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Effects of Runoff from Land Clearing and Urban Development on the Distribution and Abundance of Macroinvertebrates in Pool Areas of a River

Ian D. Hogg[A] *and Richard H. Norris*

Water Research Centre, School of Applied Science, University of Canberra, PO Box 1, Belconnen, ACT 2616, Australia.

[A] Present address: Life Sciences, Scarborough Campus, University of Toronto, 1265 Military Trail, Scarborough, Ontario M1C 1A4, Canada.

Abstract

We examined the effects of runoff from urban land clearing and development on the macroinvertebrate pool fauna of the Murrumbidgee River, Australia, over 1 year. Tuggeranong Creek, which flows through the urban development, often recorded higher instantaneous (storm) discharges than did the Murrumbidgee River. Monitoring of suspended solids during one storm event revealed high concentrations of suspended solids (max. 560 mg L^{-1}) entering the Murrumbidgee River for an 8 h period. Such concentrations were not detected by regular two-monthly sampling, although concentrations were generally higher downstream of Tuggeranong Creek. Analysis of substratum particle size revealed a higher proportion of fine inorganic material (<250 μm) at stations downstream of Tuggeranong Creek, suggesting a settling of fine material discharged during storm events. Number of taxa and macroinvertebrate density were lower at downstream stations. We conclude that the deposition of fine inorganic sediment following storm events, and the resulting change in the composition of the substratum, was the major cause of low invertebrate numbers in pools downstream of the cleared catchment.

Introduction

Land-use activities resulting in sediment addition to aquatic systems are among the most serious and widespread of human impacts on the quality of running waters (Cordone and Kelley 1961; Hynes 1970). Consequently, several studies have focused on the effects of silt and sediment inputs to lotic systems, particularly on resident invertebrate and fish communities (e.g. Barton 1977; Rosenberg and Wiens 1978; Newbold *et al.* 1980; Lemly 1982; Whiting and Clifford 1983; Culp *et al.* 1986; Berkman and Rabeni 1987), and several other studies have examined the effects of resulting changes in substratum particle size on the distribution and abundance of benthic invertebrates (e.g. Rabeni and Minshall 1977; Williams and Mundie 1978; Hawkins *et al.* 1982; Lazim and Learner 1987). Most of these studies have looked primarily at 'riffle' areas, a bias found in most lotic studies (Soluk 1983; Rae 1987), and few have considered the fauna of pools. Pool areas may be more sensitive and quicker to respond to sediment addition than are riffle areas because they are deposition sites (Cline *et al.* 1982; Logan and Brooker 1983). For example, organic food particles may be smothered by the settling of inorganic material (Hynes 1960). Pools are common in the lower reaches of large rivers, hence they are important in terms of primary and secondary production within the ecosystem (Soluk 1983).

This study was designed to assess the effect of runoff from land clearing and urban development on the macroinvertebrate pool fauna of the Murrumbidgee River.

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Materials and Methods

Study Area

The Murrumbidgee River, part of the largest river system in Australia, runs for 1600 km through south-eastern Australia before entering the Murray River. Within the Australian Capital Territory, the Murrumbidgee River consists mostly of large pools and shifting sand areas with intervening riffles.

Land clearing and urban development of the previously agricultural Tuggeranong Valley in southern Canberra led to inputs of sediment through runoff entering the Murrumbidgee River. Most of this sediment was carried through Tuggeranong Creek, which drained the development (Anon. 1988). Construction consisted of mostly single-family dwellings and a city-centre shop/office complex. Several sediment-settling ponds and a 70 ha artificial lake, with its dam, were also under development during the course of the study. Preliminary chemical and nutrient analysis of runoff from the Tuggeranong catchment (ACT Administration, unpublished data) indicated that all measured parameters were within Australian water-quality guidelines (Hart 1974) for aquatic habitats. These, and observational data, also indicated that sediment addition might be of most concern for the aquatic biota.

Six sampling stations were selected in pool areas, three upstream (1, 2, 3) and three downstream (4, 5, 6) of the confluence with Tuggeranong Creek (Fig. 1). Stations were selected on the basis of visual uniformity in areas where a wide, sandy riverbank/riverbed existed. The surrounding area was primarily agricultural, although most of the riverbanks were tree-lined with *Casuarina cunninghamiana* and *Salix babylonica*. Pools ranged from 25 to 70 m in width and from 2·5 to 3·5 m in maximum depth during low flow. All stations were open to full sunlight for most of the day. Water velocity at 3 cm above the substratum ranged from 0·19 to 0·28 m s^{-1} in September 1987 and May 1988, and there was no detectable flow at any station in March 1988. A summary of nutrient concentrations is shown in Table 1.

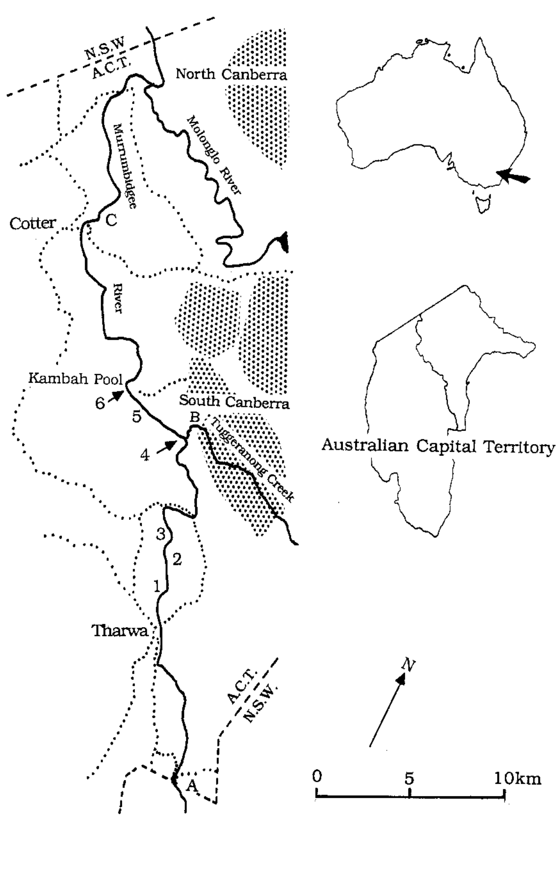

Fig. 1. Study area, showing sampling stations (1–6) and water-discharge gauging stations (A–C) along the Murrumbidgee River, ACT, Australia. Paved roads and river crossings are indicated by dotted lines; stipling indicates urban areas.

Table 1. Summary of selected physical and chemical variables in the Murrumbidgee River at each sampling station, all sampling periods combined (May 1987–May 1988)
TP, Total Phosphorus; TKN, Total Kjeldahl Nitrogen

Station No.	TP ($\mu g\ L^{-1}$)		NO_3–NO_2 ($\mu g\ L^{-1}$)		TKN ($\mu g\ L^{-1}$)	
	Mean	Max./ min.	Mean	Max./ min.	Mean	Max./ min.
1	44·7	82	35·6	84	344	390
		14		20		270
2	41·8	63	26·0	80	344	390
		26		4		290
3	35·3	57	26·6	80	346	390
		14		4		310
4	37·8	63	38·0	84	370	440
		11		4		190
5	38·5	67	60·0	124	374	410
		15		19		330
6	42·5	65	54·4	129	362	490
		23		19		220

Physical and Chemical Properties

Water

Two 1 L water samples were collected every 2 months from each station and cooled on ice for return to the laboratory. Suspended solids were measured in the laboratory as nonfilterable residues (Anon. 1985). Additionally, suspended solids were monitored during a storm event centred over the Tuggeranong catchment. Samples were taken in the Murrumbidgee River immediately upstream of the creek, downstrean of the creek (Station 4), and in Tuggeranong Creek itself. This storm event was in the 94th percentile of mean daily flows recorded for Tuggeranong Creek during the study period, and it contributed a calculated 11% of the mean daily flow of the Murrumbidgee River. The largest previous storm contributed an estimated 130% of the mean daily flow (Australian Capital Territory Electricity and Water, unpublished data).

Dissolved oxygen was measured in the field at 3 cm above the substratum with a Model SVR2-SU Hydrolab. These measurements were taken between 1000 and 1800 hours, when dissolved oxygen concentrations are generally highest (Ball and Bahr 1975; Campbell 1978). Dissolved oxygen readings were corrected for altitude and converted to percentage saturation.

Discharge and rainfall were measured at existing gauging stations upstream of, on, and downstream of Tuggeranong Creek (A, B and C respectively; Fig. 1). Discharge and rainfall were recorded daily, and monthly means were calculated.

Substrata

Preliminary visual inspection of sandy substrata at each station suggested a higher proportion of fine material (fine sand/silt) at stations downstream of Tuggeranong Creek. Preliminary sampling of the substratum was undertaken in October 1987 to determine quantitatively the amount of fine inorganic material in the substratum. Two intact substratum cores were collected from each station to a depth of 20 cm by means of a 'freeze-coring' technique (Marchant and Lillywhite 1988). This depth has been found to contain more than 97% of the animals in pool areas (Rae 1987). Each core was separated into 5 cm sections in the field to determine if the distribution of fine particles was homogeneous, thereby separating the most recently settled material from underlying substrata (Leopold *et al.* 1964). Each section was spread out in evaporating dishes (15 cm diam.) and ashed at 550°C for 60 min to determine, and remove, organic content. Preliminary analysis with reweighing after 20 min (Anon. 1985) showed that loss was less than 1% in all cases. Successive ashing resulted in little further loss because of the low organic content. Thus, it was decided to ash for 60 min (three times as long as suggested in Anon. 1985) and reweigh once. Visual inspection of samples also indicated low levels of organic matter. After ashing, sections were dry-sieved through a Wentworth sieve series (2 and 1 mm, then 500, 250, 125, 53 and 0 μm) to determine the size composition of inorganic particles.

This analysis indicated a higher proportion of fine inorganic material (<250 μm) at stations downstream of Tuggeranong Creek. On the basis of this, the procedure was repeated in February 1988 ($n = 5$), and a two-way analysis of variance (ANOVA) was used to test for differences between stations and between depths for particles less than 250 μm. Particle-size analysis was performed in May 1988 ($n = 2$), when Tuggeranong Creek contributed little water relative to the discharge of the Murrumbidgee River, to determine whether substratum composition could change as a result of hydrological events. Logistic constraints prevented the taking of sufficient replicates to allow statistical analysis.

Macroinvertebrates

An airlift sampler (Norris 1980) fitted with a 500-μm-mesh net was employed to collect benthic invertebrates. Ten replicate samples were taken from each station at a water depth of 0·75–1·25 m, using three 1 s airblasts of 50 psi (345 kPa) for each replicate. Samples were taken only from sandy substrata; aquatic vegetation was avoided. Collections were made every 2 months over 1 year.

Two two-way ANOVAs and Tukey's test were used to test for differences in animal numbers and species numbers between stations and between times of year.

Results

Physical and Chemical Properties

Water

Mean monthly discharge for the study area (Stations A, B and C, Fig. 1) was lowest during summer (January–March 1988) and highest from April to June 1988 (Fig. 2), corresponding to total monthly rainfall. Mean monthly discharges at the Murrumbidgee River gauging stations (A and C, Fig. 1) were usually one to two orders of magnitude greater than those measured in Tuggeranong Creek (Fig. 2). However, instantaneous maximum discharges showed much less difference between gauging stations, with Tuggeranong Creek frequently having greater instantaneous discharges, particularly during low-flow periods in the Murrumbidgee River. The exception was May 1988, when instantaneous discharges measured at the Murrumbidgee River stations were an order of magnitude greater than those in Tuggeranong Creek.

Monitoring of a storm event centred over the Tuggeranong catchment in November 1987 recorded maximum suspended solids of 560 mg L^{-1} in Tuggeranong Creek and 173 mg L^{-1}

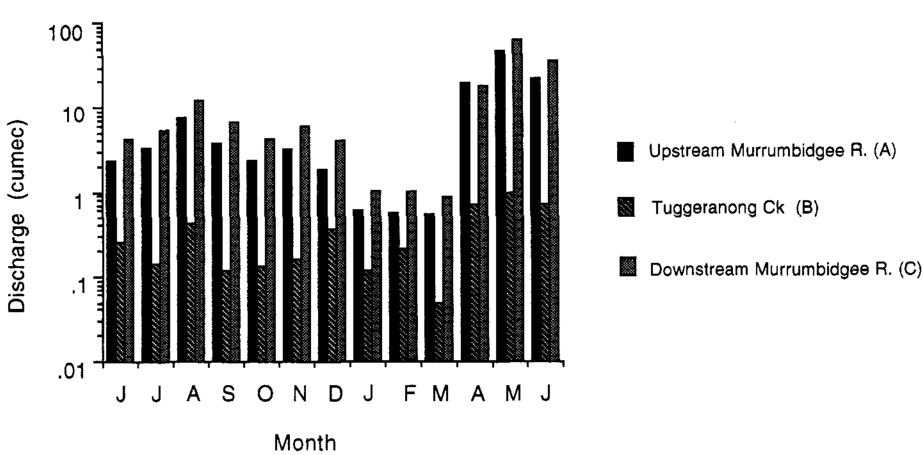

Fig. 2. Mean daily discharge for each month for Tuggeranong Creek (Station B) and the Murrumbidgee River at sites upstream (Station A) and downstream (Station C) of Tuggeranong Creek (June 1987–June 1988).

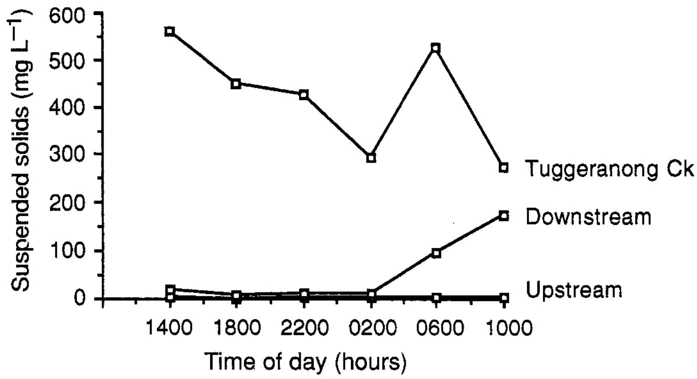

Fig. 3. Suspended solids (nonfilterable residues) in Tuggeranong Creek and the Murrumbidgee River during a storm event (November 1987).

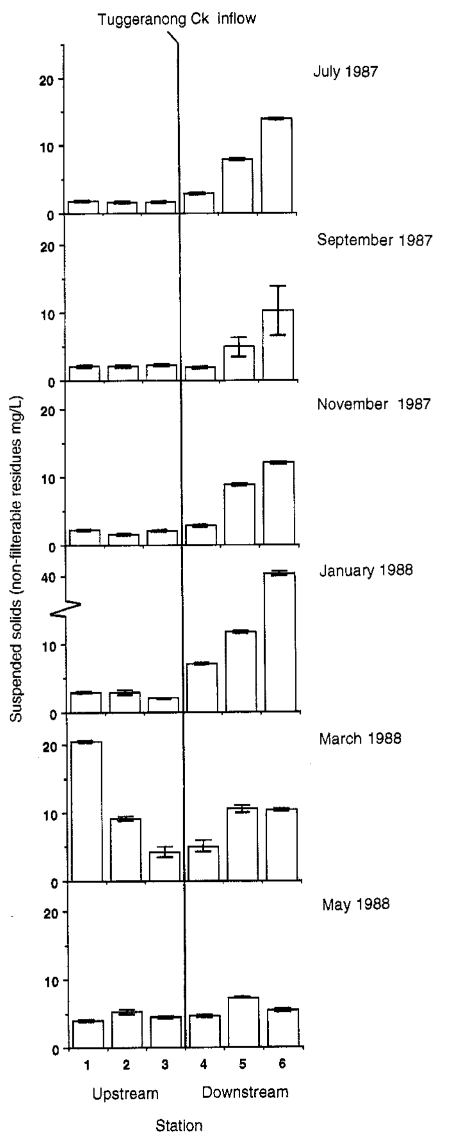

Fig. 4. Suspended solids at stations upstream and downstream of Tuggeranong Creek (July 1987–May 1988). Maximum and minimum bars are shown.

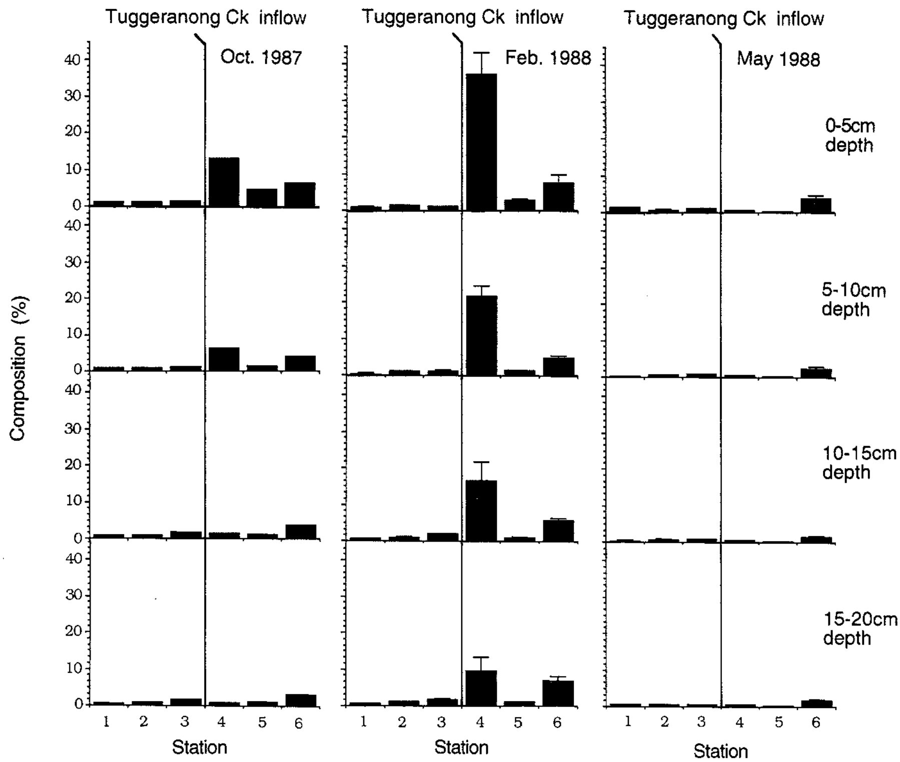

Fig. 5. Percentage composition (±s.e.) of material less than 250 μm for the top 20 cm of substratum (shown in 5 cm intervals) at stations upstream and downstream of Tuggeranong Creek in October 1987, February 1988 and May 1988. Replicates in October 1987 were combined before sieving, hence error bars are not shown.

at Station 4 immediately downstream of Tuggeranong Creek (Fig. 3). Samples taken immediately upstream of Tuggeranong Creek remained below 5 mg L^{-1} (Fig. 3). Suspended-solid concentrations in Tuggeranong Creek fluctuated hourly (Fig. 3). This was likely the result of changes in rainfall intensity and hence discharge (personal observation).

During regular sampling, suspended solids ranged from 1·6 to 20·0 mg L^{-1} at stations upstream of Tuggeranong Creek and from 2·7 to 40·0 mg L^{-1} downstream (Fig. 4). Suspended-solid concentrations were similar upstream and downstream of Tuggeranong Creek in May 1988, when discharge in the Murrumbidgee River was high relative to that in Tuggeranong Creek.

Dissolved oxygen was near or above saturation at all stations for all sampling occasions.

Substrata

Organic content of the substratum was generally less than 1% of the dry weight. Analysis of substratum inorganic particle size revealed a higher proportion of fine material (<250 μm) in the substrata of stations downstream of Tuggeranong Creek in October 1987 and February 1988 (Fig. 5). In February 1988, material less than 250 μm comprised almost 40% of the composition of the top 5 cm at Station 4 (Fig. 5). These concentrations were significantly ($P < 0{\cdot}001$, $F = 66{\cdot}13$, d.f. = 5) higher than those at stations upstream of Tuggeranong Creek. During February 1988, the percentage of material less than 250 μm at Station 5 was similar to that at stations upstream of Tuggeranong Creek (Fig. 5). Samples taken in May

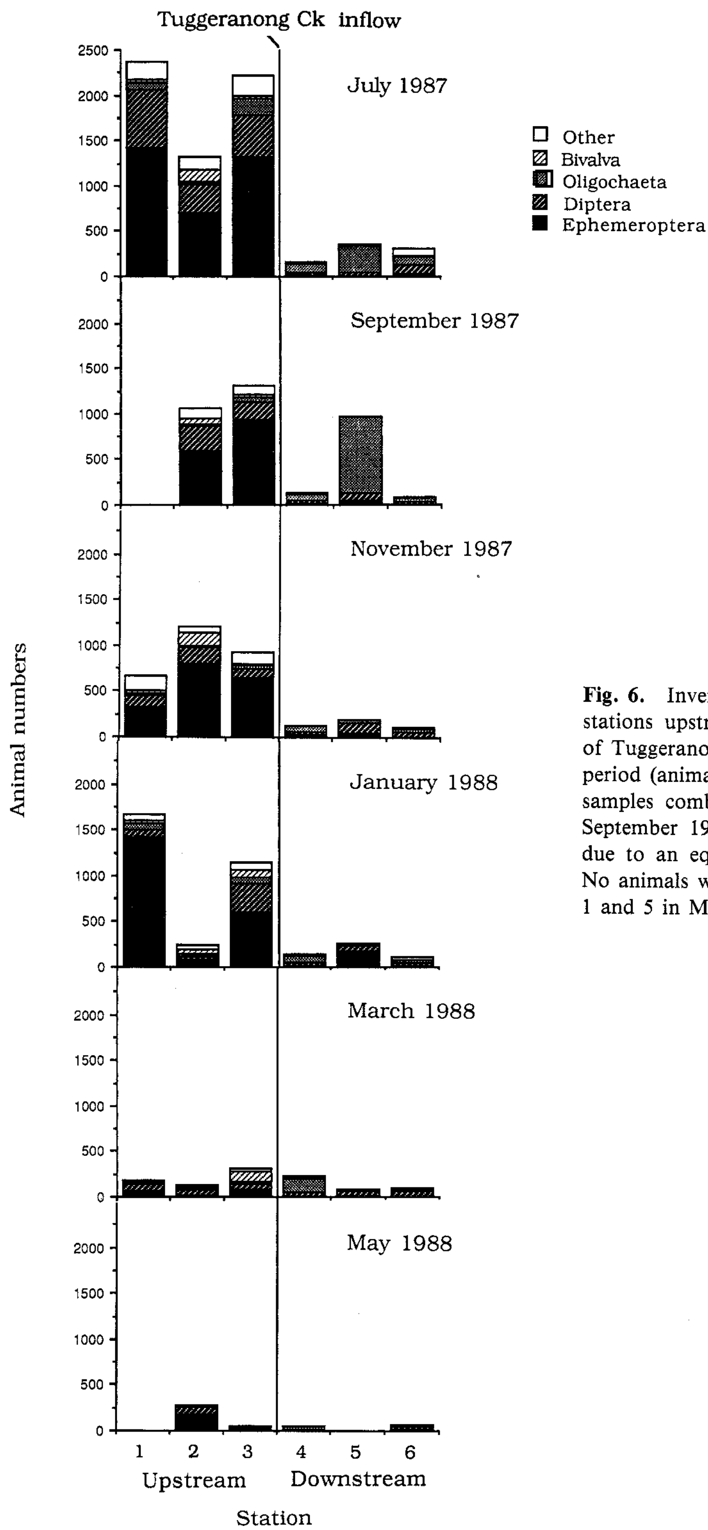

Fig. 6. Invertebrate distribution at stations upstream and downstream of Tuggeranong Creek in each sampling period (animal numbers for 10 replicate samples combined). Station 1 in September 1987 has been omitted due to an equipment malfunction. No animals were captured at Stations 1 and 5 in May 1988.

Table 2. Results of Tukey's test, showing differences in mean numbers of animals (lower triangle) and of species (upper triangle, in parentheses) between sampling stations in the Murrumbidgee River upstream (1, 2, 3) and downstream (4, 5, 6) of Tuggeranong Creek

*Significant difference ($P < 0 \cdot 05$)

Station No.	1	2	3	4	5	6
1	–	(0·4)	(1·2)	(4·2)*	(5·1)*	(4·0)*
2	16·9	–	(0·0)	(4·6)*	(5·5)*	(4·4)*
3	11·9	28·8	–	(5·4)*	(6·3)*	(5·2)*
4	73·4*	56·5*	85·2*	–	(1·0)	(0·2)
5	56·6*	39·7*	68·5*	16·8	–	(1·3)
6	74·6*	57·7*	86·4*	1·2	18·0	–

1988, immediately following a flood event in the Murrumbidgee River, contained little fine material and showed little difference between all stations (Fig. 5).

Macroinvertebrates

More than 20 000 animals from 360 samples were counted, covering 13 invertebrate orders, 36 families and approximately 70 taxa. Animal numbers were significantly ($P < 0 \cdot 001$, $F = 88 \cdot 11$, d.f. = 5) lower at stations downstream of Tuggeranong Creek (Fig. 6, Table 2). *Tasmanocoenis tillyardi* (Lestage) (Ephemeroptera) was the most common invertebrate collected upstream of Tuggeranong Creek, followed by Diptera, Bivalvia, Trichoptera, Odonata and Coleoptera (Fig. 6). Several groups, including Trichoptera, Odonata, Coleoptera and Bivalvia, were seldom collected downstream of Tuggeranong Creek (Fig. 6, Table 3). Oligochaetes were the most commonly collected group downstream of Tuggeranong Creek. Large numbers of ostracods were collected at Station 1, but these were not included with 'macroinvertebrates', although they were added to the species list (Table 3).

Animal numbers upstream of Tuggeranong Creek were highest in July 1987 and lowest in May 1988. Numbers were also low at upstream sites in March 1988, the result of a decrease in the number of *T. tillyardi* (Ephemeroptera) collected. This decrease was most likely attributable to a life-cycle stage such as egg, adult or very small individuals, none of which would be collected by the sampling apparatus used. Marchant *et al.* (1984) suggest an emergence of *Tasmanocoenis* spp. during this time in the La Trobe River, Victoria.

Numbers of *T. tillyardi* were also low at Station 2 in January 1988, corresponding to the highest macrophyte cover at this station. Plants intercept settling material (Westlake 1975), including organics, which *T. tillyardi* utilize as food (Suter, personal communication).

The number of species captured was significantly ($P < 0 \cdot 001$, $F = 201 \cdot 25$, d.f. = 5) lower at stations downstream of Tuggeranong Creek (Table 2).

Discussion

Physical and Chemical Properties

Suspended solids were higher at sites in the Murrumbidgee River downstream of Tuggeranong Creek, indicating a contribution from the creek (Fig. 4). However, concentrations of suspended solids were not higher downstream when flows were high throughout the Murrumbidgee River without there being a proportional change in the contribution from Tuggeranong Creek (May 1988, Fig. 4). High concentrations of suspended solids at Station 1, upstream of Tuggeranong Creek, in March 1988 were probably the result of wind occurring along the long axis of a shallow stretch of river near Tharwa, causing fine sediment to be disturbed and resuspended. Such events were short-lived and common in natural systems (Hellawell 1986).

Table 3. Relative abundance of selected species in pools of the Murrumbidgee River upstream and downstream of Tuggeranong Creek, all sampling periods combined (July 1987–May 1988)
A, abundant (> 1000 specimens); C, common (100–1000 specimens); U, uncommon (10–100 specimens); R, rare (< 10 specimens)

Species	Relative abundance Upstream	Relative abundance Downstream	Time collected
Group 1. Smaller numbers downstream			
Bivalvia, Corbiculidae			
Corbiculina australis (Deshayes 1830)	A	U	All year
Acari, Hygrobatidae			
Australiobates violaceus Lundblad	U	R	July–Jan.
Ostracoda, Cyprididae			
Candonocypris novaezealandia (Baird 1843)	A[A]	R	Nov.–Jan.
Ephemeroptera, Caenidae			
Tasmanocoenis tillyardi (Lestage)	A	C	All year
Odonata, Gomphidae			
Austrogomphus sp. 'c' Watson 1974	C	R	All year
A. ochraceus Selys	U		November
Trichoptera			
Leptoceridae			
Triaenodes sp.	C		All year
Ecnomidae			
Ecnomus continentalis Ulmer	U		July–Jan.
E. pansus Neboiss	U		July–Jan.
Hydroptilidae			
Hellyethira simplex (Mosely)	U	R	All year
H. ?malleoforma Wells	U	R	All year
Diptera, Chironomidae, Tanypodinae			
Procladius sp.	C	R	All year
Group 2. Similar or larger numbers downstream			
Oligochaeta			
Naididae			
Nais communis/variabilis	C	C	All year
Tubificidae			
Branchiura sowerbyi Beddard 1892	C	C	All year
Limnodrilus hoffmeisteri Claparede	U	C	All year
Copepoda, Cyclopoida			
Eucyclops speratus (Lilljiborg 1901)	U	C	All year
Diptera, Chironomidae, Chironominae			
Cryptochironomus sp.	C	C	All year
Polypedilum oresitrophus (Skuse)	C	C	All year
Riethia sp.	C	C	All year
Cladotanytarsus sp.	C	C	All year

[A] More than 80% of animals captured at one station only.

Lower suspended-solid readings at Station 4 than at Stations 5 and 6 further downstream (Fig. 4) were the result of prevailing flow conditions in the Murrumbidgee River at the time of sampling. It was observed that low discharge from Tuggeranong Creek resulted in the bulk of the suspended load being carried in a narrow band opposite the collection site, with full mixing occurring further downstream. This would have suggested a lesser impact at Station 4 than at Stations 5 and 6, but regular sampling will often miss peak inputs of sediment during storm events, which may occur between sampling occasions and at inconvenient times (e.g. Fig. 3). The monitoring of suspended solids during the November 1987 storm event (Fig. 3) revealed concentrations at Station 4 that were more than double the 80 mg L^{-1} guideline (Hart 1974; Anon. 1988).

During low-flow conditions in the Murrumbidgee River, instantaneous discharge from Tuggeranong Creek contributed up to five times the discharge measured in the river. Four months before this study, during a single storm event, instantaneous discharge from Tuggeranong Creek was 15 times that of the Murrumbidgee River (Australian Capital Territory Electricity and Water, unpublished data). Such peak discharges are typical of urban catchments as a result of runoff from sealed surfaces such as roads (Cordery 1976). During these events, it was observed that normal flow in the Murrumbidgee River was interrupted and that effluent from Tuggeranong Creek flowed upstream as well as downstream for a short period. This resulted in a 'slug' of sediment-laden water flowing through the Murrumbidgee River downstream of Tuggeranong Creek, resulting in high suspended-solid concentrations at Station 4 (Fig. 3). Most of this material presumably settles in the vicinity of the Tuggeranong Creek/Murrumbidgee River confluence (Station 4), as suggested by analysis of substratum particle size (Fig. 5).

Suspended solids create a threat to aquatic environments only when they are present over extended periods on in 'unusually' large amounts, thereby changing the character of the habitat (Hellawell 1986). The size composition of substratum inorganic particles supports the notion of a change in the character of the habitat, with the increase in fine inorganic material (<250 μm) recorded downstream of Tuggeranong Creek (October 1987 and February 1988, Fig. 5) indicating settling of suspended materials and smothering of the substratum. High discharge in the Murrumbidgee River relative to Tuggeranong Creek (May 1988, Fig. 2) removed fine deposited material from the streambed, resulting in a uniformity of results for upstream and downstream stations (May 1988, Fig. 5).

Macroinvertebrates

The benthic macroinvertebrate pool fauna of the Murrumbidgee River was numerically dominated by a single species, *Tasmanocoenis tillyardi* (Lestage) (Ephemeroptera: Insecta), which contributed up to 85% of the total animals captured at upstream stations (Fig. 6) and occurred at densities of up to 13 600 m^{-2}. Similar pool-and-shifting-sand habitats in North America (e.g. Barton 1980; Soluk 1983) are typically low in species richness but frequently support high densities of individual species (e.g. 84 000 m^{-2}, Soluk 1983).

Both number of taxa and density of benthic macroinvertebrates were lower in pools downstream of Tuggeranong Creek (Fig. 6, Table 2). Physical conditions downstream of Tuggeranong Creek presumably created an unfavourable environment for most taxonomic groups. Fine inorganic sediment (October 1987 and February 1988, Fig. 5) interferes with invertebrate life processes such as feeding and respiration, particularly in the Odonata, Trichoptera and Bivalvia (Hynes 1960; Minshall 1984), which were rarely found downstream of Tuggeranong Creek (Table 2).

Few species inhabit silty bottom areas, with the exception of 'burrowers' such as oligochaetes, chironomids and some odonates (Hynes 1960, 1970; Huggins and DuBois 1982). The larger numbers of oligochaetes collected in pools downstream of Tuggeranong Creek during November 1987 and March 1988 were therefore expected.

The increase of *T. tillyardi* (Ephemeroptera) at Station 5 in January 1988 (Fig. 6) may have been related to the lower percentage of fine inorganic material recorded at this station compared with that recorded at other downstream stations (February 1988, Fig. 5). This increase indicates either a drifting and colonization of animals, presumably from upstream, or that oviposition is occurring at this site. In either case, if conditions improved downstream, a recovery of *T. tillyardi* would be expected. Streambeds, once free of fine sediment, can be quickly colonized by drifting benthic invertebrates (Tebo 1955; Williams and Hynes 1977; Doeg *et al.* 1989) from unaffected areas.

Animal numbers were lowest in May 1988 (Fig. 6), immediately following a flood event in the Murrumbidgee River. Benthic invertebrate communities in sandy pool areas are frequently lowest in species richness and numbers during high-flow conditions but increase again during low flow when substratum stability is higher (Barton 1980; Gurtz and Wallace 1984).

This study demonstrates a negative effect of runoff from land clearing and development on benthic macroinvertebrate numbers and species richness in pool areas of a river. We conclude that the deposition of fine inorganic sediment following storm events, and the resulting change in the composition of the substratum, was the major cause of low invertebrate numbers in pools downstream of Tuggeranong Creek. This was likely intensified during low-flow periods when instantaneous discharge from the cleared catchment was higher than that of the receiving river. Following the cessation of incoming sediment and the flushing of fine deposited sediment from the substratum during high-flow events, recovery of benthic invertebrates (e.g. *T. tillyardi*) in pool-and-shifting-sand areas should be rapid.

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