Assessment of the ecological condition of freshwater streams in the Darwin region: evidence from a survey of macroinvertebrate communities and water quality in the early dry season 2001.

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Contents

Executive summary

Water quality parameters were determined at fourteen sites on streams in the Darwin area. Aquatic macroinvertebrate communities were quantitatively described at thirteen of these sites.

1. Multivariate analysis of macroinvertebrate data identified three groups of sites composed of a group of seven sites, a group of five sites and a group consisting of a single outlier site.

2. A large number of chemical and physical environmental variables were examined for correlation with the biological data: eleven variables were found to have a significant correlation with the ordination solution. The variables with the highest correlation coefficients were ionic ratio of calcium and magnesium; the percentage of calcium of total cations and zinc concentration.

3. Zinc and other metal concentrations were within national water quality guideline limits with the exception of copper at one site and aluminium. High aluminium levels almost certainly reflect high natural background levels and not anthropogenic influence.

4. Levels of all pesticides and herbicides were below detection limits in all samples.

5. There is no evidence of gross ecological impairment at any site. However, one site DW-21 (Rapid Creek) is showing symptoms of scouring from increased wet season run-off from the developed residential catchment.

6. There was evidence of nutrient enrichment at one site (DW-26, Bee's Creek). This site has the highest number of sensitive taxa (n=9) and the second highest number of taxa (n=60).

7. Future monitoring may include additional indicators such as diatom community structure, fish community structure and the occurrence of macroalgae and macrophytes.

Introduction

Within the Northern Territory (NT) and elsewhere in northern Australia, there is a need to develop and implement monitoring strategies to report changes in the ecological status of streams and rivers, and other natural systems, currently under increasing pressures of development. The distribution and abundance of aquatic biota can be used to infer the nature and extent of biological impacts from diffuse and point sources of contaminants, and habitat changes induced by catchment disturbance.

The focus of this assessment is benthic macroinvertebrate community structure and the measurement of complementary water quality variables. Macroinvertebrates provide several advantages for monitoring programs. They can be abundant and diverse, are easily sampled and with appropriate skills can be easily identified. They are known to respond to variation in water quality and are currently in widespread use throughout the world for assessing biological condition.

There are no published descriptions of communities of benthic organisms of freshwater systems in the Darwin area. Most ecological data on benthic community organisation and dynamics derive from studies in Kakadu National Park in western Arnhem Land (Douglas 1999; Paltridge *et al*. 1997; Humphrey and Dostine 1994). There is some ecological information on macroinvertebrate communities of the Daly River catchment (Dostine 2000) and the Mary River catchment (Schultz *et al.* 2002). Consequently there is limited capacity to infer ecological condition or to track subtle changes in ecological condition in Darwin area streams.

This study aims to develop this capacity and to provide preliminary assessment of the ecological health of stream systems in the Darwin area. A survey was designed to complement existing survey data from elsewhere in the Top End of the NT (Daly basin, Mary River catchment, Finniss River catchment, Reynolds River catchment, Adelaide River catchment).

There has been considerable recent effort to derive biological quality indices for freshwater systems. The innate variability both within and between river systems renders this task a difficult one. In northern Australia the highly seasonal climate and patterns of stream flow contributes another layer of complexity. There are two principal strategies: a predictive multivariate approach (eg Clarke *et al*. 1996; Smith *et al*. 1999; Chessman 1999) linking community structure and environmental variables to identify deviation from the condition expected in the absence of disturbance or impairment, or a multimetric approach using descriptive measures of community organisation (Karr 1999, Harris and Silviera 1999) to calculate an index of biotic integrity. Both approaches seek to produce easily communicated outputs (Boulton 1999).

The predictive multivariate approach requires a set of reference sites which match the type of streams for which the assessment is undertaken. There was no attempt in this survey to pair control and potentially impacted sites by stream type. Whilst this greatly facilitates interpretation of results, the prime objectives were to describe the faunal patterns across a number of stream types in the Darwin rural area, and to identify gross rather than subtle impairment of ecological integrity. Repeated annual sampling of the sites will permit tracking of the relative condition of sites.

Methods

Study area

The study area includes the Darwin Harbour catchment and the catchments of creeks and rivers eastward to the Howard River which enter Shoal Bay to the north-east of Darwin. The Darwin Harbour catchment includes 18 sub-catchments (Padovan 2001) with an area of 1,724 km^2 within the seaward limits of Charles Point and Lee Point (Anon 2000). Land use within the study area includes urban, rural residential, horticulture, industry and low intensity uses (pastoralism, conservation, recreation, vacant Crown land). Within the Darwin Harbour catchment low intensity uses are the predominant land use (85%) (Anon 2000). The largest freshwater systems within the combined area are the Blackmore River catchment, Howard River catchment and Elizabeth River catchment. The Blackmore River catchment as defined by Padovan (2001) includes the Blackmore, Darwin and Berry systems. Sampling was conducted in the early dry season (May-June 2001) during seasonal recession flows after high wet season flows.

Fourteen sites were sampled in the early dry season of 2001 between 21 May and 21 June (Appendix 1). Three sites were located in the Blackmore catchment, three sites in the Howard catchment and four sites in the Elizabeth catchment. In addition three sites were located in the Palmerston South catchment and a single site in the Rapid Creek catchment (Table 1, Fig. 1).

Table 1. Number of sampling sites within sub-catchments of the study area. Definition of sub-catchments follows Padovan (2001).

Catchment name	Number of sites
Charles Point	0
Woods Inlet	0
West Arm	0
Creek A	0
Pioneer Creek	0
Blackmore River	3
Elizabeth River	4
Mitchell Creek	1
Palmerston South	3
Myrmidon Creek	0
Hudson Creek	0
Bleesers Creek	0
Reichardt Creek	0
Sadgroves Creek	0
Darwin CBD	0
Ludmilla Creek	0
Rapid Creek	1
Sandy Creek	0
Buffalo Creek	0
Micket Creek	0
Kings Creek	0
Howard River	3

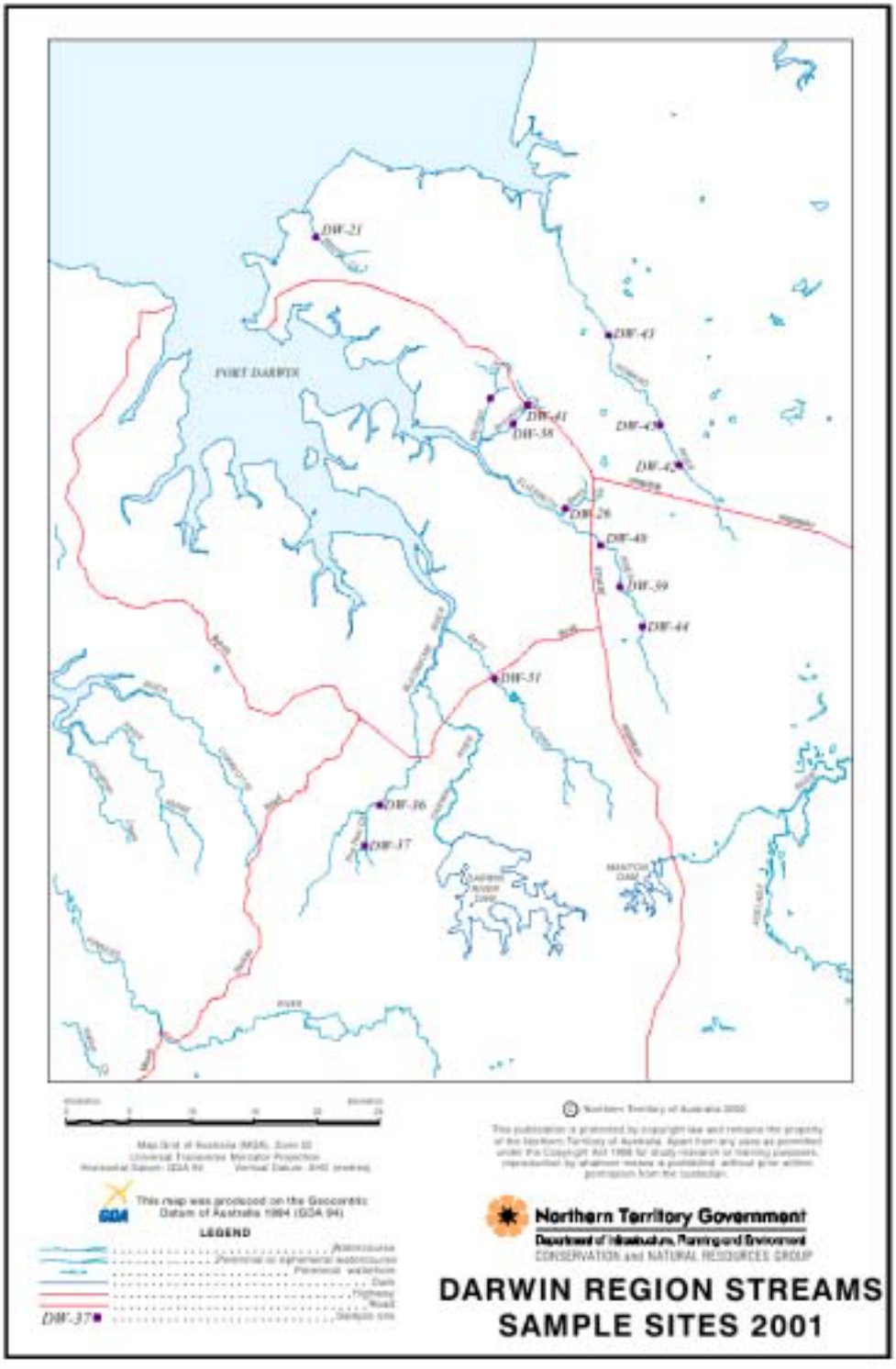

Fig. 1. Map of Darwin area showing location of stream sampling sites.

Patterns of stream flow in the region reflect the highly seasonal monsoonal climate. Most rain falls in the wet season from December-March; the intervening months are relatively rain free, though rainfall can occur in any month throughout the dry season. Stream flow patterns for the past six years are illustrated by hydrographic data for sites in the Elizabeth River and Rapid Creek (Fig 2). Flow patterns vary on at least three temporal scales: between years; and both between and within seasons. Flow reduces gradually from the end of the wet season and may cease during the dry season for several months; within each wet season there can be several flood events at intervals throughout the wet season. Flow at some sites is perennial due to ground water inflow (eg DW-43, Howard River upstream Gunn Point Road).

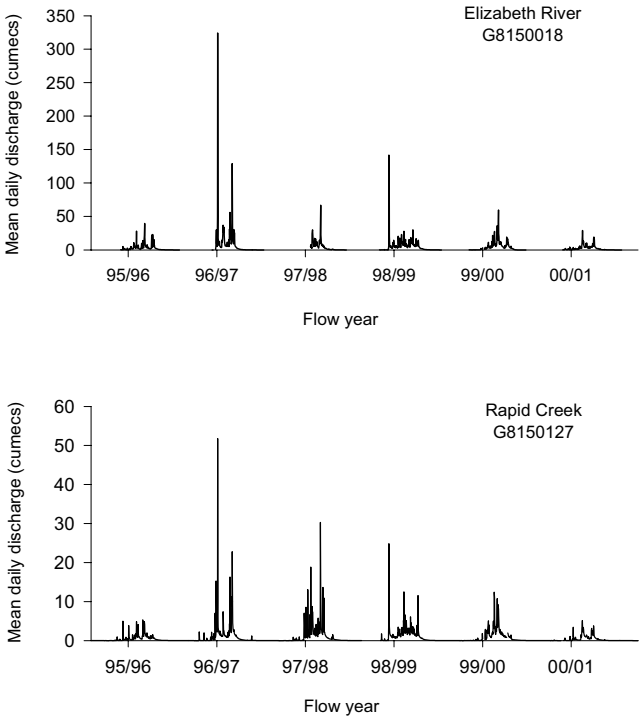

Fig 2. Mean daily discharge over past 6 years at two gauge stations G8150018 (Elizabeth River) and G8150127 (Rapid Creek).

Macroinvertebrate communities

Macroinvertebrate sample collection

Macroinvertebrates were collected at thirteen sites (Table 2). Samples of macroinvertebrates were collected from edge habitats using a triangular pond net by sweeping the pond net across the substrate along a ten metre section of stream edge. The substrate of these habitats usually consist of matted root material in a matrix of clay and or sand along a near vertical wall of channel pools. A three-pronged rake was used by a second operator to disturb the substrate immediately in advance of the pond net. All material collected by the net with the exception of large woody debris was preserved in 70% ethanol.

Table 2. Types of data collected at each of fourteen sites from Darwin area streams.

Site number	Site name	Site code	Catchment	Macroinverts	Water quality	Pesticides
1	Elizabeth River, on Elizabeth Valley Road	DW-39	Elizabeth River	X	X	
2	Elizabeth River, u/s gauging station	DW-40	Elizabeth River	X	X	X
3	Elizabeth River, u/s Alverly Road Crossing	DW-44	Elizabeth River		X	
4	Howard River, Girraween Road Crossing	DW-45	Howard River	X	X	
5	Berry Springs, u/s road crossing	DW-31	Blackmore River	X	X	X
6	Peel Creek, u/s road crossing	DW-37	Blackmore River	X	X	
7	Blackmore River, d/s crossing	DW-36	Blackmore River	X	X	X
8	Howard River, Pioneer Road Crossing	DW-42	Howard River	X	X	
9	Howard River, u/s Gunn Point Road	DW-43	Howard River	X	X	X
10	Brookings Creek, d/s Stuart Highway	DW-38	Palmerston South	X	X	
11	Brookings Creek, u/s Stuart Highway	DW-41	Palmerston South	X	X	X
12	Mitchell Creek, d/s Lambrick Ave drain	DW-23	Palmerston South	X	X	
13	Bee's Creek at Horne Road Crossing	DW-26	Elizabeth River	X	X	X
14	Rapid Creek, u/s v-weir	DW-21	Rapid Creek	X	X	X

Macroinvertebrate sample processing
In the laboratory samples of detritus and macroinvertebrates were rinsed on a 500 µm sieve. After rinsing the sample was washed into a box sub-sampler. The sampler was agitated to distribute the sample material evenly across the cells of the sub-sampler. The contents of randomly selected cells were extracted using a vacuum suction pump and organisms were sorted from a channelled sorting tray under a binocular microscope. A sample of larger organisms was collected from the sub-sampler and stored separately.

Macroinvertebrate specimen preparation
Most macroinvertebrates were identified in the laboratory using a Wild binocular microscope. Chironomid specimens were mounted on glass slides for microscopic examination. Specimens were cleared in 10% potassium hydroxide, neutralised in glacial acetic acid and dehydrated in iso-propanol before mounting in Euparol. Slides were dried overnight in a drying oven at 45°C, and were examined under high magnification using an Olympus compound microscope.

Specimen identification
All individuals were identified as fas as possible given available expertise. Generally most taxa were identified to genus, with the exception of most chironomids and some beetles. Most taxa were identified using regional taxonomic keys. Specimens of some groups were identified by relevant specialists. These include elmid coleoptera (A. Glaister: Monash University), hydracarinid water mites (J. Growns: NSW Fisheries) and dytiscid and hydrophilid water beetles (C. Watts: South Australian Museum).

Environmental variables

A large number of environmental variables were collected at each site (Table 3). These include water quality (general parameters, total metal concentrations and pesticide concentrations at a sub-set of sites) and habitat variables measured at the site, reach and catchment scales.

Water quality variables
At each of fourteen sites a suite of water quality parameters was measured by either field measurement using portable water quality meters or by collection of samples for laboratory analysis.

Field measurements. A Horiba water quality multimeter was used to measure pH, electrical conductivity, dissolved oxygen and water temperature. Turbidity was measured with a Hach turbidimeter.

Nutrients. At each site three water samples were collected for determination of (i) oxidised nitrogen and filtered reactive phosphorous, (ii) total phosphorous and (iii) total Kjeldahl nitrogen. Samples for oxidised nitrogen and filtered reactive phosphorous were filtered in the field. All samples were stored on ice and submitted to the NT government analytical chemistry laboratory at Berrimah, with the exception of samples for determination of total Kjeldahl nitrogen which were submitted to the Australian Water Quality Centre in Adelaide, SA.

General parameters. At each site water samples were collected for determination of environmental parameters including total and volatile suspended solids, ionic composition, pH, electrical conductivity, total dissolved salts, alkalinity, and hardness.

Metal concentrations. Water samples were collected for analysis of total metal concentrations from 14 stream sites in the Darwin region (Table 2). Samples were stored on ice in the field and refrigerated prior to delivery to the Australian Government Analytical Laboratories (AGAL) in Sydney, NSW. Analyses were conducted for ten metals: aluminium (Al), iron (Fe), cadmium, (Cd), arsenic (As), chromium (Cr), copper (Cu), lead (Pb), manganese, (Mn), nickel (Ni), and

zinc (Zn). Reporting limits for Al and Fe were 5 µg/L, for Cd 0.1µg/L, and for the remainder 1 µg/L.

Pesticides. Water samples were collected for analysis of pesticides from seven stream sites in the Darwin region (Table 2). Samples were stored on ice in the field and refrigerated prior to delivery to AGAL. Scans were conducted by AGAL for organochlorine pesticides, organophosphate pesticides, synthetic pyrethroids, herbicides and carbamates. The types of analyses to be conducted was determined following advice from the NT Department of Primary Industry and Fisheries. The list of compounds included in analytical scans is shown in Table 4. Samples were stored for several weeks prior to analysis (Table 5).

Habitat variables

Site scale. Eleven variables were recorded within the 10m sampling transect. These include estimates of the frequency of occurrence of attributes such as trailing roots, undercut bank and organic matter; the composition of the substrate sediment; canopy cover; habitat depth and current velocity adjacent to the substrate. Stream discharge was measured at an appropriate site in the vicinity of the sampling area.

Reach scale. Sixteen variables were recorded within a 150m reach extending between 50m downstream of the sampling point to 100m upstream of the sampling point. These include six variables describing the abundance of stream habitats within the reach; two variables describing the channel form within the reach; two variables describing the riparian zone; and four stream edge disturbance variables.

Catchment scale. Catchment area and distance to stream source were estimated using mapping software.

Data analysis

Patterns in macroinvertebrate community structure were examined using multivariate analyses in the PATN software package (Belbin 1995). Data were analysed by classification using the FUSE routine and the UPGMA option, and by ordination using the SSH routine. The Bray-Curtis dissimilarity measure was used as a measure of the compositional similarity of samples. The site-species matrix was classified using (i) untransformed relative abundance data; (ii) relative abundance data transformed by division by the most abundant taxon per sample; and (iii) presence-absence. All taxa were retained in all analyses. Ordination analysis was performed on the transformed relative abundance data only. Correlations with environmental variables were examined using the PCC routine in PATN and tested for significance using MCAO.

Data for most water quality parameters are presented as the mean and range for groups derived from classification of macroinvertebrate data. Data for pH is presented as the median value and range for each group.

Table 3. List of water quality and habitat variables collected in Darwin area stream survey.

Variable name	Units	Description
Catchment area	kms^2	Area of catchment upstream of sampling point
Log catchment area		Log 10 of catchment area
Distance	kms	Distance from sampling point to stream source
Discharge	m^3/s	Stream discharge at time of sampling
Mean channel depth	m	Average maximum depth on minimum six channel transects at 20m intervals from 50m downstream of site
Mean channel width	m	Average width of minimum six channel transects as above
pH (field)		Potential hydrogen
pH (laboratory)		Potential hydrogen
Conductivity (field)	µS/cm	Electrical conductivity
Conductivity (lab)	µS/cm	Electrical conductivity
Turbidity	NTU	
Temperature	ºC	Water temperature
Dissolved oxygen	mg/l	
% sand		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% gravel		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% riffle		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% macrophytes		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% snags		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% pool		Habitats within 150 m of sampling point, based on occurrence on 15 transects
% riparian cover		Percentage cover canopy at two points in riparian zone, using spherical densiometer
Riparian width	m	Mean of two estimates of width of riparian zone
% cover weeds		Percentage cover of weeds at 15 points within 150m reach and 10m from stream edge
% cover feral		Percentage cover of feral animal signs at 15 points within 150m reach and 10m from stream edge
% cover fire		Percentage cover of burnt ground at 15 points within 150m reach and 10m from stream edge
% cover human		Percentage cover of signs of human disturbance at 15 points within 150m reach and 10m from stream edge
% algae		Filamentous algae score based on occurrence at 10 points in sampled area
% macrophytes		Adjacent macrophyte score based on occurrence at 10 points in sampled area
% roots		Trailing root score based on occurrence at 10 points in sampled area
% undercut		Undercut bank score based on occurrence at 10 points in sampled area
% organic matter		Organic matter score based on occurrence at 10 points in sampled area
Sand		Dominant particle size in 3 substrate samples, scored 0-3
Silt		Dominant particle size in 3 substrate samples, scored 0-3
Gravel		Dominant particle size in 3 substrate samples, scored 0-3
% cover canopy		Percent canopy cover on stream edge at sampling point, using spherical densiometer
velocity	m/s	Mean of 3 measurements of velocity adjacent to substrate
Depth	m	Mean of 3 measurements of vertical depth of edge habitat
Aluminium	ug/l	Total concentration
Arsenic	ug/l	Total concentration
Cadmium	ug/l	Total concentration

Chromium	ug/l	Total concentration
Copper	ug/l	Total concentration
Iron	ug/l	Total concentration
Lead	ug/l	Total concentration
Manganese	ug/l	Total concentration
Nickel	ug/l	Total concentration
Zinc	ug/l	Total concentration
Chloride	mg/l	
Chloride	meq/l	Expressed as milliequivalents per litre
% chloride		Milliequivalents divided by total anions
Sulphate	mg/l	
Sulphate	meq/l	Expressed as milliequivalents per litre
% Sulphate		Milliequivalents divided by total anions
Bicarbonate	mg/l	
Bicarbonate	meq/l	Expressed as milliequivalents per litre
% Bicarbonate		Milliequivalents divided by total anions
Carbonate	mg/l	
Carbonate	meq/l	Expressed as milliequivalents per litre
% Carbonate		Milliequivalents divided by total anions
Total anions	meq/l	Expressed as milliequivalents per litre
Sodium	mg/l	
Sodium	meq/l	Expressed as milliequivalents per litre
% sodium		Milliequivalents divided by total cations
Potassium	mg/l	
Potassium	meq/l	Expressed as milliequivalents per litre
% potassium		Milliequivalents divided by total cations
Calcium	mg/l	
Calcium	meq/l	Expressed as milliequivalents per litre
% calcium		Milliequivalents divided by total cations
Magnesium	mg/l	
Magnesium	meq/l	Expressed as milliequivalents per litre
% magnesium		Milliequivalents divided by total cations
Total cations	meq/l	Expressed as milliequivalents per litre
TSS	mg/l	Total suspended solids
VSS		Volatile suspended solids
% VSS		Percentage volatile of total suspended solids
TDS	mg/l	Total dissolved salts
Ca:Mg		Calcium to magnesium ration, using milliequivalent data
Iron	mg/l	
Fluoride	mg/l	
Silicon	mg/l	
Hardness		
Alkalinity	mg/l	Total alkalinity as $CaCO_3$
Sodium chloride	mg/l	
Oxidised nitrogen	mg/l	
TKN	mg/l	Total kjeldahl nitrogen
Total phosphorous	mg/l	
Reactive phosphorous	mg/l	

Table 4. Pesticide compounds measured in water samples from Darwin area streams.

Organochlorine pesticides	
HCB	Lindane
Heptachlor	Aldrin
BHC Total (other than lindane)	Methoxychlor
Heptachlor epoxide	Endosulfan Total
Chlordane	Endrin
DDE	DDD
Dieldrin	DDT
Mirex	
Organophosphate pesticides	
Demeton-S-Methyl	Diazinon
Dimethoate	Pirimiphos-Methyl
Chlorpyrifos	Parathion
Malathion	Fenthion
Ethion	Azinphos-Methyl
Synthetic pyrethroids	
Bifenthrin	Permethrin
Cypermethrin	Deltamethrin
Fenvalerate	Cyhalothrin
Herbicides	
Atrazine	Linuron
Metolachlor	Molinate
o-Phenylphenol	Simazine
Trifluralin	Diuron
Carbamates	
Fenoxycarb	Carbaryl
Methomyl	Pirimicarb

Table 5. Dates of collection, extraction and analysis of pesticides in stream water samples in the Darwin region.

Site	Collection date	Extraction date	Analysis date
DW-41	13 June 01	20 Sep 01	11 Oct 01
DW-26	13 June 01	20 Sep 01	11 Oct 01
DW-21	21 June 01	20 Sep 01	11 Oct 01
DW-43	5 June 01	20 Sep 01	11 Oct 01
DW-36	20 June 01	20 Sep 01	11 Oct 01
DW-31	12 June 01	20 Sep 01	11 Oct 01
DW-40	6 June 01	20 Sep 01	11 Oct 01

Results

Macroinvertebrate communities

A total of 2787 macroinvertebrate specimens were identified from thirteen samples (Appendix 2). One hundred and thirty taxa were recorded. The majority of taxa were relatively rare and made minor contributions to the total number of identified specimens. Only 22 taxa comprised greater than 1% of the total number of identified specimens, and only two taxa comprised greater than 10% of total number of identified specimens (ie Trichoptera: Leptoceridae: *Triaenodes* sp. and Ephemeroptera: Caenidae: *Tasmanocoenis* spp.) (Fig. 3, Table 6).

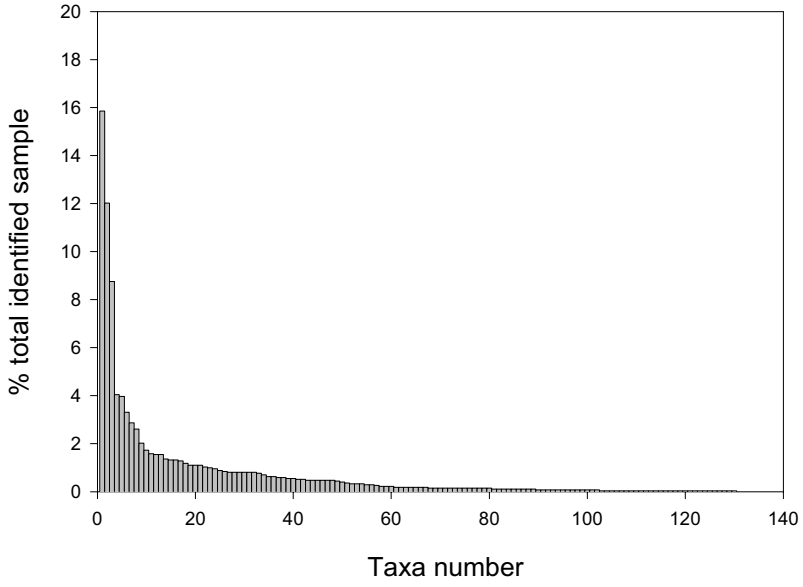

Fig. 3. Histogram showing percentage of total number of individuals of each taxon in rank order.

Taxa richness
The total number of taxa per site varied from 35-61 (median 46). The highest values were recorded at Blackmore River (DW36) (n=61) and Bee's Creek sample (DW26) (n=60).The lowest values were recorded at Brooking's Creek upstream (DW41) (n=35) and Rapid Creek (DW21) (n=36).

Sensitive taxa
The number of taxa known to be sensitive to poor water quality (including Baetidae, Elmidae and Orthocladiinae) varied from 3-9 (median 5). The highest value was recorded at Bee's Creek (DW26) (n=9) and the lowest values (n=3) at upstream Brooking's Creek (DW41) and Rapid Creek (DW21).

Table 6. Relative abundance (% total number of individuals) of taxa comprising greater than one percent of number of inviduals.

Taxa	% total
Triaenodes	15.85
Tasmanocoenis	12.03
Oribatida	8.75
Oecetis	4.05
Family Ceratopogonidae	3.97
Paratanytarsus D2	3.31
Djalmabatista	2.87
Rheotanytarsus	2.61
Cloeon	2.02
Paramerina	1.73
Polypedilum D1	1.58
Wundacaenis	1.54
Ablabesmyia	1.54
Sub-order ZYGOPTERA	1.36
Caridinides wilkinsi	1.32
Ablabesmyia hilli	1.32
Recifella	1.29
CLASS OLIGOCHAETA	1.18
Tanytarsus sp. 1	1.10
Polypedilum watsoni	1.10
Riethia	1.10
Nanocladius	1.03

Classification of untransformed relative abundance data revealed three discrete groups of sites. Group 1 included both Elizabeth River sites, the two upstream Howard River sites, Berry Creek, Peel Creek and the Blackmore River site. Group 2 included the downstream Howard River site, both Brooking Creek sites, Mitchell Creek and Bee's Creek. Group 3 was comprised of a single site in Rapid Creek (Fig. 4). Group 1 sites were located in relatively large catchments whereas group 2 sites with the exception of the Howard River site are in relatively small catchments. The single site in group 3 is located within an urban catchment.

Classification of relative abundance data transformed by division by most abundant taxon revealed an identical pattern of site groups, though the sequence of sites varied slightly (Fig. 5).

The pattern of site groups derived by classification of presence-absence data was less distinctive. Clustering occurred at a lower level of dissimilarity. The Rapid Creek site was separated from a heterogeneous large second group (Fig. 6).

Results of semi-strong hybrid ordination of the transformed relative abundance data are shown in Fig. 7 with sites clustered by groups identified from UPGMA classification. Of 82 environmental variables examined for correlation with the ordination solution by PCC, eleven were significant at $P<0.05$ (Table 7, Fig. 8). None were significant at $P<0.01$.

Despite the differences in community structure inferred by multivariate techniques, differences in species composition between groups 1 and 2 are relatively subtle, and few taxa demonstrate unambiguous differences. The few taxa that differ between groups include the chironomids *Nilotanypus, Rheotanytarsus* and *Riethia.* All three taxa tend to be more abundant at sites with moderate current. Few "significant" (in the sense of conservation or taxonomic interest) taxa were recorded. The exception is the polycentropodid trichopteran *Plectrocnemia* from sites

DW36 (Blackmore River) and DW37 (Peel Creek). *Plectrocnemia* has thus far been rarely recorded in the NT (Dostine 2000).

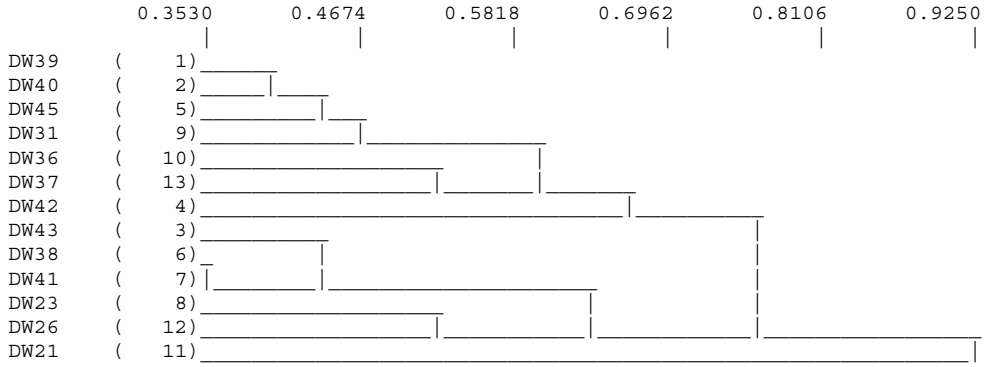

Fig. 4. Dendrogram of UPGMA classification of macroinvertebrate communities using untransformed relative abundance data.

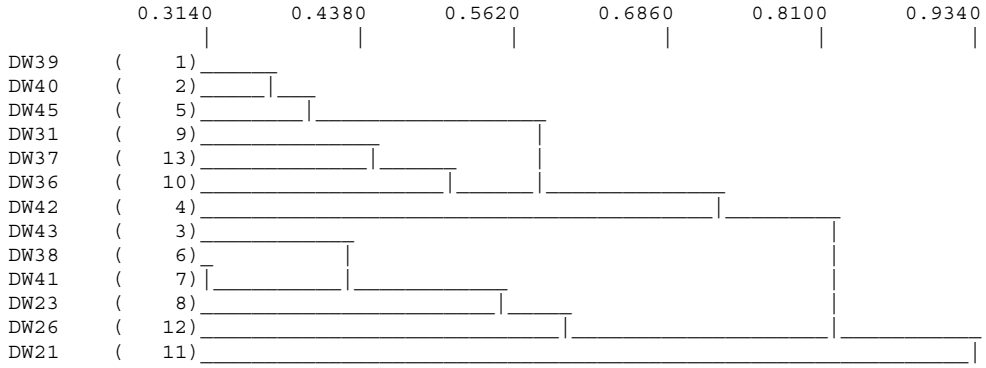

Fig. 5. Dendrogram of UPGMA classification of macroinvertebrate communities using relative abundance data transformed by division by most abundant taxon per sample.

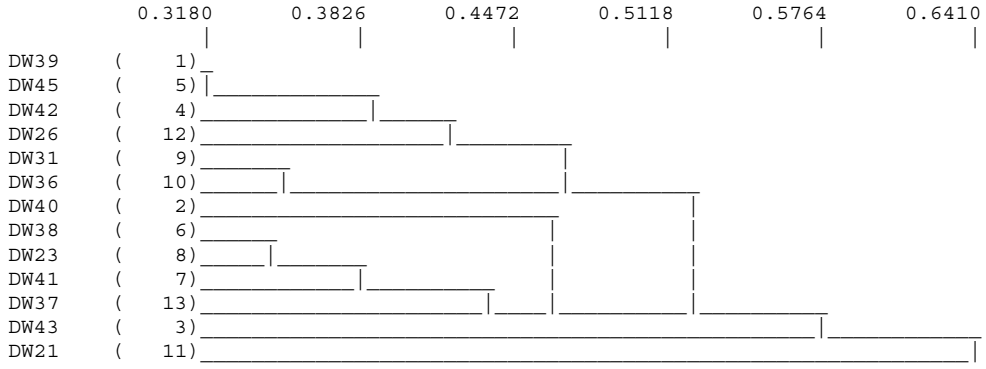

Fig. 6. Dendrogram of UPGMA classification of macroinvertebrate communities using presence-absence data.

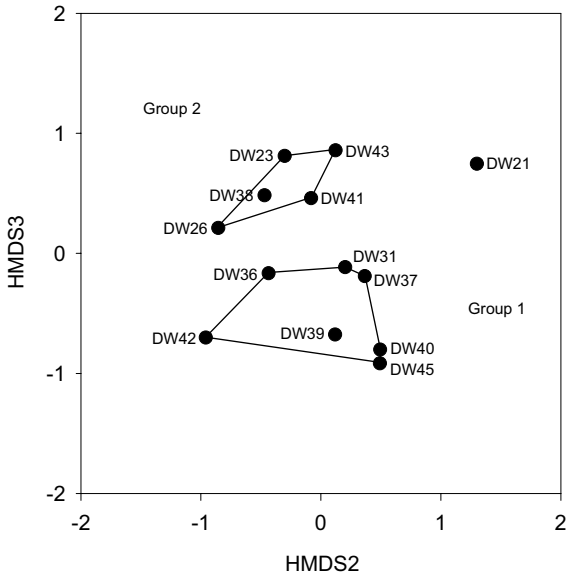

Fig. 7. HMDS ordination of macroinvertebrate communities at sites in Darwin area streams.

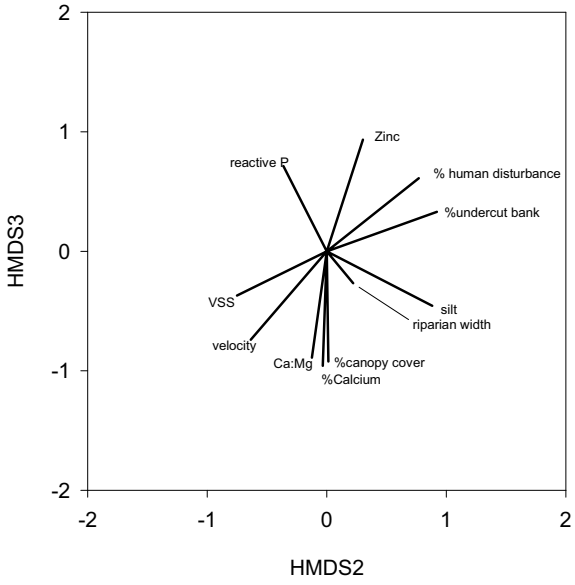

Fig. 8. HMDS ordination axes 2 and 3 with vectors for significant variables from PCC analysis.

Table.7 Environmental variables with significant correlations (P<0.05) with ordination solution.

Variable name	*r* value
Ca/Mg	0.86
% calcium	0.85
Zinc	0.82
% canopy cover	0.79
Riparian width	0.78
Velocity	0.78
Silt	0.77
Reactive phosphorous	0.76
VSS	0.75
% cover human disturbance	0.74
% undercut bank	0.74

Water quality

Raw data for water quality parameters are shown in Appendices 3-8.

Nutrients
Nutrient levels were generally low at most sites with the exception of Bee's Creek which had relatively elevated levels of oxidised nitrogen. There were no marked differences between site groups for oxidised nitrogen. Total Kjeldahl nitrogen averaged 0.2 mg/L (range 0.07-0.38) for group 1 sites and averaged 0.09 mg/L (range <0.05-0.17) for group 2 sites. The highest total Kjeldahl nitrogen value (0.38 mg/L) was measured at Peel Creek in the Blackmore River catchment. Both total phosphorous and filtered reactive phosphorous were low at all sites (Appendix 8).

Temperature
Temperature plays an important role in determining rates of fundamental biological processes. In this study temperatures averaged 23.1 °C with a range of 19.3-26.3 °C (Table 8). Much of the variation is due to uncontrolled diurnal or seasonal variation.

Table 8. Mean and range of values for water temperature (°C) classified by faunal groups in water samples from Darwin area streams.

	Water temperature ˚C	
Group	**Mean**	**Range**
1	22.7	19.3-26.3
2	23.8	22.5-25.6
3	24.0	
Total	**23.1**	**19.3-26.3**

Turbidity and suspended solids
Both turbidity and suspended solids were relatively low in all groups (Tables 9 and 10). Volatile suspended solids averaged 55% of total suspended solids. Approximately 55% of the suspended particulate matter was organic (ie volatile).

Table 9. Mean and range of values for turbidity (NTU) classified by faunal groups in water samples from Darwin area streams

	Turbidity (NTU)	
Group	**Mean**	**Range**
1	3.0	2.0-4.8
2	3.7	2.0-4.9
3	2.4	
Total	**3.3**	**2.0-4.9**

Table 10. Mean and range of values for suspended solids (TSS) and volatile suspended solids (VSS) classified by faunal groups in water samples from Darwin area streams. VSS expressed as a percentage of TSS is shown in brackets.

	Total suspended solids		Volatile suspended solids	
Group	**Mean**	**Range**	**Mean**	**Range**
1	2.5	1.0-4.7	1.5 (59.6)	0.7-2.8
2	2.2	1.3-2.6	1.2 (54.0)	0.9-1.5
3	1.4		0.4 (28.6)	
Total	**2.19**	**1.0-4.7**	**1.20 (55.2)**	**0.4-2.8**

Dissolved oxygen

Dissolved oxygen is produced in streams by photosynthetic activity and aeration and consumed by respiration. High organic loading in streams can lead to oxygen depletion and stressful conditions for aquatic organisms. Dissolved oxygen averaged 5.8 mg/L with a range of 4.4-7.6 mg/L (Table 11).

Table 11. Mean and range of values for dissolved oxygen classified by faunal groups in water samples from Darwin area streams.

	Dissolved oxygen (mg L^{-1})	
Group	**Mean**	**Range**
1	5.76	4.54-7.56
2	5.21	4.42-6.54
3	6.96	
Total	**5.81**	**4.42-7.56**

pH - acidity, alkalinity and hardness

pH was measured in the field and in the laboratory. Field measurements were done using a Horiba water quality meter, the laboratory measurements were performed as part of the ionic analysis. There was no significant relationship between the two measurements ($F = 0.86$; $df = 1,12$; $P = 0.37$) (Fig. 9). The laboratory measurements provide greater reliability and accuracy of the instruments but storage can result in changed pH due to microbial respiration. A more reliable field instrument is the preferred option for future monitoring.

Median values for groups 1 and 2 were near neutral (Table 12). The pH at site DW21 (group 3) was slightly more acidic (6.1).

Alkalinity and hardness values were similarly relatively higher at group 1 and 2 sites and low at site Dw21 (group 3) (Table 13).

Table 12. Median and range of field and laboratory measurements of pH values classified by faunal groups.

	Field measurement		Laboratory measurement	
Group	**Median**	**Range**	**Median**	**Range**
1	7.0	6.48-7.8	6.8	6.1-8.7
2	6.78	6.08-7.0	6.7	6.4-7.1
3	7.5		6.1	
Total	**7.0**	**6.08-7.8**	**6.75**	**6.1-8.7**

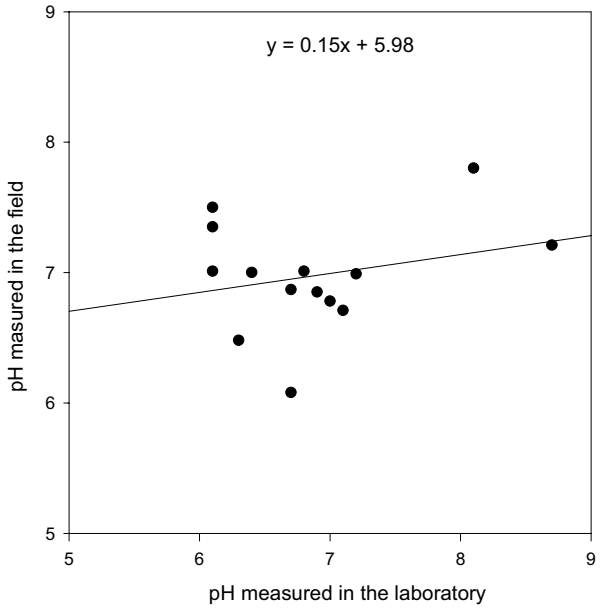

Figure 9. Relationship between pH measurements in the laboratory and field. The value of r^2 is 0.07.

Table 13. Mean and range of values for alkalinity (measured as mg Ca CO_3 L^{-1}) and total hardness (the sum of calcium and magnesium concentrations expressed as mg Ca CO_3 L^{-1}) in Darwin area streams.

	Alkalinity (mg $CaCO_3$ L^{-1})		Hardness (mg $CaCO_3$ L^{-1})	
Group	**Mean**	**Range**	**Mean**	**Range**
1	27.3	5.0-86.1	27.8	9.1-84.2
2	25.1	9.8-42.7	24.8	7.6-41.2
3	5.7		5.1	
Total	**23.6**	**5.0-86.1**	**23.6**	**5.1-84.2**

Electrical conductivity, total dissolved salts and ionic composition

Electrical conductivity was measured in the field using a hand-held meter and in the laboratory. Field measurements were generally lower than laboratory measurements. A regression between the two measurements is significant with an r^2 of 0.95 (Fig. 10). Field measurements averaged 57 µS/cm, with a range of 14-172 µS/cm. The maximum value of 172 µS/cm is well below the definition for freshwaters but was recorded at a site which receives occasional tidal inundation. Conductivity was highly variable within faunal groups (Table 14).

Table 14. Field and laboratory measurements of electrical conductivity classified by faunal groups. Data are median and range of values.

		Field measurement		Laboratory measurement	
Group	**n**	**Mean**	**Range**	**Mean**	**Range**
1	7	47	14-159	63	18-171
2	5	83	20-172	89	28-189
3	1	40		44	
Total	**13**	**57**	**14-172**	**68**	**18-189**

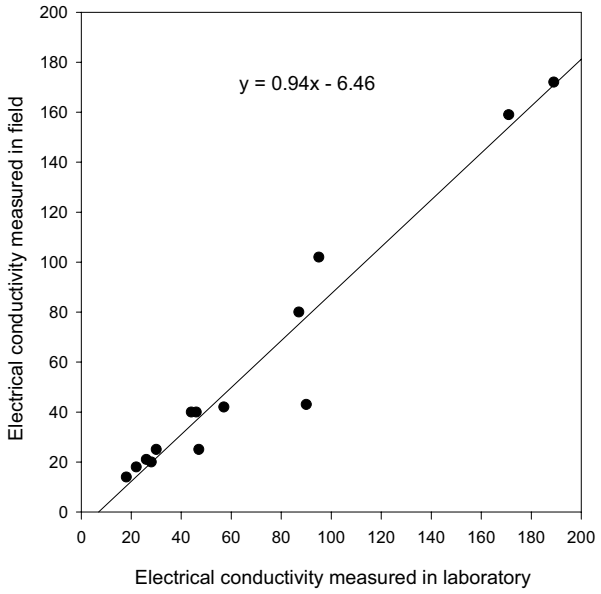

Fig. 10. Relationship between electrical conductivity measured in the laboratory and in the field.

The weight of dissolved salts is a measure of salinity and is calculated by weighing the amount of residue after evaporation. The residue includes total dissolved salts and any colloidal or organic material. The relationship between field conductivity and total dissolved salts provides a method to estimate the amount of colloidal or organic material by extrapolation to the y-axis at a field conductivity of zero. Fig. 11 indicates that at a field conductivity of zero there is approximately 20 mg of colloidal or organic material in the sample.

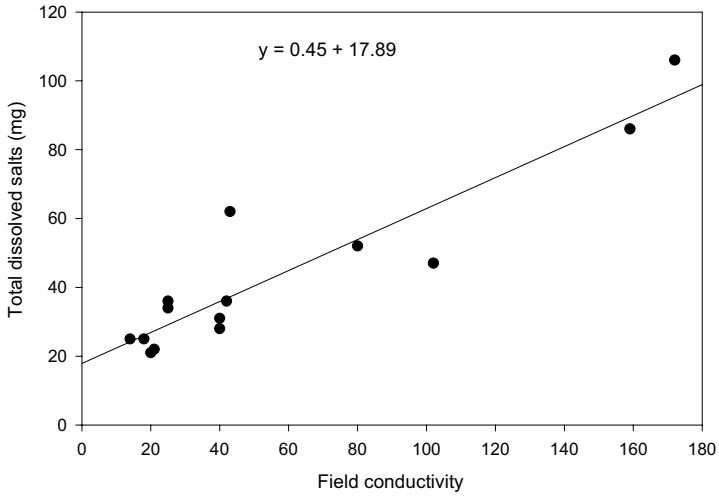

Fig. 11. Relationship between electrical conductivity measured in the field and total dissolved salts. The r^2 value is 0.85.

The mean concentrations of cations and anions in Darwin area streams is shown in Tables 15 and 16. Sodium, calcium and magnesium ions dominate the cations, and carbonate and chloride ions dominate the anions. The ionic composition of stream waters differed slightly between faunal groups. Calcium ions dominate in group 1 sites but sodium and magnesium are both important in group 2 sites. The ionic composition of the group 3 site is dominated by sodium and chloride ions.

A Piper diagram represents the relative dominance of major ions in water samples. Fig. 12 shows that most group 1 sites share similar dominance of calcium ions.

Table 15. The mean concentration of cations in Darwin area streams classified by faunal groups. Data is presented as milliequivalents per litre. Percentage contribution of each ion to the total ionic composition is shown in brackets.

	Cation concentration (meq L^{-1})				
Group	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Total**
1	0.12 (17)	0.01 (1)	0.34 (49)	0.22 (33)	0.69
2	0.29 (37)	0.01 (1)	0.19 (24)	0.30 (38)	0.79
3	0.23 (69)	0.00 (1)	0.04 (13)	0.06 (17)	0.34
Total	**0.19 (28)**	**0.01 (1)**	**0.25 (37)**	**0.23 (34)**	**0.67**

Table 16. The mean concentration of anions in Darwin area streams classified by faunal groups. Data is presented as milliequivalents per litre. Percentage contribution of each ion to the total ionic composition is shown in brackets.

	Anion concentration (meq L^{-1})				
Group	**Cl^-**	**$SO4^{2-}$**	**$HCO3^-$**	**$CO3^{2-}$**	**Total**
1	0.08 (12)	0.02 (4)	0.54 (83)	0.01 (1)	0.65
2	0.30 (35)	0.06 (7)	0.50 (58)	0.00 (0)	0.86
3	0.20 (63)	0.00 (0)	0.11 (37)	0.00 (0)	0.31
Total	**0.16 (24)**	**0.03 (5)**	**0.47 (70)**	**0.00 (1)**	**0.67**

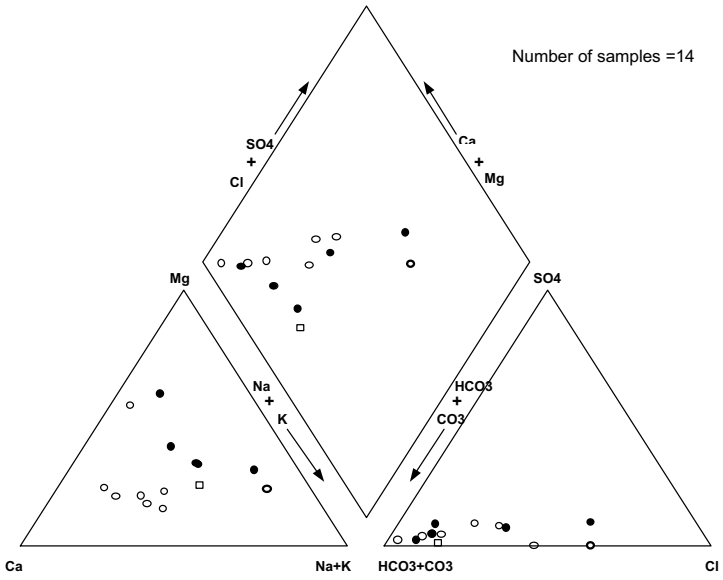

Fig. 12. A Piper diagram illustrating the relative dominance of major cations and anions in water samples from the Darwin area. Hollow circle = group 1 sites; solid circle = group 2 sites;

Metal concentrations

Individual metal concentrations in all samples were low and within recommended levels (ANZECC and ARMCANZ 2000) with the exception of aluminium at several sites and copper at sites DW-42 and DW-38 (Table 16). Aluminium is the most abundant metallic element in the lithosphere but has little biological function. The toxicity of aluminium to fish and invertebrates is increased at low and high pH; at neutral pH values the toxicity of aluminium is greatly reduced. Concentrations greater than 100 µg/L would be deleterious to aquatic life (CCREM 1991). The recommended trigger values for aluminium at pH values greater than 6.5 is 55 µg/L. Aluminium concentrations at most sites (11 of 14) exceeded this value.

Copper is an essential trace element required by most aquatic organisms but is toxic at concentrations slightly above those required for optimum growth. Background copper levels in Australian freshwaters are in the vicinity of 0.11 µg/L (ANZECC and ARMCANZ 2000). The recommended trigger value for copper is 1.4 µg/L. The high copper levels at two sites warrants further investigation to identify its source and ecological effects.

Pesticides

Levels of all pesticides and herbicides were below detection limits (ie <0.1 µg/L) in all samples.

Discussion

Patterns in community organisation

This study revealed a number of patterns in macroinvertebrate community organisation in streams of the Darwin region. The number of taxa recorded at each site varied considerably by almost a factor of 2 (mean 43, range 35-61). The general trend for sites with larger catchments to have higher numbers of taxa was contradicted by the site on Bee's Creek (60 taxa). A similar general trend was apparent for the number of sensitive taxa at each site.

Classification of relative abundance data from thirteen sites identified two groups with a single site (Rapid Creek, DW21) as an outlier. These two groups were spatially distinct, though the reasons for the observed differences are not clear. Most group 1 sites were situated in relatively larger catchments and may experience a prolonged period of seasonal recession flows. Most group 2 sites were situated in relatively small catchments which cease to receive surface run-off early in the dry season. Group 1 sites associate weakly with three environmental variables: percent canopy cover, percentage calcium of total cations, and calcium magnesium ratio. Group 2 sites were associated with the variable reactive phosphorous concentration. The outlier site DW26 was associated with the environmental variables: zinc concentration, human disturbance and undercut bank.

Assessment of ecological condition

There is no evidence of gross impoverishment of benthic communities at any site. In particular all group 1 sites appear to be in satisfactory ecological condition as far as can be assessed within the limits of the existing data. However some group 2 sites and the Rapid Creek site may be exhibiting some signs of degradation. Further work in matching reference streams is required for more precise interpretation of this pattern. The fauna of the Rapid Creek site has some characteristics of degraded stream sites, including the absence of most Ephemeroptera, orthoclad chironomids and elmid Coleoptera. It was the only site at which caenid ephemeroptera were not recorded. Rapid Creek receives run-off from large areas of suburban development and the Darwin airport. The creek has few macrophytes (Dostine pers. obs.) and a general appearance of receiving high scouring flows. Scouring flows from excessive run-off from the developed catchment is probably responsible for habitat loss and consequently a relatively depauperate fauna.

Nutrients. Water quality parameters from Darwin area streams are within guideline limits and provide no evidence of degradation. Nutrients tend to be low at most sites. Nitrogen concentration at one site (DW26, Bee's Creek, 0.038 mg/L) was at least an order magnitude above that observed at most other sites. Elevated levels of total nitrogen and total phosphorous and other contaminants were noted in Bee's Creek by Padovan (2002) during the 2001/2002 wet season. The source of nitrogen in the Bee's Creek catchment may derive from commercial chicken farming, septic systems or domestic animals.

Metal concentrations. Concentrations of ten metals in stream waters were for the most part extremely low with the exception of aluminium at some sites and copper at two sites. The concentration of zinc was relatively high at DW26 (Rapid Creek). This may provide a surrogate for other variables with more direct impact on stream communities, such as increased run-off coefficients due to catchment development.

Pesticides. The results of four separate studies on pesticides in surface water, ground water or sediments in the Darwin region have been summarised by Potter (in prep). Surface waters from 16 sites have been analysed. The insecticide dieldrin was detected on several occasions during

the wet season in urban storm water drains. In the rural area the carbamate insecticide Carbaryl was detected on one occasion in the late wet season and chlordane detected on one occasion in the early wet season. Dieldrin and endosulfan were also detected in sediment analyses from Brookings Creek downstream of the Howards Springs tip in the early wet season. Most surface water samples analysed by these studies were collected during the wet season. There is no evidence from this present study of impacts on benthic communities from pesticides.

Recommendations for further work

Monitoring programs benefit from the inclusion of several indicators which provide complementary or corroborative evidence of the nature of impacts or which provide information from different trophic groups and across different spatio-temporal scales (Humphrey and Dostine 1994). Future monitoring programs will include diatom communities and the occurrence of macroalgae and macrophytes. Large mobile organisms such as fish can move throughout the system and provide an integrated view of habitat quality throughout whole streams or catchments rather than the site-specific assessment provided by macroinvertebrates or diatoms. Monitoring also needs to be linked with broad-scale catchment information and indices.

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Appendix 1. Dates of sampling and geographic coordinates of sample sites on Darwin region streams.

Date	Site name	Site code	Catchment	Latitude	Longitude
21 June 01	Rapid Creek, u/s v-weir	DW-21	Rapid Creek	12° 23.596’	130° 52.250’
21 May 01	Mitchell Creek, d/s Lambrick Ave drain	DW-23	Palmerston South	12° 30.458’	130° 59.935’
13 June 01	Bee’s Creek at Horne Road Crossing	DW-26	Elizabeth River	12° 35.204’	131° 03.230’
29 May 01	Berry Creek, u/s road crossing	DW-31	Blackmore River	12° 42.539’	131° 00.177’
12 June 01	Blackmore River, d/s crossing	DW-36	Blackmore River	12° 48.029’	130° 55.193’
20 June 01	Peel Creek, u/s road crossing	DW-37	Blackmore River	12° 49.311’	130° 54.559’
28 May 01	Brookings Creek, d/s Stuart Highway	DW-38	Palmerston South	12° 31.613’	131° 00.897’
24 May 01	Elizabeth River, on Elizabeth Valley Road	DW-39	Elizabeth River	12° 38.622’	131° 05.699’
6 June 01	Elizabeth River, u/s gauging station	DW-40	Elizabeth River	12° 36.798’	131° 04.832’
21 May 01	Brookings Creek, u/s Stuart Highway	DW-41	Palmerston South	12° 30.762’	131° 01.535’
30 May 01	Howard River, Pioneer Road Crossing	DW-42	Howard River	12° 33.323’	131° 08.272’
5 June 01	Howard River, u/s Gunn Point Road	DW-43	Howard River	12° 27.739’	131° 05.138’
21 May 01	Elizabeth River, u/s Alverly Road Crossing	DW-44	Elizabeth River	12° 40.319’	131° 06.678’
5 June 01	Howard River, Girraween Road Crossing	DW-45	Howard River	12° 31.594’	131° 07.397’

Appendix 2. List of macroinvertebrate taxa recorded at 13 sites in Darwin area streams. Divisions between classification groups are shown.

	Group 1							Group 2					Group 3
Taxon	**DW-39**	**DW-40**	**DW-45**	**DW-31**	**DW-37**	**DW-36**	**DW-42**	**DW-43**	**DW-38**	**DW-41**	**DW-23**	**DW-26**	**DW-21**
PHYLUM ARTHROPODA													
CLASS CRUSTACEA													
Order DECAPODA													
Family Atyidae													
Caridina serratirostris	1	1		1	12			5	1	1	1	1	
Caridina nilotica		1				1			1	1	1	1	13
Caridina gracilirostris								6					
Caridinides wilkinsi	1	1	1		13	1	13	5				1	
Family Palaemonidae													
Macrobrachium	1	1	1	1	2	1	8	2	1	1	1	1	1
Indet juv carid*	6				1								
Family Parastacidae													
Cherax			1										
Family Holthusianidae					1					1			
CLASS ARACHNIDA													
Mesostigmata													1
Halacaridae								3					
Hydracarina													
Family Hydrodromidae													
Hydrodroma			1				9				2		1
Family Limnesiidae													
Limnesia				1		1							25
Family Oxidae													
Frontipoda	1		2	1									
Oxus						3							
Family Aturidae													
Albia						4					1		
Axonopsella						1							1
Twarntaturus						1							
Family Hygrobatidae													
Australiobates		3			2								
Coaustraliobates		1	3			1					1		3
Hygrobates				2	1							1	
Family Unionicolidae													
Koenikea								2		2			
Recifella	3			1		1	26	1		2			1
Unionicola		1			1								
Family Mideopsidae													
Gretacarus							1						
Piona									1				
Indet Hydracarina*					1	3		3	1		1		4
Oribatida	5	4		22	16	5	6	61	2	21	8	9	79
CLASS INSECTA													
Order EPHEMEROPTERA													

Family Baetidae													
Cloeon	7	7	1	8	3	1			5	17	2	1	3
Baetid genus B	1		1	1								1	
Family Leptophlebiidae													
Thraulus	4	4	1		4	4		1	1	1	2		
Atalophlebia					2								
Family Caenidae													
Tasmanocoenis	43	73	67	47	35	20	6	6	6	10	3	11	
Wundacaenis	10	29		1								2	
Order DIPTERA													
Family Chironomidae													
Sub-family Tanypodinae													
Ablabesmyia	1		1	3	6	8	4		5	3	8		3
Ablabesmyia hilli	7	5	1		3		1	1	5		1	12	
Clinotanypus					1			4		1		1	
Djalmabatista	2	3	10	7	8	7	17	3	6	1	2	12	
Fittkauimyia	1				2	2	1		4	5	2	5	
Larsia			2	1	3	2	1		1	1		2	2
Nilotanypus	1	5	2				2					3	
Paramerina	1	3	1	4	11	6	3		3	10	1	1	3
Procladius		1	2	3	1	2	2				1		1
?Telmatopelopia			1				1			1			11
Tanypodinae indet.*					1	2	2					2	
Sub-family Orthocladiinae													
Cricotopus			2				5					1	
Nanocladius	4	1	4	2		6	6				1	4	
Thienemaniella	2	3											
Rheocricotopus		1											
Parametriocnemus												1	
Corynoneura	1		3		1				1		4	3	3
Sub-family Chironominae													
Tanytarsus sp. 1	7	1	2	4	3		3	3	1		4		2
Tanytarsus sp. 4			1	3		1	1	1				2	
Tanytarsus sp. 5							1	1					
Tanytarsus sp. 7B						3	1						
Tanytarsus sp. 8				1		1							
Tanytarsus sp. 9			1		1						2		
Tanytarsus hardwicki							1						
Tanytarsus micksmithi	1		2			2						3	2
Tanytarsus rosario					3								
*Tanytarsus unid.**	2			1			1						
Paratanytarsus D2	16	1	4	2	2	5		6	7	6	38	3	
Rheotanytarsus	4	23	24	2		3	14					1	
Cladotanytarsus	2		3		1	1	8		2		2		2
Cryptochironomus					1								
Chironomus												1	
Polypedilum D1	3		4	3	7	5	13	5				3	
Polypedilum D3	3	3		1	2		2		1	1	2	4	3
Polypedilum watsoni				3	5	4	3		2		5		8
Polypedilum leei			1		4				5	1			
Stenochironomus	2	2						1	3		5	3	
Dicrotendipes D2			1				3						1
Dicrotendipes D3			1		1	4	3		1			2	1
Dicrotendipes D1				1				1				12	
Kiefferulus						1			2				
Xenochironomus		1											
Harnischia D1	1		1					1				1	
Parachironomus D1	2				1							1	

Parachironomus D2		1			1	1	2	1					
Stempellina					2	1						1	
Stempellinella		1		2		1							
Paratendipes		1	1	1	2	1			2	1	2	1	1
Riethia	3	2	1	2	2	13	5	2					
Unk. genus D1		1											
Unk. genus D3							1						
Unk. genus D4											1		
Unk. genus D6			1										
Unk. genus D7								1					
Conochironomus						3							
Skusella						4			2	1			5
?Stictochironomus		1		1	2	1		1			2		
Unk. genus ? (Cranston)							3					1	
Unk. genus K1				3		2							
Indet pupae*	2	1	2			1	1	2	2	1	2	2	4
Indet larvae*			2		2	5	1		1	1	1	3	1
Family Culicidae					5								
Family Ceratopogonidae	5	10	8	12	5	14	10	9	3	7	11	14	
Family Empididae												1	
Family Psychodidae													1
Order TRICHOPTERA													
Family Hydroptilidae													
Orthotrichia	3	2	7	1		1	8	1		2		1	
Hellyethira	1		3	3			12		2				1
Family Ecnomidae													
Ecnomus	1		3	2		1	7				1	1	1
Ecnomina				1								1	
Family Leptoceridae													
Triaenodes	14	13	6	29	3	13	23	82	102	81	32	31	2
Triplectides		1	1	2	3	2	3	3				6	1
Oecetis	10	3	22	12	5	3	34	7	3	9	1	1	
Family Polycentropodidae													
Plectrocnemia					3	1							
Family Hydropsychidae													
Cheumatopsyche												1	
Family Calamoceratidae													
Anisocentropus		3		1	5	5	1	4		1	1	2	
Order HEMIPTERA													
Family Pleidae												1	
Family Corixidae				3	4					1	1		
Family Notonectidae						1				1			
Family Mesoveliidae	1								1				
Family Veliidae					1							2	
Family Nepidae		1											
Order COLEOPTERA													
Family Elmidae													
Austrolimnius sp. 1 (larva)				2		1							
Austrolimnius sp. 2 (larva)							2	1					
Graphelmis sp. L74E (larva)						1		1					
Austrolimnius N. sp. 1(B)					1								
Family Dytiscidae													
Hydrovatus ovalis				1		1			2				
Laccophilus cingulatus					1								
Tiporus josepheni						1							
Hydroglyphus godeffroyi													2
Limbodessus compactus									1				
Family Hydrochidae													

Hydrochus				1		2		1	7			2	
Family Hydrophilidae													
Amphiops												1	
Berosus				1		1	1			2	1		
Paracymus pygmaeus									1				
Family Hydraenidae													
Hydraena	2	1		1					3	1		1	6
Family Noteridae													
Notomicrus tenellus												1	
Order ODONATA													
Sub-order ZYGOPTERA	2	4		4	3			1	14	6	2	1	
Sub-order ANISOPTERA	1	1	2	1	1		3		2	1		5	
Order LEPIDOPTERA													
Family Pyralidae							1					1	
Order NEUROPTERA													
Family Sisyriidae				1	1								
CLASS COLLEMBOLA	1	1											1
PHYLUM ANNELIDA													
CLASS OLIGOCHAETA	3		4	8		1	9		1		3	3	
PHYLUM NEMATODA				1	1		1	1				1	
No. taxa	46	44	47	52	57	61	52	38	42	35	40	60	36
No. sensitive taxa	7	7	6	5	5	6	4	5	4	3	5	9	3

Appendix 3. Concentrations of cations in Darwin area streams expressed as milliequivalents per litre and percentage contribution of each ion to the total ionic composition. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance.

Site	Group	Na me	%Na	K me	%K	Ca me	%Ca	Mg me	%Mg	Total cations
DW44		0.09	41.67	0.00	1.22	0.07	33.46	0.05	23.65	0.21
DW31	1	0.10	5.58	0.01	0.43	0.70	38.95	0.99	55.05	1.79
DW36	1	0.14	28.83	0.01	1.54	0.26	53.11	0.08	16.52	0.50
DW37	1	0.21	24.27	0.02	2.08	0.47	54.52	0.16	19.13	0.86
DW39	1	0.09	18.43	0.01	1.08	0.29	61.31	0.09	19.18	0.47
DW40	1	0.08	13.40	0.01	0.83	0.39	63.10	0.14	22.68	0.62
DW42	1	0.10	35.29	0.00	0.90	0.14	49.29	0.04	14.51	0.28
DW45	1	0.10	32.47	0.00	0.83	0.14	45.34	0.07	21.36	0.31
	Mean	**0.11**	**24.99**	**0.01**	**1.11**	**0.31**	**49.89**	**0.20**	**24.01**	**0.63**
DW23	2	0.29	36.25	0.01	1.29	0.24	30.25	0.26	32.21	0.79
DW26	2	0.09	37.26	0.00	1.10	0.07	29.92	0.07	31.72	0.23
DW38	2	0.86	54.49	0.03	1.94	0.22	13.89	0.47	29.68	1.58
DW41	2	0.11	25.37	0.01	1.15	0.15	34.71	0.17	38.77	0.45
DW43	2	0.11	12.57	0.00	0.28	0.25	27.72	0.53	59.43	0.90
	Mean	**0.29**	**33.19**	**0.01**	**1.15**	**0.19**	**27.30**	**0.30**	**38.36**	**0.79**
DW21	3	0.23	69.09	0.00	0.75	0.04	13.21	0.06	16.94	0.34

Appendix 4. Concentrations of anions in Darwin area streams expressed as millequivalents per litre and percentage contribution of each ion to the total ionic composition. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance.

Site	Group	Cl me	%Cl	SO4 me	%SO4	HCO3 me	%HCO3	CO3 me	%CO3	Total anions
DW44		0.03	15.86	0.00	1.17	0.15	82.96	0.00	0.00	0.18
DW31	1	0.06	3.10	0.04	2.29	1.72	94.61	0.00	0.00	1.82
DW36	1	0.08	31.42	0.02	7.73	0.16	60.85	0.00	0.00	0.27
DW37	1	0.11	12.65	0.04	4.67	0.74	82.68	0.00	0.00	0.89
DW39	1	0.08	15.30	0.02	4.52	0.38	68.14	0.07	12.05	0.55
DW40	1	0.06	9.92	0.02	3.66	0.49	86.42	0.00	0.00	0.57
DW42	1	0.08	45.84	0.00	0.00	0.10	54.16	0.00	0.00	0.18
DW45	1	0.06	23.40	0.02	8.63	0.16	67.97	0.00	0.00	0.24
	Mean	**0.08**	**20.23**	**0.02**	**4.50**	**0.54**	**73.55**	**0.01**	**1.72**	**0.65**
DW23	2	0.28	33.90	0.06	7.01	0.49	59.09	0.00	0.00	0.83
DW26	2	0.03	11.48	0.02	8.47	0.20	80.05	0.00	0.00	0.25
DW38	2	1.07	58.55	0.17	9.21	0.59	32.23	0.00	0.00	1.83
DW41	2	0.06	12.42	0.02	4.58	0.38	83.00	0.00	0.00	0.45
DW43	2	0.08	8.84	0.02	2.17	0.85	88.99	0.00	0.00	0.96
	Mean	**0.30**	**25.04**	**0.06**	**6.29**	**0.50**	**68.67**	**0**	**0**	**0.86**
DW21	3	0.20	63.25	0.00	0.00	0.11	36.75	0.00	0.00	0.31

Appendix 5. Concentrations of ten metals (expressed as µg/L) in fourteen water samples from streams in the Darwin area. For calculation of group means, concentration assumed to be half detection limit. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance.

Site code	Group	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
DW-44		110	<1	<0.1	<1	<1	250	<1	3.2	<1	<1
DW-31	1	38	<1	<0.1	<1	<1	550	<1	97	<1	<1
DW-36	1	64	<1	<0.1	<1	<1	2100	<1	40	<1	1.5
DW-37	1	120	<1	<0.1	<1	<1	530	<1	16	<1	<1
DW-39	1	110	<1	<0.1	<1	<1	260	<1	4.3	<1	1.1
DW-40	1	140	<1	<0.1	<1	<1	310	<1	6.6	<1	<1
DW-42	1	140	<1	<0.1	<1	5.4	360	<1	5.4	<1	<1
DW-45	1	170	<1	<0.1	<1	<1	410	<1	9.5	<1	<1
	Mean	**112**	**0.5**	**0.05**	**0.5**	**1.2**	**646**	**0.5**	**25.5**	**0.5**	**0.7**
DW-23	2	44	<1	<0.1	<1	<1	470	<1	14	<1	1.5
DW-26	2	130	<1	<0.1	<1	<1	590	<1	13	<1	1.2
DW-38	2	36	<1	<0.1	<1	3.7	260	<1	32	<1	1.1
DW-41	2	110	<1	<0.1	<1	<1	680	<1	13	<1	2.5
DW-43	2	89	<1	<0.1	<1	<1	680	<1	13	<1	2.5
	Mean	**82**	**0.5**	**0.05**	**0.5**	**1.1**	**536**	**0.5**	**17**	**0.5**	**1.8**
DW-21	3	67	<1	<0.1	<1	<1	330	<1	6.4	<1	2.8

Appendix 6. Chemical parameters for fourteen water samples collected from stream in the Darwin region. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance. Values for pH are the median values.

Site code	Group	pH (lab)	EC (lab)	TDS	Na	K	Ca	Mg	Fe	Cl	SO4	HCO3	CO3	F
DW44		6.9	22	25	2.0	0.1	1.4	0.6	0.28	1	0.1	9	0	0
DW31	1	7.2	171	86	2.3	0.3	14	12	0.60	2	2	105	0	0
DW36	1	6.1	30	34	3.3	0.3	5.3	1.0	2.30	3	1	10	0	0
DW37	1	8.1	90	62	4.8	0.7	9.4	2.0	0.50	4	2	45	0	0.1
DW39	1	8.7	47	36	2.0	0.2	5.8	1.1	0.01	3	1.2	23	2	0
DW40	1	6.8	57	36	1.9	0.2	7.8	1.7	0.30	2	1	30	0	0
DW42	1	6.1	18	25	2.3	0.1	2.8	0.5	0.40	3	0	6.1	0	0
DW45	1	6.3	26	22	2.3	0.1	2.8	0.8	0.40	2	1	10	0	0
	Mean	**6.8**	**63**	**43**	**2.7**	**0.3**	**6.8**	**2.7**	**0.6**	**2.7**	**1.2**	**32.7**	**0.3**	**0.01**
DW23	2	6.7	87	52	6.6	0.4	4.8	3.1	0.53	10	2.8	30	0	0
DW26	2	6.4	28	21	2.0	0.1	1.4	0.9	0.80	1	1	12	0	0
DW38	2	7.0	189	106	19.8	1.2	4.4	5.7	0.34	38	8.1	36	0	0
DW41	2	6.7	46	31	2.6	0.2	3.1	2.1	0.02	2	1	23	0	0
DW43	2	7.1	95	47	2.6	0.1	5.0	6.5	0.30	3	1	52	0	0
	Mean	**6.7**	**89**	**51**	**6.7**	**0.4**	**3.7**	**3.7**	**0.4**	**11**	**2.8**	**31**	**0**	**0**
DW21	3	6.1	44	28	5.4	0.1	0.9	0.7	0.30	7	0	7	0	0

Appendix 7. Chemical parameters for fourteen water samples collected from stream in the Darwin region. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance. Values for pH are the median values.

Site code	Group	pH (field)	EC (field)	DO	Turbidity	Temperature	TSS	VSS	%VSS/TSS
DW44		6.85	18	7.99	4.6	21.5	1.3	0.7	53.85
DW31	1	6.99	159		2	21.8	1.0	0.8	80
DW36	1	7.35	25	4.81	2.9	26.3	4.7	2.8	59.57
DW37	1	7.8	43	4.54	2.7	22.3	1.9	1.1	57.89
DW39	1	7.21	25	7.56	3	20.9	1.8	0.7	38.89
DW40	1	7.01	42	6.25	4.8	23.9	2.1	1.2	57.14
DW42	1	7.01	14	5.72	2.3	19.3	3.0	2.0	66.67
DW45	1	6.48	21	5.7	3.3	24.5	2.8	1.6	57.14
	Mean	**7.01**	**47**	**5.76**	**3**	**22.7**	**2.5**	**1.5**	**59.6**
DW23	2	6.87	80	5.13	2	22.5	1.3	1.0	76.92
DW26	2	7	20	6.54	4.6	25.6	2.6	1.3	50
DW38	2	6.78	172	4.87	2.7	24.0	2.3	1.3	56.52
DW41	2	6.08	40	4.42	4.4	22.7	2.0	0.9	45
DW43	2	6.71	102	5.1	4.9	24.2	2.4	1.0	41.67
	Mean	**6.78**	**82.8**	**5.21**	**3.7**	**23.8**	**2.1**	**1.3**	**54.0**
DW21	3	7.5	40	6.96	2.4	24.0	1.4	0.4	28.57

Appendix 8. Nutrient parameters for fourteen water samples collected from stream in the Darwin region. Means are calculated for groups defined by classification of data on macroinvertebrate relative abundance. For calculation of group means, concentration assumed to be half detection limit.

Site code	Group	Oxidised nitrogen	TKN	Total phosphorous	Reactive phosphorous
DW44		< 0.001	<0.05	0.004	0.002
DW31	1	0.006	0.12	0.007	< 0.001
DW36	1	< 0.001	0.22	0.012	< 0.001
DW37	1	< 0.001	0.38	0.021	< 0.001
DW39	1	< 0.001	0.07	0.005	< 0.001
DW40	1	0.005	0.17	0.009	< 0.001
DW42	1	0.002	0.18	0.007	< 0.001
DW45	1	0.002	0.23	0.01	< 0.001
	Mean	**0.002**	**0.20**	**0.010**	**<0.001**
DW23	2	< 0.001	0.06	0.003	0.002
DW26	2	0.038	0.09	0.005	< 0.001
DW38	2	< 0.001	0.15	0.009	0.002
DW41	2	0.001	<0.05	0.004	0.002
DW43	2	0.010	0.17	0.012	0.001
	Mean	**0.010**	**0.10**	**0.007**	**0.002**
DW21	3	0.003	<0.05	0.003	< 0.001

Appendix 9. Habitat parameters for fourteen sites on Darwin area streams.

Site code	Group	Catchment area (km^2)	Cat. area log	Dist from source (km)	Discharge (m^3/s)	Mean channel depth (m)	Mean channel width (m)	Mean bankfull width (m)
DW44		35.5	1.55	7.9	0.143	0.49	4.5	
DW31	1	141.7	2.15	23.6	0.006	0.6	7	14.3
DW36	1	145.6	2.16	20.3	0.011	0.71	7.9	32.7
DW37	1	61.5	1.79	14.5	0	0.51	7.3	9
DW39	1	65.5	1.82	12.6	0.151	0.5	5.62	11.8
DW40	1	82.5	1.92	17.2	0.073	0.19	4.7	16.3
DW42	1	39.9	1.60	8.5	0.125	0.87	5.9	18.4
DW45	1	59.7	1.78	12.4	0.163	0.47	5.5	6.3
	Mean	**85.2**	**1.89**	**15.6**	**0.076**	**0.55**	**6.3**	**15.5**
DW23	2	9.6	0.98	3.8	0.003	0.47	5.6	8.8
DW26	2	9.2	0.96	3.9	0.071	0.37	4.9	27.5
DW38	2	11.2	1.05	4.7	0	0.69	7.4	8.5
DW41	2	3.7	0.57	2.4	0	0.58	3.7	5.6
DW43	2	145.9	2.16	23.9	0.385	0.97	7.7	
	Mean	**35.9**	**1.14**	**7.7**	**0.092**	**0.62**	**5.9**	**12.6**
DW21	3	13.7	1.14	5.1	0.017	0.73	6.9	11.8

Site code	Group	Mean habitat velocity (m/s)	Mean habitat depth (m)	%Riparian cover	Riparian width (m)	%Weed cover	%Feral cover	%Fire cover	%Human disturbance
DW44				94.4	100	0	0	0	0
DW31	1	0	0.55	85.3	6	0	0	5.5	0
DW36	1	0.02	0.82	85.6	25	1.5	0	0	0
DW37	1	0	0.45	79.9	20	0	0	0	0
DW39	1	0.02	0.62	90.5	5.3	24.2	1.5	0	0
DW40	1	0	0.42	67.5	10	28	1.5	1.7	5.4
DW42	1	0.05	0.76	84.1	5	0	0	0	0
DW45	1	0.03	0.42	93.4	17.5	0	0	0	0
	Mean	**0.02**	**0.58**	**83.8**	**12.7**	**7.7**	**0.4**	**1.0**	**0.8**
DW23	2	0	0.64	60.6	4	3.7	0	12.4	12.2
DW26	2	0.02	0.34	87.8	7.5	10.7	0	0	3.7
DW38	2	0	0.47	45.7	1.5	5.9	0	0	0
DW41	2	0	0.46	87.4	6.5	11.7	0	0	0
DW43	2	0	0.72	81.8	6.5	0	0	0	2.9
	Mean	**0.004**	**0.53**	**72.7**	**5.2**	**6.4**	**0**	**2.5**	**3.8**
DW21	3	0	0.62	93	8	10.4	0	0	36.4

Appendix 10. Habitat parameters for fourteen sites on Darwin area streams.

		Reach habitat scores							Site habitat scores					Site substrate		
Site code	**Group**	**%sand**	**%gravel**	**%riffle**	**%macr**	**%snag**	**%organic matter**	**%pool**	**%algae**	**%adjacent macrophytes**	**%roots**	**%under cut bank**	**%organic matter**	**Sand**	**Silt**	**Gravel**
DW44		60	60	0	46.7	20	53.3	0								
DW31	1	21.4	85.7	0	14.3	7.1	21.4	35.7	0	0	100	0	40	0	3	0
DW36	1	33.3	13.3	0	60	13.3	0	53.3	0	0	100	0	20	3	0	0
DW37	1	0	86.7	0	6.7	13.3	86.7	13.3	0	0	100	0	57.1	3	0	0
DW39	1	100	33.3	7.1	14.3	21.4	78.6	0	0	0	100	10	80	0	3	0
DW40	1	20	73.3	13.3	33.3	26.7	13.3	6.7	0	0	83.3	66.7	66.7	1	2	0
DW42	1	0	13.3	0	46.7	13.3	26.7	46.7	0	0	100	0	10	3	0	0
DW45	1	46.7	40	0	40	6.7	60	0	0	0	77.8	0	0	0	3	0
	Mean	**31.6**	**49.4**	**2.9**	**30.8**	**14.5**	**41.0**	**22.2**	**0**	**0**	**94.4**	**11.0**	**39.1**	**1.4**	**1.6**	**0**
DW23	2	0	93.3	0	0	20	53.3	0	50	0	100	30	60	2	1	0
DW26	2	0	66.7	25	16.7	16.7	83.3	8.3	0	0	40	0	30	3	0	0
DW38	2	0	93.3	0	13.3	6.7	66.7	33.3	60	0	90	0	70	0	0	3
DW41	2	0	92.9	0	0	14.3	21.4	21.4	0	0	100	0	90	3	0	0
DW43	2	40	13.3	0	33.3	73.3	46.7	46.7	0	10	100	40	0	3	0	0
	Mean	**8.0**	**71.9**	**5.0**	**12.7**	**26.2**	**54.3**	**21.9**	**22**	**2**	**86.0**	**14.0**	**50.0**	**2.2**	**0.2**	**0.6**
DW21	3	20	40	6.7	0	13.3	66.7	33.3	0	0	100	100	0	0	3	0