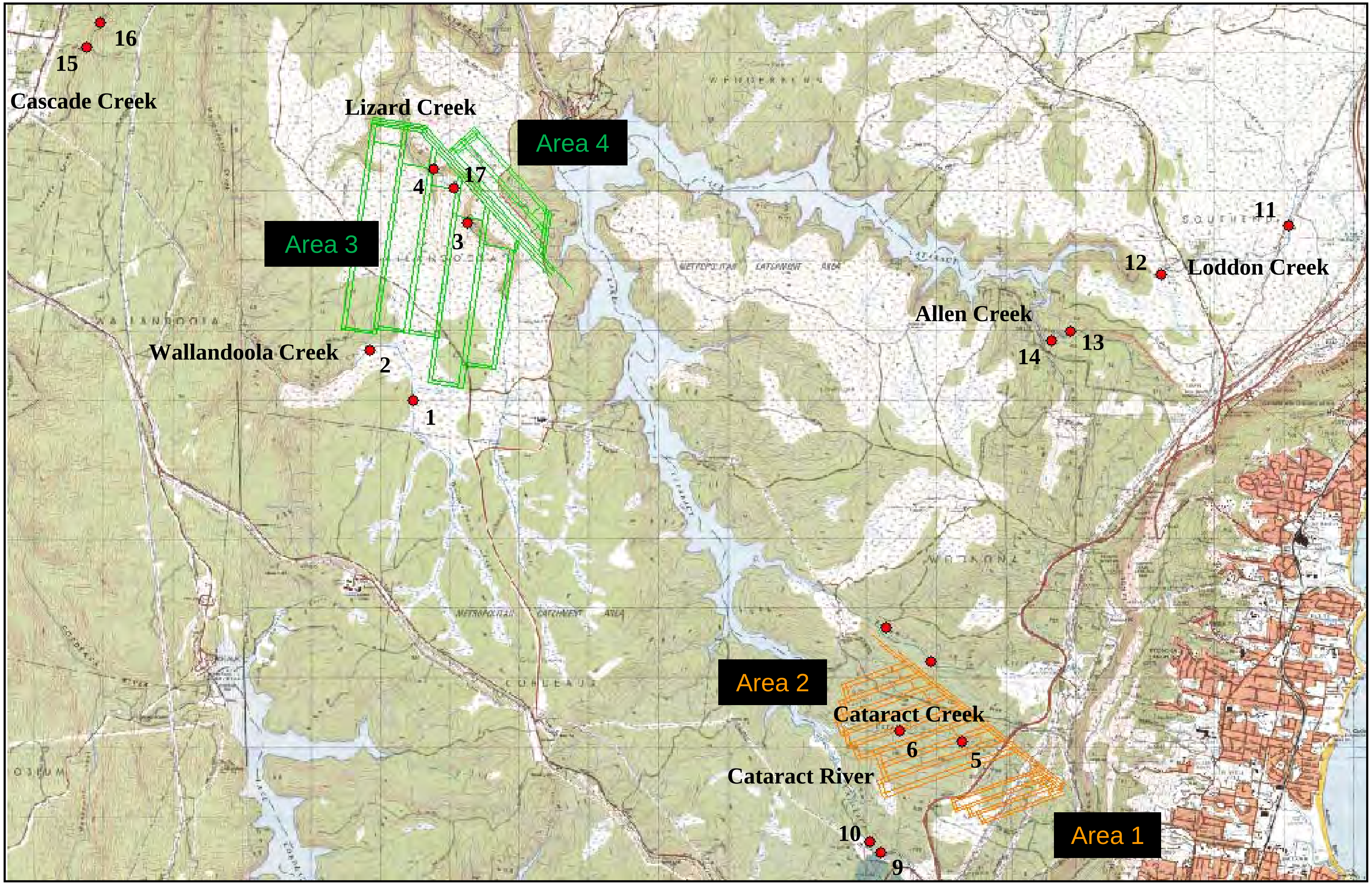


Figure 1: Map showing the position of aquatic ecology monitoring sites in relation to the Wongawilli East (orange lines) and Wongawilli West (green lines) Mine Areas.

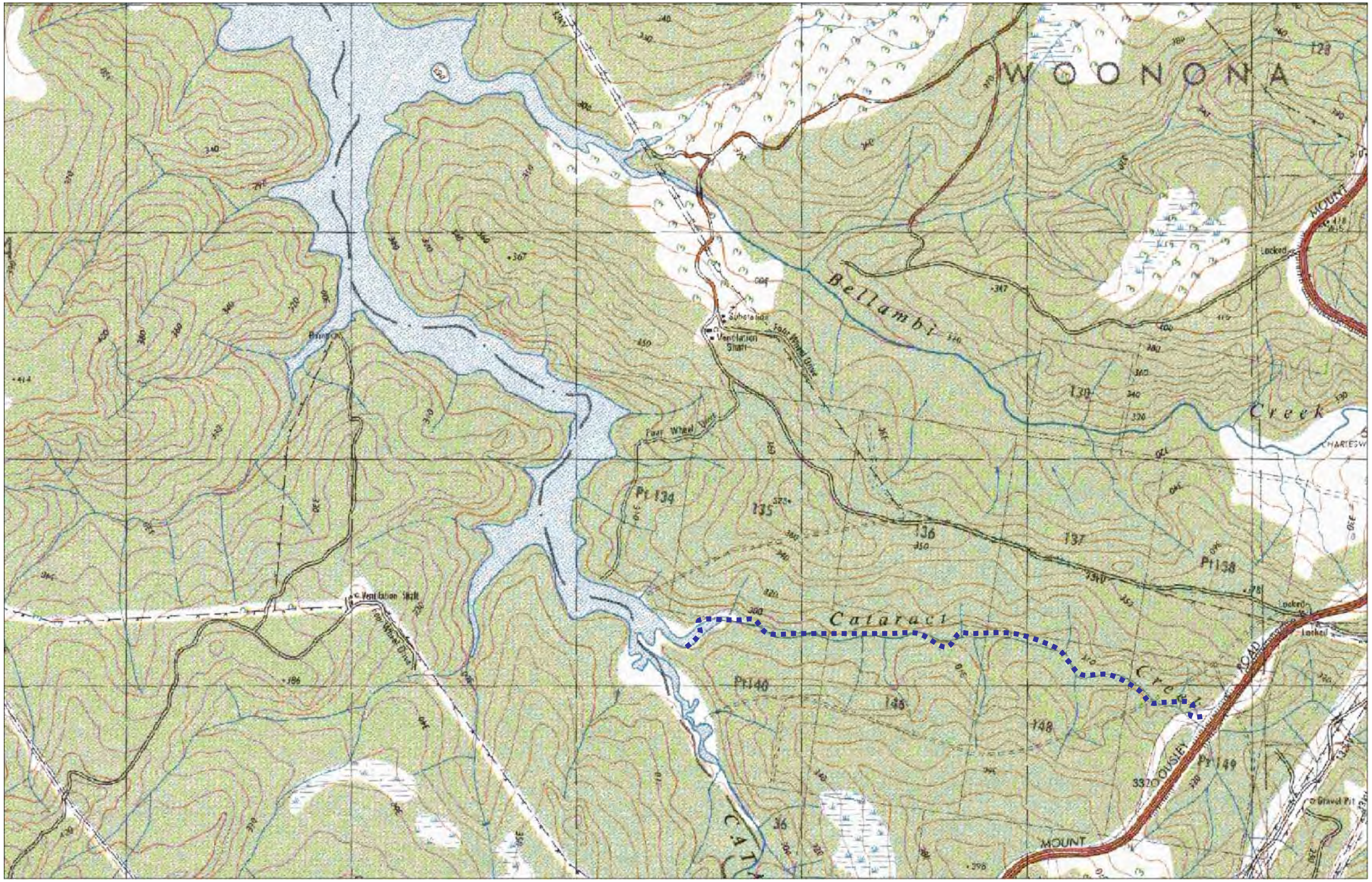


Figure 2: Map showing the reach of Cataract Creek (blue dotted line) in which targeted Macquarie Perch surveys were undertaken.

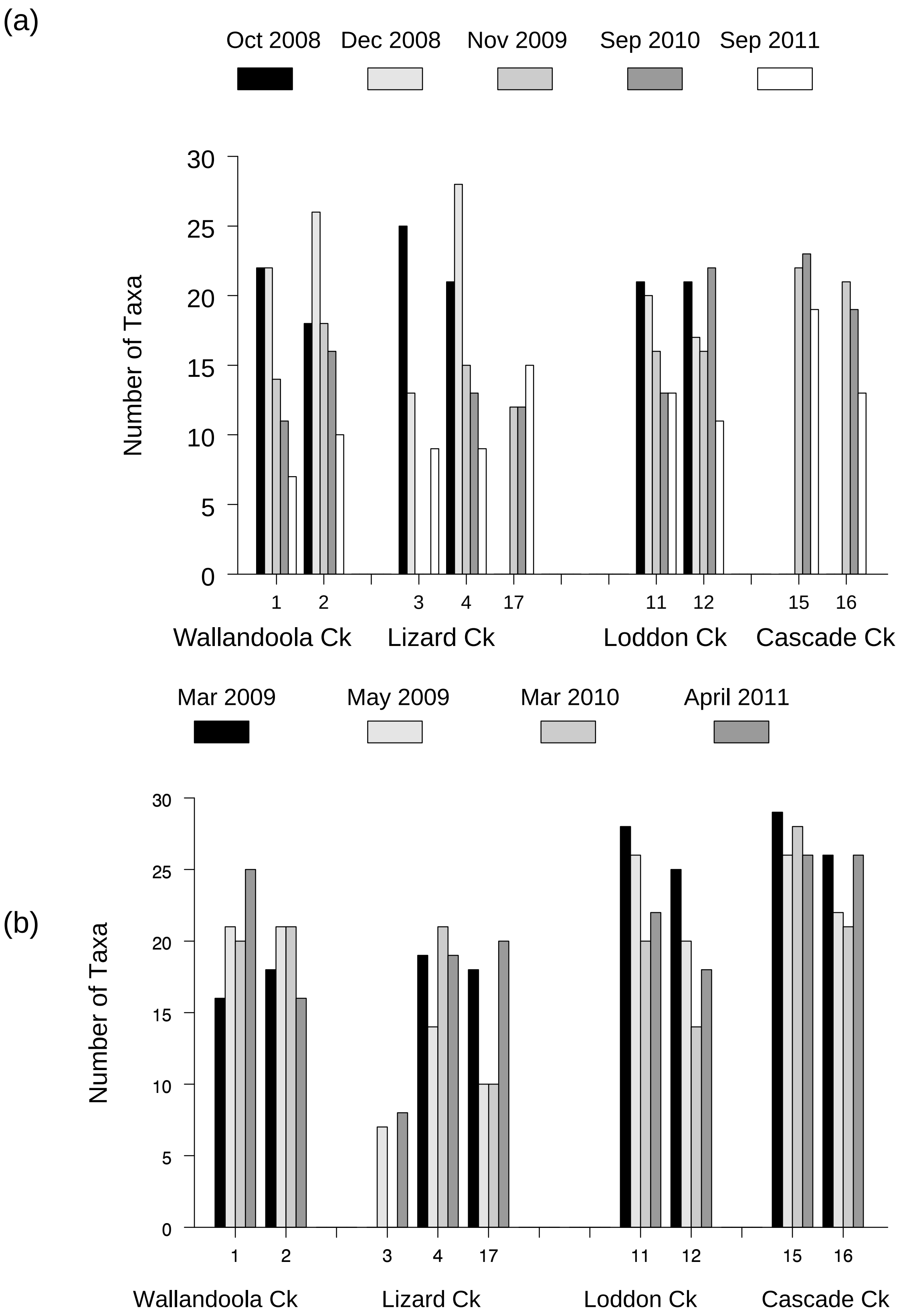


Figure 3: Wongawilli West Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Wallandoola, Lizard, Loddon and Cascade Creeks in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.

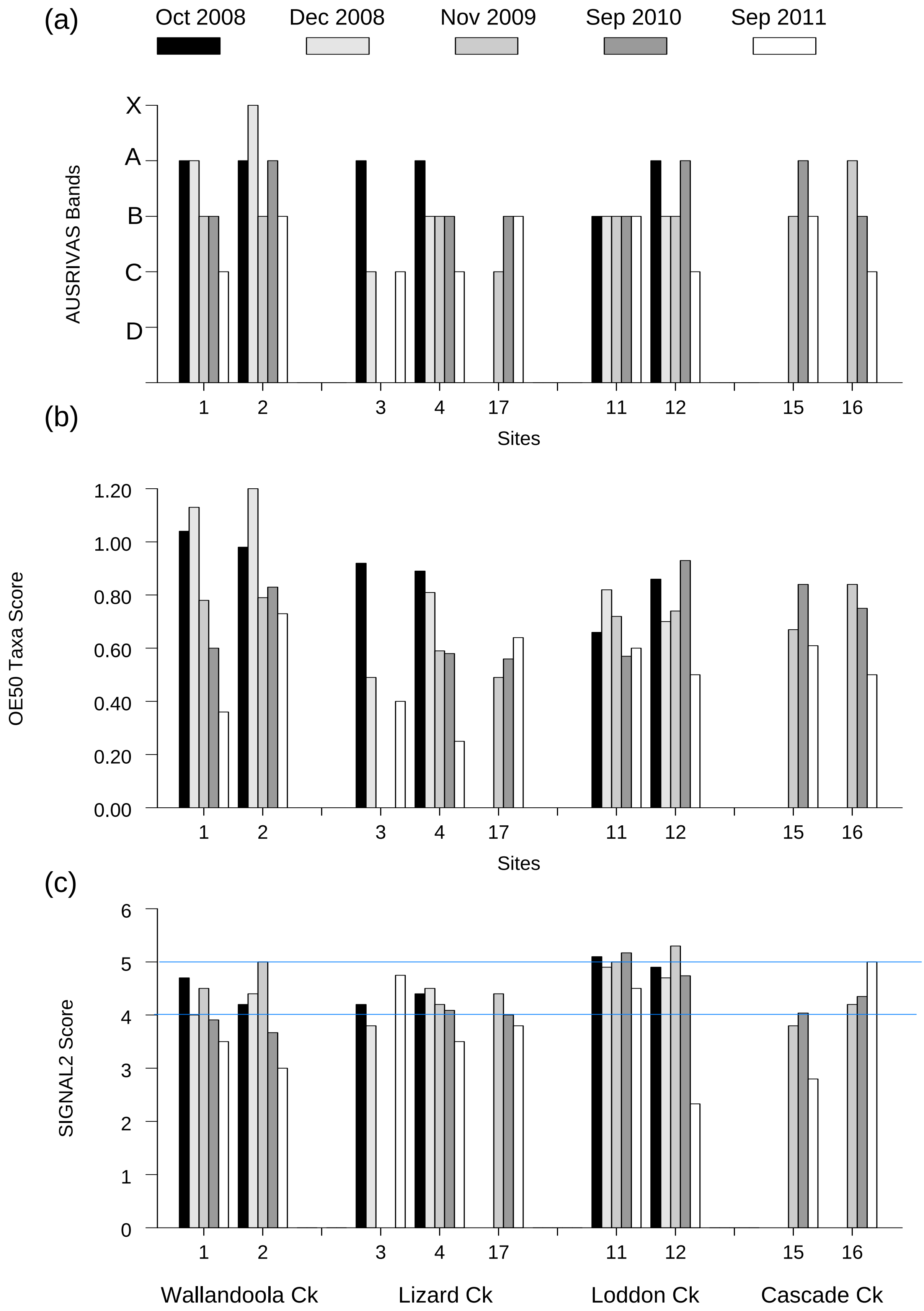


Figure 4: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.

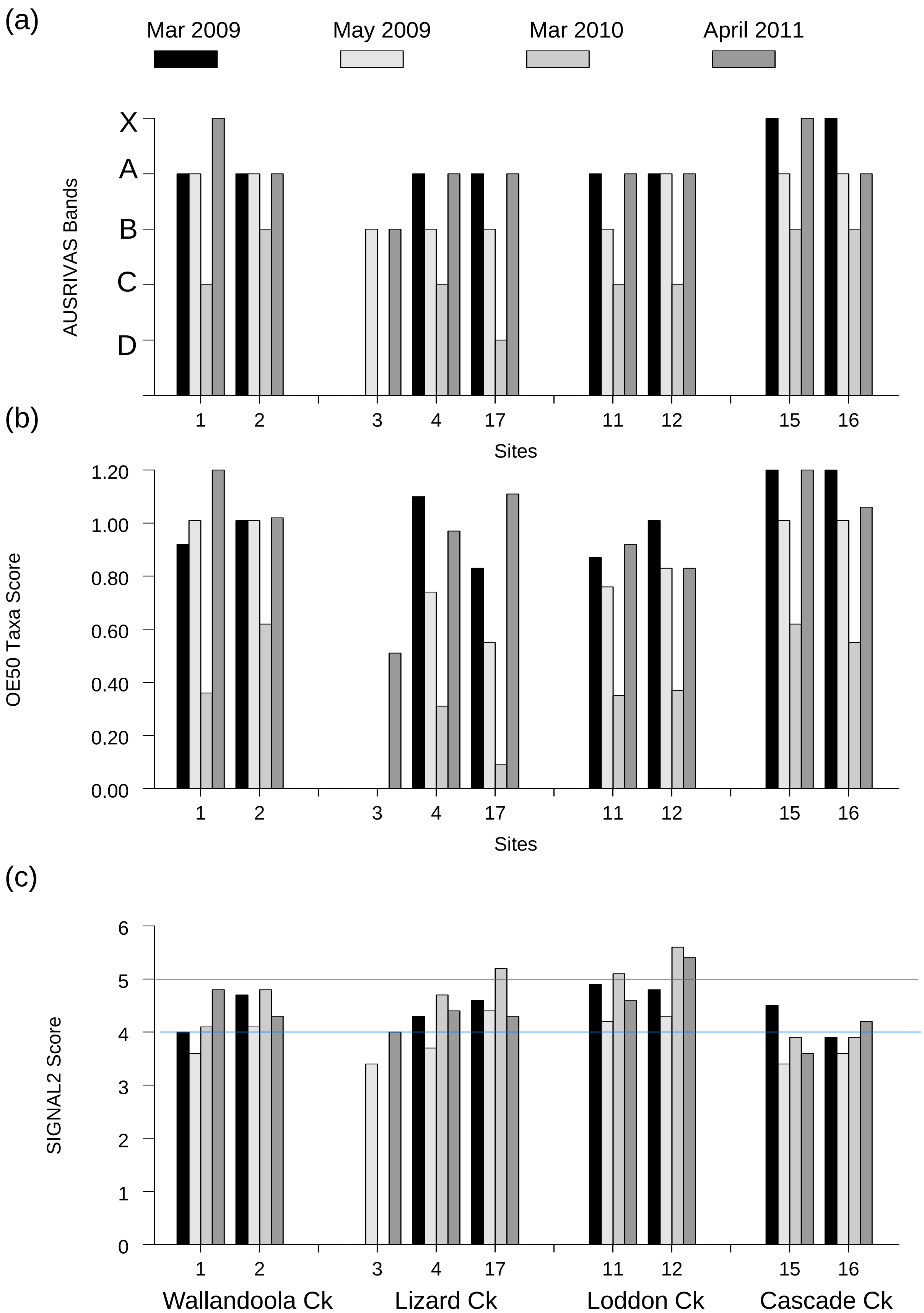
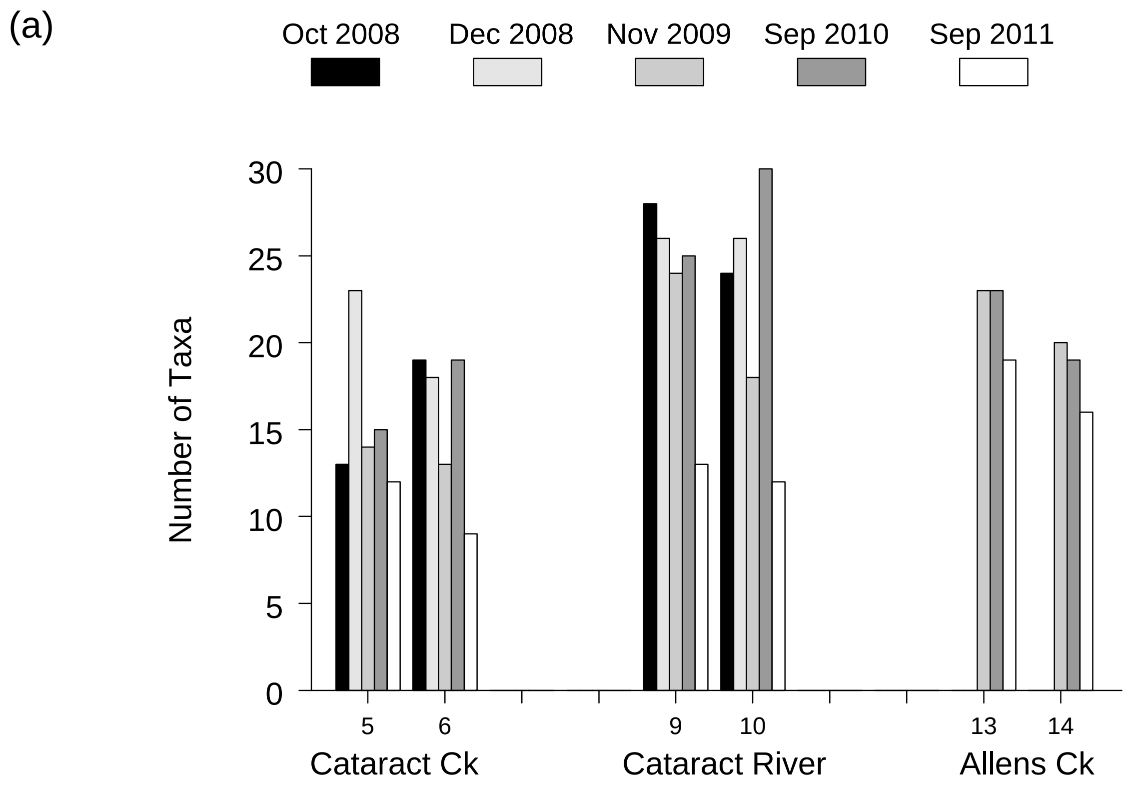


Figure 5: Wongawilli West Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.



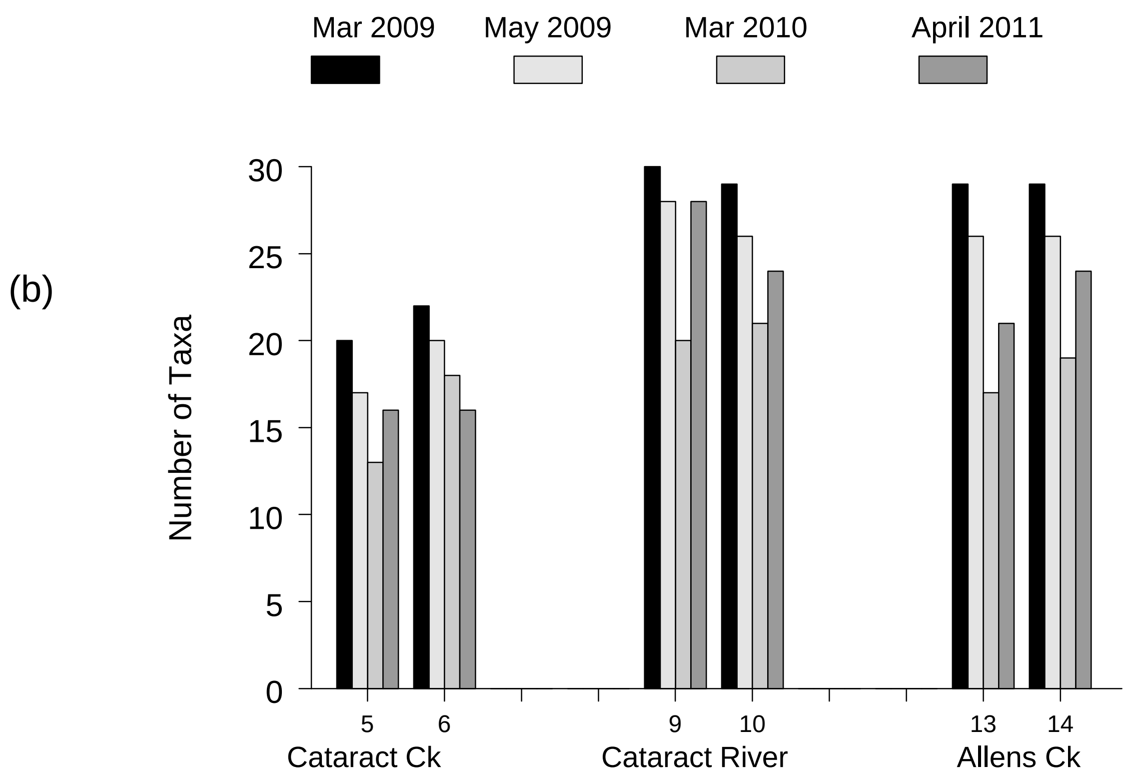


Figure 6: Wongawilli East Study Area – Number of taxa found in the AUSRIVAS samples collected at the monitoring sites in Cataract Creek, Cataract River and Allens Creek in (a) the spring 2008-2011 surveys and (b) autumn 2009-2011 surveys.

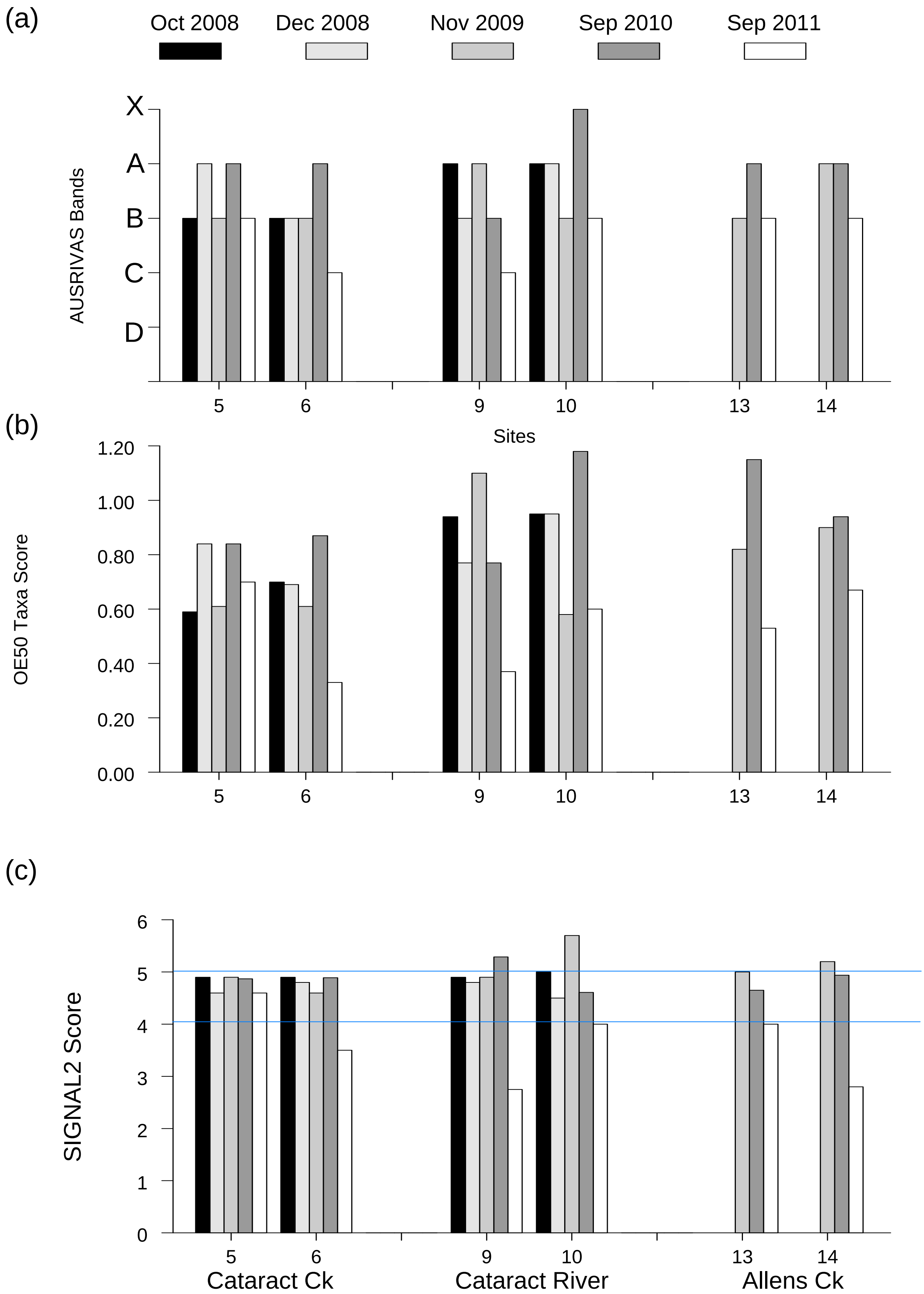


Figure 7: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the spring of 2008-2011.

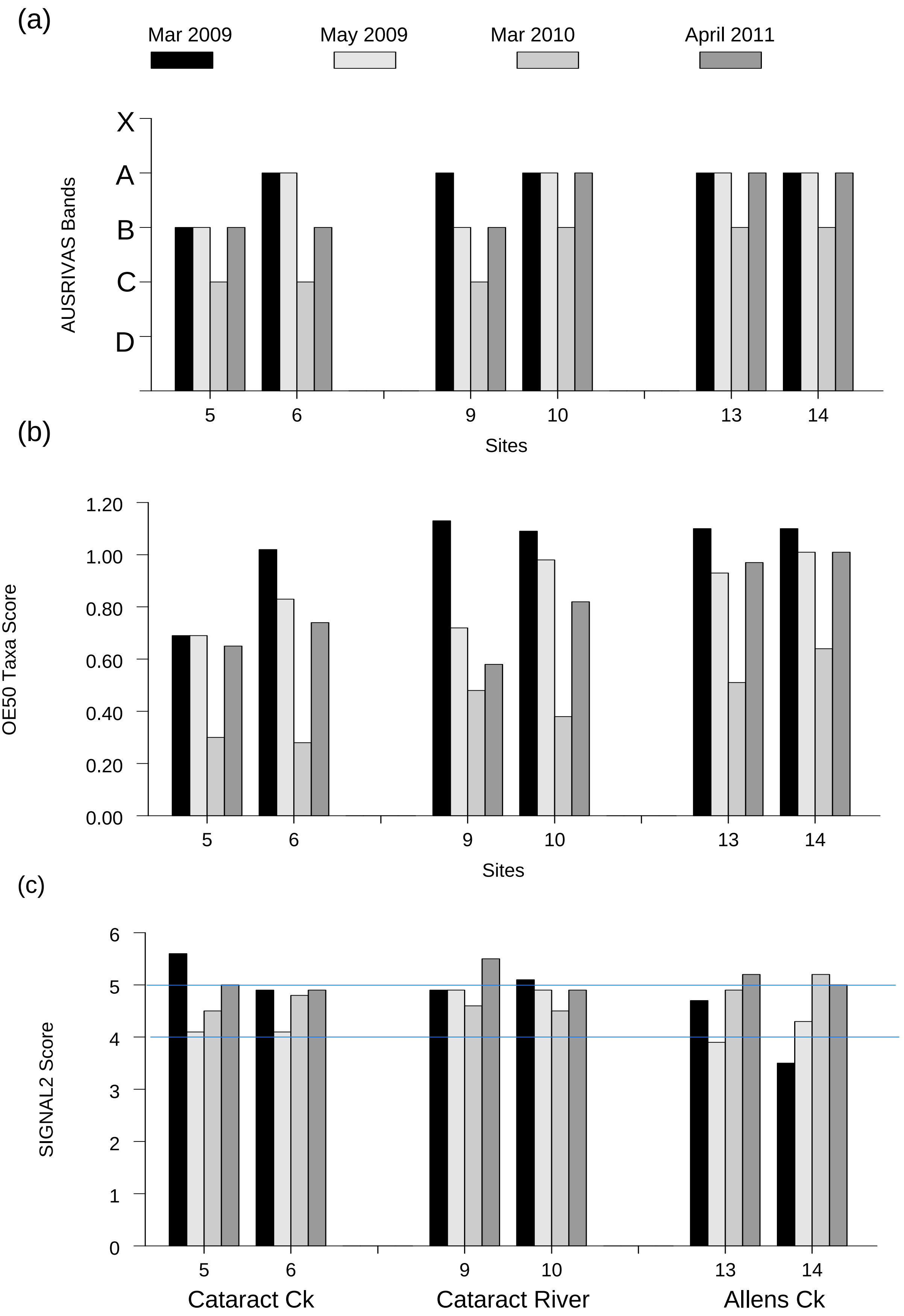


Figure 8: Wongawilli East Study Area – (a) AUSRIVAS Bands; (b) OE50 Taxa Score; (c) SIGNAL2 Scores for each site in the autumn of 2009-2011.

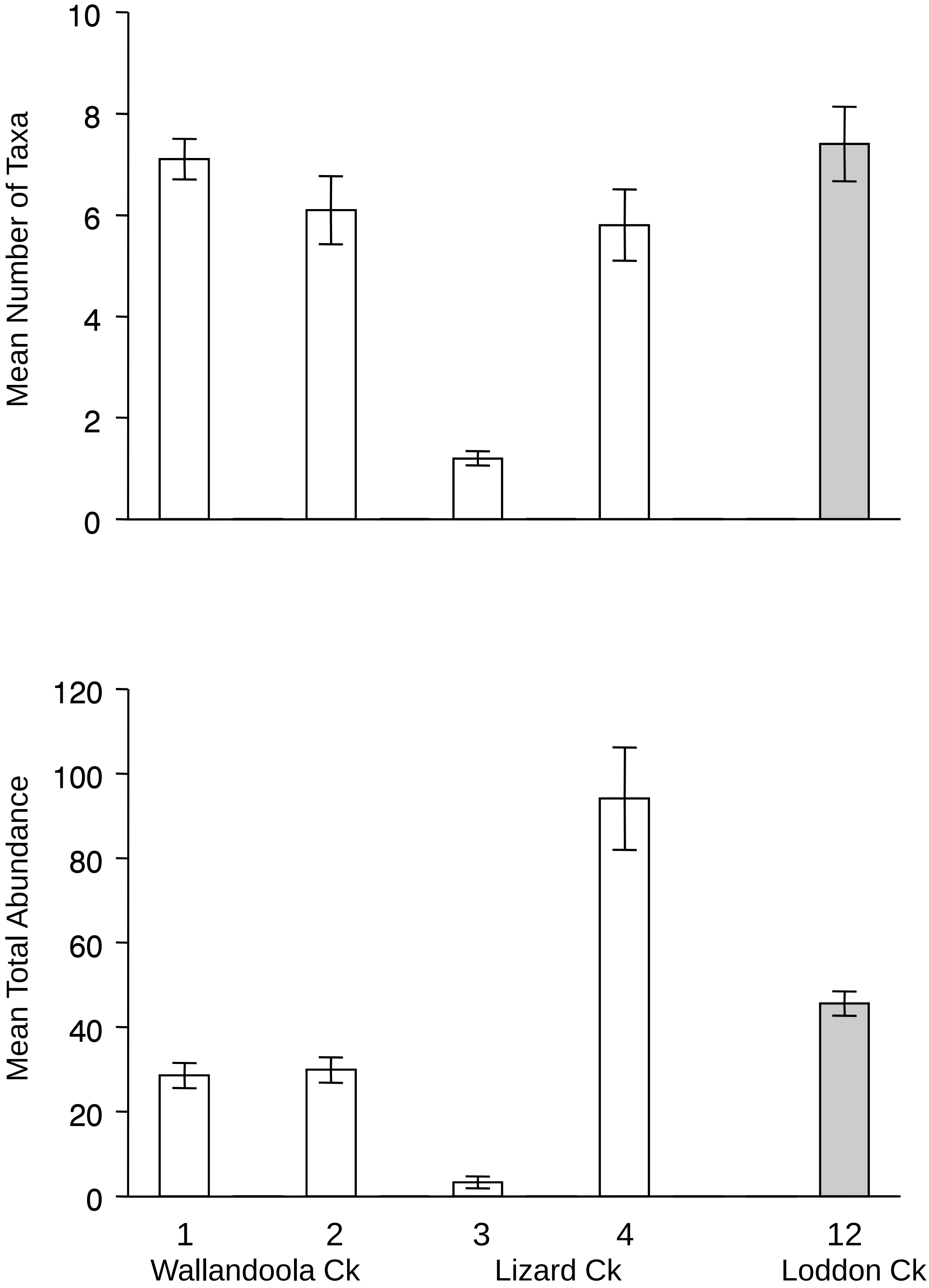


Figure 9: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from monitoring sites in the Wongawilli West Study Area in spring 2008.

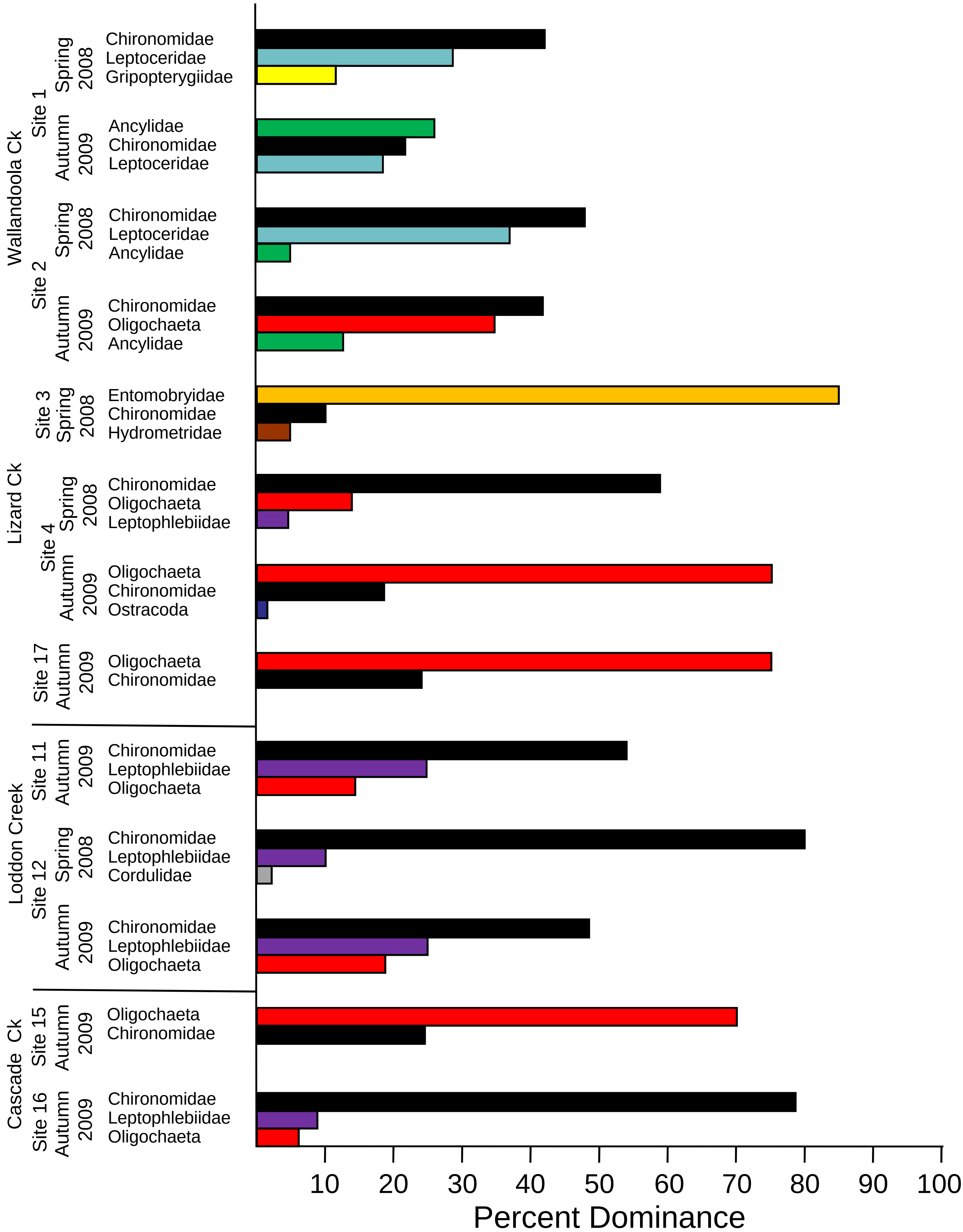


Figure 10: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in spring 2008 and autumn 2009.

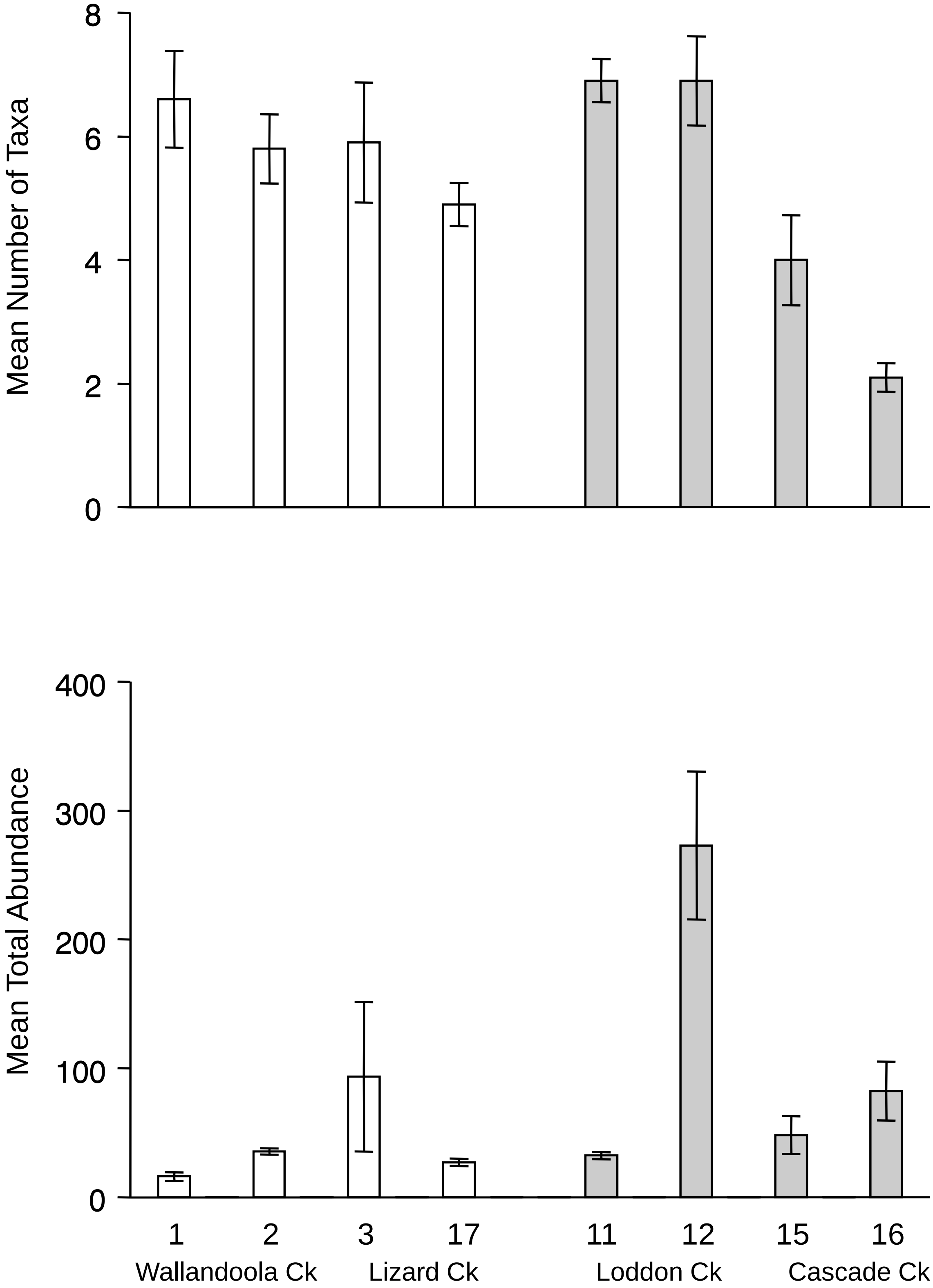


Figure 11: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli West Study Area in autumn 2009.

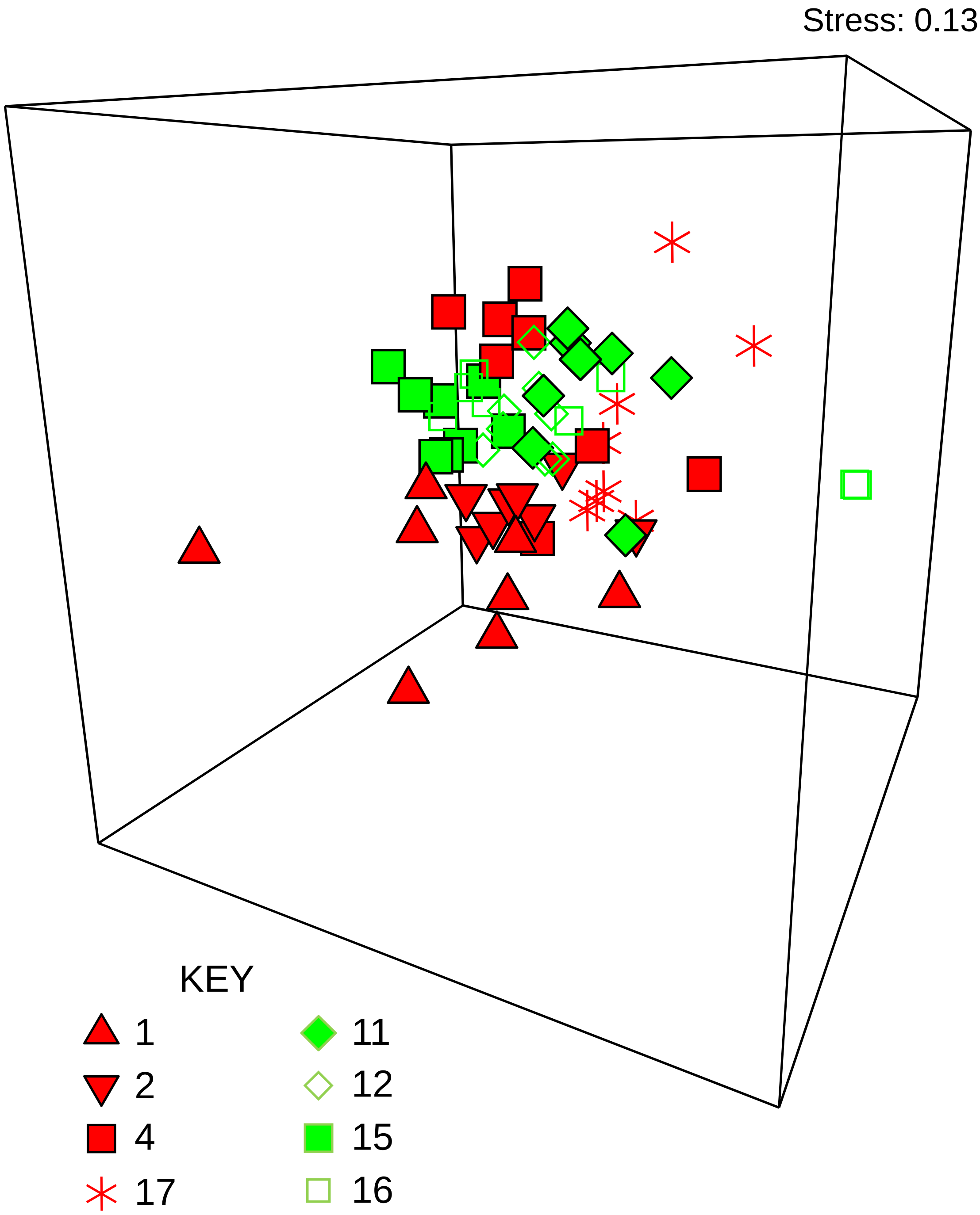


Figure 12: MDS of macroinvertebrates assemblages found on collectors at the study sites on Wallandoola Creek (1 & 2), Lizard Creek (4 & 17), Loddon Creek (11 and 12) and Cascade Creek (15 &16) in autumn 2009.

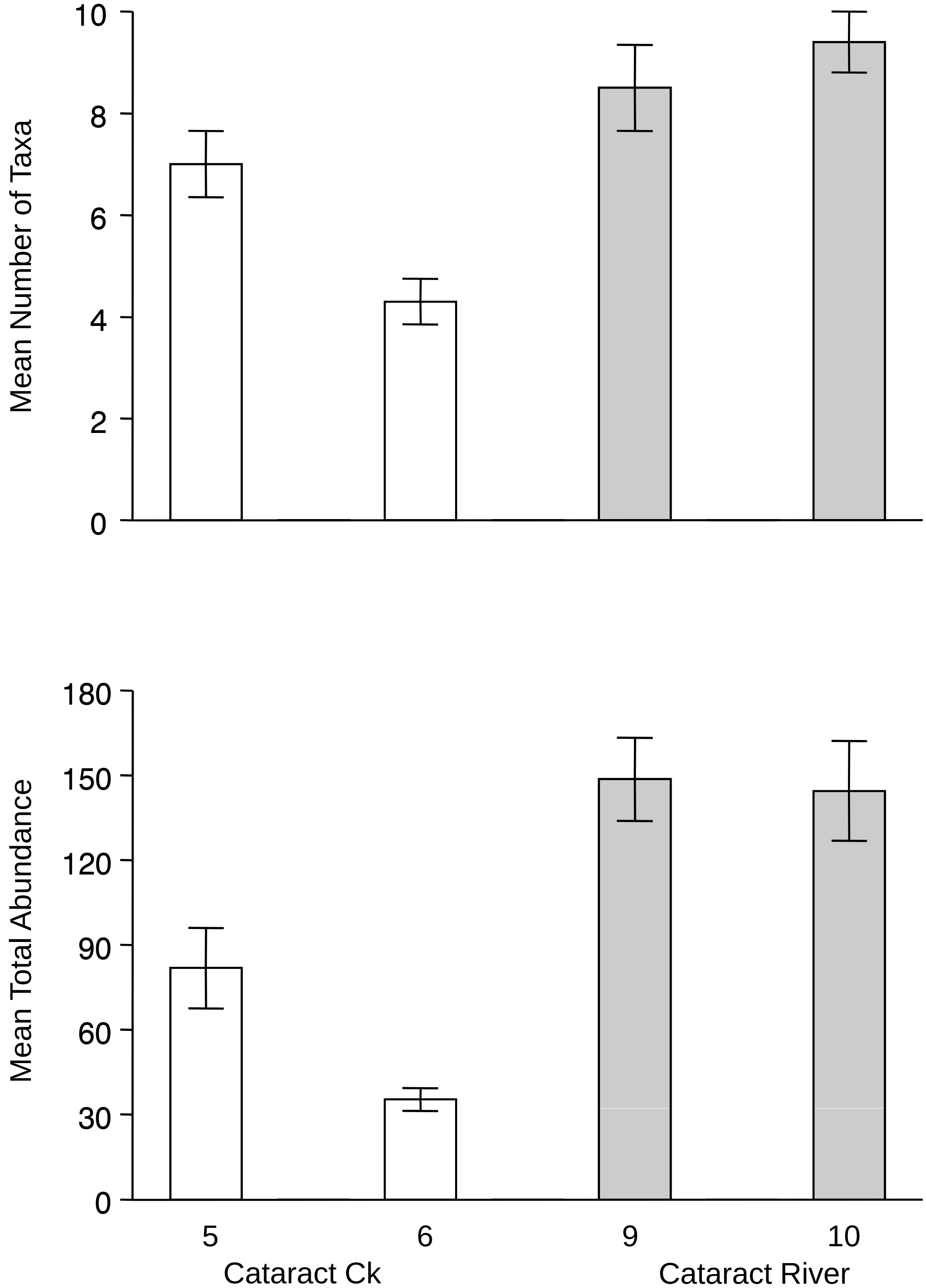


Figure 13: Mean number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008 (*n* = 8).

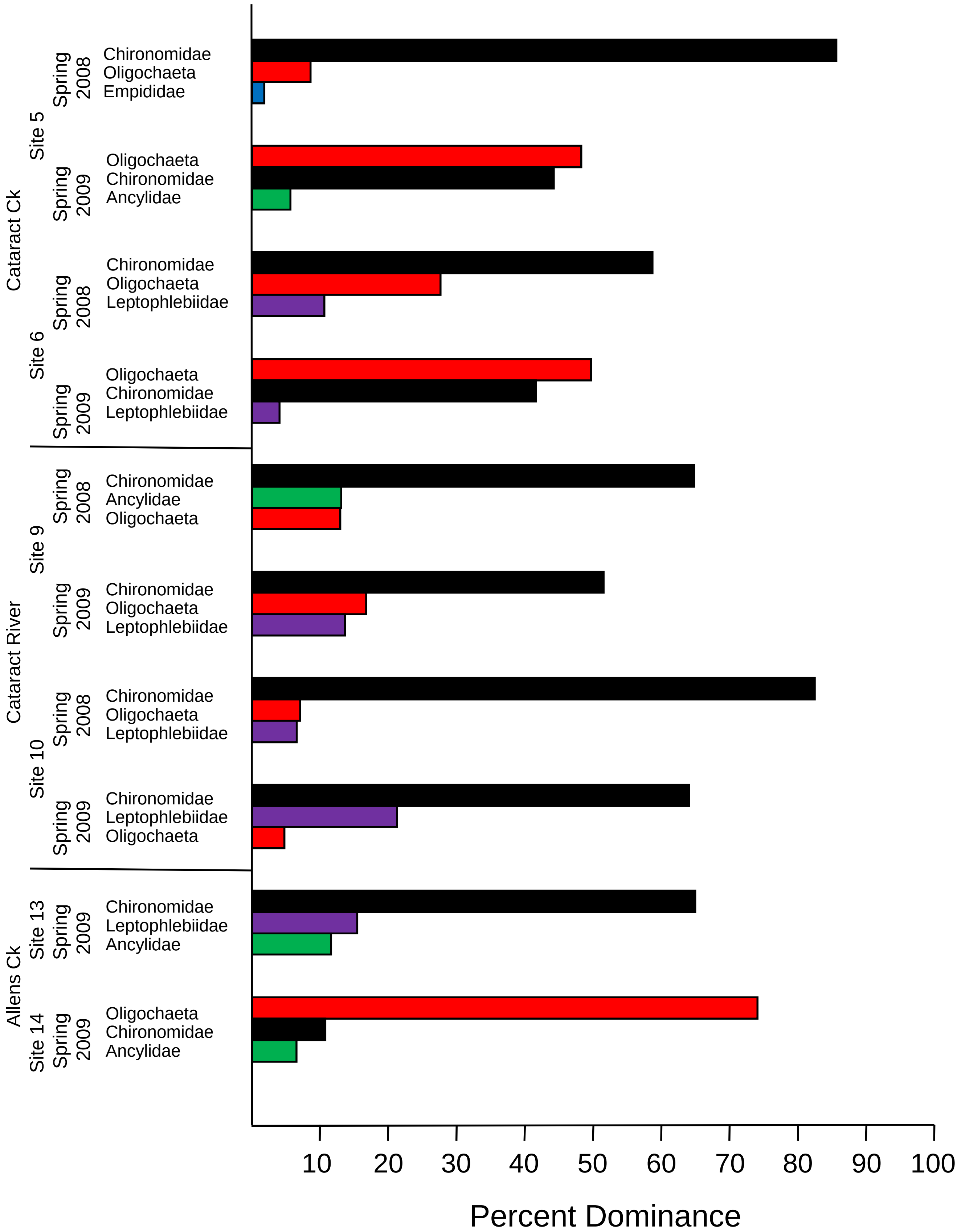


Figure 14: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2008 and 2009.

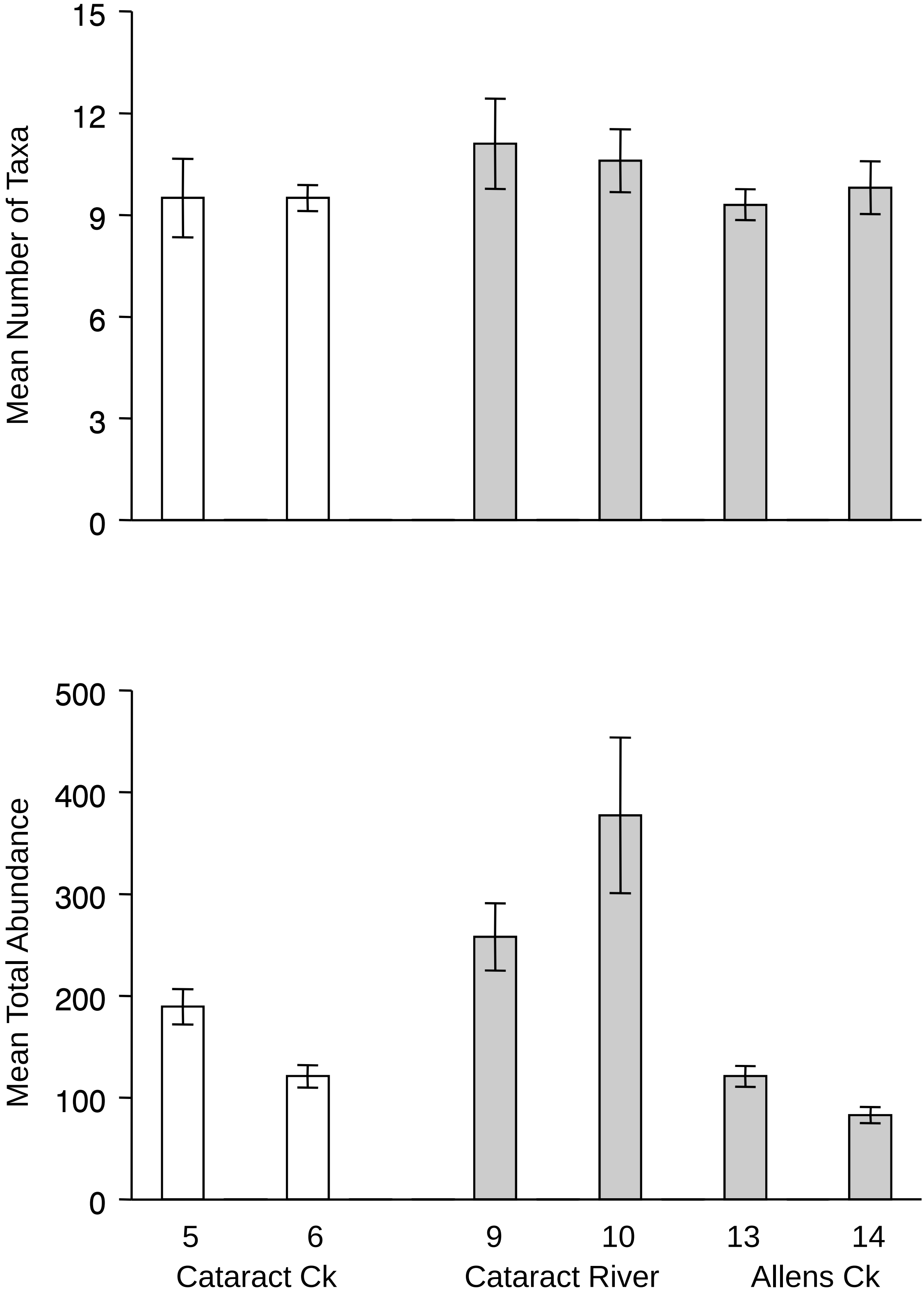


Figure 15: Mean (± S.E.) number of taxa and mean numbers of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009 (*n* = 8).

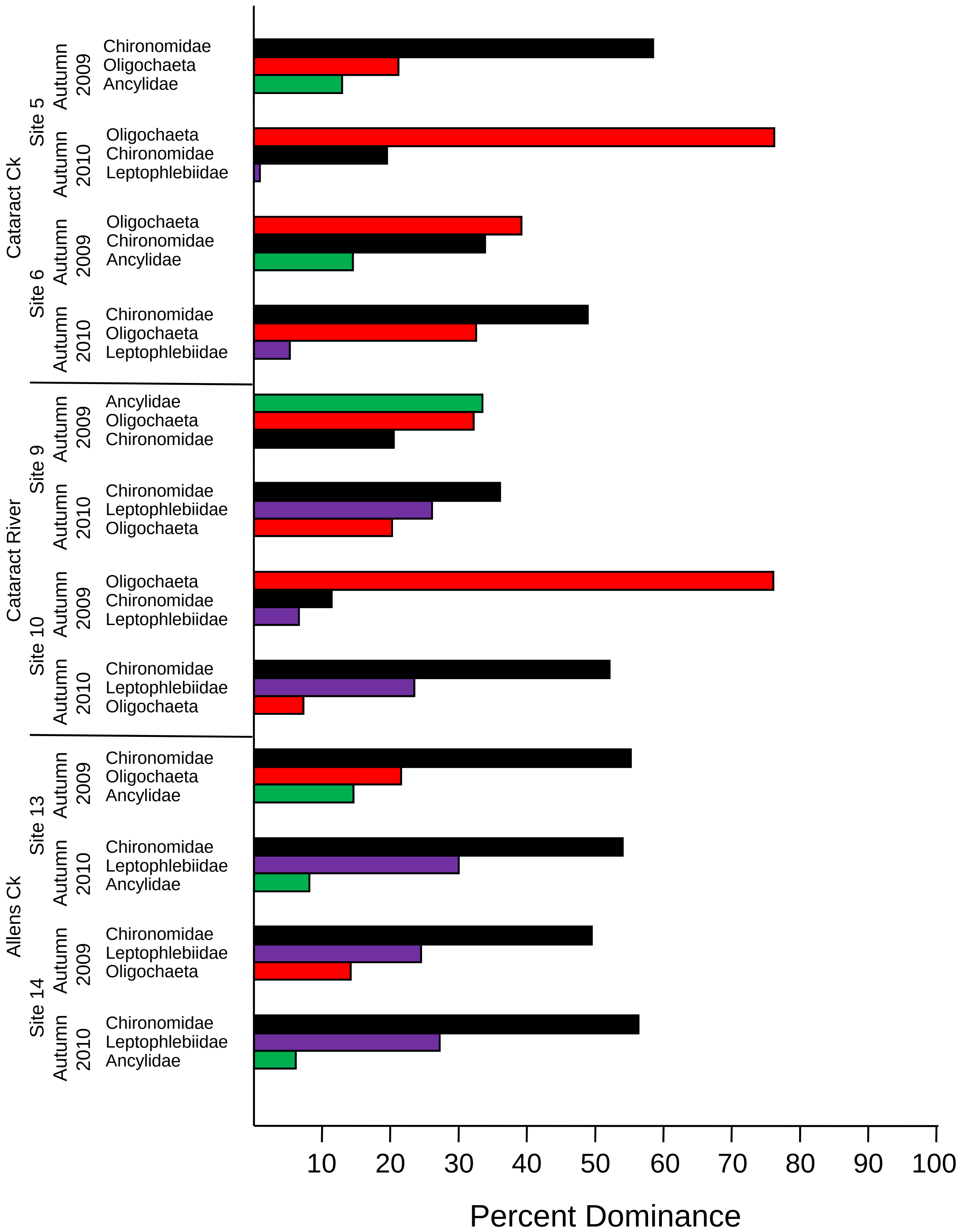


Figure 16: Numerically dominant macroinvertebrate taxa found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2009 and 2010.

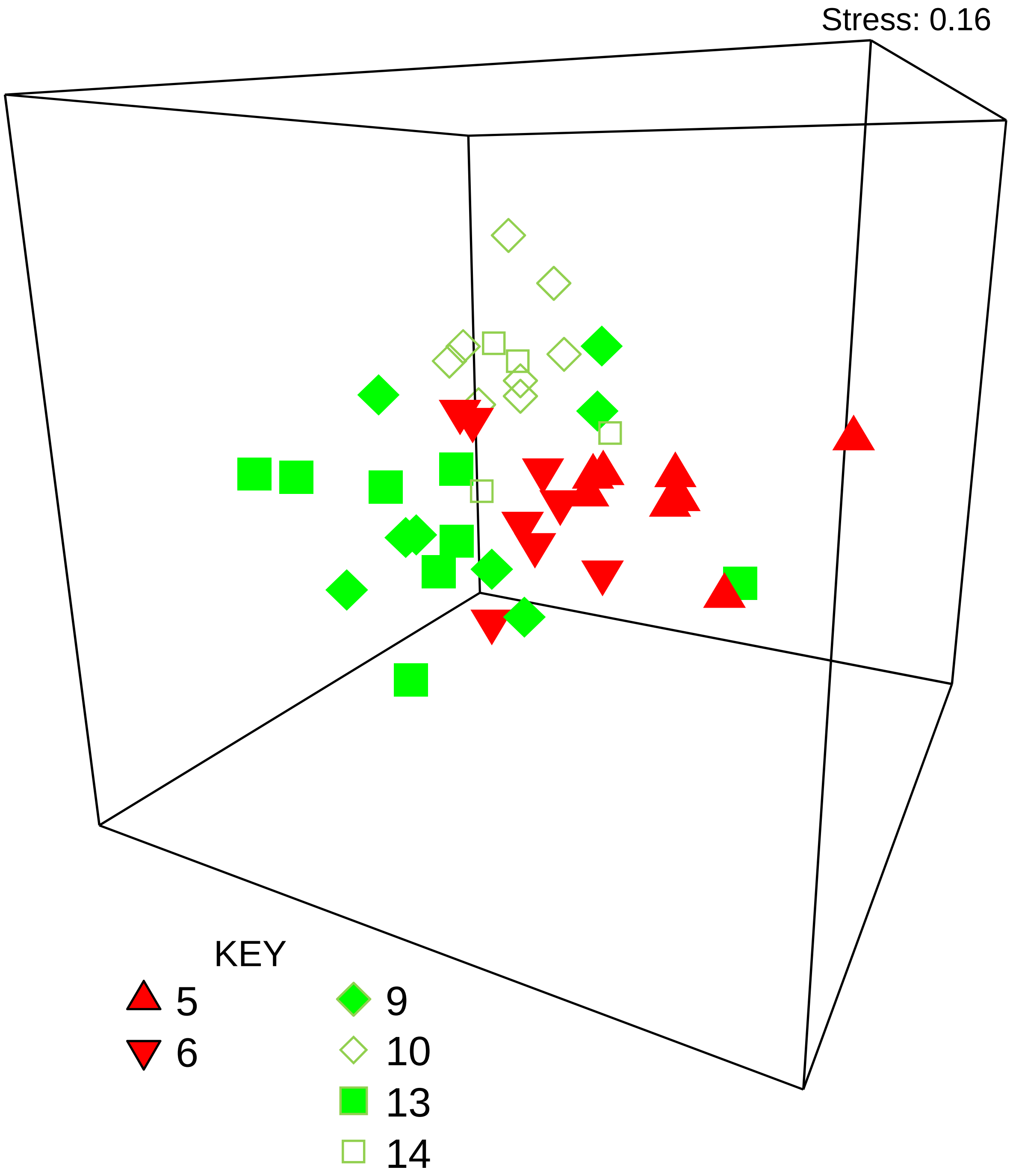


Figure 17: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2009.

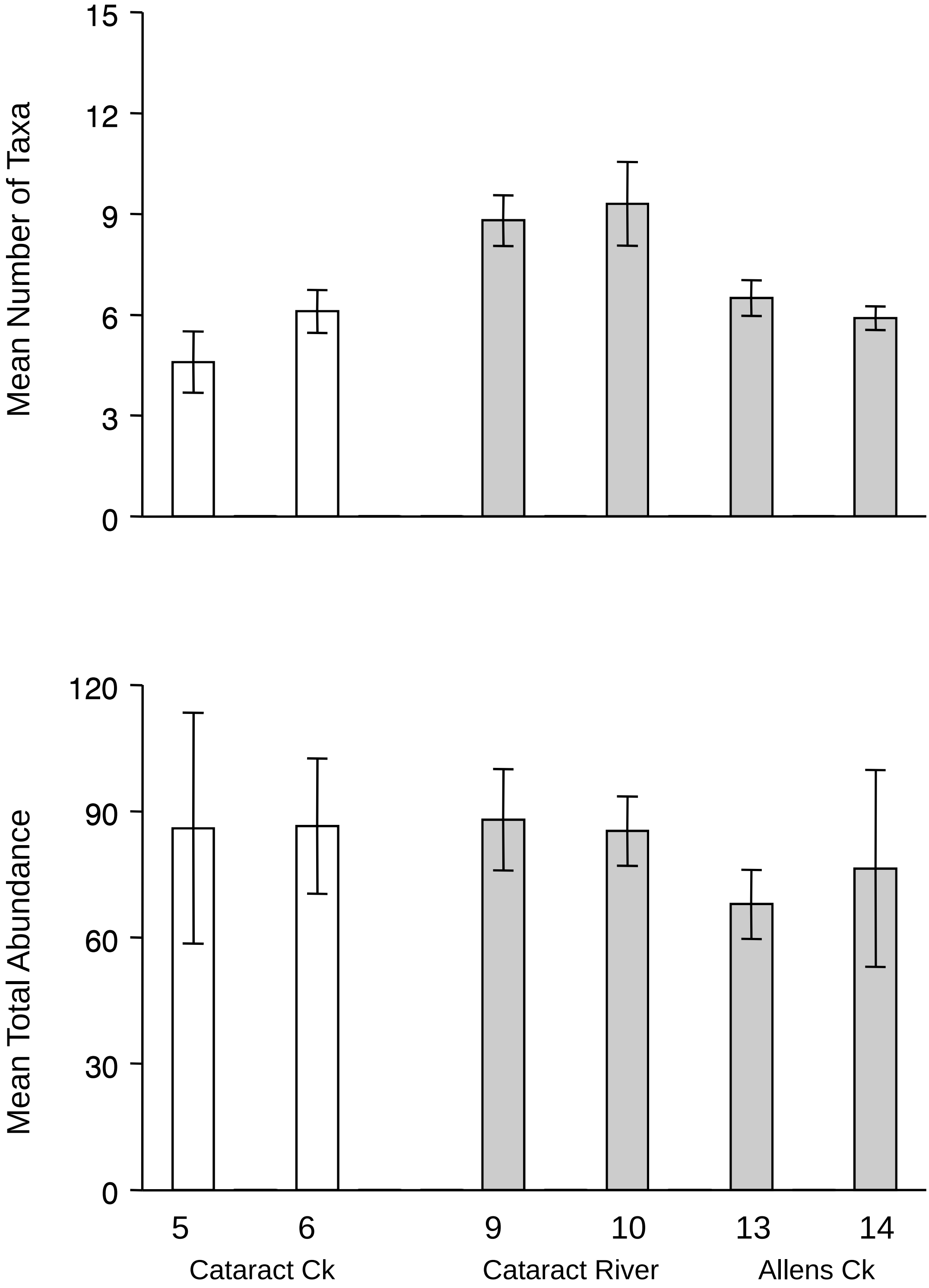


Figure 18: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in spring 2009 (*n* = 8).

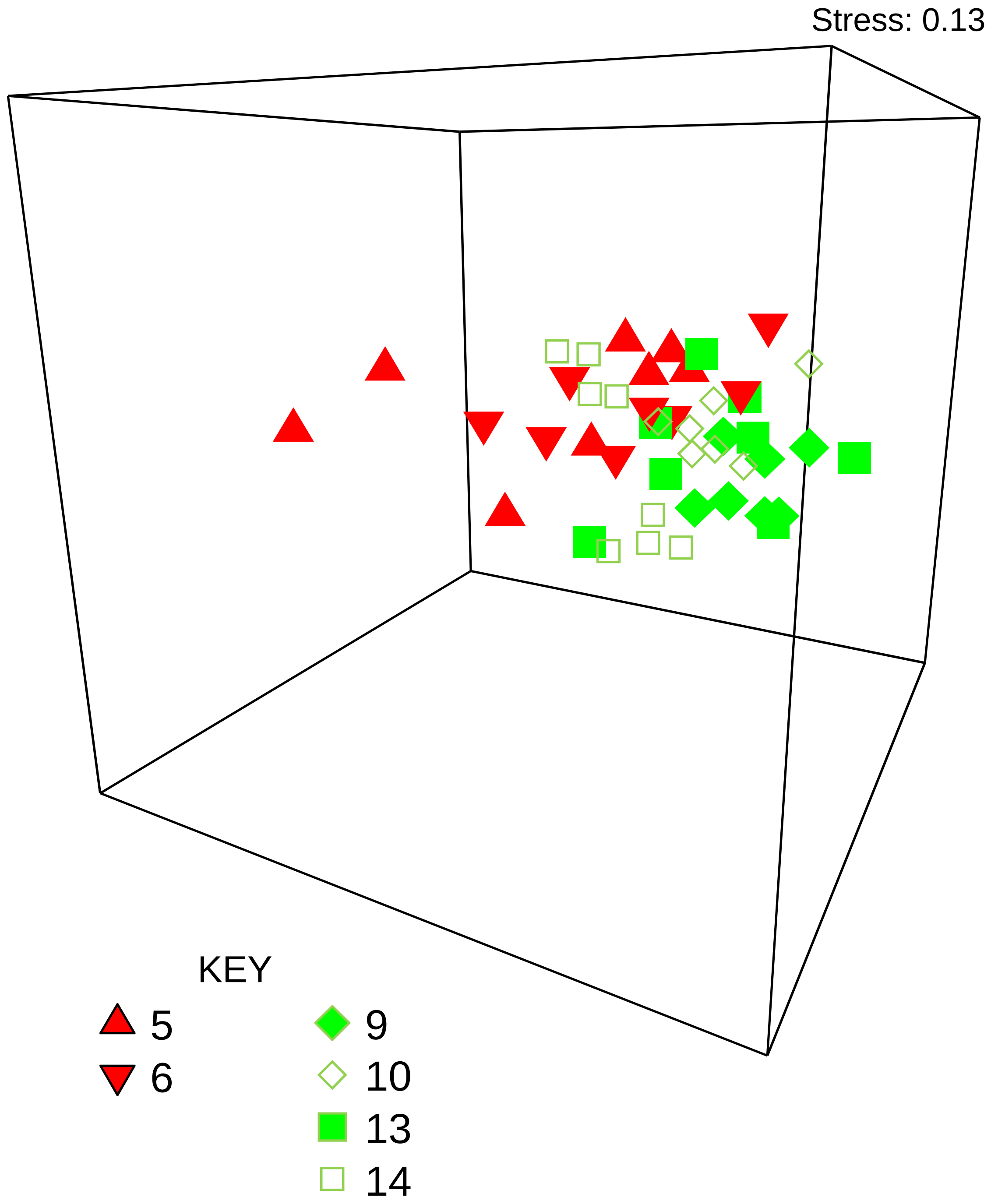


Figure 19: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in spring 2009.

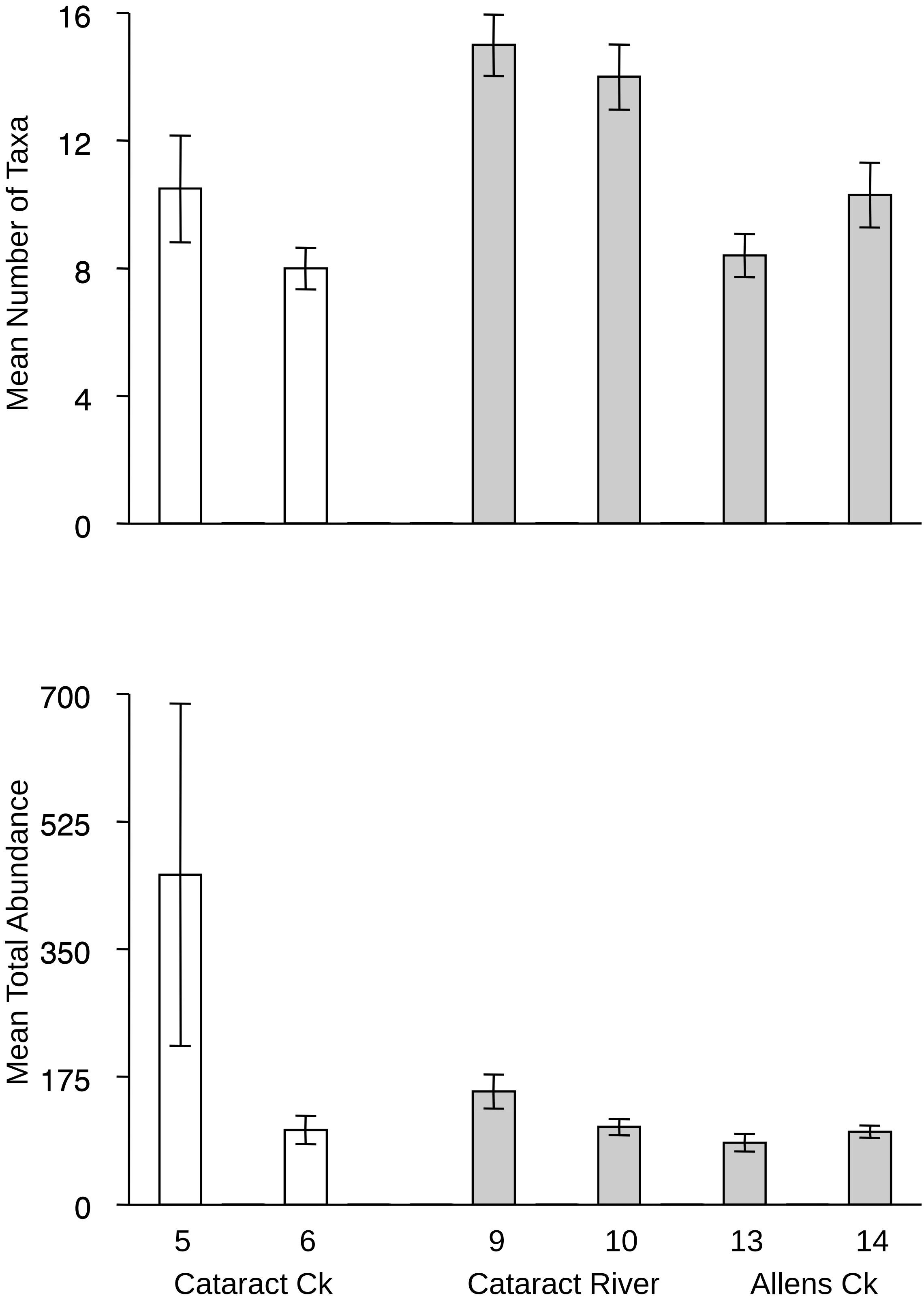


Figure 20: Mean (± S.E.) number of taxa and mean number of macroinvertebrates found on collectors retrieved from the monitoring sites in the Wongawilli East Study Area in autumn 2010.

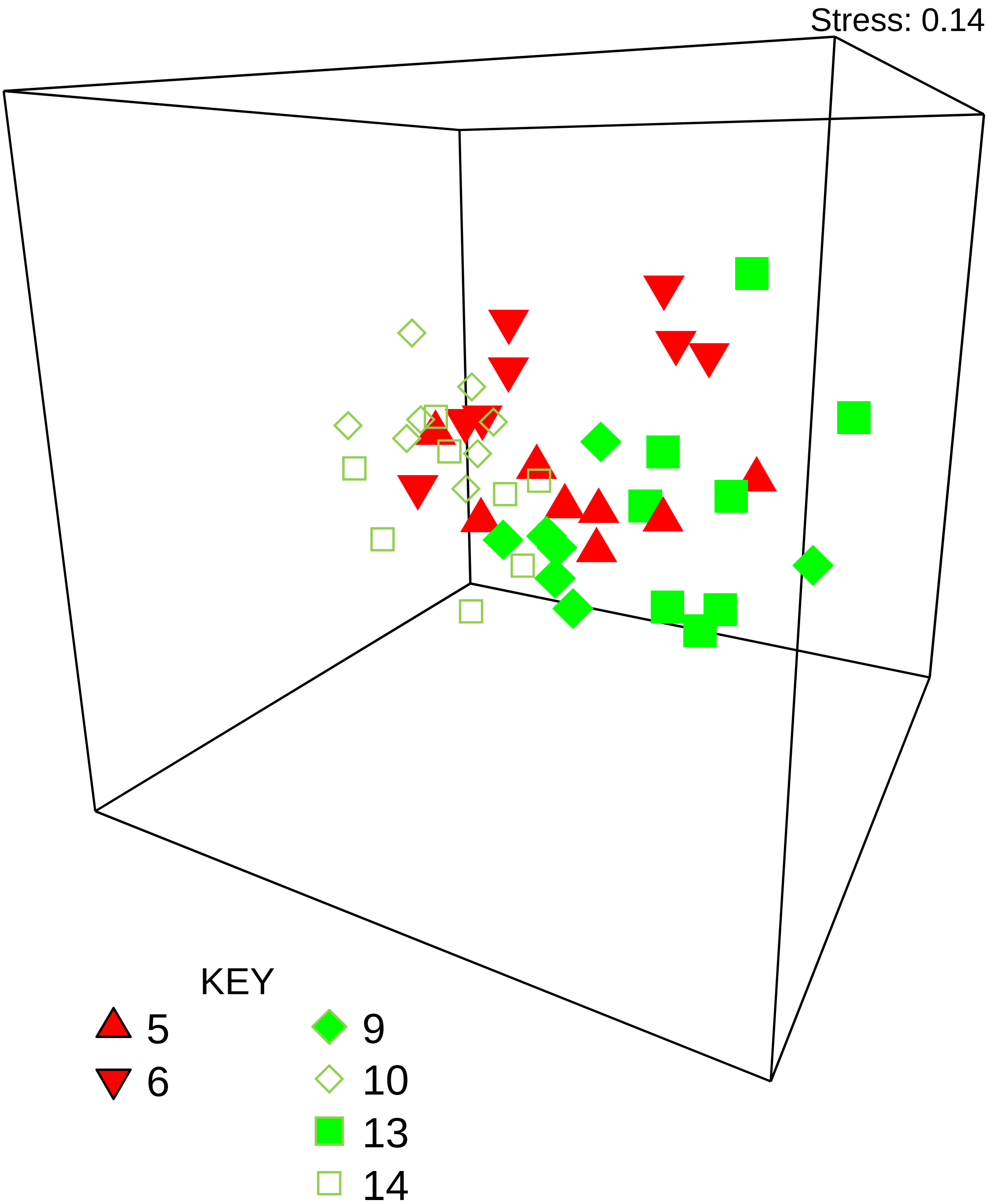
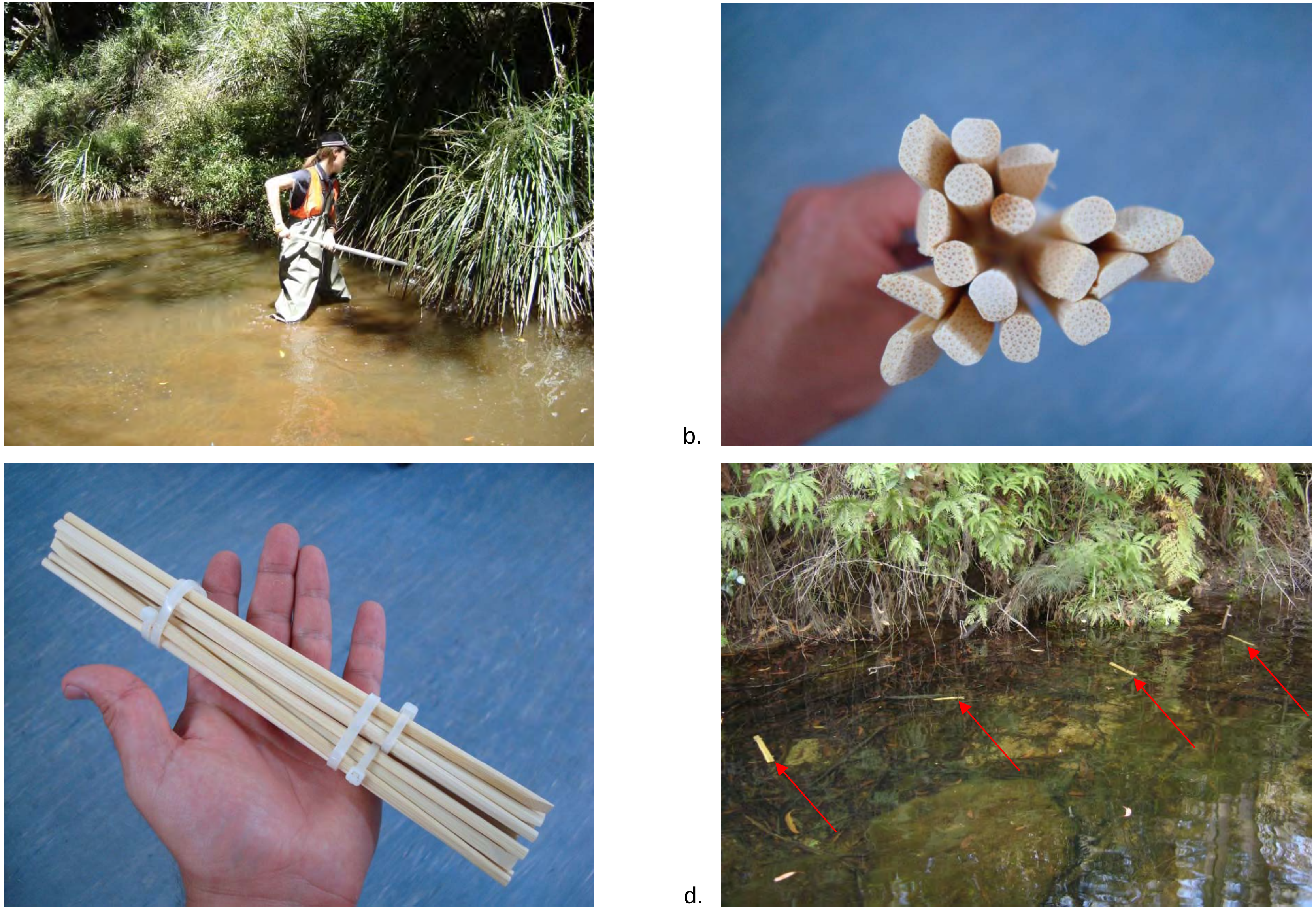


Figure 21: MDS of macroinvertebrates assemblages found on collectors at the study sites on Cataract Creek (5 & 6), Cataract River (9 & 10) and Allens Creek (13 & 14) in autumn 2010.

10 Plates

Plate 1: Aquatic macroinvertebrate collecting techniques used in baseline survey: (a) AUSRIVAS macroinvertebrate edge sampling technique; (b) Macroinvertebrate artificial collector, viewed head-on; (c) Macroinvertebrate artificial collector, side view; (d) Four artificial collectors (see arrows) in pool edge habitat.
Plate 2: Macquarie Perch survey sites - (a) Confluence of Cataract River and Cataract Creek - the downstream limit of the Macquarie Perch survey; (b) Cataract Creek near the upstream limit of the full supply level; (c) Cataract Creek upstream of the full supply level.
Plate 3: Aquatic habitats in (a) Cascade Creek and (b) Lizard Creek surrounded by open sclerophyll woodland/heath and with a substratum consisting of primarily bedrock and soft sediment; (c) Allen Creek and (d) Cataract Creek surrounded by closed temperate rainforest and with a substratum consisting of a combination of bedrock, boulder, cobble, and pebble.
Plate 4: Downstream site within Wallandoola Creek, where (a) cracking and (b) iron floc was observed and potential impact site within Lizard Creek exhibiting (c) extensive cracking and (d) iron floc associated with previous mining activity.
Plate 5: Aquatic macroinvertebrates found at monitoring sites in NRE No 1 Mine Area.
Plate 6: Various species of fish caught during backpack electrofishing surveys of Cataract Creek.



a. b. c. d.

Plate 1: Aquatic macroinvertebrate collecting techniques used in baseline survey. (a) AUSRIVAS macroinvertebrate edge sampling technique; (b) Macroinvertebrate artificial collector, viewed head-on; (c) Macroinvertebrate artificial collector, side view; (d) Four artificial collectors (see arrows) in pool edge habitat.

(a)

(b)

(c)

Plate 2: Macquarie Perch survey sites - (a) Confluence of Cataract River and Cataract Creek - the downstream limit of the Macquarie Perch survey; (b) Cataract Creek near the upstream limit of the full supply level; (c) Cataract Creek upstream of the full supply level.

a.


b.


c.


d.


Plate 3: Aquatic habitats in (a) Cascade Creek and (b) Lizard Creek surrounded by open sclerophyll woodland/heath and with a substratum consisting of primarily bedrock and soft sediment; (c) Allen Creek and (d) Cataract Creek surrounded by closed temperate rainforest and with a substratum consisting of a combination of bedrock, boulder, cobble, and pebble.

a.


b.

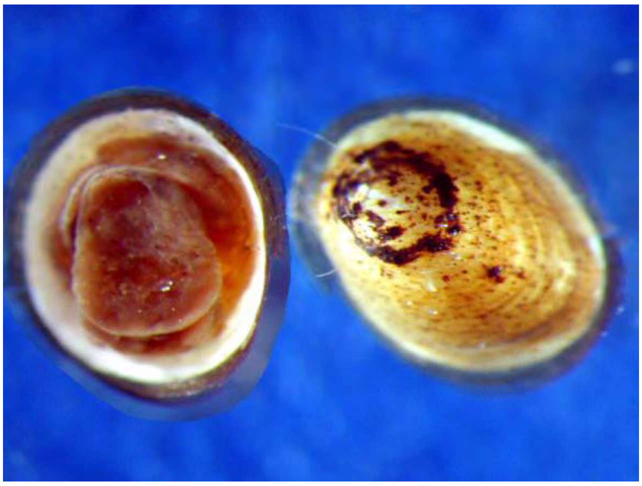

c.


d.


Plate 4: Downstream site within Wallandoola Creek, where (a) cracking and (b) iron floc was observed, and potential impact site within Lizard Creek exhibiting (c) extensive cracking and (d) iron floc associated with previous mining activity.

(a) Chironomidae (Non-biting midges)

(b) Oligochaeta (Segmented Worms)



(c) Ancylidae (Freshwater limpets

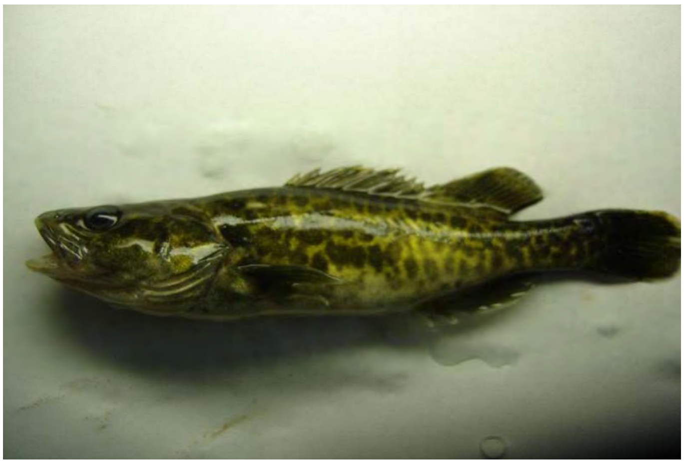
(d) Leptophlebiidae (Prong Gilled Mayflies)

(e): Entomobryidae (Springtails)

(f) Freshwater crayfish sampled in Cataract Creek

Plate 5: Aquatic macroinvertebrates found at monitoring sites in NRE No 1 Mine Area.

(a) Macquarie Perch



(b) Juvenile Cod

(c) Silver Perch

(d) Mountain Galaxid

(e) Goldfish

(f) Australian Smelt

·**Plate 6:** Various species of fish caught during backpack electrofishing surveys of Cataract Creek.

11 Appendices

Appendix 1: (a) Geographic coordinates of the NRE No. 1 Mine aquatic ecology monitoring sites and (b) survey dates.
Appendix 2: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011.
Appendix 3: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli East Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011.
Appendix 4: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.
Appendix 5: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.
Appendix 6: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli West Study Area in (a) spring 2008 and (b) autumn 2009. Species of fish and large crustaceans observed at the monitoring sites in the Wongawilli West and Wongawilli East Study Areas.
Appendix 7: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli East Study Area in (a) spring 2008; (b) autumn 2009; (c) spring 2009 and (d) autumn 2010.
Appendix 8: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli West in autumn 2009.
Appendix 9: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2009.
Appendix 10: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in spring 2009.
Appendix 11: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2010.
Appendix 12: Geographic location and caudal length of each specimen of Macquarie Perch sampled by backpack electrofishing in Cataract Creek in (a) 15 December 2009; (b) 8 January 2010; (c) 29 January 2010, and (d) 25 February 2010.
Appendix 13: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011.
Appendix 14: Mean (± S.E.) water quality parameters recorded in Cataract Creek downstream of the confluence with Cataract River and at Site 6 the most upstream site sampled during the targeted Macquarie Perch surveys undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.
Appendix 15: Geographic co-ordinates of each specimen of Freshwater Cod and Silver Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011.

Appendix 1: (a) Geographic coordinates of the NRE No. 1 Mine aquatic ecology monitoring sites and (b) survey dates. Datum: WGS84 Zone: 56H.

b. Geographic Coordinates

Study Area	Watercourse	Location	Site	Easting	Northing
Wongawilli West	Wallandoola Creek	Upstream	1	295553	6202172
	Wallandoola Creek	Downstream	2	294921	6202891
	Lizard Creek	Upstream	3	296328	6204716
	Lizard Creek	Downstream	4	295852	6205499
	Lizard Creek	Upstream	17	296143	6205240
	Loddon Creek	Upstream	11	308176	6204692
	Loddon Creek	Downstream	12	306327	6203985
	Cascade Creek	Upstream	15	290854	6207283
	Cascade Creek	Downstream	16	291065	6207641
Wongawilli East	Cataract Creek	Upstream	5	303466	6197246
	Cataract Creek	Downstream	6	302558	6197048
	Cataract River	Upstream	9	302290	6195634
	Cataract River	Downstream	10	302136	6195806
	Allen Creek	Upstream	13	305020	6203163
	Allen Creek	Downstream	14	304744	6203029
Targeted Macquarie Perch survey	Cataract Creek	Downstream		301376	6197498
		Upstream		302558	6197048

a. Sampling Dates

Season	Date	Cataract Dam Storage Level (m)
Spring 2008 -1st	28/10/2008-31/10/2008	
Spring 2008 -2nd	16-18/12/2008	
Autumn 2009 - 1st	24/03/2209-27/03/2009	
Autumn 2009 - 2nd	5/05/0009-08/05/2009	
Spring 2009	6/11/2009 and 10/11/2009 - 11/11/2009	
Spring 2009	15/12/2009 - 16/12/2009	
Autumn 2010	29/3/2010 - 31/3/2010	
Autumn 2010	11/5/2010 - 13/5/2010	
Spring 2010	27/9/2010 - 1/10/2010	
Autumn 2011	04/04/2011 - 08/4/2011	
Spring 2011	20/9/2011 - 23/9/2011	
Macquarie Perch - 1st	15/12/2009	-6.5
Macquarie Perch - 2nd	8/01/2010	-7.35
Macquarie Perch - 3rd	29/01/2010	-7.82
Macquarie Perch - 4th	25/02/2010	-6.10
Macquarie Perch - 5th	8/12/2010	-3.39
Macquarie Perch - 6th	7/01/2011	-3.53
Macquarie Perch - 7th	25/01/2011	-3.6
Macquarie Perch - 8th	21/02/2011	-4.1

Appendix 2: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011. Values outside available ANZECC guidelines for upland streams are highlighted.

A. October 2008

WQ Parameter	Creek	Wallandoola Ck					Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		14.5	0.1	17.2	0.2	15.9	0.0	15.9	0.1	NS*		14.8	0.0	14.7	0.0	NS		NS	
Conductivity (µS/cm)		170.5	25.5	232.5	2.5	75.0	5.0	105.0	0.0			136.0	8.0	133.5	5.5				
pH		6.6	0.0	6.5	0.0	6.8	0.0	6.7	0.0			5.9	0.0	6.2	0.0				
ORP (mV)		490.0	1.0	414.0	3.0	411.5	2.5	278.0	7.0			509.0	0.0	489.0	0.0				
DO (mg/L)		8.1	0.0	8.3	0.1	6.6	0.1	7.5	0.0			8.2	0.0	8.7	0.0				
DO (%sat'n)		78.7	0.9	85.4	0.1	66.5	0.9	76.3	0.3			80.3	0.5	85.3	0.1				
Turbidity (ntu)		4.0	0.4	4.3	0.1	3.0	0.0	6.7	0.1			7.1	0.3	5.1	0.2				

B. December 2008

WQ Parameter	Creek	Wallandoola Ck					Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		15.6	0.0	18.0	0.1	15.9	0.1	15.9	0.0	NS		18.5	0.0	19.7	0.0	NS		NS	
Conductivity (µS/cm)		FP[#]		FP		FP		FP		NS		FP		FP		NS		NS	
pH		6.6	0.0	6.5	0.1	6.4	0.2	6.8	0.0			5.9	0.1	6.2	0.1				
ORP (mV)		356.5	52.5	443.5	0.5	504.5	1.5	417.5	18.5			561.0	4.0	526.0	5.0				
DO (mg/L)		7.4	0.0	7.3	0.0	2.1	0.1	4.9	0.1			7.0	0.0	7.5	0.0				
DO (%sat'n)		75.1	0.5	73.9	2.2	22.2	1.1	49.3	0.5			74.6	0.9	82.1	0.9				
Turbidity (ntu)		1.7	0.6	2.3	0.1	1.2	0.1	4.8	0.2			1.3	0.1	1.2	0.1				

C. March 2009

WQ Parameter	Creek	Wallandoola Ck					Lizard Ck				Loddon Ck				Cascade Ck			
	Site	1		2		3		4		17		11		12		15		16
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (^{0}C)		25.7	0.0	27.8	0.0	DRY		18.1	0.1	17.1	0.1	22.3	0.0	25.2	0.1	19.8	0.0	19.2	0.0
Conductivity (µS/cm)		57.0	4.0	109.5	7.5			199.5	4.5	245.5	9.5	8.0	0.0	0.0	0.0	685.0	0.0	1133.5	4.5
pH		FP		FP				FP		FP		6.0	0.0	5.7	0.0	FP		FP	
ORP (mV)		547.0	4.0	519.0	0.0			363.0	9.0	248.0	45.0	495.0	1.0	532.0	3.0	537.0	1.0	451.5	3.5
DO (mg/L)		6.6	0.0	7.5	0.0			1.3	0.7	0.8	0.2	7.0	0.0	7.2	0.1	3.1	0.1	2.4	0.1
DO (%sat'n)		80.6	0.0	95.1	0.0			14.1	7.5	7.8	1.2	80.2	0.1	86.9	0.1	33.6	0.6	25.4	0.1
Turbidity (ntu)		FP		FP				32.0	0.3	36.6	14.3	FP		FP		6.5	0.1	8.5	0.2

continued

Appendix 2: Continued.

D. May 2009

WQ Parameter / Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	12.1	0.0	14.2	0.0	14.4	0.0	14.6	0.0	14.7	0.0	12.9	0.0	13.6	0.0	12.3	0.0	12.5	0.0
Conductivity (µS/cm)	100.0	0.0	124.0	0.0	142.0	0.0	155.5	4.5	141.0	0.0	88.0	0.0	97.0	0.0	674.0	5.0	989.0	5.0
pH	5.8	0.0	6.5	0.0	6.3	0.0	6.8	0.0	6.7	0.0	5.9	0.0	5.8	0.0	6.1	0.0	5.6	0.0
ORP (mV)	324.5	2.5	327.5	1.5	373.5	1.5	472.0	3.0	459.5	5.5	376.5	1.5	566.0	4.0	262.0	0.0	283.0	3.0
DO (mg/L)	14.7	0.3	17.2	0.0	6.8	0.1	10.3	0.1	13.1	0.4	15.0	0.1	15.3	0.1	9.4	0.1	8.6	0.1
DO (%sat'n)	137.3	2.8	165.9	0.7	67.0	0.5	100.4	0.0	129.0	4.0	142.1	0.5	159.7	14.7	88.3	1.2	80.8	1.3
Turbidity (ntu)	0.5	0.2	FP	0.0	7.5	0.4	3.0	0.4	FP	0.1	FP	0.0	FP	0.1	2.0	0.0	15.5	0.3

E. November 2009

WQ Parameter / Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	15.7	0.0	20.8	0.0			16.3	0.1	14.7	0.0	18.5	0.0	18.6	0.0	20.1	0.2	26.3	0.1
Conductivity (µS/cm)	117.0	0.0	142.5	0.5			194.5	0.5	208.0	2.0	86.5	0.5	87.0	0.0	641.5	1.5	1007.0	2.0
pH	5.8	0.0	6.3	0.0			6.4	0.0	6.7	0.0	5.6	0.0	5.5	0.0	5.8	0.0	5.3	0.0
ORP (mV)	191.5	1.5	184.0	1.0			146.0	4.0	95.0	2.0	227.0	1.0	240.5	0.5	192.5	4.5	143.0	0.0
DO (mg/L)	9.1	0.2	7.4	0.0			2.7	0.0	2.6	0.1	8.6	0.0	7.3	0.2	6.9	0.2	2.5	0.0
DO (%sat'n)	92.0	1.6	82.8	0.7			27.7	0.2	24.9	0.4	90.2	0.9	84.3	1.8	76.4	2.0	30.4	0.8
Turbidity (ntu)	7.8	0.4	0.7	0.0			23.4	0.1	181.7	0.2	1.8	0.3	1.8	0.5	0.4	0.1	1.3	0.1

F. March 2010

WQ Parameter / Creek	Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	19.7	0.0	20.8	0.0			18.5	0.0	17.7	0.0	21.4	0.0	21.7	0.0	20.6	0.0	19.6	0.0
Conductivity (µS/cm)	303.0	2.0	223.5	1.5			191.0	0.0	215.5	0.5	104.0	0.0	97.0	2.0	805.0	0.0	1096.5	0.5
pH	5.8	0.0	6.5	0.0			6.4	0.0	6.5	0.0	5.7	0.0	5.5	0.0	6.1	0.0	5.7	0.0
ORP (mV)	83.0	5.0	201.0	1.0			406.0	0.0	265.0	3.0	463.5	0.5	460.5	2.5	413.5	1.5	292.5	2.5
DO (mg/L)	4.9	0.0	6.6	0.0			1.2	0.0	1.9	0.0	7.2	0.0	7.2	0.0	4.8	0.0	0.3	0.0
DO (%sat'n)	53.2	0.4	73.9	0.1			13.1	0.1	20.0	0.1	81.7	0.1	82.0	0.1	53.8	0.1	2.9	0.1
Turbidity (ntu)	15.1	0.5	1.4	0.1			40.7	0.5	90.4	1.8	2.2	0.0	0.5	0.1	16.3	0.2	55.1	1.2

continued

Appendix 2: Continued.

G. September 2010

WQ Parameter	Creek: Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	12.1	0.0	15.6	0.1	13.1	0.0	14.2	0.0	13.4	0.0	13.6	0.0	16.7	0.0	14.0	0.0	13.9	0.0
Conductivity (µS/cm)	101.5	0.5	98.5	22.5	2.0	2.0	0.0	0.0	132.0	9.0	89.0	0.0	95.0	8.0	448.5	3.5	808.5	2.5
pH	5.8	0.0	5.9	0.0	6.1	0.0	6.3	0.0	6.3	0.0	5.6	0.0	5.6	0.0	5.8	0.0	5.3	0.0
ORP (mV)	456.0	0.0	458.5	3.5	414.5	4.5	419.5	2.5	393.5	1.5	439.0	1.0	448.5	0.5	448.0	0.0	435.5	2.5
DO (mg/L)	6.2	0.1	4.7	0.1	5.9	0.1	6.1	0.3	3.7	0.0	12.9	0.1	9.6	0.3	4.8	0.4	6.2	0.1
DO (%sat'n)	56.5	0.5	46.9	0.1	55.8	0.3	60.0	3.1	32.1	0.7	123.5	0.6	98.8	2.8	47.0	3.7	59.1	1.0
Turbidity (ntu)	2.6	0.0	2.4	0.1	4.2	0.0	5.9	0.1	3.1	0.1	1.7	0.1	1.4	0.1	4.9	0.2	2.8	0.1

H. April 2011

WQ Parameter	Creek: Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	17.2	0.0	18.1	0.1	16.4	0.1	16.8	0.0	16.7	0.0	17.5	0.2	18.6	0.0	17.1	0.0	17.4	0.1
Conductivity (µS/cm)	76.0	12.0	93.0	16.0	106.0	12.0	158.5	0.5	122.0	0.0	73.0	23.0	71.5	0.5	241.0	0.0	401.0	29.0
pH	5.9	0.0	6.3	0.0	6.0	0.1	6.3	0.0	6.3	0.0	5.9	0.0	6.1	0.0	6.0	0.0	5.6	0.0
ORP (mV)	346.5	0.5	308.0	4.0	423.0	2.0	256.5	4.5	239.5	7.5	326.5	2.5	297.5	3.5	320.5	0.5	271.5	4.5
DO (mg/L)	8.4	0.0	9.0	0.0	3.2	0.1	6.6	0.0	2.1	0.1	8.5	0.0	9.1	0.0	4.6	0.0	5.7	0.8
DO (%sat'n)	86.8	0.3	95.5	0.1	32.5	0.9	67.8	0.4	21.1	0.6	88.4	0.5	96.8	0.1	47.6	0.3	58.4	9.3
Turbidity (ntu)	3.1	0.1	3.1	0.1	1.0	0.1	4.3	0.1	0.8	0.1	3.0	0.1	1.3	0.1	4.5	0.1	5.1	0.1

I. September 2011

WQ Parameter	Creek: Wallandoola Ck						Lizard Ck				Loddon Ck				Cascade Ck			
Site	1		2		3		4		17		11		12		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	12.9	0.0	14.9	0.0	12.4	0.0	13.0	0.0	12.7	0.0	14.5	0.0	15.5	0.0	12.6	0.0	13.9	0.0
Conductivity (µS/cm)	93.0	0.0	114.0	0.0	120.5	0.5	174.0	0.0	143.5	2.5	97.0	1.0	128.0	0.0	343.5	0.5	603.5	29.5
pH	5.4	0.0	5.7	0.0	6.1	0.0	6.1	0.0	6.0	0.0	5.6	0.0	5.8	0.0	5.6	0.0	5.3	0.0
ORP (mV)	224.0	1.0	146.0	0.0	173.0	1.0	55.0	0.0	54.0	7.0	196.5	2.5	225.5	0.5	189.0	0.0	103.5	2.5
DO (mg/L)	7.0	0.0	7.4	0.0	6.3	0.0	6.2	0.0	3.6	0.0	6.9	0.1	7.1	0.0	5.3	0.0	3.6	0.2
DO (%sat'n)	65.8	0.3	43.4	30.1	59.0	0.2	58.8	0.5	34.0	0.1	67.2	0.3	71.4	0.1	49.2	0.1	35.0	2.3
Turbidity (ntu)	0.7	0.1	2.0	0.4	0.6	0.0	18.7	1.1	8.9	1.3	3.3	0.4	6.7	0.2	0.6	0.0	13.7	0.1

*NS = no sample
FP = faulty probe

Appendix 3: Mean (± S.E.) water quality measurements recorded at each of the monitoring sites in the Wongawilli East Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2011; (h) April 2011; and (i) September 2011. Values outside available ANZECC guidelines for upland streams are highlighted.

A. October 2008

WQ Parameter / Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	13.4	0.0	13.5	0.0	14.4	0.0	14.3	0.0	NS*		NS	
Conductivity (µS/cm)	138.0	0.0	146.5	1.5	161.0	0.0	161.0	0.0				
pH	7.3	0.0	6.9	0.0	7.1	0.1	7.1	0.1				
ORP (mV)	442.5	2.5	378.0	9.0	456.0	17.0	494.0	5.0				
DO (mg/L)	8.5	0.0	6.7	0.1	7.1	0.0	7.4	0.1				
DO (%sat'n)	80.9	0.7	63.9	0.3	67.5	1.8	72.2	0.6				
Turbidity (ntu)	7.9	0.1	9.6	0.2	18.1	0.1	11.5	0.1				

B. December 2008

WQ Parameter / Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	14.2	0.0	14.6	0.0	15.8	0.2	16.0	0.1	NS		NS	
Conductivity (µS/cm)	FP#		FP		FP		FP					
pH	7.2	0.1	7.0	0.1	6.8	0.0	6.8	0.0				
ORP (mV)	393.0	7.0	402.5	9.5	445.0	6.0	460.5	0.5				
DO (mg/L)	7.4	0.1	6.1	0.0	6.5	0.1	7.0	0.1				
DO (%sat'n)	72.0	0.9	59.8	0.5	66.2	1.3	71.2	0.8				
Turbidity (ntu)	9.7	0.1	9.0	0.4	4.5	0.1	16.0	0.5				

C. March 2009

WQ Parameter / Creek	Cataract Ck				Cataract River				Allens Ck			
Site	5		6		9		10		13		14	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)	17.8	0.0	17.4	0.0	17.3	0.1	17.1	0.0	18.2	0.0	18.3	0.0
Conductivity (µS/cm)	4.0	4.0	126.0	0.0	131.0	5.0	9.0	0.0	110.5	4.5	115.0	9.0
pH	6.9	0.0	6.5	0.0	6.8	0.0	6.6	0.0	13.4	0.0	13.4	0.0
ORP (mV)	478.5	1.5	437.0	0.0	393.0	9.0	429.0	1.0	563.0	0.0	523.0	1.0
DO (mg/L)	7.4	0.1	5.0	0.1	5.4	1.0	5.7	0.1	6.9	0.0	7.3	0.0
DO (%sat'n)	77.6	0.6	51.8	0.3	56.1	10.4	58.6	0.2	72.8	0.2	77.8	0.0
Turbidity (ntu)	2.2	0.1	22.1	1.0	5.9	1.2	2.3	0.1	0.1	0.0	0.7	0.0

continued

Appendix 3: Continued.

D. May 2009

WQ Parameter	Creek Site	Cataract Ck 5 Mean	5 S.E.	6 Mean	6 S.E.	Cataract River 9 Mean	9 S.E.	10 Mean	10 S.E.	Allens Ck 13 Mean	13 S.E.	14 Mean	14 S.E.
Temperature (°C)		11.3	0.0	11.5	0.0	12.7	0.0	12.8	0.0	12.4	0.0	12.0	0.0
Conductivity (µS/cm)		112.0	0.0	112.0	0.0	108.0	0.0	98.0	0.0	114.0	5.0	110.0	0.0
pH		7.0	0.0	6.9	0.0	6.8	0.0	6.5	0.0	6.6	0.0	6.6	0.0
ORP (mV)		369.5	0.5	387.0	2.0	413.5	2.5	379.5	3.5	283.5	49.5	327.5	0.5
DO (mg/L)		16.6	0.1	15.8	0.6	15.7	0.4	15.5	0.4	15.8	0.5	14.9	0.0
DO (%sat'n)		150.7	0.5	145.2	5.1	148.1	3.9	146.1	2.9	153.3	0.1	138.5	0.1
Turbidity (ntu)		1.8	0.1	0.5	0.0	0.4	0.2	1.3	0.1	0.7	0.3	0.1	0.0

E. November 2009

WQ Parameter	Creek Site	Cataract Ck 5 Mean	5 S.E.	6 Mean	6 S.E.	Cataract River 9 Mean	9 S.E.	10 Mean	10 S.E.	Allens Ck 13 Mean	13 S.E.	14 Mean	14 S.E.
Temperature (°C)		14.4	0.0	14.6	0.0	14.9	0.0	14.7	0.0	15.1	0.0	15.0	0.0
Conductivity (µS/cm)		112.0	0.0	72.5	2.5	96.0	2.0	94.0	0.0	102.0	0.0	64.5	4.5
pH		6.8	0.0	6.8	0.0	6.6	0.0	6.4	0.1	6.5	0.0	6.8	0.0
ORP (mV)		362.0	0.0	352.5	0.5	147.0	0.0	142.0	2.0	184.0	1.0	409.5	0.5
DO (mg/L)		10.6	0.0	18.9	0.9	6.9	0.0	8.7	0.0	8.1	0.5	11.8	0.2
DO (%sat'n)		101.4	4.7	177.2	19.0	68.1	0.1	85.8	0.2	79.8	4.6	119.5	1.8
Turbidity (ntu)		20.9	0.6	28.8	1.3	0.6	0.1	1.2	0.3	1.9	0.1	31.4	0.9

F. March 2010

WQ Parameter	Creek Site	Cataract Ck 5 Mean	5 S.E.	6 Mean	6 S.E.	Cataract River 9 Mean	9 S.E.	10 Mean	10 S.E.	Allens Ck 13 Mean	13 S.E.	14 Mean	14 S.E.
Temperature (°C)		17.9	0.0	17.9	0.0	17.4	0.0	17.5	0.0	17.7	0.0	17.8	0.0
Conductivity (µS/cm)		214.0	0.0	126.5	2.5	188.5	5.5	56.0	0.0	224.5	1.5	73.0	0.0
pH		6.7	0.0	6.4	0.0	6.2	0.0	5.8	0.0	5.9	0.0	5.9	0.0
ORP (mV)		148.0	0.0	474.0	0.0	188.0	0.0	483.0	3.0	206.0	1.0	499.5	1.5
DO (mg/L)		7.0	0.0	6.6	0.0	7.9	0.1	9.0	0.1	8.0	0.0	10.3	0.3
DO (%sat'n)		74.1	0.0	69.7	0.2	82.4	0.8	94.7	1.3	84.0	0.1	105.7	0.6
Turbidity (ntu)		19.2	0.3	5.5	0.1	51.8	4.7	13.9	0.2	20.7	0.5	10.4	0.2

continued

Appendix 3: Continued.

G. September 2010

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		9.4	0.0	9.8	0.0	11.7	0.0	11.8	0.0	11.8	0.0	11.9	0.0
Conductivity (µS/cm)		108.5	10.5	123.0	0.0	112.0	0.0	102.5	0.5	127.0	0.0	104.5	2.5
pH		6.5	0.0	6.3	0.0	6.6	0.0	6.6	0.0	6.2	0.0	6.4	0.0
ORP (mV)		410.0	0.0	420.5	0.5	456.5	2.5	472.0	2.0	416.5	0.5	357.0	3.0
DO (mg/L)		8.5	0.5	8.7	0.0	8.3	0.3	9.2	0.1	10.4	0.0	7.8	0.3
DO (%sat'n)		74.7	4.3	77.8	0.5	75.9	2.3	84.0	0.3	96.9	0.9	72.2	1.3
Turbidity (ntu)		3.4	0.1	4.2	0.1	7.2	0.4	5.4	0.3	1.9	0.1	2.5	0.1

H. April 2011

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		14.9	0.0	15.0	0.0	14.8	0.0	14.9	0.0	15.4	0.0	15.4	0.0
Conductivity (µS/cm)		114.5	2.5	117.0	1.0	122.0	0.0	112.0	0.0	120.0	0.0	98.5	2.5
pH		6.5	0.0	6.4	0.0	6.8	0.0	6.9	0.0	6.3	0.1	6.6	0.0
ORP (mV)		287.5	2.5	266.5	2.5	250.5	3.5	229.5	2.5	348.5	8.5	387.5	2.5
DO (mg/L)		10.2	0.0	7.1	0.0	9.1	0.0	9.1	0.0	9.8	0.0	10.6	0.1
DO (%sat'n)		101.1	0.5	72.3	1.1	89.7	0.6	89.9	0.6	98.1	0.1	106.3	1.1
Turbidity (ntu)		27.3	0.5	9.8	0.2	4.1	0.0	7.3	0.1	6.0	0.1	8.6	0.3

I. September 2011

WQ Parameter	Creek	Cataract Ck				Cataract River				Allens Ck			
	Site	5		6		9		10		13		14	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature (°C)		13.0	0.0	13.0	0.0	12.9	0.0	13.8	0.0	11.0	0.0	11.4	0.0
Conductivity (µS/cm)		146.0	1.0	162.5	31.5	215.0	2.0	282.0	2.0	202.5	2.5	194.0	0.0
pH		6.5	0.0	6.5	0.0	6.5	0.0	6.6	0.0	6.3	0.0	6.3	0.0
ORP (mV)		42.5	5.5	10.0	2.0	12.5	0.5	57.0	0.0	133.0	1.0	142.5	0.5
DO (mg/L)		8.1	0.0	7.4	0.1	7.1	0.0	7.6	0.0	7.7	0.0	7.4	0.0
DO (%sat'n)		85.1	0.3	77.6	0.8	67.0	0.7	72.9	0.3	69.6	0.3	67.7	0.2
Turbidity (ntu)		1.4	0.2	6.1	0.4	5.7	0.4	2.8	0.3	2.5	0.1	2.3	0.2

*NS = no sample
FP = faulty probe

Appendix 4: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.

(a) October 2008

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		5	0	0	2		0	0		
Araneae		0	0	1	4		1	0		
Athericidae		0	0	0	0		0	0		
Atyidae		10	10	4	2		10	10		
Austrocorduliidae		2	0	0	0		0	0		
Baetidae		0	0	3	1		0	0		
Caenidae		0	10	0	0		0	1		
Ceinidae		1	1	0	0		0	0		
Ceratopogonidae		0	0	0	2		0	1		
Chironomidae/Chironominae		5	1	0	2		4	10		
Chironomidae/Orthocladiinae		2	0	1	2		1	1		
Chironomidae/Tanypodinae		5	5	2	2		0	1		
Chrysomelidae		0	0	0	0		1	0		
Coenagrionidae		0	0	1	0		0	0		
Copepoda		2	0	1	0		0	0		
Corbiculidae/ Sphaeriidae		0	0	0	0		0	0		
Cordulephyidae		5	1	0	2		0	3		
Corixidae		1	0	1	0		0	0		
Corydalidae		0	0	0	0		0	0		
Culicidae		0	0	1	0		0	0		
Diphlebiidae		0	0	0	0		0	2		
Dixidae		7	9	0	0		0	0		
Dytiscidae		3	7	2	0		2	1		
Ecnomidae		0	0	0	0		0	0		
Elmidae		0	0	0	0		8	1		
Gelastocoridae		0	0	0	0		0	0		
Gerridae		2	1	1	2		1	1		
Gomphidae		1	2	0	0		0	0		
Gripopterygiidae		10	8	2	0		10	10		
Gyrinidae		0	1	1	1		0	0		
Hirudinidae		0	0	0	0		0	0		
Hydracarina		6	10	0	2		10	4		
Hydraenidae		0	0	0	0		0	0		
Hydrometridae		0	0	1	0		0	0		
Hydrophilidae		0	0	0	0		0	0		
Hydropsychidae		0	0	0	0		0	0		
Hydroptilidae		0	0	0	0		2	0		
Leptoceridae		10	10	10	10		10	10		
Leptophlebiidae		10	10	10	10		10	1		
Megapodagrionidae		1	0	5	3		0	1		
Nematoda		0	0	0	0		0	1		
Noteridae		0	0	0	0		0	0		
Notonectidae		3	4	1	5		0	0		
Oligochaeta		0	0	10	0		0	1		
Oniscidae		0	0	0	0		0	0		
Oniscigastridae		0	0	0	0		1	0		
Ostracoda		6	3	3	3		1	0		
Parastacidae		0	0	0	1		0	0		
Psephenidae		0	0	0	0		1	0		
Pyralidae		0	0	1	2		1	0		
Scirtidae		2	0	6	3		0	0		
Sialidae		0	0	0	0		0	0		
Simuliidae		0	0	0	0		1	0		
Synlestidae		0	0	3	10		3	1		
Synthemistidae		0	1	0	0		1	0		
Telephlebiidae		0	0	1	0		1	1		
Tipulidae		0	0	0	0		0	0		
Veliidae		0	0	5	0		0	1		
Total number of taxa		**22**	**18**	**25**	**21**		**21**	**21**		

Appendix 4 continued:

(b) December 2008

Order or Family	Location	Wallandoola Ck		Lizard Ck			Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		1	0	0	0		0	0		
Araneae		2	0	0	2		0	1		
Athericidae		0	0	0	0		0	0		
Atyidae		10	10	0	0		10	7		
Baetidae		0	2	0	4		0	0		
Ceinidae		3	0	0	0		0	0		
Ceratopogonidae		0	1	0	7		0	0		
Chironomidae/Chironominae		2	4	0	9		5	1		
Chironomidae/Orthocladiinae		1	1	0	1		0	2		
Chironomidae/Tanypodinae		1	1	0	7		1	1		
Cladocera		0	0	0	0		0	0		
Coenagrionidae		1	0	0	0		0	0		
Copepoda		1	0	0	1		1	1		
Corbiculidae/ Sphaeriidae		0	0	0	1		0	0		
Corixidae		1	1	0	0		0	0		
Culicidae		0	1	0	0		0	0		
Dixidae		5	0	1	0		0	0		
Dytiscidae		1	2	3	0		1	0		
Ecnomidae		0	0	0	1		0	0		
Elmidae		0	0	0	0		1	4		
Empididae		0	0	0	0		0	0		
Entomobryidae		0	0	0	1		0	0		
Gelastocoridae		0	0	0	0		0	0		
Gerridae		3	1	1	0		0	0		
Gomphidae		2	1	0	0		2	0		
Gripopterygiidae		10	10	0	0		10	10		
Gyrinidae		0	1	1	4		0	0		
Hirudinidae		0	0	0	0		0	0		
Hydracarina		3	8	2	4		10	10		
Hydraenidae		0	0	1	0		0	0		
Hydrobiosidae		0	0	0	0		0	0		
Hydrophilidae		2	0	0	0		2	0		
Hydroptilidae		0	0	0	1		2	1		
Leptoceridae		10	10	4	10		10	10		
Leptophlebiidae		10	10	0	10		10	3		
Megapodagrionidae		0	1	2	10		1	0		
Nematoda		0	0	0	0		0	0		
Noteridae		0	0	0	0		0	0		
Notonectidae		4	10	2	7		0	2		
Oligochaeta		0	1	3	1		1	1		
Oniscigastridae		0	0	0	0		0	0		
Ostracoda		0	1	4	9		2	2		
Parastacidae		1	1	0	1		4	1		
Polycentropodidae		0	0	0	3		0	0		
Psychodidae		0	0	0	0		0	0		
Pyralidae		0	0	0	1		0	0		
Sciomyzidae		0	0	0	0		0	0		
Scirtidae		0	2	1	2		0	0		
Sialidae		0	0	0	0		0	0		
Synlestidae		0	2	0	10		1	0		
Synthemistidae		0	0	2	1		0	0		
Telephlebiidae		0	3	0	1		1	4		
Tipulidae		0	1	0	1		0	0		
Veliidae		1	1	0	2		1	0		
Total number of taxa		**22**	**26**	**13**	**28**		**20**	**17**		

Appendix 4 continued:

(c) March 2009

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		8	1	DRY	2	8	0	0	4	2
Ancylidae		0	0	DRY	0	0	0	0	0	0
Araneae		0	0	DRY	0	0	1	0	0	0
Athericidae		0	0	DRY	0	0	0	0	0	0
Atyidae		10	7	DRY	0	0	6	10	5	8
Austrocorduliidae		0	1	DRY	0	0	0	3	0	2
Baetidae		0	0	DRY	0	0	3	2	0	0
Caenidae		0	10	DRY	0	0	1	2	0	0
Calamoceratidae		0	0	DRY	0	0	0	0	0	0
Ceinidae		1	0	DRY	0	0	0	0	10	9
Ceratopogonidae		0	0	DRY	0	0	1	0	2	0
Chironomidae/Aphroteniinae		0	0	DRY	0	0	0	0	0	0
Chironomidae/Chironominae		0	1	DRY	7	10	0	2	7	2
Chironomidae/Orthocladiinae		0	0	DRY	0	0	0	1	0	0
Chironomidae/Tanypodinae		0	0	DRY	1	0	1	2	8	5
Cladocera		0	0	DRY	0	1	0	0	1	0
Coenagrionidae		0	0	DRY	0	0	2	0	10	0
Copepoda		0	0	DRY	0	10	2	0	10	3
Corbiculidae/ Sphaeriidae		0	0	DRY	4	3	0	0	5	10
Cordulephyidae		0	0	DRY	0	0	3	3	1	1
Corixidae		0	0	DRY	0	0	2	0	0	4
Corydalidae		0	0	DRY	0	1	0	0	0	0
Dixidae		0	0	DRY	0	0	0	0	0	0
Dugesiidae		0	0	DRY	0	0	0	0	1	0
Dytiscidae		3	2	DRY	2	10	7	10	3	6
Ecnomidae		0	1	DRY	0	0	1	2	0	0
Elmidae		0	0	DRY	1	0	8	10	0	0
Empididae		0	0	DRY	0	0	0	0	0	0
Gelastocoridae		1	0	DRY	0	0	0	0	0	0
Gerridae		1	1	DRY	1	1	0	1	1	1
Gomphidae		4	4	DRY	1	0	4	10	1	1
Gripopterygiidae		0	6	DRY	0	0	10	10	0	0
Gyrinidae		1	1	DRY	1	1	0	0	1	1
Haliplidae		0	0	DRY	0	0	0	0	3	1
Hemicorduliidae		1	0	DRY	0	7	0	0	1	8
Hirudinidae		0	0	DRY	0	0	0	0	0	0
Hydracarina		4	2	DRY	1	3	10	10	7	3
Hydraenidae		0	0	DRY	0	1	0	0	0	0
Hydrochidae		0	0	DRY	0	0	0	0	0	0
Hydrometridae		0	0	DRY	0	1	0	0	0	0
Hydrophilidae		3	0	DRY	1	2	0	0	0	0
Hydroptilidae		0	1	DRY	0	0	1	0	0	0
Leptoceridae		9	10	DRY	2	0	10	10	10	10
Leptophlebiidae		2	2	DRY	10	0	10	5	10	10
Lestidae		0	0	DRY	0	0	0	0	1	0
Megapodagrionidae		1	2	DRY	5	10	0	1	10	10
Nematomorpha		0	0	DRY	0	0	2	0	0	1
Nepidae		0	0	DRY	0	0	0	0	1	0
Noteridae		0	0	DRY	0	0	0	0	0	0
Notonectidae		8	10	DRY	10	1	0	3	10	10
Notonemouridae		0	0	DRY	0	0	0	0	0	0
Odontoceridae		0	0	DRY	0	0	0	0	0	1
Oligochaeta		0	0	DRY	0	0	0	0	1	0
Oniscigastridae		0	0	DRY	0	0	0	0	0	0
Ostracoda		1	0	DRY	7	3	3	2	10	10
Parastacidae		0	0	DRY	0	0	0	1	0	0
Philorheithridae		0	0	DRY	0	0	0	0	0	0
Planorbidae		0	0	DRY	0	0	0	0	0	0
Psephenidae		0	0	DRY	0	0	4	1	0	0
Pyralidae		0	0	DRY	3	0	2	0	0	1
Scirtidae		0	0	DRY	1	3	4	0	0	1
Sialidae		0	0	DRY	0	0	0	0	4	0
Sminthuridae		0	0	DRY	0	0	0	0	0	0
Synlestidae		0	1	DRY	0	0	1	0	0	0
Synthemistidae		0	0	DRY	0	0	0	0	1	0
Telephlebiidae		0	0	DRY	0	0	1	3	0	0
Tipulidae		0	0	DRY	1	0	1	1	0	0
Veliidae		0	0	DRY	0	0	2	2	0	0
Total number of taxa		**16**	**18**	DRY	**19**	**18**	**28**	**25**	**29**	**26**

Appendix 4 continued:

(d) May 2009

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		0	1	0	0	1	0	0	4	1
Ancylidae		0	0	0	0	0	0	0	0	0
Araneae		0	0	0	0	0	0	0	0	0
Athericidae		0	0	0	0	0	0	0	0	0
Atyidae		10	10	0	0	0	6	10	3	2
Austrocorduliidae		1	0	0	0	0	0	3	0	1
Baetidae		1	1	0	0	0	1	1	0	0
Caenidae		10	10	0	0	0	0	2	0	0
Calamoceratidae		0	0	0	0	0	0	0	0	0
Ceinidae		1	0	0	0	0	0	0	10	10
Ceratopogonidae		0	0	0	2	0	3	0	2	6
Chironomidae/Aphroteniinae		0	0	0	0	0	0	1	0	0
Chironomidae/Chironominae		1	1	1	0	10	10	6	2	7
Chironomidae/Orthocladiinae		0	0	0	0	0	1	0	0	0
Chironomidae/Tanypodinae		4	2	2	5	0	2	1	3	6
Cladocera		0	0	0	0	0	0	0	1	0
Coenagrionidae		0	0	0	0	0	7	0	10	0
Copepoda		1	1	0	1	8	1	0	4	1
Corbiculidae/ Sphaeriidae		0	0	0	5	7	0	2	0	3
Cordulephyidae		1	2	0	0	0	0	2	1	1
Corixidae		2	1	0	1	0	6	0	1	4
Corydalidae		0	0	0	0	0	0	0	0	0
Dixidae		0	0	0	0	0	0	0	0	0
Dytiscidae		2	10	1	0	6	3	4	6	3
Ecnomidae		1	0	0	0	0	3	3	0	0
Elmidae		0	0	0	0	0	0	6	0	0
Gelastocoridae		0	0	0	0	0	0	0	0	0
Gerridae		1	1	0	1	1	0	0	4	0
Gomphidae		4	2	1	0	0	2	5	1	1
Gripopterygiidae		0	2	0	0	0	7	8	0	0
Gyrinidae		1	1	0	1	1	0	0	1	1
Haliplidae		0	0	0	0	0	0	0	1	0
Hemicorduliidae		0	0	0	0	2	6	0	6	7
Hirudinidae		0	0	0	0	0	0	0	0	0
Hydracarina		4	3	2	7	7	10	10	2	7
Hydridae		0	0	0	0	0	0	0	1	0
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrophilidae		0	0	0	0	0	0	0	0	1
Hydroptilidae		0	0	0	0	0	4	3	0	0
Isostictidae		1	0	0	0	0	0	0	0	0
Leptoceridae		10	10	1	1	1	10	10	1	6
Leptophlebiidae		5	1	0	10	0	4	6	7	7
Lestidae		0	0	0	0	0	1	0	10	0
Megapodagrionidae		0	2	0	2	0	1	0	4	7
Nematoda		0	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	0	0
Notonectidae		1	10	1	0	0	0	0	10	6
Odontoceridae		0	0	0	0	0	0	0	0	0
Oligochaeta		0	0	0	0	0	3	0	0	0
Oniscigastridae		0	0	0	0	0	0	0	0	0
Ostracoda		1	1	0	10	0	5	0	4	3
Parastacidae		0	0	0	0	0	0	0	0	0
Philopotamidae		0	0	0	0	0	0	0	0	0
Philorheithridae		0	0	0	0	0	0	0	0	0
Ptilodactylidae		0	0	0	0	0	0	0	0	0
Pyralidae		0	0	0	0	0	4	0	0	0
Scirtidae		0	0	0	1	0	0	0	0	0
Sialidae		0	0	0	0	0	0	0	3	0
Simuliidae		0	0	0	0	0	0	1	0	0
Synthemistidae		0	1	0	0	0	1	0	0	0
Tanyderidae		0	0	0	0	0	0	0	0	0
Telephlebiidae		0	0	0	0	0	1	1	0	0
Tipulidae		0	0	0	1	0	1	0	0	0
Veliidae		0	0	0	0	0	0	0	0	0
Total number of taxa		**21**	**21**	**7**	**14**	**10**	**26**	**20**	**26**	**22**

Appendix 4 continued:

(e) November 2009

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		1	0	DRY	0	0	0	0	1	1
Araneae		0	0	DRY	2	0	0	0	1	0
Athericidae		0	0	DRY	0	0	0	1	0	0
Atyidae		5	10	DRY	0	0	7	10	6	10
Austrocorduliidae		0	1	DRY	0	0	0	0	0	3
Baetidae		0	0	DRY	0	0	1	2	0	1
Caenidae		0	10	DRY	0	0	0	2	0	0
Calamoceratidae		0	0	DRY	0	0	0	0	0	0
Ceinidae		0	0	DRY	0	1	0	0	10	10
Ceratopogonidae		1	1	DRY	1	0	0	0	2	0
Chironomidae/Chironominae		4	0	DRY	10	5	3	2	10	6
Chironomidae/Orthocladiinae		0	0	DRY	0	0	1	0	0	0
Chironomidae/Tanypodinae		3	0	DRY	0	1	1	1	4	2
Cladocera		0	0	DRY	1	0	0	0	0	0
Coenagrionidae		0	0	DRY	1	0	0	0	3	1
Copepoda		0	0	DRY	0	2	0	0	5	2
Corbiculidae/ Sphaeriidae		0	0	DRY	2	3	0	0	3	2
Cordulephyidae		0	0	DRY	0	0	0	0	1	4
Corixidae		0	1	DRY	2	0	0	0	6	3
Corydalidae		0	0	DRY	0	0	0	0	1	0
Culicidae		0	0	DRY	0	0	0	0	0	0
Dixidae		0	0	DRY	0	0	0	0	0	0
Dytiscidae		4	4	DRY	2	1	7	2	2	6
Ecnomidae		0	1	DRY	0	0	0	0	0	0
Elmidae		0	0	DRY	0	0	2	8	0	0
Gelastocoridae		0	0	DRY	0	0	0	0	0	0
Gerridae		0	0	DRY	0	0	0	0	1	0
Gomphidae		1	7	DRY	0	0	3	3	1	0
Gripopterygiidae		9	6	DRY	0	0	10	10	0	0
Gyrinidae		0	0	DRY	2	1	0	0	0	0
Hemicorduliidae		0	0	DRY	0	2	0	0	3	0
Hirudinidae		0	0	DRY	0	0	0	0	0	0
Hydracarina		3	4	DRY	3	4	10	4	1	3
Hydraenidae		0	0	DRY	0	0	0	0	0	0
Hydrobiosidae		0	0	DRY	0	0	0	1	0	0
Hydrophilidae		0	0	DRY	0	0	0	0	0	0
Hypogastruridae		0	0	DRY	0	0	0	0	0	0
Leptoceridae		7	10	DRY	1	0	7	6	0	10
Leptophlebiidae		10	4	DRY	2	1	8	5	9	10
Lestidae		0	0	DRY	0	0	0	0	1	0
Megapodagrionidae		0	0	DRY	0	0	0	0	0	2
Nematoda		0	0	DRY	0	0	0	0	0	0
Noteridae		0	0	DRY	0	0	0	0	0	0
Notonectidae		1	3	DRY	3	0	0	0	2	7
Oligochaeta		0	0	DRY	0	0	2	1	0	0
Oniscigastridae		0	0	DRY	0	0	0	0	0	0
Ostracoda		0	1	DRY	10	1	6	1	5	2
Parastacidae		0	0	DRY	0	0	0	0	0	0
Scirtidae		0	1	DRY	0	0	0	0	0	0
Simuliidae		0	0	DRY	0	1	0	0	0	0
Synlestidae		0	0	DRY	1	0	1	0	0	2
Synthemistidae		1	2	DRY	0	0	0	0	0	0
Telephlebiidae		1	3	DRY	0	0	0	0	0	0
Tipulidae		0	1	DRY	0	0	3	0	0	0
Urothemistidae		0	0	DRY	0	0	0	0	0	1
Veliidae		0	0	DRY	0	0	0	0	0	0
Total number of taxa		**14**	**18**	DRY	**15**	**12**	**16**	**16**	**22**	**21**

Appendix 4 continued:

(f) March 2010

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		6	1	DRY	2	2	0	0	2	0
Araneae		0	1	DRY	0	1	0	0	1	0
Athericidae		0	0	DRY	0	0	0	0	0	0
Atyidae		2	5	DRY	0	0	6	6	3	10
Austrocorduliidae		0	2	DRY	1	0	1	1	0	0
Caenidae		0	10	DRY	0	0	0	0	10	0
Ceinidae		2	0	DRY	0	0	0	0	0	10
Ceratopogonidae		0	0	DRY	1	0	1	1	7	0
Chironomidae/Chironominae		0	1	DRY	10	0	0	2	4	6
Chironomidae/Orthocladiinae		0	0	DRY	0	0	1	0	0	0
Chironomidae/Tanypodinae		2	1	DRY	3	0	0	0	4	1
Cladocera		0	0	DRY	0	1	1	0	1	1
Coenagrionidae		0	0	DRY	0	0	1	0	2	0
Copepoda		1	1	DRY	0	10	0	0	4	10
Corbiculidae/ Sphaeriidae		0	0	DRY	1	1	0	0	0	1
Cordulephyidae		0	0	DRY	0	0	1	1	2	6
Corixidae		6	1	DRY	0	0	1	0	7	6
Corydalidae		1	0	DRY	1	0	0	0	0	0
Culicidae		0	0	DRY	0	0	0	0	1	0
Diphlebiidae		0	0	DRY	0	0	0	1	0	0
Dixidae		0	0	DRY	0	0	0	0	0	0
Dytiscidae		7	3	DRY	1	5	3	10	3	5
Elmidae		0	1	DRY	0	0	7	3	0	0
Gerridae		0	2	DRY	1	0	0	0	0	2
Gomphidae		0	5	DRY	0	0	1	2	1	1
Gripopterygiidae		0	7	DRY	0	0	10	8	0	0
Gyrinidae		0	0	DRY	1	0	0	0	0	1
Haliplidae		0	0	DRY	0	0	0	0	0	1
Hebridae		1	0	DRY	0	0	0	0	0	0
Hemicorduliidae		1	0	DRY	0	0	0	0	3	5
Hirudinidae		0	0	DRY	0	0	0	0	0	0
Hydracarina		3	1	DRY	2	1	10	8	4	4
Hydrobiosidae		0	1	DRY	0	0	0	0	0	0
Hydrometridae		1	0	DRY	0	0	0	0	0	0
Hydrophilidae		0	0	DRY	0	0	0	0	0	0
Hydroptilidae		0	0	DRY	0	0	2	0	0	0
Hypogastruridae		0	0	DRY	0	1	0	0	0	0
Leptoceridae		6	10	DRY	1	0	10	10	1	3
Leptophlebiidae		0	5	DRY	10	1	8	1	10	10
Lestidae		0	0	DRY	0	0	0	0	4	0
Libellulidae		0	0	DRY	0	0	0	0	1	0
Megapodagrionidae		1	2	DRY	1	0	0	0	2	7
Mesoveliidae		0	0	DRY	0	0	0	0	0	0
Nematoda		0	0	DRY	0	0	0	0	2	0
Notonectidae		4	8	DRY	3	0	0	0	4	10
Oligochaeta		0	0	DRY	0	0	0	0	1	0
Oniscigastridae		0	0	DRY	0	0	0	0	0	0
Ostracoda		1	0	DRY	4	0	0	0	8	3
Parastacidae		2	0	DRY	1	0	1	0	0	0
Philopotamidae		0	0	DRY	0	0	0	0	0	0
Philorheithridae		1	0	DRY	0	0	0	0	0	0
Psephenidae		0	0	DRY	0	0	1	0	0	0
Pyralidae		0	0	DRY	1	0	2	0	0	0
Scirtidae		0	0	DRY	0	4	0	0	0	0
Sialidae		0	0	DRY	2	0	0	0	2	0
Simuliidae		0	0	DRY	0	0	0	0	0	0
Synlestidae		0	0	DRY	1	0	0	0	0	0
Synthemistidae		0	1	DRY	0	0	0	0	0	0
Telephlebiidae		0	0	DRY	0	0	0	0	1	0
Temnocephalidae		1	0	DRY	0	0	0	0	0	0
Tipulidae		0	0	DRY	1	0	2	1	0	0
Veliidae		2	0	DRY	0	0	0	0	0	0
Total number of taxa		**20**	**21**	DRY	**21**	**10**	**20**	**14**	**28**	**21**

Appendix 4 continued:

(g) September 2010

Order or Family — Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
Site	1	2	3	4	17	11	12	15	16
Aeshnidae	1	3		1	0	0	0	3	2
Araneae	0	0		1	0	3	0	0	2
Atyidae	4	7		0	0	10	6	6	10
Baetidae	0	0		0	0	0	1	0	0
Caenidae	0	10		0	0	0	5	0	0
Ceinidae	0	2		0	0	0	0	0	7
Ceratopogonidae	1	0		0	0	0	0	2	0
Chironomidae/Chironominae	0	4		1	0	3	10	2	3
Chironomidae/Orthocladiinae	0	0		2	1	3	5	0	0
Chironomidae/Tanypodinae	1	0		0	0	0	2	1	0
Cladocera	0	0		0	1	0	0	0	1
Coenagrionidae	0	0		0	0	0	0	6	0
Copepoda	0	0		0	1	0	0	0	0
Corbiculidae/ Sphaeriidae	0	0		0	0	0	0	4	1
Cordulephyidae	0	1		0	0	0	1	0	2
Corixidae	0	0		1	0	0	1	0	0
Corydalidae	0	0		0	0	0	0	0	0
Curculionidae	0	0		0	0	1	0	0	0
Dixidae	0	0		0	0	0	0	0	0
Dytiscidae	4	2		0	2	0	4	2	1
Ecnomidae	0	0		0	0	0	0	0	0
Elmidae	0	0		0	0	4	2	0	1
Eusiridae	0	0		0	0	0	0	10	0
Gelastocoridae	0	0		0	0	0	0	3	0
Gerridae	0	1		1	1	1	0	0	0
Gomphidae	0	0		0	0	0	5	1	1
Gripopterygiidae	0	10		0	0	3	10	0	0
Gyrinidae	0	1		0	0	0	0	0	1
Hemicorduliidae	0	0		0	0	0	0	5	0
Hydracarina	1	6		0	0	4	7	3	1
Hydraenidae	0	0		0	0	0	0	2	0
Hydrobiosidae	0	0		0	0	0	1	0	0
Hydrometridae	0	1		0	0	0	2	0	0
Hydrophilidae	1	0		0	1	0	0	0	0
Hypogastruridae	0	0		0	0	0	0	0	0
Leptoceridae	10	10		8	1	9	7	10	10
Leptophlebiidae	0	0		5	4	3	4	5	10
Lestidae	0	0		0	0	0	0	1	0
Megapodagrionidae	0	0		0	0	0	0	1	2
Noteridae	0	0		0	0	0	0	0	0
Notonectidae	4	3		2	1	0	0	7	7
Oligochaeta	0	0		0	0	0	2	0	0
Oniscigastridae	0	0		0	0	0	0	0	0
Ostracoda	2	1		3	2	0	1	3	0
Parastacidae	0	0		0	0	1	1	0	0
Pyralidae	0	0		0	0	0	0	4	0
Scirtidae	0	0		1	5	0	1	4	1
Synlestidae	0	0		0	0	2	0	0	0
Synthemistidae	0	0		1	0	0	1	0	0
Telephlebiidae	1	0		0	0	0	0	0	0
Tipulidae	0	0		2	1	0	0	0	1
Veliidae	0	4		0	0	0	0	1	0
Total number of taxa	**11**	**16**		**13**	**12**	**13**	**22**	**23**	**19**

Appendix 4 continued:

(h) April 2011

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		4	0	0	1	2	0	0	4	10
Ancylidae		0	0	0	0	0	1	0	0	0
Araneae		0	0	0	0	3	0	0	1	0
Athericidae		0	0	0	0	0	0	0	0	0
Atriplectididae		0	0	0	0	0	1	0	0	0
Atyidae		10	10	0	0	0	10	9	3	3
Austrocorduliidae		3	0	0	0	0	0	0	0	2
Caenidae		0	10	0	0	0	0	0	0	0
Calamoceratidae		0	0	0	0	0	0	0	0	0
Ceinidae		0	0	0	0	0	0	0	6	6
Ceratopogonidae		0	3	0	1	2	1	0	4	1
Chironomidae/Aphroteniinae		1	0	0	0	0	0	0	0	0
Chironomidae/Chironominae		1	1	0	1	0	4	1	1	10
Chironomidae/Orthocladiinae		2	0	0	0	0	0	0	0	0
Chironomidae/Tanypodinae		1	1	9	1	3	1	0	8	10
Cladocera		0	0	0	0	0	0	0	0	1
Coenagrionidae		0	0	0	0	0	0	0	10	0
Copepoda		0	0	0	3	5	0	0	0	10
Corbiculidae/ Sphaeriidae		0	0	0	0	5	0	0	0	5
Cordulephyidae		6	2	0	0	0	0	3	0	5
Corixidae		2	0	0	0	0	0	0	1	2
Corydalidae		0	0	0	0	1	0	0	0	0
Culicidae		0	0	0	0	0	1	0	0	0
Curculionidae		0	0	0	0	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0	1	0	0
Dixidae		0	0	0	0	0	0	0	0	0
Dugesiidae		0	0	0	0	0	0	0	3	0
Dytiscidae		7	3	0	0	6	3	10	6	2
Ecnomidae		0	0	0	0	0	0	0	0	0
Elmidae		0	0	0	0	0	1	0	0	0
Empididae		0	0	0	0	0	0	0	0	0
Gerridae		1	1	1	4	1	6	1	3	1
Gomphidae		8	1	0	0	0	2	1	1	1
Gripopterygiidae		5	4	0	0	0	10	9	0	0
Gyrinidae		1	1	0	5	2	0	0	1	2
Haliplidae		0	0	0	0	0	0	0	1	5
Hemicorduliidae		3	0	1	2	1	0	0	0	4
Hirudinidae		0	0	0	0	0	0	0	0	0
Hydracarina		6	4	0	1	1	4	3	2	1
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrometridae		0	0	0	0	0	0	0	0	0
Hydrophilidae		0	0	0	0	0	0	0	0	0
Hydroptilidae		0	0	0	1	0	5	4	0	0
Leptoceridae		10	7	3	3	6	9	10	1	5
Leptophlebiidae		4	2	0	10	10	10	4	10	10
Lestidae		0	0	0	0	0	0	0	6	1
Megapodagrionidae		1	0	0	10	4	1	0	2	8
Nematomorpha		0	0	0	0	0	0	1	0	0
Nepidae		0	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	0	0
Notonectidae		8	6	1	2	2	0	0	6	8
Odontoceridae		0	0	0	0	0	0	1	0	0
Oligochaeta		0	0	0	0	3	0	0	2	0
Ostracoda		0	1	0	1	0	1	1	4	1
Parastacidae		1	0	0	3	1	1	0	0	0
Philorheithridae		3	0	0	0	0	0	0	3	0
Polycentropodidae		0	0	0	0	0	0	0	0	0
Psephenidae		0	0	0	0	0	1	0	0	1
Pyralidae		0	0	1	1	2	1	0	0	0
Scirtidae		0	0	1	0	1	0	0	0	0
Sialidae		0	0	1	0	0	0	0	3	0
Simuliidae		0	0	0	0	0	0	1	0	0
Synlestidae		0	0	0	1	0	0	0	0	0
Synthemistidae		1	0	0	0	0	0	0	2	0
Telephlebiidae		0	0	0	0	0	0	1	0	0
Tipulidae		1	0	0	3	0	0	2	0	0
Veliidae		1	0	0	0	0	2	0	0	0
Total number of taxa		**25**	**16**	**8**	**19**	**20**	**22**	**18**	**26**	**26**

Appendix 4 continued:

(i) September 2011

Order or Family	Location	Wallandoola Ck			Lizard Ck		Loddon Ck		Cascade Ck	
	Site	1	2	3	4	17	11	12	15	16
Aeshnidae		0	0	0	0	0	0	0	0	3
Ancylidae		0	0	0	0	0	0	0	0	0
Atyidae		0	10	0	0	0	7	10	8	0
Austrocorduliidae		0	1	0	0	0	0	0	0	0
Baetidae		0	0	0	0	0	1	0	0	0
Caenidae		0	0	0	2	0	0	0	0	0
Ceinidae		0	0	0	0	0	0	0	10	8
Ceratopogonidae		0	0	0	0	3	0	0	0	0
Chironomidae/Chironominae		0	2	0	2	2	2	2	2	0
Chironomidae/Orthocladiinae		0	0	0	0	2	0	0	0	0
Chironomidae/Tanypodinae		0	0	5	0	2	0	0	3	5
Coenagrionidae		0	0	0	0	0	0	0	2	0
Copepoda		1	0	0	0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	1	1	0	0	3	2
Corixidae		0	0	0	0	0	0	0	0	0
Corydalidae		0	0	0	0	0	0	0	0	0
Dixidae		1	0	0	0	0	0	0	0	0
Dytiscidae		1	1	1	1	1	1	4	0	1
Ecnomidae		0	0	0	0	0	0	3	2	0
Elmidae		0	0	0	0	0	5	0	0	0
Gelastocoridae		0	0	0	1	0	0	0	1	0
Gomphidae		0	0	0	0	0	2	3	1	0
Gripopterygiidae		0	2	0	0	0	10	3	5	0
Gyrinidae		1	1	0	0	1	0	0	0	0
Helicopsychidae		0	0	0	0	0	0	0	0	0
Hemicorduliidae		0	0	0	0	0	0	0	1	0
Hydracarina		0	2	0	0	3	10	3	0	3
Hydraenidae		0	0	1	0	0	0	0	0	0
Hydrobiosidae		0	0	0	0	0	0	0	0	0
Hydrometridae		0	0	0	0	1	0	0	0	1
Leptoceridae		0	7	1	0	1	3	5	1	1
Leptophlebiidae		9	1	6	10	10	6	3	10	10
Libellulidae		0	0	0	0	1	0	0	0	1
Megapodagrionidae		0	0	0	1	2	1	0	6	3
Naucoridae		0	0	0	0	0	0	1	0	0
Nematoda		1	0	0	0	0	0	0	0	0
Noteridae		0	0	0	0	0	0	0	1	0
Notonectidae		1	3	0	0	0	0	0	1	0
Odontoceridae		0	0	0	0	0	0	0	0	0
Oligochaeta		0	0	6	0	0	0	4	0	0
Oniscigastridae		0	0	0	0	0	0	0	0	0
Ostracoda		0	0	0	0	0	0	0	1	0
Philorheithridae		0	0	0	0	0	0	0	0	0
Pyralidae		0	0	0	0	2	0	0	0	2
Scirtidae		0	0	10	0	1	0	0	0	1
Sialidae		0	0	1	0	0	0	0	0	0
Synthemistidae		0	0	1	2	0	3	0	1	0
Telephlebiidae		0	0	0	0	0	0	0	1	0
Tipulidae		0	0	0	3	0	2	0	0	0
Veliidae		0	0	0	0	0	0	0	0	0
Total number of taxa		**7**	**10**	**9**	**9**	**15**	**13**	**11**	**19**	**13**

Appendix 5: Aquatic macroinvertebrate taxa recorded in each sample collected from edge habitat at the monitoring sites in the Wongawilli West Study Area in (a) October 2008; (b) December 2008; (c) March 2009; (d) May 2009; (e) November 2009; (f) March 2010; (g) September 2010; (h) April 2011 and (i) September 2011.

(a) October 2008

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0		
Araneae		0	2	0	2		
Athericidae		1	0	1	1		
Atyidae		0	0	0	0		
Austrocorduliidae		0	0	0	0		
Baetidae		0	0	0	0		
Caenidae		0	0	0	0		
Ceinidae		0	0	0	0		
Ceratopogonidae		0	1	8	1		
Chironomidae/Chironominae		2	4	10	7		
Chironomidae/Orthocladiinae		1	4	2	1		
Chironomidae/Tanypodinae		4	4	10	1		
Chrysomelidae		0	0	0	0		
Coenagrionidae		0	0	0	0		
Copepoda		0	0	1	0		
Corbiculidae/ Sphaeriidae		0	0	1	0		
Cordulephyidae		0	0	0	0		
Corixidae		0	0	2	0		
Corydalidae		1	0	0	0		
Culicidae		0	0	0	0		
Diphlebiidae		0	0	0	0		
Dixidae		0	1	3	3		
Dytiscidae		0	0	4	1		
Ecnomidae		1	1	0	0		
Elmidae		0	0	0	2		
Gelastocoridae		0	1	1	0		
Gerridae		0	0	0	0		
Gomphidae		0	0	4	1		
Gripopterygiidae		0	4	2	7		
Gyrinidae		3	2	5	1		
Hirudinidae		0	3	0	1		
Hydracarina		6	10	7	8		
Hydraenidae		0	3	1	0		
Hydrometridae		0	0	0	0		
Hydrophilidae		0	0	3	4		
Hydropsychidae		0	0	0	0		
Hydroptilidae		0	0	0	0		
Leptoceridae		10	10	10	10		
Leptophlebiidae		10	10	10	10		
Megapodagrionidae		0	2	3	0		
Nematoda		0	0	0	0		
Noteridae		0	0	1	1		
Notonectidae		0	0	0	1		
Oligochaeta		0	0	1	0		
Oniscidae		0	0	0	0		
Oniscigastridae		0	0	10	4		
Ostracoda		0	0	0	0		
Parastacidae		0	0	0	1		
Psephenidae		0	0	0	0		
Pyralidae		0	0	0	1		
Scirtidae		0	1	1	5		
Sialidae		0	0	3	0		
Simuliidae		0	0	0	0		
Synlestidae		0	0	1	0		
Synthemistidae		5	2	2	0		
Telephlebiidae		0	0	0	1		
Tipulidae		2	1	1	0		
Veliidae		1	0	0	0		
Total number of taxa		**13**	**19**	**28**	**24**		

Appendix 5 continued:

(b) December 2008

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0		
Araneae		2	0	2	4		
Athericidae		0	1	1	0		
Atyidae		0	0	0	1		
Baetidae		0	0	0	0		
Ceinidae		0	1	0	0		
Ceratopogonidae		6	0	4	5		
Chironomidae/Chironominae		1	2	5	3		
Chironomidae/Orthocladiinae		1	0	3	2		
Chironomidae/Tanypodinae		4	0	6	4		
Cladocera		0	0	0	0		
Coenagrionidae		0	0	0	0		
Copepoda		1	0	0	0		
Corbiculidae/ Sphaeriidae		0	2	0	0		
Corixidae		0	0	0	0		
Culicidae		1	0	1	2		
Dixidae		10	10	4	7		
Dytiscidae		0	0	2	1		
Ecnomidae		3	3	10	2		
Elmidae		0	0	0	0		
Empididae		0	0	0	0		
Entomobryidae		1	0	0	0		
Gelastocoridae		0	0	1	1		
Gerridae		0	0	0	0		
Gomphidae		0	0	2	1		
Gripopterygiidae		0	0	0	4		
Gyrinidae		2	1	2	3		
Hirudinidae		1	0	0	0		
Hydracarina		10	10	3	4		
Hydraenidae		0	1	1	2		
Hydrobiosidae		0	0	0	0		
Hydrophilidae		0	0	0	1		
Hydroptilidae		0	0	0	0		
Leptoceridae		10	10	10	10		
Leptophlebiidae		9	8	10	10		
Megapodagrionidae		0	5	1	6		
Nematoda		0	2	0	0		
Noteridae		0	3	2	1		
Notonectidae		0	0	0	0		
Oligochaeta		1	0	1	2		
Oniscigastridae		0	0	0	7		
Ostracoda		0	0	0	0		
Parastacidae		0	0	0	0		
Polycentropodidae		0	0	0	0		
Psychodidae		0	0	0	0		
Pyralidae		0	1	0	0		
Sciomyzidae		1	0	0	0		
Scirtidae		3	4	4	0		
Sialidae		0	0	1	0		
Synlestidae		4	2	4	10		
Synthemistidae		6	0	0	0		
Telephlebiidae		3	0	1	0		
Tipulidae		1	0	6	3		
Veliidae		3	1	1	4		
Total number of taxa		**23**	**18**	**26**	**26**		

Appendix 5 continued:

(c) March 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		1	0	1	0	2	1
Araneae		1	3	5	3	3	0
Athericidae		10	0	0	0	0	0
Atyidae		0	10	0	10	4	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	1	1
Calamoceratidae		0	0	0	0	0	1
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		0	0	1	0	1	0
Chironomidae/Aphroteniinae		0	0	0	0	0	0
Chironomidae/Chironominae		2	2	10	1	3	3
Chironomidae/Orthocladiinae		1	0	0	0	2	1
Chironomidae/Tanypodinae		4	5	4	1	9	1
Cladocera		0	0	1	1	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		1	2	2	0	1	0
Cordulephyidae		0	0	0	0	0	1
Corixidae		0	0	5	0	10	3
Corydalidae		0	0	0	0	0	0
Dixidae		1	0	1	6	4	0
Dugesiidae		0	0	0	1	0	0
Dytiscidae		0	0	9	0	0	6
Ecnomidae		0	1	0	1	0	0
Elmidae		0	0	0	0	1	1
Empididae		2	0	0	0	0	0
Gelastocoridae		0	2	1	2	0	0
Gerridae		0	0	5	3	3	2
Gomphidae		0	1	4	3	3	3
Gripopterygiidae		0	0	10	10	6	2
Gyrinidae		5	2	1	1	2	3
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	1	0	0	1
Hirudinidae		0	0	1	0	0	1
Hydracarina		6	10	10	10	10	10
Hydraenidae		0	0	0	1	0	0
Hydrochidae		0	0	0	3	0	0
Hydrometridae		0	0	0	0	0	0
Hydrophilidae		0	0	4	0	0	0
Hydroptilidae		0	0	5	0	0	2
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		7	7	10	8	10	3
Lestidae		0	0	0	0	0	0
Megapodagrionidae		1	1	3	2	1	0
Nematomorpha		0	0	0	0	0	0
Nepidae		0	0	0	0	0	0
Noteridae		0	3	5	3	2	2
Notonectidae		0	0	2	3	1	1
Notonemouridae		1	0	0	0	0	0
Odontoceridae		0	0	0	0	0	0
Oligochaeta		0	0	0	0	0	0
Oniscigastridae		0	3	0	1	1	0
Ostracoda		0	0	2	1	1	0
Parastacidae		3	7	1	0	1	1
Philorheithridae		0	0	0	0	0	0
Planorbidae		0	0	1	0	0	0
Psephenidae		0	0	0	0	0	1
Pyralidae		0	0	0	0	0	0
Scirtidae		2	1	2	6	3	1
Sialidae		0	0	0	1	0	0
Sminthuridae		0	1	0	0	0	0
Synlestidae		1	1	1	2	0	0
Synthemistidae		0	8	0	0	1	0
Telephlebiidae		2	0	3	3	5	2
Tipulidae		2	3	2	1	0	1
Veliidae		0	1	4	9	1	2
Total number of taxa		**20**	**22**	**33**	**29**	**29**	**29**

Appendix 5 continued:

(d) May 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	1	1	1	1	2
Araneae		0	1	0	0	0	0
Athericidae		3	1	2	0	0	0
Atyidae		0	10	0	10	4	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	1	1
Calamoceratidae		0	0	0	0	0	2
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		1	0	6	0	3	1
Chironomidae/Aphroteniinae		1	0	0	1	0	1
Chironomidae/Chironominae		1	2	6	1	3	2
Chironomidae/Orthocladiinae		0	0	0	0	0	1
Chironomidae/Tanypodinae		7	3	7	7	3	3
Cladocera		0	0	0	0	1	0
Coenagrionidae		0	0	0	1	0	0
Copepoda		0	1	0	1	1	0
Corbiculidae/ Sphaeriidae		0	3	6	0	2	2
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	5	0	3	2
Corydalidae		2	0	0	0	0	0
Dixidae		1	0	3	2	4	3
Dytiscidae		0	0	4	2	0	2
Ecnomidae		0	0	1	4	0	0
Elmidae		0	0	1	1	1	0
Gelastocoridae		1	0	1	0	0	0
Gerridae		0	0	0	0	2	2
Gomphidae		0	1	7	5	4	5
Gripopterygiidae		0	1	1	7	0	0
Gyrinidae		1	7	1	3	5	2
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	0	2	0	0
Hirudinidae		0	0	0	0	0	1
Hydracarina		3	10	8	10	6	5
Hydridae		0	0	0	0	0	0
Hydrobiosidae		0	0	1	0	0	0
Hydrophilidae		0	0	0	1	0	0
Hydroptilidae		0	0	4	1	5	2
Isostictidae		0	0	0	0	0	0
Leptoceridae		10	10	8	10	10	10
Leptophlebiidae		10	10	10	10	10	5
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	4	2	3	2	0
Nematoda		0	0	1	0	0	0
Noteridae		0	0	1	0	0	1
Notonectidae		0	0	0	1	0	1
Odontoceridae		0	0	0	0	0	1
Oligochaeta		0	1	2	0	0	0
Oniscigastridae		0	0	1	1	0	0
Ostracoda		0	0	1	1	3	0
Parastacidae		0	1	0	0	1	0
Philopotamidae		0	0	0	0	0	0
Philorheithridae		0	1	0	0	0	0
Ptilodactylidae		0	0	0	0	0	0
Pyralidae		0	0	0	0	0	0
Scirtidae		10	0	2	0	1	1
Sialidae		0	0	0	0	0	0
Simuliidae		1	0	0	0	0	0
Synthemistidae		4	0	0	1	1	0
Tanyderidae		0	1	0	0	0	0
Telephlebiidae		1	0	0	0	2	0
Tipulidae		8	0	6	2	2	3
Veliidae		0	2	0	0	0	0
Total number of taxa		**17**	**20**	**28**	**26**	**26**	**26**

Appendix 5 continued:

(e) November 2009

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	0	0	1	0
Athericidae		4	1	0	0	0	0
Atyidae		0	5	0	0	1	10
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	4
Calamoceratidae		0	0	0	0	0	3
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		10	4	5	4	3	8
Chironomidae/Chironominae		0	2	3	4	0	1
Chironomidae/Orthocladiinae		0	0	0	1	1	1
Chironomidae/Tanypodinae		4	0	0	0	2	3
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	3	1	0
Corbiculidae/ Sphaeriidae		2	2	0	0	0	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	1	0	0	10
Corydalidae		0	0	0	0	0	0
Culicidae		0	0	3	0	0	0
Dixidae		2	0	4	3	8	0
Dytiscidae		0	0	4	1	2	5
Ecnomidae		0	0	0	0	0	0
Elmidae		0	0	0	1	1	1
Gelastocoridae		0	0	0	0	1	0
Gerridae		0	0	1	0	1	0
Gomphidae		0	2	2	0	0	6
Gripopterygiidae		0	0	1	4	1	2
Gyrinidae		2	2	3	1	2	1
Hemicorduliidae		0	0	0	0	0	0
Hirudinidae		1	0	0	2	2	1
Hydracarina		10	10	5	5	0	10
Hydraenidae		0	0	0	0	1	0
Hydrobiosidae		0	0	1	0	0	0
Hydrophilidae		0	2	4	0	0	0
Hypogastruridae		0	0	0	0	1	0
Leptoceridae		5	10	10	10	10	10
Leptophlebiidae		3	6	10	10	3	6
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	0	1	0	0	0
Nematoda		1	0	0	0	0	0
Noteridae		0	1	1	0	0	0
Notonectidae		0	0	0	0	0	0
Oligochaeta		0	0	1	0	0	0
Oniscigastridae		0	0	1	7	0	7
Ostracoda		0	0	1	1	1	2
Parastacidae		0	0	0	0	1	0
Scirtidae		0	0	1	4	2	0
Simuliidae		0	0	0	0	0	0
Synlestidae		0	0	2	0	0	2
Synthemistidae		8	2	0	0	0	0
Telephlebiidae		0	0	0	1	4	0
Tipulidae		2	0	1	2	0	0
Urothemistidae		0	0	0	0	0	0
Veliidae		1	0	1	0	2	0
Total number of taxa		**14**	**13**	**24**	**18**	**23**	**20**

Appendix 5 continued:

(f) March 2010

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	1	0	0	1
Athericidae		0	1	0	0	0	0
Atyidae		0	10	0	10	9	10
Austrocorduliidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	0
Ceinidae		0	0	1	0	0	0
Ceratopogonidae		0	2	0	0	0	0
Chironomidae/Chironominae		4	2	6	1	1	5
Chironomidae/Orthocladiinae		0	0	0	1	0	0
Chironomidae/Tanypodinae		1	8	1	3	2	4
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	4	2	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	0	0	0
Cordulephyidae		0	1	0	0	0	0
Corixidae		0	0	3	8	3	10
Corydalidae		0	0	0	0	0	0
Culicidae		0	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0
Dixidae		1	0	1	2	2	0
Dytiscidae		0	1	0	0	0	1
Elmidae		0	0	0	1	1	2
Gerridae		0	0	6	4	3	3
Gomphidae		1	0	0	5	0	0
Gripopterygiidae		0	0	0	2	9	0
Gyrinidae		2	1	4	2	3	3
Haliplidae		0	0	0	0	0	0
Hebridae		0	0	0	0	0	0
Hemicorduliidae		0	0	0	1	0	0
Hirudinidae		1	1	5	0	10	0
Hydracarina		1	4	2	0	3	4
Hydrobiosidae		0	0	0	0	0	0
Hydrometridae		0	0	0	0	0	0
Hydrophilidae		0	0	0	1	0	0
Hydroptilidae		0	0	0	0	1	1
Hypogastruridae		0	0	0	2	0	0
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		2	4	6	7	1	7
Lestidae		0	0	0	0	0	0
Libellulidae		0	0	0	0	0	0
Megapodagrionidae		1	0	0	0	0	0
Mesoveliidae		1	0	3	0	0	0
Nematoda		0	0	0	0	0	0
Notonectidae		0	0	4	1	4	0
Oligochaeta		0	0	0	2	0	0
Oniscigastridae		0	0	3	1	6	10
Ostracoda		0	0	0	0	0	0
Parastacidae		0	0	0	0	0	0
Philopotamidae		0	0	0	0	0	1
Philorheithridae		0	1	0	0	0	2
Psephenidae		0	0	0	0	0	0
Pyralidae		0	1	0	0	0	1
Scirtidae		0	1	0	0	0	0
Sialidae		0	0	0	0	0	0
Simuliidae		0	0	7	0	1	0
Synlestidae		0	0	0	0	0	0
Synthemistidae		1	4	0	1	0	1
Telephlebiidae		0	0	1	0	0	1
Temnocephalidae		0	0	0	0	0	0
Tipulidae		0	1	2	1	0	0
Veliidae		1	0	4	0	0	0
Total number of taxa		**13**	**18**	**20**	**21**	**17**	**19**

Appendix 5 continued:

(g) September 2010

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Araneae		0	0	2	2	3	1
Atyidae		1	1	0	2	9	4
Baetidae		0	0	0	1	0	0
Caenidae		0	0	0	0	0	0
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		9	5	6	8	5	3
Chironomidae/Chironominae		3	3	0	3	0	1
Chironomidae/Orthocladiinae		0	0	6	1	0	0
Chironomidae/Tanypodinae		2	6	7	7	1	4
Cladocera		0	0	0	0	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	1	2	0	0
Corbiculidae/ Sphaeriidae		1	1	1	0	0	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	1	0	0	0
Corydalidae		0	1	0	0	0	0
Curculionidae		0	0	0	0	0	0
Dixidae		1	2	0	0	2	0
Dytiscidae		0	0	0	2	1	3
Ecnomidae		2	1	0	3	0	0
Elmidae		2	0	0	1	0	1
Eusiridae		0	0	0	0	0	0
Gelastocoridae		0	0	1	2	2	0
Gerridae		0	0	0	0	1	1
Gomphidae		0	0	10	5	0	1
Gripopterygiidae		0	2	4	5	6	3
Gyrinidae		7	2	5	1	1	1
Hemicorduliidae		0	0	1	0	0	0
Hydracarina		2	3	2	5	6	5
Hydraenidae		2	1	0	0	2	1
Hydrobiosidae		0	0	0	0	0	0
Hydrometridae		0	0	2	0	0	0
Hydrophilidae		0	0	0	1	1	0
Hypogastruridae		0	0	2	1	0	0
Leptoceridae		10	10	10	10	9	10
Leptophlebiidae		3	10	10	10	7	10
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	5	5	5	2	0
Noteridae		0	0	5	5	4	1
Notonectidae		0	0	0	2	2	0
Oligochaeta		0	0	3	2	0	0
Oniscigastridae		0	0	5	3	0	0
Ostracoda		0	0	0	0	0	0
Parastacidae		0	0	0	0	1	0
Pyralidae		0	0	0	0	0	0
Scirtidae		1	3	3	3	3	1
Synlestidae		0	0	6	1	1	0
Synthemistidae		0	3	0	1	0	0
Telephlebiidae		0	0	3	2	3	1
Tipulidae		0	3	0	0	0	0
Veliidae		1	4	4	3	4	3
Total number of taxa		**15**	**19**	**25**	**30**	**23**	**19**

Appendix 5 continued:

(h) April 2011

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	0	0	0	0	1
Araneae		1	0	2	2	1	0
Athericidae		1	3	0	0	0	2
Atriplectididae		0	0	0	0	0	0
Atyidae		0	4	0	4	3	10
Austrocorduliidae		0	0	0	0	0	0
Caenidae		0	0	0	0	0	0
Calamoceratidae		0	0	0	0	0	1
Ceinidae		0	0	0	1	0	0
Ceratopogonidae		1	5	5	1	1	1
Chironomidae/Aphroteniinae		0	0	0	0	0	0
Chironomidae/Chironominae		0	3	4	3	0	1
Chironomidae/Orthocladiinae		0	0	0	0	0	0
Chironomidae/Tanypodinae		2	4	3	0	2	0
Cladocera		0	0	0	1	0	0
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	3	0	0	0	0
Corbiculidae/ Sphaeriidae		0	0	0	0	3	0
Cordulephyidae		0	0	0	0	0	0
Corixidae		0	0	5	0	3	5
Corydalidae		1	0	1	1	0	0
Culicidae		0	0	0	0	0	0
Curculionidae		1	0	0	0	0	0
Diphlebiidae		0	0	0	0	0	0
Dixidae		0	0	2	0	0	0
Dugesiidae		0	0	0	0	0	0
Dytiscidae		0	0	10	0	4	4
Ecnomidae		0	0	1	0	0	0
Elmidae		0	0	2	1	0	2
Empididae		0	1	0	0	0	0
Gerridae		0	0	0	1	2	0
Gomphidae		0	4	8	3	0	4
Gripopterygiidae		0	3	4	6	4	1
Gyrinidae		3	1	5	3	2	2
Haliplidae		0	0	0	0	0	0
Hemicorduliidae		0	0	2	1	0	0
Hirudinidae		1	0	0	0	0	1
Hydracarina		3	0	4	8	3	8
Hydrobiosidae		0	0	1	0	0	0
Hydrometridae		0	0	0	0	1	0
Hydrophilidae		1	0	0	0	0	0
Hydroptilidae		0	0	0	0	3	5
Leptoceridae		10	10	10	10	10	10
Leptophlebiidae		2	10	10	10	10	5
Lestidae		0	0	0	0	0	0
Megapodagrionidae		0	3	6	0	0	2
Nematomorpha		0	0	0	0	0	0
Nepidae		0	0	0	0	1	0
Noteridae		0	0	2	2	0	0
Notonectidae		0	0	0	2	0	2
Odontoceridae		0	0	0	0	0	0
Oligochaeta		0	0	6	0	0	0
Ostracoda		0	0	0	1	0	0
Parastacidae		4	1	0	2	0	2
Philorheithridae		0	0	1	0	2	8
Polycentropodidae		0	0	2	1	0	0
Psephenidae		0	0	0	0	1	0
Pyralidae		0	0	0	0	0	0
Scirtidae		0	0	0	0	1	0
Sialidae		0	0	0	0	0	0
Simuliidae		0	0	1	0	0	0
Synlestidae		0	0	1	0	0	0
Synthemistidae		1	5	1	0	0	1
Telephlebiidae		1	0	2	2	1	2
Tipulidae		4	2	1	3	3	4
Veliidae		0	0	0	3	0	0
Total number of taxa		**16**	**16**	**28**	**24**	**21**	**24**

Appendix 5 continued:

(i) September 2011

Order or Family	Location	Cataract Ck		Cataract Rvr		Allen Ck	
	Site	5	6	9	10	13	14
Aeshnidae		0	0	0	0	0	0
Ancylidae		0	1	0	0	0	0
Atyidae		0	0	0	0	0	4
Austrocorduliidae		0	0	0	0	0	0
Baetidae		0	0	0	0	0	0
Caenidae		0	0	0	0	3	1
Ceinidae		0	0	0	0	0	0
Ceratopogonidae		0	0	1	0	2	0
Chironomidae/Chironominae		1	0	1	2	2	3
Chironomidae/Orthocladiinae		0	0	0	0	0	0
Chironomidae/Tanypodinae		2	0	1	2	2	2
Coenagrionidae		0	0	0	0	0	0
Copepoda		0	0	0	0	0	0
Corbiculidae/ Sphaeriidae		0	2	0	0	0	0
Corixidae		0	0	0	0	1	1
Corydalidae		1	0	0	0	0	0
Dixidae		0	0	0	0	0	0
Dytiscidae		0	0	0	4	0	0
Ecnomidae		0	0	0	0	0	0
Elmidae		0	0	0	1	0	1
Gelastocoridae		1	0	1	0	1	1
Gomphidae		0	0	2	0	2	1
Gripopterygiidae		1	1	2	3	7	7
Gyrinidae		1	3	0	1	0	0
Helicopsychidae		0	0	0	0	1	0
Hemicorduliidae		0	0	0	0	0	0
Hydracarina		1	1	0	0	10	6
Hydraenidae		0	0	1	0	2	0
Hydrobiosidae		0	0	0	1	0	0
Hydrometridae		0	0	0	0	0	0
Leptoceridae		2	8	6	5	10	10
Leptophlebiidae		10	4	8	6	10	6
Libellulidae		0	0	0	0	0	0
Megapodagrionidae		0	0	0	0	1	0
Naucoridae		0	0	0	0	0	0
Nematoda		0	0	0	0	0	0
Noteridae		0	0	1	1	3	7
Notonectidae		0	0	0	0	0	0
Odontoceridae		0	2	0	0	0	0
Oligochaeta		0	0	0	0	0	0
Oniscigastridae		0	0	4	1	2	0
Ostracoda		0	0	0	0	0	0
Philorheithridae		0	0	0	0	0	1
Pyralidae		0	0	0	0	0	0
Scirtidae		1	0	0	0	5	0
Sialidae		0	0	0	0	0	0
Synthemistidae		3	1	0	0	0	1
Telephlebiidae		0	0	1	0	3	2
Tipulidae		2	0	2	3	3	0
Veliidae		1	0	0	1	0	2
Total number of taxa		**12**	**9**	**13**	**12**	**19**	**16**

Appendix 6: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli West Study Area in (a) Spring 2008 and (b) Autumn 2009. **ND = no data.**

(a) Spring 2008

Order or Family	Wallandoola Ck		Lizard Creek		Loddon Ck	
	1	2	3	4	11	12
Ancylidae	0	13	0	43	0	1
Araneae	0	0	0	0	0	0
Athericidae	0	0	0	0	0	0
Austrocorduliidae	5	7	0	0	0	6
Ceratopogonidae	0	0	0	0	0	0
Chironomidae/Aphroteniinae	0	0	0	0	0	0
Chironomidae/Chironominae	66	89	0	449	0	186
Chironomidae/Orthocladiinae	4	4	0	8	0	35
Chironomidae/Tanypodinae	26	22	0	60	0	68
Cladocera	0	1	0	0	0	0
Copepoda	0	0	0	0	0	1
Corbiculidae/ Sphaeriidae	1	0	0	2	0	0
Corydalidae	0	0	0	1	0	0
Diptera	0	0	0	0	0	0
Dugesiidae	0	0	0	0	0	1
Dytiscidae	0	0	0	0	0	1
Ecnomidae	2	1	0	1	0	3
Elmidae	0	1	0	1	0	1
Empididae	2	0	0	1	0	0
Entomobryidae/Isotomidae	0	0	0	0	0	0
Glacidorbidae	0	0	0	0	0	0
Gripopterygiidae	26	0	0	1	0	3
Gyrinidae	2	0	0	2	0	0
Hydracarina	0	0	0	1	0	2
Hydridae	0	0	0	2	0	6
Hydrobiosidae	0	0	0	0	0	0
Hydrometridae	0	0	0	0	0	0
Hydroptilidae	0	0	0	0	0	0
Leptoceridae	21	5	0	0	0	5
Leptophlebiidae	67	88	0	76	0	38
Libellulidae	1	1	0	0	0	0
Megapodagrionidae	1	3	0	1	0	3
Nematoda	0	0	0	0	0	0
Notonemouridae	0	0	0	0	0	0
Oligochaeta	3	2	0	102	0	1
Oniscigastridae	0	0	0	0	0	0
Ostracoda	2	2	0	1	0	4
Physidae	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	0
Scirtidae	0	0	0	1	0	0
Synlestidae	0	0	0	0	0	0
Tanyderidae	0	0	0	0	0	0
Tipulidae	0	0	0	0	0	0

continued

Appendix 6 continued:

(b) Autumn 2009

	Wallandoola Ck		Lizard Creek		Loddon Ck	
Order or Family	1	2	3	4	11	12
Ancylidae	34	37	ND	0	0	0
Araneae	0	0	ND	0	0	0
Athericidae	0	0	ND	0	0	0
Austrocorduliidae	7	6	ND	0	0	0
Ceinidae	4	0	ND	0	0	0
Ceratopogonidae	0	0	ND	3	0	0
Chironomidae/Aphroteniinae	0	0	ND	0	0	0
Chironomidae/Chironominae	10	64	ND	128	64	86
Chironomidae/Orthocladiinae	5	3	ND	0	34	8
Chironomidae/Tanypodinae	13	52	ND	8	18	30
Cladocera	0	0	ND	3	0	0
Coenagrionidae	0	0	ND	0	0	0
Copepoda	3	0	ND	10	1	3
Corbiculidae/ Sphaeriidae	0	0	ND	4	0	2
Corydalidae	0	0	ND	0	0	1
Dixidae	0	0	ND	0	0	0
Dugesiidae	0	0	ND	0	0	0
Dytiscidae	0	0	ND	0	0	0
Ecnomidae	0	0	ND	0	0	3
Elmidae	0	0	ND	0	0	0
Empididae	0	1	ND	0	0	0
Gerridae	0	0	ND	0	0	0
Gomphidae	0	0	ND	0	0	0
Gripopterygiidae	3	0	ND	0	9	1
Gyrinidae	0	1	ND	1	0	0
Hydracarina	0	0	ND	3	0	1
Hydraenidae	0	0	ND	0	0	0
Hydridae	0	0	ND	3	0	0
Hydrobiosidae	0	0	ND	0	0	0
Hydrophilidae	0	0	ND	0	0	0
Hydroptilidae	0	0	ND	0	0	0
Leptoceridae	23	5	ND	1	3	12
Leptophlebiidae	14	15	ND	6	55	61
Megapodagrionidae	5	1	ND	0	0	0
Nematoda	0	0	ND	1	0	0
Nemertea	0	0	ND	0	0	0
Oligochaeta	8	98	ND	560	31	48
Ostracoda	0	1	ND	17	0	1
Planorbidae	0	0	ND	0	0	0
Psychodidae	0	0	ND	0	0	0
Scirtidae	0	0	ND	0	0	0
Tanyderidae	0	0	ND	0	0	0
Telephlebiidae	0	0	ND	0	1	1
Tipulidae	0	0	ND	0	0	0

Appendix 7: Total numbers of each aquatic macroinvertebrate taxon found on collectors deployed in the Wongawilli East Study Area in (a) Spring 2008; (b) Autumn 2009; (c) Spring 2009 and (d) Autumn 2010. ND = no data.

(a) Spring 2008

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	2	0	156	7	ND	ND
Araneae	0	1	0	0	ND	ND
Athericidae	0	0	0	1	ND	ND
Austrocorduliidae (=Corduliidae)	0	0	0	0	ND	ND
Ceratopogonidae	0	1	4	4	ND	ND
Chironomidae/Aphroteniinae	0	0	0	0	ND	ND
Chironomidae/Chironominae	406	110	663	818	ND	ND
Chironomidae/Orthocladiinae	94	1	4	28	ND	ND
Chironomidae/Tanypodinae	60	4	103	108	ND	ND
Cladocera	0	0	0	2	ND	ND
Copepoda	0	0	0	0	ND	ND
Corbiculidae/ Sphaeriidae	3	0	1	0	ND	ND
Corydalidae	1	0	0	1	ND	ND
Diptera	0	0	0	0	ND	ND
Dugesiidae	0	0	0	0	ND	ND
Dytiscidae	0	0	4	4	ND	ND
Ecnomidae	0	2	0	2	ND	ND
Elmidae	0	0	0	0	ND	ND
Empididae	12	0	1	7	ND	ND
Entomobryidae/Isotomidae	0	0	0	0	ND	ND
Glacidorbidae	0	0	5	0	ND	ND
Gripopterygiidae	0	0	5	4	ND	ND
Gyrinidae	7	1	2	5	ND	ND
Hydracarina	0	0	1	2	ND	ND
Hydridae	0	0	0	1	ND	ND
Hydrobiosidae	0	0	0	0	ND	ND
Hydrometridae	0	0	0	0	ND	ND
Hydroptilidae	0	0	1	0	ND	ND
Leptoceridae	2	1	2	4	ND	ND
Leptophlebiidae	9	21	78	76	ND	ND
Libellulidae	0	0	0	0	ND	ND
Megapodagrionidae	0	0	0	0	ND	ND
Nematoda	0	0	1	0	ND	ND
Notonemouridae	1	0	0	0	ND	ND
Oligochaeta	56	54	154	82	ND	ND
Oniscigastridae	0	0	0	0	ND	ND
Ostracoda	0	0	2	0	ND	ND
Physidae	0	0	1	0	ND	ND
Psychodidae	0	0	1	0	ND	ND
Scirtidae (= Helodidae, Cyphonidae)	0	0	0	0	ND	ND
Synlestidae	0	0	0	0	ND	ND
Tanyderidae	0	0	0	0	ND	ND
Tipulidae	1	0	0	0	ND	ND

continued

Appendix 7 continued:

(b) Autumn 2009

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	196	140	691	99	141	21
Araneae	1	0	0	0	0	0
Athericidae	11	0	4	1	0	0
Austrocorduliidae (=Corduliidae)	0	0	0	0	0	0
Ceinidae	0	0	0	0	0	0
Ceratopogonidae	2	12	14	7	4	1
Chironomidae/Aphroteniinae	0	0	2	0	0	0
Chironomidae/Chironominae	575	177	241	168	309	98
Chironomidae/Orthocladiinae	163	25	4	71	23	19
Chironomidae/Tanypodinae	150	126	176	106	202	47
Cladocera	0	0	2	1	21	0
Coenagrionidae	0	0	0	0	0	0
Copepoda	3	0	0	0	3	1
Corbiculidae/ Sphaeriidae	0	1	0	0	0	0
Corydalidae	3	2	0	0	0	0
Dixidae	0	0	1	0	0	0
Dugesiidae	0	0	2	0	0	2
Dytiscidae	0	0	3	4	0	2
Ecnomidae	2	6	0	8	2	1
Elmidae	0	0	3	1	5	2
Empididae	4	0	1	3	0	0
Gerridae	0	0	0	0	0	0
Gomphidae	0	0	2	0	0	0
Gripopterygiidae	1	3	0	4	2	0
Gyrinidae	1	4	1	2	4	1
Hydracarina	55	5	3	5	0	3
Hydraenidae (= Limnebiidae)	0	0	1	0	0	0
Hydridae	0	2	6	0	0	0
Hydrobiosidae	1	0	0	1	0	0
Hydrophilidae	0	0	7	2	0	0
Hydroptilidae	0	0	5	0	4	0
Leptoceridae	5	11	7	2	2	1
Leptophlebiidae	18	63	206	198	36	81
Megapodagrionidae	0	0	2	0	0	1
Nematoda	0	0	4	1	0	0
Nemertea	0	0	0	0	0	0
Oligochaeta	322	379	665	2298	209	47
Ostracoda	0	0	4	3	0	0
Planorbidae	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	1
Scirtidae (= Helodidae, Cyphonidae)	1	0	0	19	0	1
Tanyderidae	0	12	5	14	0	0
Telephlebiidae (=Aeshnidae)	0	0	0	0	1	1
Tipulidae	3	0	1	2	0	0

continued

Appendix 7 continued:

(c) Spring 2009

	Cataract Ck		Cataract River		Allens Ck	
Order or Family	5	6	9	10	13	14
Ancylidae	31	8	52	12	63	40
Ceratopogonidae	3	2	8	7	0	0
Chironomidae/Chironominae	273	230	248	320	266	41
Chironomidae/Orthocladiinae	0	3	0	5	0	0
Chironomidae/Tanypodinae	31	55	115	112	87	25
Copepoda	0	0	0	0	1	0
Corbiculidae/ Sphaeriidae	1	0	0	0	0	0
Cordulephyidae	0	0	1	0	0	0
Culicidae	0	0	0	0	1	0
Curculionidae	0	0	1	1	0	0
Dixidae	4	1	0	0	0	0
Dytiscidae	2	0	5	5	0	1
Ecnomidae	1	1	0	5	0	0
Elmidae	0	0	2	1	2	7
Empididae	3	3	5	9	4	1
Entomobryidae/Isotomidae	1	0	2	0	0	0
Glossiphoniidae	0	0	3	0	0	0
Glossosomatidae	0	0	0	0	1	0
Gomphidae	0	0	1	0	0	0
Gripopterygiidae	1	4	4	1	1	4
Gyrinidae	1	6	1	0	1	1
Helicopsychidae	0	0	1	0	0	0
Hydracarina	0	3	0	4	0	1
Hydrobiosidae	0	0	0	0	1	0
Hydrophilidae	0	0	7	0	0	0
Hydroptilidae	0	0	1	3	1	0
Leptoceridae	0	0	1	2	0	1
Leptophlebiidae	3	28	96	145	84	35
Megapodagrionidae	0	4	0	0	0	0
Oligochaeta	332	344	118	33	26	453
Ostracoda	0	0	3	8	3	0
Physidae	0	0	0	0	1	0
Psephenidae	0	0	0	2	0	0
Synlestidae	0	0	1	0	0	0
Tanyderidae	0	0	28	5	0	0
Telephlebiidae	0	0	0	1	0	1
Temnocephalidae	0	0	0	1	0	0
Thysanoptera	1	0	0	0	0	0

continued

Appendix 7: Continued

(d) Autumn 2010

Order or Family	Cataract Ck		Cataract River		Allens Ck	
	5	6	9	10	13	14
Ancylidae	26	33	1	15	55	49
Araneae	0	0	1	1	0	0
Athericidae	2	1	0	0	0	0
Calamoceratidae	0	0	1	0	0	1
Ceinidae	0	1	0	0	0	0
Ceratopogonidae	10	13	30	2	1	0
Chironomidae/Chironominae	575	360	304	236	273	330
Chironomidae/Orthocladiinae	40	0	32	65	2	15
Chironomidae/Tanypodinae	92	41	111	85	92	104
Copepoda	1	0	0	1	0	0
Corbiculidae/ Sphaeriidae	0	0	4	1	0	0
Corydalidae	5	1	1	5	1	0
Dixidae	1	0	4	1	1	0
Dolichopodidae	0	0	0	0	1	0
Dugesiidae	2	0	18	5	0	1
Dytiscidae	0	0	1	3	4	9
Ecnomidae	0	1	4	7	1	1
Elmidae	1	1	8	3	1	2
Empididae	15	0	2	7	3	10
Entomobryidae/Isotomidae	0	0	1	2	0	0
Gelastocoridae	0	0	0	1	0	0
Glossiphoniidae	0	0	2	0	1	0
Gordiidae	0	0	1	0	0	0
Gripopterygiidae	1	1	5	5	2	9
Gyrinidae	1	2	2	4	5	9
Helicopsychidae	0	0	0	0	1	1
Hydracarina	6	3	23	21	4	2
Hydraenidae	7	0	9	3	0	1
Hydridae	0	0	2	0	1	2
Hydrobiidae	1	0	0	0	0	0
Hydrobiosidae	3	0	0	8	0	8
Hydrophilidae	3	1	2	0	0	0
Hydroptilidae	0	0	3	0	3	2
Hypogastruridae	0	0	2	0	0	0
Leptoceridae	3	8	13	4	0	2
Leptophlebiidae	33	43	324	174	204	217
Megapodagrionidae	0	2	3	1	1	0
Nematoda	0	0	1	0	0	0
Nemertea	2	0	0	0	0	0
Noteridae	0	0	1	8	0	0
Oligochaeta	2759	267	251	54	20	17
Ostracoda	0	0	2	0	0	0
Physidae	0	0	1	0	0	0
Psephenidae	0	2	0	0	0	1
Psychodidae	1	3	0	0	0	0
Scirtidae	16	22	56	6	1	0
Simuliidae	0	0	0	1	0	1
Sminthuridae	0	0	1	0	0	0
Stratiomyidae	0	0	2	0	0	0
Tanyderidae	10	10	5	10	0	0
Telephlebiidae	0	0	2	1	0	1
Temnocephalidae	0	0	3	1	1	2
Tipulidae	3	4	1	0	0	0

Appendix 8: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli West in autumn 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	2	14394	7197	1.11	0.399
Sites (Location)	**5**	**32344**	**6469**	**7.02**	**0.001**
Residual	56	51595	921		
Total	63	98333			
b)					
Location	2	7	3	0.11	0.916
Sites (Location)	**5**	**147**	**29**	**9.14**	**<0.001**
Residual	56	180	3		
Total	63	333			
c)					
Location	2	6	3.1	1.05	0.445
Sites (Location)	**5**	**15**	**2.9**	**9.22**	**<0.001**
Residual	56	18	0.3		
Total	63	38			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 9: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p* *
a)					
Location	2	5265	2632	1.35	0.090
Sites (Location)	**3**	**5938**	**1980**	**3.93**	**<0.001**
Residual	38	19142	504		
Total	43	30852			
b)					
Location	**2**	**18.9**	**9.5**	**14.51**	**0.012**
Sites (Location)	3	1.7	0.6	0.08	0.969
Residual	38	255.0	6.7		
Total	43	277.0			
c)					
Location	2	6.5	3.2	8.11	0.057
Sites (Location)	3	1.2	0.4	2.74	0.051
Residual	38	5.6	0.1		
Total	43	13.0			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 10: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in spring 2009. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	2	10335	5167	2.26	0.060
Sites (Location)	**3**	**6872**	**2291**	**2.52**	**<0.001**
Residual	42	38148	908		
Total	47	55355			
b)					
Location	**2**	**115.8**	**57.9**	**15.02**	**0.028**
Sites (Location)	3	11.6	3.9	0.78	0.519
Residual	42	208.6	5.0		
Total	47	336.0			
c)					
Location	2	0.40	0.20	2.41	0.232
Sites (Location)	3	0.25	0.08	0.32	0.821
Residual	42	11.03	0.26		
Total	47	11.69			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 11: PERMANOVA of a) macroinvertebrate assemblages, b) number of taxa and c) total abundance of macroinvertebrates on collectors deployed at Wongawilli East in autumn 2010. Significant factors in bold.

Source	df	SS	MS	*F*	*p**
a)					
Location	**2**	**12057**	**6028**	**3.65**	**0.004**
Sites (Location)	**3**	**4956**	**1652**	**2.17**	**0.002**
Residual	41	31193	761		
Total	46	48390			
b)					
Location	2	654230	327120	1.10	0.437
Sites (Location)	**3**	**894870**	**298290**	**1.82**	**0.005**
Residual	41	6705000	163540		
Total	46	8251500			
c)					
Location	2	2.63	1.32	0.79	0.554
Sites (Location)	**3**	**4.97**	**1.66**	**5.99**	**<0.001**
Residual	41	11.35	0.28		
Total	46	18.95			

*Monte Carlo simulations used where unique permutations < 100.

Appendix 12: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek in (a) 15 December 2009; (b) 8 January 2010; (c) 29 January 2010, and (d) 25 February 2010. GPS data is datum: WGS 84 zone: 56H

a. 15 December 2009

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301660	6197447	80	1.1
301660	6197447	90	1.2
301759	6197509	140	1.3

b. 8 January 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301652	6197442	80	2.1
301652	6197442	180	2.2
301652	6197442	125	2.3
301652	6197442	125	2.4
301909	6197469	105	2.5
302059	6197405	120	N/A

c. 29 January 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301655	6197449	80	3.1
301655	6197449	190	3.2
301942	6197445	165	3.3
301942	6197445	100	3.4
302086	6197404	100	3.5
302162	6197431	155	3.6

d. 25 February 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301376	6197498	230	4.1
301623	6197414	145	4.2
301623	6197414	190	4.3
301623	6197414	175	4.4
301623	6197414	100	4.5
301623	6197414	130	4.6
301650	6197442	200	4.7
301650	6197442	95	4.8
301901	6197467	95	4.9
301901	6197467	190	4.10
301978	6197412	155	4.11
302173	6197413	95	4.12
302372	6197376	175	4.13
302432	6197382	130	4.14
302432	6197382	180	4.15

Appendix 13: Geographic location and caudal length of each specimen of Macquarie Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011. GPS data is datum: WGS 84 zone: 56H

a. 8 December 2010

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301719	6197488	370	1.1
301847	6197467	155	1.2
301874	6197472	185	1.3
301969	6197415	180	1.4
302018	6197406	150	1.5
302168	6197424	190	1.6
302254	6197398	130	1.7
302341	6197377	130	1.8
302366	6197386	210	1.9
302366	6197386	130	1.10
302435	6197400	125	1.11

b. 7 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301674	6197464	150	2.1
301701	6197481	195	2.2
301749	6197502	105	2.3
301849	6197470	190	2.4
301849	6197470	125	2.5
301849	6197470	150	2.6
301977	6197410	180	2.7
302016	6197405	130	2.8
302116	6197412	135	2.9
302139	6197412	145	2.10
302174	6197414	225	2.11
302174	6197414	175	2.12
302174	6197414	200	2.13
302256	6197404	120	2.14

c. 25 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301698	6197480	150	3.1
301698	6197480	135	3.2
301726	6197497	120	3.3
301726	6197497	135	3.4
301726	6197497	120	3.5
301726	6197497	100	3.6
301726	6197497	215	3.7
301726	6197497	145	3.8
301726	6197497	115	3.9
301726	6197497	90	3.10
301726	6197497	135	3.11
301763	6197504	175	3.12
301763	6197504	260	3.13
301847	6197463	150	3.14
301847	6197463	155	3.15
301847	6197463	215	3.16
301847	6197463	170	3.17
301939	6197448	150	3.18
301939	6197448	145	3.19
301963	6197424	190	3.20

Appendix 13 continued:

c. 25 January 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301963	6197424	165	3.21
301963	6197424	180	3.22
302113	6197403	155	3.23
302144	6197406	150	3.24
302169	6197405	150	3.25
302169	6197405	200	3.26
302169	6197405	245	3.27
302169	6197405	220	3.28
302169	6197405	170	3.29
302169	6197405	190	3.30
302169	6197405	140	3.31
302301	6197405	115	3.32
302301	6197405	140	3.33
302357	6197382	135	3.34
302357	6197382	140	3.35
302514	6197434	125	3.36
302515	6197432	175	3.37

d. 21 February 2011

Location		Caudal Fork Length (mm)	Fin Clip I.D.
Easting	Northing		
301598	6197401	255	4.1
301598	6197401	180	4.2
301598	6197401	135	4.3
301598	6197401	210	4.4
301621	6197423	160	4.5
301621	6197423	125	4.6
301621	6197423	245	4.7
301635	6197436	165	4.8
301710	6197487	120	4.9
301710	6197487	115	4.10
301710	6197487	110	4.11
301710	6197487	120	4.12
301710	6197487	170	4.13
301710	6197487	130	4.14
301710	6197487	170	4.15
301754	6197505	175	4.16
301754	6197505	165	4.17
301847	6197460	120	4.18
301847	6197460	135	4.19
301971	6197412	205	4.20
301971	6197412	165	4.21
302143	6197407	190	4.22
302144	6197406	235	4.23
302144	6197406	150	4.24
302144	6197406	110	4.25
302264	6197375	145	4.26
302517	6197384	180	4.27
302517	6197384	170	4.28

Appendix 14: Mean (± S.E.) water quality parameters recorded in Cataract Creek downstream of the confluence with Cataract River and at Site 6 the most upstream site sampled during the targeted Macquarie Perch surveys undertaken in the summer of (a) 2009/2010 and (b) 2010/2011.

A. Summer 2009/2010

Date	15/12/2009		15/12/2009		8/01/2010		8/01/2010		29/01/2010		29/01/2010		25/02/2010		25/02/2010	
Creek	Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek	
Site	confluence w/ Cataract River		6		confluence w/ Cataract River		6		confluence w/ Cataract River		Near Full Supply Level		confluence w/ Cataract River		Near Full Supply Level	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature ℃	21.8	0.0	17.0	0.0	20.1	0.0	18.0	0.0	19.6	0.0	22.3	0.0	19.9	0.3	16.5	0.0
Conductivity (µS/cm)	111.5	6.5	121.0	0.0	109.0	0.0	39.0	9.0	45.0	20.0	91.5	18.5	FP	FP	199.5	7.5
pH	6.6	0.0	6.7	0.0	6.6	0.0	6.7	0.0	7.2	0.1	7.1	0.0	FP	FP	6.8	0.0
ORP (mV)	278.5	3.5	388.0	2.0	267.0	1.0	407.5	0.5	379.5	10.5	349.0	3.0	FP	FP	FP	FP
DO (mg/L)	13.4	0.2	7.9	0.2	9.2	0.0	12.1	0.5	2.3	0.0	3.6	0.3	FP	FP	8.5	0.2
DO (%sat'n)	145.0	5.0	81.0	5.7	100.3	1.6	126.7	6.0	24.7	0.3	40.6	1.8	FP	FP	85.4	0.8
Turbidity (ntu)	10.9	0.1	5.5	0.1	5.4	0.1	4.1	0.1	6.1	0.1	9.2	1.5	FP	FP	FP	FP

B. Summer 2010/2011

Date	8/12/2010		8/12/2010		7/01/2011		7/01/2011		25/01/2011		25/01/2011		21/02/2011		21/02/2011	
Creek	Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek		Cataract Creek	
Site	confluence w/ Cataract River		6		confluence w/ Cataract River		6		confluence w/ Cataract River		Near Full Supply Level		confluence w/ Cataract River		Near Full Supply Level	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Temperature ℃	24.9	0.0	17.4	0.0	21.7	0.0	16.6	0.0	18.5	0.5	25.3	0.1	19.0	0.0	25.6	0.0
Conductivity (µS/cm)	FP	FP	120.0	0.0	109.0	0.0	131.0	0.0	FP	FP	FP	FP	179.0	2.0	134.0	4.0
pH	5.6	0.0	6.1	0.0	6.3	0.0	6.6	0.0	6.8	0.0	7.0	0.0	6.6	0.0	6.7	0.1
ORP (mV)	436.0	3.0	441.5	0.5	437.5	7.5	390.5	12.5	277.0	2.0	330.0	1.0	362.5	0.5	325.0	5.0
DO (mg/L)	5.4	0.0	4.2	0.1	4.7	0.1	2.9	0.5	4.8	0.1	8.2	0.4	20.0	0.0	20.0	0.0
DO (%sat'n)	64.8	2.4	43.8	1.3	54.3	0.8	29.2	4.1	97.3	4.5	51.4	0.6	300.0	0.0	163.8	136.3
Turbidity (ntu)	5.4	0.3	11.6	0.2	4.4	0.2	15.5	0.7	2.1	0.3	17.6	1.9	2.2	0.5	22.7	0.3

Appendix 15: Geographic co-ordinates of each specimen of Freshwater Cod and Silver Perch sampled by back pack electrofishing in Cataract Creek on (a) 8 December 2010; (b) 7 January 2011; (c) 25 January 2011, and (d) 21 February 2011. GPS data is datum: WGS 84 zone: 56H.

a. 8 December 2010

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301874	6197472	1	0
302018	6197406	1	0
302168	6197424	1	0
302435	6197400	2	0

b. 7 January 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301701	6197481	1	0
301749	6197502	3	0
301849	6197470	1	0
302139	6197412	1	0
302174	6197414	1	0
302256	6197404	1	0

c. 25 January 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301698	6197480	2	1
301763	6197504	5	1
301847	6197463	1	1
301963	6197424	2	1
302030	6197409	1	0
302113	6197403	2	0
302169	6197405	1	0
302357	6197382	3	1
302515	6197432	1	0

d. 21 February 2011

Location		Freshwater Cod	Silver Perch
Easting	Northing		
301390	6197492	4	0
301598	6197401	2	0
301621	6197423	1	1
301635	6197436	3	0
301710	6197487	1	0
301754	6197505	1	0
301847	6197460	2	1
301971	6197412	2	2
302143	6197407	2	0
302144	6197406	0	0
302264	6197375	5	0
302517	6197384	1	0