AQUATIC MACROINVERTEBRATES OF HEADWATER STREAMS IN THE SOUTH EAST FORESTS - DIVERSITY AND CONSERVATION MANAGEMENT ISSUES

Jan Miller[1] and Robert Miller[2]

[1]JM Ecological Services, 13 Park Road, Bulli NSW.
[2]Cumberland Flora & Fauna Interpretive Services, 13 Park Road, Bulli NSW.

ABSTRACT

The South East Forests National Park Draft Plan of Management states that "Invertebrate taxa in the south east forests, as indeed the rest of Australia, are largely unknown" (NSW NPWS 2005). A lack of scientific data creates difficulties for the ecological management of national parks and state forests in the region. This study provides data on macroinvertebrates collected from streams in the South East Forests of NSW, and assesses the management implications arising from the data.

Analyses of the taxa distributions and rarity indicated that all study streams supported some taxa that were not present at other streams. At least five new species of invertebrate were collected. These results suggest that it may not be sufficient to conserve only representative habitat types. To adequately manage the South East Forests region for the conservation of biological diversity and scientific knowledge, all aquatic habitats should be protected from impacts.

Aquatic habitats can be impacted by altered hydrology, reduction of water quality and sediment incursion. To avoid these impacts, this study recommends the removal of road-to-stream connections such as fords through streams, and the prevention of practices that could result in accidental fires or water pollution.

INTRODUCTION

The South East Forests National Park (SEFNP) was formed in 1997 from previously existing national parks and some areas of state forest (NSW NPWS 2005). The NSW National Parks and Wildlife Service is currently preparing a Plan of Management for the park. The main focus of any conservation management plan is usually the preservation and enhancement of habitat, however, a knowledge of the species that utilise or comprise that habitat is also important. Determining the success of management strategies requires that key species be identified and monitored. Biological indicators can be used to assess aquatic ecosystem health and ecological integrity. While bacteria, algae, microfauna, fish and macrophytes are used as biological indicators of freshwater ecosystems, macroinvertebrates are the most commonly used indicator taxa (Norris & Norris 1995). Data on the invertebrate taxa of the SEFNP streams would provide information on the species that inhabit the SEFNP, the habitat requirements of those species, and identify taxa that are appropriate to be used for monitoring purposes.

There has been a paucity of information about the aquatic macroinvertebrate taxa that inhabit the headwater streams of the South East Forests region. The Eden Management Area EIS (State Forests of NSW 1994) conducted invertebrate surveys of riffles in six second and third order streams in the region, using 3 minute kick samples and hand picks. They collected a total of 81 taxa, and identified these to species where possible. Due to the lack of taxonomic keys available at the time of that study, many species were assigned a number. The National Assessment of River Health in New South Wales has also sampled invertebrates within the South East Forest region (pers. comm. Eren Turak, NSW EPA) and identified these to family level.

As recently as 1995 biological assessment of water quality was still in its infancy in Australia (Norris & Norris 1995, Chessman 1995). Standardised protocols for bio-assessment and data analysis are essential tools for the widespread application of biological assessment and monitoring. These tools were already well developed in Europe and America (Cairns & Pratt 1993). Australia, however, has a unique flora and fauna, with a high level of macroinvertebrate species endemism (Williams & Campbell 1987). Research was required to develop and apply such tools to the Australian environment. The response to this challenge is evidenced by the rapid development of taxonomic and ecological information on the Australian macroinvertebrate fauna over the last 10 years (for example, see Hawking 2000 and Pearson & Hawking 2001).

The aims of this study were to identify macroinvertebrate taxa of headwater streams in the South East Forests region; characterise the habitats of these species; and suggest management strategies that were based on this information. The invertebrate and habitat data were gained from a previous, unpublished, research project that was performed between 1997 and 2004. The research project "The Use of Macroinvertebrates and Integrated Environmental Assessment to Differentiate Land Use Impacts from Natural Variability" (Miller 2004) sampled seven headwater streams in the South East Forests area for macroinvertebrates, water quality, algae, sediment particle size, channel morphology and riparian vegetation. The research utilised a Before-After-Control-Impact (BACI) design to determine the effectiveness of riparian vegetation in maintaining water quality. The intensive invertebrate sampling of the study, combined with identification to species level where possible and detailed habitat characterisation, provided a large amount of new data on the macroinvertebrates of South East Forest headwater streams.

Study Site Locations

The BACI design of the research project required that both treatment and control sites were sampled. Treatment sites were located within Forests NSW logging compartments in the Nullica, Gnupa and Yambula State Forests. Control sites were located in the Yowaka National Park, a Forests NSW compartment that was preserved from logging, and a flora reserve buffer. The locations of the study sites within the region are shown on Figure 1, and the creek details of the site locations are given in Table 1. Each of the sampling sites extended through a series of 3 riffles and 3 pools. Surveys during the site selection process revealed that the majority of headwater streams in the region were intermittent. Surface water flow was often only evident where the stream bed was confined by bedrock close to the surface, and this condition dictated the locations of the sampling reaches.

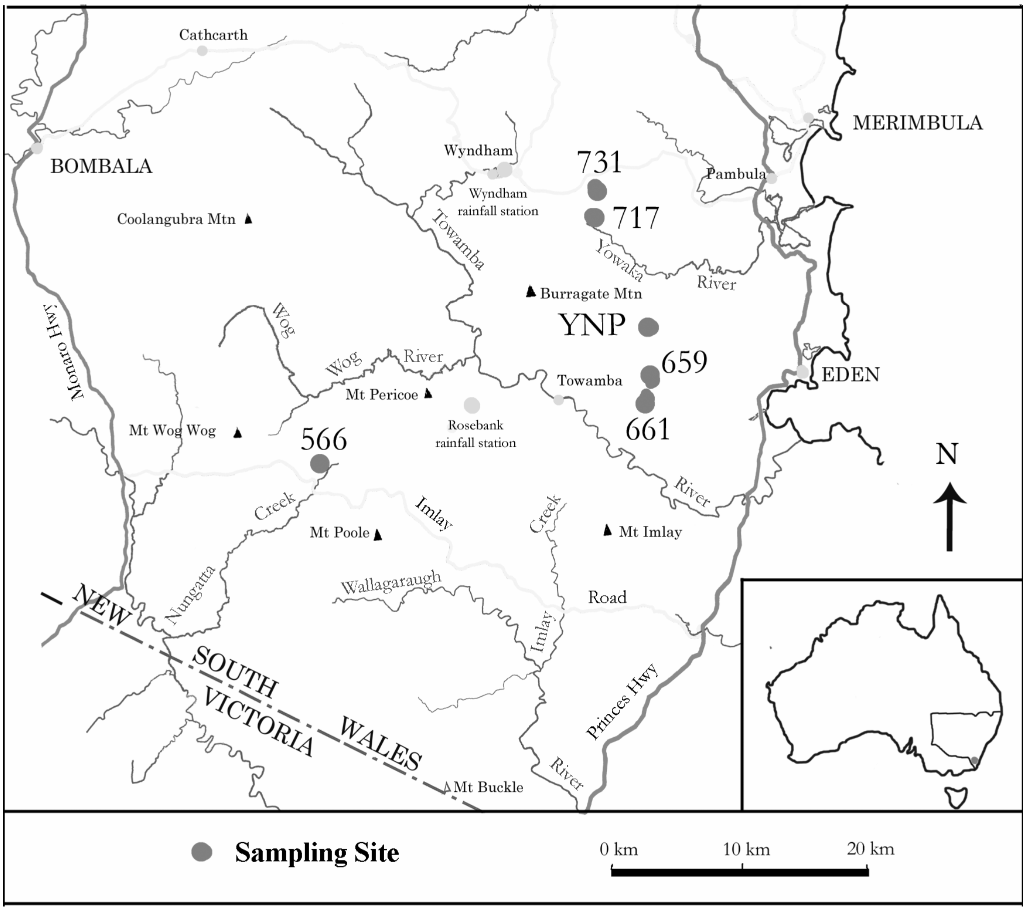

Figure 1: Location of sampling sites within the regional context.
Note: Sites 487 and 567 are located adjacent to site 566.

Study Site	UG Northing	UG Easting	Stream
Yowaka N.P.	58 97931	557 47269	unnamed tributary of Old Hut Creek
Comp. 659	58 93289	557 48200	headwaters of the Nullica River
Comp. 661	58 92971	557 46680	unnamed tributary of the Nullica River
Comp. 731	59 08277	557 43366	unnamed tributary of Crawleys Creek
Comp. 717	59 05392	557 42844	unnamed tributary of the Yowaka River
Comp. 487	58 87498	557 20603	Nungatta Creek
Comp. 566[1]	58 87800	557 20770	Nungatta Creek
Comp. 567	58 88220	557 20940	unnamed tributary of Nungatta Creek
Comp. 566[2]	58 88180	557 20965	Nungatta Creek
Comp. 566[3]	58 88198	557 21723	Nungatta Creek

Table 1: Location details of the sampling site locations.
Note: Comp. is Forests NSW compartment, [1] downstream site, [2] upstream site, [3] control site in buffer to flora reserve.

METHODS

Invertebrate Sampling

The BACI sampling was performed at the same time of year to avoid seasonal differences. Sites 731, 717, 659 and YNP were sampled in June, and sites 661 and YNP were sampled in October. All Nungatta Creek sites were sampled in February.

At each of the study sites 3 pools and 3 riffles were sampled for aquatic macroinvertebrates. Three collection methods were utilised at each site. The first was kick sampling with an aquatic insect collecting net of mesh size 0.9 x 0.3mm. The net was held in the water flow while cobbles and sands immediately upstream from the net were disturbed by kicking. Invertebrates, cobbles and debris dislodged by the kicking flowed downstream and were collected in the net. In deeper pools the net was swept through the water while the bottom of the pool was being kicked. Vegetation growing within the streams was lightly beaten with the net to dislodge invertebrates. The second sampling method was hand picking. Those invertebrates that cling to rocks and boulders were collected with a pair of forceps. The third method was leaf grabs, which collected invertebrates that feed or take refuge amongst leaf litter, bark and woody debris at the edges of streams.

The material collected by these three methods was placed into plastic bags, and 70% ethyl alcohol was added to preserve the invertebrate specimens. The bags were sealed and placed into a bucket for transport to the laboratory. The streams at the study site reaches were all very small, and the intensive sampling effort covered every part of the channel. The sampling methods that were used were not suitable for the representative collection of Annelida or Decapoda. Although both of these invertebrate groups were present at the study sites, they were not included in the study. All material that was collected by the sampling was sorted in the laboratory. Large leaf material was washed and removed, and the remaining sample material was placed into a Petri dish and examined under a dissecting microscope at 7x magnification. All invertebrates were removed for identification.

Invertebrate identification keys produced or updated over the last 10 years make identification to species level possible for many of the aquatic invertebrates found in Australian waters. The study identified invertebrates utilising published keys and identifications by relevant experts. Literature on species descriptions and keys to identifications were sourced from Hawking (2000), Hawking and Smith (1997), Williams (1980), CSIRO (Ed.) (1991) and Hubbard and Campbell (1996). Experts who identified species for the study were David Cartwright of Melbourne Water, John Dean of the Environment Protection Authority Victoria, Alena Glaister of Monash University, John Hawking of the Murray Darling Freshwater Research Centre, Phil Perkins of Harvard University, Massachusetts, USA, Winston Ponder of the Australian Museum, Phil Suter of La Trobe University, Gunther Theisinger of the NSW Environment Protection Authority, Chris Watts of the South Australian Museum, Alice Wells of the Australian Biological Resources Study, and Tom Weir of CSIRO Entomology Canberra.

The identification of invertebrates to species level is a time-consuming process, particularly when a great many specimens are collected by the sampling. A total of 263,120 macroinvertebrates were identified for this study. It was not feasible to identify to species level all of the invertebrate groups that were collected. Some invertebrate groups, for example Ostracoda, Copepoda and Acarina, were well represented in the samples. Because of the very small size of the diagnostic features, careful examination under a compound microscope is necessary to identify these invertebrate groups to species level. This was not possible within the time constraints of the study. As a result, these invertebrates were identified to class, sub-class or family level only. All early instars and Diptera, Acariformes, Ostracoda, Copepoda, Isopoda, Neuroptera and Collembola were identified either to class or family level. Coleoptera, Hemiptera, Trichoptera, Odonata, Plecoptera, Megaloptera, Ephemeroptera, Gastropoda (Ancylidae) and Amphipoda were all identified to species.

Habitat Sampling

The invertebrate habitats were sampled for water quality, channel morphology, stream bed particle size and riparian vegetation. Water quality measurements were performed prior to any disturbance of the stream waters by kick sampling. A Yeokal 611 Intelligent Water Quality Analyser was used to measure water pH, temperature, dissolved oxygen saturation and turbidity. Mapping of the channel morphology comprised theodolite survey of stream long- and cross-sections, mapping of channel units and descriptions of channel characteristics.

Two methods were used to assess the particle sizes of the study reaches. The first method was the collection of bulk samples of the bed materials from all accumulation zones. These samples were transported to the laboratory where they were air dried, weighed and sieved. The fine fraction of the sample (b-axis of less than 2mm) was sub-sampled by cone and quartering. A sub-sample of the fine fraction was used to calculate moisture content. A second sub-sample of the fine fraction was used for particle size analysis. The sub-sample was weighed, chemically dispersed for 24 hours in 25ml of sodium hexametaphosphate and water, and then mechanically dispersed in a shaker. The sub-sample was then washed through a 63μm sieve. The fraction retained on the sieve was oven dried and passed through a nest of sieves.

The fraction that passed through the 63μm sieve was placed in a 1000ml cylinder in a constant temperature room, and tap water added to make up the 1000ml volume. The determination of particle sizes of the fine fraction utilised Stokes law for sediment settling velocity. The sub-sample and water in the cylinders was stabilised at 20ºC, stirred, and hydrometer readings taken at 5 minutes, 30 minutes, 1 hour, 2 hours, 4½ hours, 8 hours and 24 hours. Finally, the samples were decanted and Stokes law applied to remove the clay and fine silt fractions by repeated 5 minute decantation. The remaining coarse silt fraction was oven dried, passed through a 45μm sieve, and weighed.

The second method that was used to assess the bed material particle size was gravel counts. To overcome problems of bulk sampling size and weight restrictions, the grid-by-number surface sampling technique was devised by Wolman (1954) to determine bed surface gravel size *in-*

situ. For this study, a series of transects were paced along the channel at each study site riffle, centred on the surveyed long section, and the b axis diameter of 100 gravel clasts were measured. At least 100 clasts are required to obtain a reliable grain size distribution (W. Erskine pers. comm.). The above method implicitly assumes that the surficial sediment is the most important for characterising bed sediment and resistance to flow (Kellerhals & Bray, 1971).

The riparian vegetation at the study sites was surveyed by the Random Meander Method (Cropper 1993). A species list was compiled at each site, and the percentage vegetation cover at the tree, shrub and ground level was visually estimated with an accuracy of ±10%.

Statistical Analyses

The distribution of invertebrate species across the region is pertinent to management for the conservation of biodiversity. Species that are common and widespread can be conserved in reserves, however, when there are numerous species that are rare and of restricted distribution their conservation requires more encompassing strategies. The study examined the invertebrate data for distribution using cluster analysis and species-area curves. The analyses used Primer v5 software (Clarke and Warwick 2001).

Cluster analysis was applied to the riffle and pool data from each of the study sites, using presence/absence data, the Bray-Curtis measure of similarity, and hierarchical agglomerative clustering. Sites 487 and 566[1] were located in close proximity, and their samples were combined for this analysis. The resultant plot showed the similarity of the sites' species composition. Species-area curves plot the cumulative number of taxa collected as each new sample is added to the data. The species-area curve was compiled using every replicate sample that had been collected by the study. The kick samples and leaf grabs collected at 3 pools and 3 riffles of each site over two collection times totaled 330 replicate samples. The samples were added to the species-area plot in groups determined by stream location.

RESULTS

Aquatic Macroinvertebrates

A total of 221 taxa were collected from the study sites, and identified to species (147), genus (48), family (20) or class/order (6). These taxa included at least 5 species that were new to science and 4 species that are not yet described. A list of these taxa, and the sites from which they were collected, is provided in Table 2. The new and the not yet described species are identified in the table. While there were numerous taxa that were present at most sites, there were also a number of taxa that were found to be of limited distribution. An example of this was the rare hydraenid beetles. Two specimens of a previously unrecorded species were collected from one leaf grab at one site only. One specimen of another previously unrecorded hydraenid beetle was collected from the second kick sample at one riffle at one site.

The cluster analysis showed that the samples grouped by stream reach rather than by habitat. This means that the riffle fauna from one stream was more similar to the pool fauna at that stream than to the riffle fauna at another stream. The similarity of riffle fauna with pool fauna within each stream ranged from 79% to 84%. There was one exception to this. The most upstream site on Nungatta Creek (566^3) was approximately 1km upstream from the other 566 sites, and had a similarity of only 61% with the downstream 566 site invertebrate fauna. The similarity of the invertebrate fauna between the study streams ranged from 55% to 80%. The plot of the cluster analysis is shown in Figure 2.

Taxa	**Sampling Site**									
	659	YNP	661	731	717	487	566^1	567	566^2	566^3
Gastropoda										
Ancylidae early instars	*	*	*	*	*	*	*			
Ferrissia petterdi	*	*	*	*	*	*	*	*		
Amphipoda										
Eusiridae early stage										*
Pseudomoera fontana										*
Talitrid Unknown species		*	*		*	*	*	*	*	*
Ephemeroptera										
Leptophlebiidae early instars	*	*	*	*	*	*	*	*	*	*
Atalomicria species AV1	*	*	*	*	*	*	*	*	*	
Atalomicria bifasciata		*			*	*	*	*	*	
Atalophlebia species AV4	*	*		*	*	*	*	*	*	*
Atalophlebia species AV8						*	*	*	*	
Atalophlebia species AV13	*			*		*	*			
Austrophleboides pusillus	*	*			*	*	*	*	*	
Austrophleboides marchanti		*			*	*				
Koorrnonga species AV1	*	*	*	*	*	*	*	*	*	*
Neboissophlebia hamulata	*	*			*	*	*	*		
Nousia species AV1	*	*	*	*	*	*	*	*	*	*
Nousia species AV2					*	*	*			*
Nousia species AV3		*			*		*			
Tillyardophlebia species AV3		*			*		*	*	*	
Ulmerophlebia species AV2	*	*	*	*	*	*	*	*	*	*
Genus K species AV1		*								
Caenidae early instars	*	*		*	*	*	*	*	*	
Tasmanocoenis ? tillyardi		*			*	*	*	*		
Baetidae early instars	*	*		*	*	*	*			
Bungona narilla	*	*	*	*	*	*	*			
Genus 1 MV sp4						*	*			
Centroptilum species	*					*	*			
Oniscigastridae early instars						*	*			
Tasmanophlebia lacus-coerulei						*				
Odonata										
Telephlebiidae early instars	*	*	*	*	*	*	*	*	*	*
Austroaeschna obscura		*	*	*	*	*	*	*	*	*
Austroaeschna subapicalis						*	*			
Austroaeschna pulchra		*			*	*	*	*		
Telephlebia ? brevicauda			*		*					
Synthemistidae early instars		*			*	*	*	*	*	*

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)
Note: (NEW) = new species, (NOT DESC.) = not yet described species, L = larvae, A = adult

Taxa	**Sampling Site**									
	659	YNP	661	731	717	487	566 [1]	567	566 [2]	566 [3]
Eusynthemis brevistyla							*			
Eusynthemis guttata							*	*	*	*
Megapodagrionidae early instars	*	*		*	*	*	*	*	*	*
Austroargiolestes icteromelas	*	*		*		*	*	*	*	
Synlestidae early instars		*				*	*			
Synlestes weyersii				*		*	*			
Diphlebiidae early instars						*	*			
Diphlebia lestoides						*	*			
Plecoptera										
Gripopterygidae early instars	*	*	*	*	*	*	*	*	*	*
Riekoperla rugosa	*	*	*	*	*	*	*		*	
Illiesoperla ? australis / mayi	*	*	*		*	*	*	*	*	*
Dinotoperla ? serricauda	*	*		*	*	*	*	*	*	*
Dinotoperla christinae						*	*			
Leptoperla neboissi						*	*	*		
Leptoperla species 3		*				*	*	*	*	
Newmanoperla thoreyi		*								
Notonemouridae early instars		*	*	*		*		*	*	
Austrocercella species		*			*	*	*	*	*	
Austrocerca ? tasmanica			*	*		*	*	*	*	*
Austroperlidae early instars		*			*			*	*	*
Austroheptura illiesi		*			*	*	*	*	*	*
Eustheniidae early instars		*			*	*	*	*	*	*
Cosmioperla kuna		*			*	*	*		*	
Eusthenia venosa										*
Megaloptera										
Corydalidae early instars	*	*		*	*	*	*	*	*	*
Archichauliodes plomleyi	*	*	*	*	*	*	*	*	*	*
Hemiptera										
Veliidae early instars	*		*	*	*	*	*	*	*	*
Microvelia childi	*	*	*	*		*		*	*	
Microvelia margaretae	*	*		*	*		*		*	*
Microvelia milleri (NEW)					*					
Notonectidae early instars	*			*						
Enithares woodwardi				*						
Nerthra species	*			*						
Dipsocoridae early instars	*	*	*	*			*		*	*
Cryptostemma species	*	*	*	*			*		*	*
Coleoptera										
Psphenidae early instars	*	*	*	*	*	*	*	*	*	*
Sclerocyphon striatus		*			*	*	*	*	*	*
Sclerocyphon basicollis	*	*	*	*	*	*	*	*	*	
Sclerocyphon ? type F										*
Elmidae early instars	*	*		*	*	*	*		*	*
Austrolimnius - L *Austrolimnius* sp.1		*			*	*	*	*		
Austrolimnius - L *waterhousei*	*	*		*						
Austrolimnius - L *Austrolimnius* sp.3	*	*	*	*	*					
Austrolimnius - L *mormo*	*				*	*	*	*	*	
Austrolimnius - L *Limnelmis* sp.5	*	*		*	*	*	*	*		

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)

Taxa	**Sampling Site**									
	659	YNP	661	731	717	487	566 [1]	567	566 [2]	566 [3]
Austrolimnius - L *? resa*		*								
Austrolimnius - A *mormo*				*		*	*			
Austrolimnius - A *oblongus*	*	*	*	*	*					
Austrolimnius - A *hebrus*	*			*			*			
Austrolimnius - A *Limnelmis* gp.		*					*			
Kingolus - A *quatuormaculatus*	*	*		*	*		*			
Kingolus - L *quatuormaculatus*	*	*			*	*	*			
Kingolus - A *heroni*		*			*	*	*			
Kingolus - L sp. L47E		*				*	*			
Kingolus - A *tyrrhenus*						*	*			
Kingolus - L *tyrrhenus*		*			*	*	*			
Simsonia - L *tonnoiri*						*				
Simsonia - L *tasmanica*							*			
Simsonia - L *angusta*										*
Notriolus - A *quadriplagiatus*						*	*		*	
Notriolus - L *quadriplagiatus*						*	*		*	
Notriolus - A *simsoni*					*		*			
Notriolus - L *simsoni*									*	
Notriolus - A *victoriae*							*			
Dytiscidae										
Carabhydrus - A JM1 (NEW)	*		*	*						
Carabhydrus - L JM1 (NEW)	*	*	*							
Chostonectes - A *sharpi*	*			*						
Chostonectes - A *johnsoni*	*			*						
Chostonectes - A *gigas*				*						
Chostonectes - L species	*			*						
Platynectes - A *decempunctatus*				*				*		
Sternopriscus - A *hansardi*		*				*				
Sternopriscus - L *hansardi*						*				
Australphilus - A *saltus*						*				
Australphilus - L *saltus*						*	*			
Rhantus - A *saturalis*				*						
Hydaticus - A *parrallelus*				*						
Gyrinidae										
Macrogyrus - A *rivularis*						*	*	*	*	*
Macrogyrus - L *rivularis*						*	*	*	*	*
Macrogyrus - A *australis*				*						
Hydrophiloidea										
Hydrochus - A *granicollis*		*		*						
Berosus - A *involutus*						*				
Berosus - L *species*						*				
Notohydrus - A *australis*	*		*			*		*	*	*
Paranaceana - A *species*			*							
? Crenitis - L species									*	
Hydrophilid Unknown - L Ch.2.			*							
Scirtidae early instars	*	*	*	*	*	*	*	*	*	*
Unknown - L Eden Cs.1	*	*	*		*	*	*	*	*	
Unknown - L Eden Cs.2	*	*	*	*	*	*	*	*	*	*
Unknown - L Eden Cs.3						*				

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)

Taxa	**Sampling Site**									
	659	YNP	661	731	717	487	566 [1]	567	566 [2]	566 [3]
Unknown - L Eden Cs.4	*	*	*	*	*	*	*	*	*	*
Unknown - L Eden Cs.5	*	*		*		*				
Hydraenidae										
Hydraena - A *tricantha*						*				
Hydraena - A *hamifera*		*		*						
Hydraena - A *castanea*	*	*	*	*	*	*	*	*	*	*
Hydraena - A *hynesi*		*		*	*	*	*	*	*	
Hydraena - A *hilli*										*
Hydraena - A ns 32 (NOT DESC.)	*			*			*			
Hydraena - A ns 34 (NOT DESC.)				*						
Hydraena - A ns 43 (NOT DESC.)	*			*		*	*	*	*	
Hydraena - A ns 44 (NOT DESC.)	*									
Hydraena - A ns x (NEW)						*				
Hydraena - A ns y (NEW)	*									
Hydraena Unknown - L species	*	*	*		*	*	*		*	*
Ptilodactylidae early instars	*	*			*	*	*	*	*	*
Byrrocryptus - L species		*				*	*	*	*	*
Nanophyes - L species		*	*			*	*	*	*	
Erirhininae - A species				*						
? Stenus - L species			*							
Trichoptera										
Ecnomidae early instars	*	*		*	*	*	*	*	*	*
Ecnomina D species AV2						*	*	*	*	
Ecnomina E species AV1						*	*			
Ecnomina E species AV3		*			*	*	*	*	*	*
Ecnomina F species AV3							*	*	*	
Ecnomina F species AV5	*	*	*	*	*	*	*	*	*	
Ecnomina F species 30		*				*	*	*		
Ecnomus nr tillyardi	*					*	*			
Leptoceridae early instars	*	*	*	*	*	*	*	*	*	*
Triplectides truncatus		*		*	*	*	*	*	*	*
Triplectides similis						*				
Triplectides ciuskus ciuskus		*				*	*			
Triplectides altenogus	*	*		*	*	*	*	*	*	
Triplectides species AV10	*	*								
Lectrides varians	*	*	*	*	*	*	*	*	*	*
Triaenodes species		*	*		*					
Oecetis species		*				*	*	*	*	*
Hydroptilidae early instars	*	*		*	*	*	*	*	*	
Hellyethira species	*	*		*	*	*	*	*	*	*
Orthotrichia species		*	*		*	*	*	*		
Maydenoptila cuneola		*			*	*				
Oxyethira species (NEW)	*	*				*	*	*	*	
Orphninotrichia species	*	*			*	*		*		
Polycentropodidae early instars	*	*		*	*	*	*	*	*	*
Paranyctiophylax species AV3		*			*	*	*	*	*	
Plectrocnemia species AV1	*	*	*	*	*	*	*	*	*	*
Neureclipsis napaea							*			
Genus G species AV1						*				

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)

Taxa	Sampling Site									
	659	YNP	661	731	717	487	566[1]	567	566[2]	566[3]
Calocidae early instars		*		*	*	*	*	*	*	*
Caenota plicata		*		*	*	*	*	*	*	*
Tamasia acuta		*				*	*	*	*	
Cal/Helicophidae early instars	*	*				*	*	*	*	
Cal/Hel C species AV2		*			*	*	*	*		
Cal/Hel D species AV2		*			*			*		
Philopotamidae early instars	*	*			*	*	*	*	*	*
Hydrobiosella species AV2	*									*
Hydrobiosella species AV8		*	*		*	*	*	*	*	
Hydrobiosella species AV13						*		*	*	
Hydrobiosella species AV24 (NEW)					*					
Chimara australica	*					*				
Helicopsychidae early instars						*	*	*		
Helicopsyche species AV12			*							
Helicopsyche tillyardi						*	*	*	*	
Hydropsychidae early instars	*	*			*	*	*		*	*
Diplectrona species AV1					*					
Diplectrona species AV3		*			*	*	*		*	*
Cheumatopsyche species AV3		*				*	*			
Hydrobiosidae early instars	*	*	*		*	*	*	*	*	
Apsilochorema obliquum		*			*	*	*	*		
Apsilochorema gisbum	*			*	*		*			
Taschorema kimminski		*			*	*	*	*	*	*
Taschorema evansi						*	*		*	
Antipodoecia early instars					*					
Antipodoecia species AV1					*					
Antipodoecia species AV2					*		*			
Antipodoecia species AV3		*								
Odontoceridae early instars		*	*		*	*	*	*	*	*
Barynema costatum		*	*		*	*	*	*	*	*
Glossosomatidae early instars	*	*			*	*	*		*	
Agapetus species AV1		*			*	*	*	*		
Calamoceratidae early instars						*	*	*	*	
Anisocentropus species JM1						*	*	*	*	
Philorheithridae early instars						*	*			*
Aphilorheithrus species AV3						*	*	*	*	*
Austrheithrus species							*			
Conoesucidae early instars						*	*			
Costora species AV1						*	*	*		
Matasia satana						*				
Tasmiidae early instars	*	*		*	*	*	*	*	*	*
Tasiagma ciliata	*	*	*	*	*	*	*	*		
Tasimia species AV1						*	*	*	*	
Atriplectididae early instars							*			
Atriplectides dubius							*			
Chironomidae early instars	*	*	*	*	*	*	*	*	*	*
Harrisius species	*	*	*	*	*	*	*	*	*	*
Polypedilum species	*	*	*	*	*	*	*	*	*	*
Dicrotendipes species	*	*		*				*	*	*

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)

Taxa	**Sampling Site**									
	659	YNP	661	731	717	487	566 [1]	567	566 [2]	566 [3]
Zavreliella species	*	*	*	*	*			*	*	*
Chironomid Unknown 1 species							*		*	
Riethia species	*	*	*	*	*	*	*	*	*	*
Tanytarsus species	*	*		*	*	*	*	*	*	*
Cladotanytarsus species	*	*	*	*	*	*	*	*	*	*
Rheotanytarsus species	*	*	*	*	*	*	*	*	*	
Podonomopsis species	*	*		*	*		*	*	*	*
Parochlus species	*								*	*
Podochlus species				*						
Corynoneura species 1	*	*	*	*	*	*	*	*	*	*
? *Corynoneura* species 2	*	*	*	*	*	*	*	*	*	*
Cricotopus species	*	*		*	*	*	*	*	*	*
Eukiefferiella species		*								
"grape th" species	*	*	*	*	*	*	*	*	*	*
Austrobrillia species		*			*	*	*	*	*	*
"SO4" species		*	*		*	*	*	*	*	*
Psectrocladius species		*								
? *Gymnometriocnemis* species	*	*	*	*		*	*	*	*	*
Chironomid unknown 2 species		*	*	*	*					
Chironomid unknown 4 species	*	*	*		*	*	*	*	*	*
? *Pentaneurini* species group	*	*	*	*	*	*	*	*	*	*
Genus E species		*								
Procladius species	*	*	*	*	*	*	*	*	*	*
Aphroteniella tenuicornis	*	*		*	*	*	*	*	*	*
Aphrotenia australiensis					*		*			*
Tanyderidae								*	*	*
Dixidae	*	*	*	*	*	*	*	*	*	*
Culicidae	*	*	*	*	*	*	*	*	*	*
Chaoboridae	*	*	*	*	*					
Ceratopogonidae	*	*	*	*	*	*	*	*	*	*
Athericidae	*	*	*	*	*	*	*	*	*	*
Stratiomyidae		*	*	*	*	*	*	*	*	*
Empididae	*	*	*	*	*	*	*	*	*	*
Tipulidae	*	*	*	*	*	*	*	*	*	*
Thaumaleidae	*	*	*	*	*	*	*	*	*	*
Psychodidae	*	*	*	*	*	*	*	*	*	*
Musciidae				*	*					
Dolichopodidae	*	*	*		*					
Syrphidae		*			*					
Simuliidae	*	*	*		*	*	*	*	*	*
Ephydridae	*		*							
Sciomyzidae	*	*	*	*	*	*	*	*	*	*
Tabanidae										*
Order Acariformes	*	*	*	*	*	*	*	*	*	*
Subclass Ostracoda	*	*	*	*	*	*	*	*	*	*
Order Cyclopoida	*	*	*	*	*	*	*	*	*	*
Order Gordioidea	*	*	*	*	*	*	*	*	*	*
Family Oniscidae	*		*		*	*	*	*	*	*
Class Collembola	*	*	*	*	*	*	*	*	*	*
Order Neuroptera		*	*	*	*		*	*	*	*

Table 2: List of aquatic macroinvertebrate taxa and site where collected (cont.)

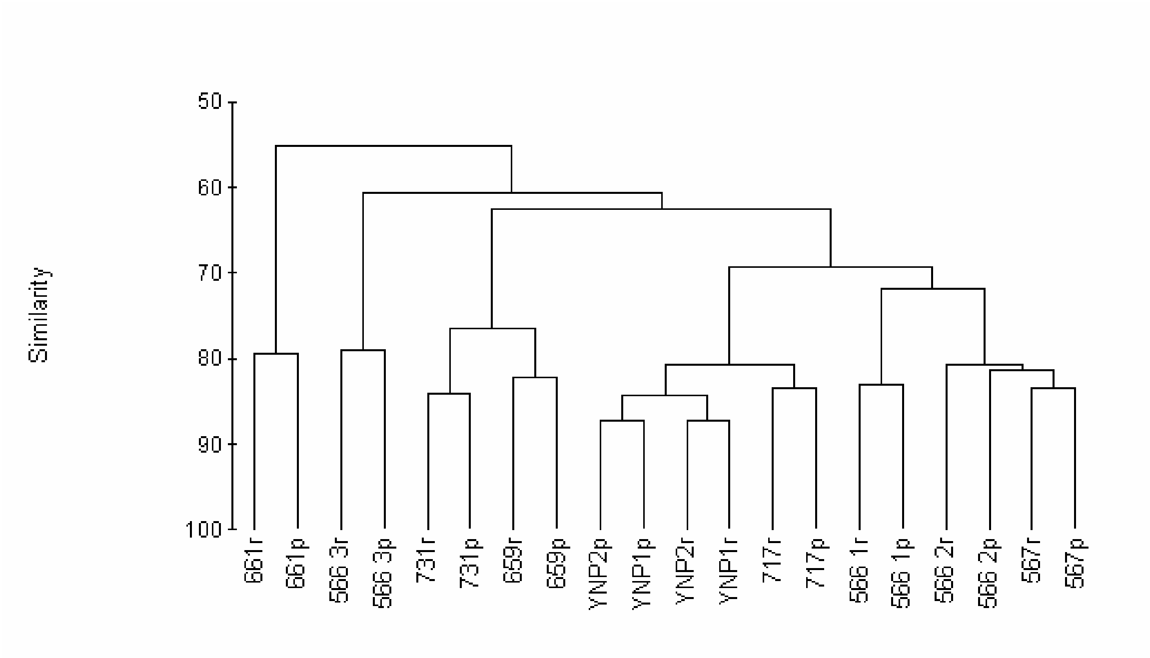

Figure 2: Cluster analysis of the riffle and pool invertebrate assemblages at the study sites. Note: r = riffle, p = pool, YNP = Yowaka N.P.

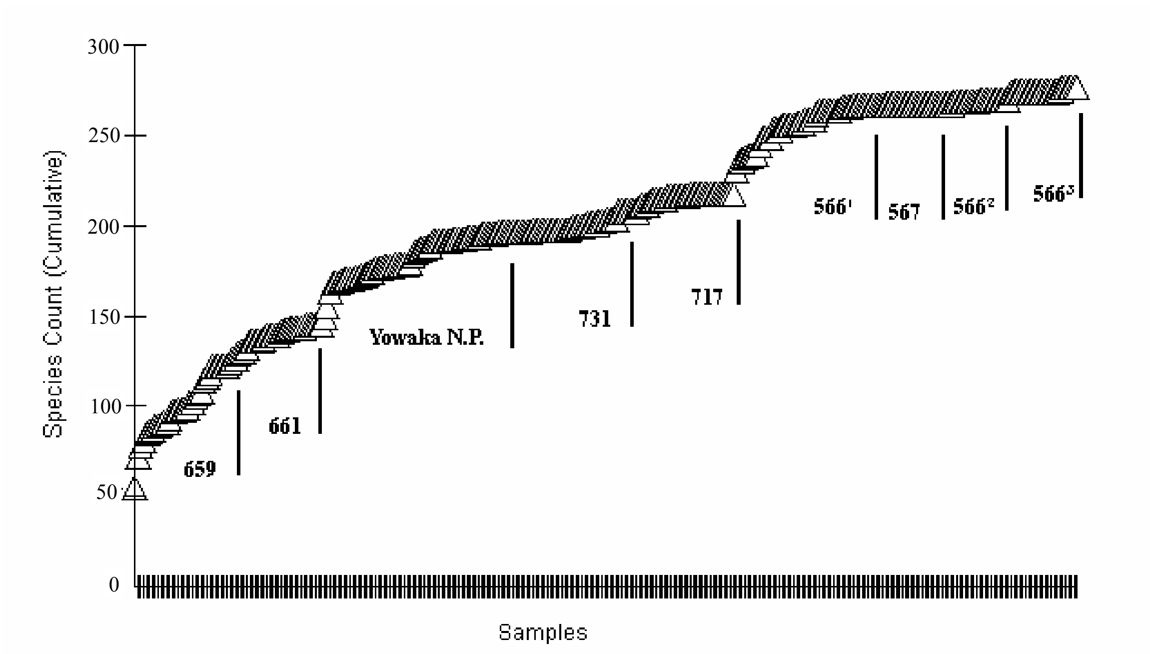

Figure 3: Species-area curve of the study invertebrate sample data. The vertical lines and labels delineate the samples that were collected from each of the study sites.

The results of the species-area curve analysis are shown above in Figure 3. It can be seen from the figure that each stream site adds a number of new taxa to the total taxon list, while within streams most samples add one or more new taxa. The Yowaka National Park site was sampled in June and October.

The sampling in different seasons can be seen to add a number of taxa to the collection. The sites that were in close proximity on the same stream, that is, sites 566[1] and 487, were combined for the species-area curve. The samples were added in order of collection from downstream to upstream, and it is evident from the curve that taxa are added with each new riffle or pool that was sampled. Two sites were adjacent but on different streams. Site 566[2] was located on the Nungatta Creek and site 567 was on a tributary, just 50m distant. Only 1 additional taxon was added to the list by the sampling of site 567, and site 566[2] added two more.

The results of the invertebrate sampling and analyses show that the invertebrate species diversity is widespread across the South East Forests region. While there are common and widespread taxa, such as *Hydraena castanea*, there are also numerous taxa that are rare and that have a very restricted distribution, such as *Hydraena tricantha* and *H. hilli*. Every stream that was sampled supported some taxa that were not collected from other streams (refer Table 2).

Habitat Characteristics

The water quality at the study streams was measured twice at each site. Turbidity was low on each occasion, and this would be the direct result of the very low flows experienced during the sampling. There were some localised (within pool or riffle) high turbidity measurements at the Nungatta Creek sites. The localised nature of the disturbance suggests that this turbidity was most probably caused by the activity of tadpoles and macroinvertebrates such as hemipterans. This turbidity indicated that the sediments of the stream would readily entrain in the event of higher flows or stream bed disturbance. Water temperatures ranged from 8^{o} C at site 659 in winter to 18.5^{o} C at site 487 in summer (Miller 2004). This range demonstrated the temperature tolerance of those species that were present at all site and season samplings. Water pH ranged from 6.3 to 7.7. Dissolved oxygen ranged from 58% to 100%, and was directly related to the flow experienced during sampling and time since rainfall (Miller 2004).

Examination of the channel morphology demonstrated that the streams provided a complex habitat for the invertebrates. Each study reach had step pools or scour pools (Erskine 2004), riffles, boulders, cobbles, gravels, large woody debris and leaf litter. Some of the streams exhibited morphological elements such as transverse ribs that indicated previous high velocity flows. There were also areas of undercut bank at each site that were indicative of active bank erosion. Channel widths were from 2.5 to 19m wide, and the surveyed slope along the thalweg of the study reaches ranged from 0.0274 to 0.1340m/m.

Stream bed particle size analysis showed that a high percentage of the bed material in deposition zones was made up of the coarse fraction, that is, cobbles and gravels. At sites 659, 661, Yowaka N.P., 731 and 717 the percentage of coarse fraction in the bulk samples was between 56% and 92%. At the Nungatta Creek sites there was a higher proportion of the fine fraction, with cobbles and gravels comprising between 0% and 89% of the samples. Silts and clays generally made up only a tiny proportion of the sediments in the deposition zones, with coarse, medium and fine sands making up the remainder. The gravel count analyses determined that the median surface particle size at the site riffles was between 50 and 80mm b-axis diameter. This armour layer sat above the finer bed material sediments, and provided wet interstitial spaces between the gravels for invertebrate habitat. Miller (2004) provides a detailed analysis of the bed material particle sizes.

The riparian vegetation at the study streams generally had mesic species on the south-facing slopes and drier species on the north-facing slopes. There were areas at most sites where the mesic species developed into closed-canopy rainforest. Miller (2004) provides a comprehensive description of the vegetation at the study sites and a species list. The canopy cover provided good stream shading at all sites except site 487, where active bank erosion had caused riparian trees to fall across the channel. The vegetation adjacent to this site was a pine plantation.

The ground cover in the riparian zone comprised some dense shrub thickets, areas of ferns and vines, and a diversity of grasses and forbs. The sites had approximately 10% of the ground within the riparian zone that did not support vegetation, and these areas were covered with rocks and boulders, loose leaf litter and other organic matter. These areas all evidenced the digging activities of lyrebirds, and several lyrebird mounds were sighted. The riparian zone had a continuous strip of vegetation at the study sites with the exception of two logging track crossings. These crossings provided a hillside-to-stream connection for the incursion of sediment through the riparian zone. One of these crossings had a bridge, the other comprised earth that had been scraped into the channel for vehicles to drive across.

DISCUSSION

This study sampled for aquatic invertebrates in high-energy, low order, intermittent streams. This is a habitat that is not frequently sampled due to inaccessibility and uncertainty of water flow. The sampling intensity was much greater than that usually applied by studies. As a result, some of the fauna that was collected added to the scientific knowledge of invertebrate distribution and taxonomy. It is likely that further new species were collected by this study, most probably amongst the Chironomidae and other dipterans that were not identified to species. It is also likely that further new species await discovery in the South East Forests region.

This study found that there were taxa of restricted distribution in every stream. The Eden Management Area EIS (State Forests of NSW 1994) invertebrate surveys collected 81 taxa. Due to the lack of taxonomic keys available at the time of that study, many species were assigned a number and direct comparison of the species collected with this study was not possible. Approximately 50% of those taxa that could be identified to species names, were different species to those collected by this study. The lack of intensive invertebrate surveys of the South East Forests region, combined with the findings of this study, have implications for management of the region. The findings show that there are invertebrate fauna of scientific interest, and that each stream reach supports taxa that are of limited distribution. The implication is that, to manage the area for the conservation of species diversity, all stream habitats should be protected from impact. Impacts to aquatic invertebrates are generally the result of impacts to their habitat that affect the ability of the taxa to survive. The assessment of the habitat at the study sites showed that stream flow was low to intermittent, and that the stream channels had a complex habitat that included cobbles and gravels with many wet interstitial spaces. There were a few localised occurrences of bed material that had a high proportion of fine sediment. The majority of the sites, however, had a high proportion of gravels and cobbles with few fines. Impacts to these invertebrate habitats could result from alteration of hydrology, increased sediment in the stream bed, and increased turbidity. The prevention of these impacts are issues to be addressed by a management plan.

Decreased evapotranspiration and infiltration in logged catchments has been found to increase water yields (Clinnick 1985, Cornish 1993, Vertessy 1999), and this effect would be the same for catchments that have been affected by intense wildfire. Studies have found that water yield does not return to pre-logging levels until vegetation has re-established on the site one to five years after disturbance (Harper & Lacey 1997, Cornish 1993, Erskine 2001), and runoff to the stream may be reduced during the period of regeneration. To avoid the impact of altered hydrology caused by wildfire, management strategies that reduce inappropriate access should be enforced. This might include restricting the access of all but the most essential vehicles, appropriate fire management plans and sufficient resources to contain wildfires.

The prevention of sedimentation and turbidity is best achieved by the maintenance of riparian vegetation. Riparian vegetation can prevent sediment transported by runoff from entering waterways. Vegetation spreads and divides the flow, thus reducing the runoff velocity and causing coarse particulate matter to settle. Suspended finer particles are then filtered out of the flow by leaf litter and the soil profile (Clinnick 1985, Croke *et al*. 1999, Pearce *et al*. 1998). Riparian vegetation can also maintain bank stability, thereby reducing the incidence of bank erosion (Smith 1976, Riding & Carter 1992, Metzeling *et al.* 1995). The protection of the riparian vegetation from clearing should be an aim of the management plan. This includes protection of the understorey and ground cover. Riparian vegetation should also be excluded from any control burns.

Unsealed road crossings create a breach in the riparian vegetation, and can be a point source of sediment entering the waterway (Cornish 1980, Croke & Mockler 2001, Wemple *et al.* 2001, Lane & Sheridan 2002). This can impact on invertebrate community structure downstream from the crossing (Richardson 1985). The unsealed road crossing at study site 661 was on a properly constructed bridge, and there was no evidence of hillslope-to-stream erosion during the duration of the study sampling. The crossing at site 566 placed sediment directly into the stream channel, and further sediment was added to the stream when sediment control measures failed during a major storm (Miller 2004). It should be a priority of any management plan that unsealed tracks across streams are closed where possible, and the riparian vegetation restored. Where a track must be kept open to vehicular traffic for maintenance or fire-fighting reasons, access to these crossings should be restricted and appropriate sediment control measures put in place beside the crossing. The best method for a creek crossing is a constructed bridge.

During field work the authors observed that driving a vehicle across a stream in the South East Forests region, even over cobbles, creates a plume of fine sediment. American studies have shown that low levels of suspended sediment sustained over a long period of time have the same impact on macroinvertebrate communities as high levels of sediment over shorter periods (Metzeling *et al.* 1995). Species composition and diversity can be altered when habitat is lost through siltation of interstitial spaces, rock surfaces and food resources (Metzeling *et al.* 1995), when invertebrate feeding filtration becomes clogged (Growns & Davis 1994), and when turbidity increases (Campbell & Doeg 1989). All unsealed creek crossings that carry a high volume of traffic should have a properly constructed bridge above the creek, and not a ford through the creek.

Metzeling *et al.* (1995) provide a review of studies that examined the impact of sediment on macroinvertebrate communities, and a list of invertebrate species that had been consistently affected in the studies. Pearson and Hawking (2001) provide a bibliography of literature relevant to the impact of sedimentation on macroinvertebrates. This existing literature provides a reference for the interpretation of invertebrate data from sedimentation studies. A number of the invertebrates that were collected by this study are known to be sensitive to turbidity or increased sediment. These species might be useful for the monitoring of water quality protection measures that are recommended by any management plan.

Finally, it is a recommendation of this study that any management plan make provision for further research into the invertebrates of the South East Forests region, both aquatic and terrestrial.

Acknowledgements

The Ph.D. research project that provided the data used in this study was part-funded by Forests NSW and the School of Geography, UNSW. The research licences were granted by Forests NSW and the NSW National Parks and Wildlife Service. The invertebrate taxonomic experts who provided identifications for this study are gratefully acknowledged.

REFERENCES

Cairns J Jr. and Pratt JR (1993) A History of Biological Monitoring Using Benthic Macroinvertebrates, *Freshwater Biomonitoring and Benthic Macroinvertebrates* (eds. Rosenberg DM and Resh VH) Chapman and Hall, New York, pp.10-27.

Campbell IC and Doeg TJ (1989) Impact of timber harvesting and production on streams: a review, *Australian Journal of Marine and Freshwater Research* **40**:519-539.

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

Clarke KR and Warwick RM (2001) *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation 2nd edition*, Primer-E Ltd, Plymouth Marine Laboratory, UK.

Clinnick PF (1985) Buffer strip management in forest operations: a review, *Australian Forestry* **48**:34-45.

Cornish PM (1980) Water quality studies in New South Wales state forests. 1. A North Coast eucalypt forest near Lismore, *Australian Forestry* **43**:105-110.

Cornish PM (1993) The effects of logging and forest regeneration on water yield in a moist eucalypt forest in New South Wales, Australia, *Journal of Hydrology* **150**:301-322.

Croke J, Hairsine P and Fogarty P (1999) Sediment transport, redistribution and storage on logged forest hillslopes in south-eastern Australia, *Hydrological Processes* **13**:2705-2720.

Croke J and Mockler S (2001) Gully initiation and road-to-stream linkage in a forested catchment, southeastern Australia, *Earth Surface Processes and Landforms* **26**:205-217.

Cropper S (1993) *Management of Endangered Plants*, CSIRO, Victoria.

CSIRO (ed.) (1991) *The Insects of Australia. A textbook for students and research workers,* Melbourne University Press, Carlton.

Erskine WD (2001) Water yield response to integrated native forest management in southeastern Australia. In: M Marino and P Simonovic (Eds) *Integrated Water Resource Management,* Proceedings of a symposium held at Davis, California, International Association of Hydrological Sciences Publ. No.272, pp:249-255.

Erskine WD (2004) SW-966 Stream Classification. In: JH Lehr, J Keeley, and J Lehr (Eds), *The Encyclopedia of Water,* Wiley, New York.

Growns IO and Davis JA (1994) Effects of forestry activities (clearfelling) on stream macroinvertebrate fauna in south-western Australia, *Australian Journal of Marine and Freshwater Research* **45**:963-975.

Harper PB and Lacey ST (1997) A review of findings from the Yambulla catchments forest hydrology research project 1977-1990, Research Paper No.33, State Forests of New South Wales.

Hawking JH (2000) *Key to Keys, A guide to keys and zoological information to identify invertebrates from Australian inland waters,* Co-operative Research Centre for Freshwater Ecology Identification Guide No. 2, Albury.

Hawking JH and Smith FJ (1997) *Colour Guide to Invertebrates of Australian Inland Waters, Identification Guide No.8,* Cooperative Research Centre for Freshwater Ecology, Albury.

Hubbard MD and Campbell IC (1996) Catalogue of the Australian Mayflies, Recent and Fossil (Insecta: Ephemeroptera), *Special Publication No.11 of the Australian Society of Limnology,* 43pp.

Kellerhals R and Bray DI (1971) Sampling procedures for coarse fluvial sediments, *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*, **97**:1165-1180.

Lane PNJ and Sheridan GJ (2002) Impact of an unsealed forest road stream crossing: water quality and sediment sources, *Hydrological Processes* **16**:2599-2612.

Metzeling LH, Doeg T and O'Connor W (1995) The impact of salinization and sedimentation on aquatic biota. In: RA Bradstock, TD Auld, DA Keith, RT Kingsford, D Lunney and DP Sivertsen. (Eds) *Conserving Biodiversity: Threats and Solutions*, Surrey Beatty. pp. 126-136.

Miller J (2004) The Use of Macroinvertebrates and Integrated Environmental Assessment to Differentiate Land Use Impacts from Natural Variability, *Unpublished Ph.D. Thesis, School of Geography, University of New South Wales.*

Norris RH and Norris KR (1995). The need for biological assessment of water quality: Australian perspective, *Australian Journal of Ecology* **20**:1-6.

NSW National Parks and Wildlife Service (2005) South East Forests National Park & Egan Peaks Nature Reserve Draft Plan of Management *Report of the Department of Environment and Conservation NSW.*

Pearce RA, Trlica MJ, Leininger WC, Mergen DE and Frasier G (1998) Sediment movement through riparian vegetation under simulated rainfall and overland flow, *Journal of Range Management* **51**:301-308.

Pearson MJ and Hawking JH (2001) *A Bibliography of Some of the Ecological and Biological Literature of Invertebrates from Australian Inland Waters*, *Identification Guide No.36*, Cooperative Research Centre for Freshwater Ecology, Thurgoona, NSW.

Richardson BA (1985) The impact of forest road construction on the benthic invertebrate and fish fauna of a coastal stream in southern New South Wales, *Australian Society of Limnology Bulletin* **10**:65-88.

Riding T and Carter R (1992) *The Importance of the Riparian Zone in Water Resource Management: A Literature Review*, Department of Water Resources, NSW.

Smith DG (1976) Effect of vegetation on lateral migration of anastomised channels of a glacier meltwater river, *Geological Society of America Bulletin* **87**:857-860.

State Forests of New South Wales (1994) *Proposed Forestry Operations in Eden Management Area, Environmental Impact Statement*, State Forests of NSW.

Vertessy RA (1999) The impacts of forestry on streamflows: a review, *Forest Management for Water Quality and Quantity, Proceedings of the Second Forest Erosion Workshop May 1999*, Cooperative Research Centre for Catchment Hydrology, pp.93-109.

Wemple BC, Swanson FJ and Jones JA (2001) Forest roads and geomorphic process interactions, Cascade Range, Oregon, *Earth Surface Processes and Landforms* **26**:191-204.

Williams WD (1980) *Australian Freshwater Life, The Invertebrates of Australian Inland Waters,* 2nd edition, Macmillan, Melbourne.

Williams WD and Campbell IC (1987) The inland aquatic environment and its fauna, *Fauna of Australia*, Australian Government Publishing Service, Canberra, pp.156-183.

Wolman MG (1954) A method of sampling coarse river-bed material, *Transactions of American Geophysical Union*, **35**:951-956