CONSERVATION STATUS AND HABITAT ASSOCIATIONS OF AQUATIC INVERTEBRATES IN PILBARA COASTAL RIVER POOLS

Report to

Department of Water

by

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Our environment, our future

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INTRODUCTION

The Western Australian Department of Water (DoW) is investigating options for developing additional groundwater resources in the Pilbara, including a number of aquifers associated with coastal reaches of the region's major rivers on the Roebourne Plains (State Water Plan, Government of Western Australia 2007). A number of aquifers have been selected for detailed investigation and assessment to be completed as part of DoW's Pilbara Water Smart Australia project. The project will include hydrogeological investigation and assessment, estimation of ecological water requirements and determination of allocation limits for these resources. Ultimately, this information will be summarised as water resource management plans due for completion in 2011.

As a contribution to this process, the Department of Environment and Conservation (DEC) was contracted to undertake an investigation into the relationships between river pool aquatic invertebrates and habitat variables that may be affected by groundwater drawdown associated with water extraction. The objectives were:

- To provide an improved understanding of the relative ecological values and significance of pools within proposed groundwater extraction areas, in relation to other wetlands in the catchment and the region.
- To investigate relationships between river pool invertebrate faunas and pool size, permanence and the type and diversity of functional habitats.
- To provide advice, based on the above, which will contribute to an assessment of the ecological water requirements of Pilbara river pools.

Null hypotheses based on these objectives were:

1. That river pools within potential groundwater extraction areas are essentially uniform with respect to their physical, chemical and biological characteristics.
2. That river pools within potential groundwater extraction areas do not have ecological values that are not well represented elsewhere, i.e. they do not have particularly high conservation significance in a regional context.
3. That there are no relationships between aquatic invertebrate communities and pool characteristics such as pool size, permanence, depth and habitat characteristics that may be affected by groundwater extraction.

Pilbara rivers and river pools

Rivers in the Pilbara region mostly arise in the Chichester and Hamersely Ranges and, for the Ashburton River, a number of ranges south of the Pilbara region. Some shorter creeks arise on the coastal Roebourne Plains and these fill from local runoff or when major rivers overflow onto the plains. Figure 1 shows daily discharge at one lowland gauging station on each of the three rivers under consideration in this project (Fortescue, Yule and De Grey rivers). It should be noted however, that flow at a gauge does not imply flow through any particular downstream pool. As in most arid zones (see Puckridge *et al.* 1998) Pilbara rivers are characterised by intermittent and highly variable flows. Following significant rainfall events, surface flow rises very rapidly (with 48 hours in some instances) from zero to between hundreds to hundreds of thousands of megalitres per day, depending on extent and intensity of rainfall. Flows decline over weeks to months depending on patterns of supplementary rainfall and nature of the catchment (Figure 1). Floods peak very quickly because of the very intense rainfall, rugged topography and largely impervious geology of the ranges on which most of the rivers arise. These high velocity, high volume flash floods, leave behind few non-riverine wetlands within the relatively confined inland valleys within which these rivers mostly flow. Floodplains are largely restricted to the coastal plains, although the middle Fortescue River (Fortescue Marsh and areas upstream and downstream of there), the middle Ashburton River and some of the plateau areas of the Hamersely Ranges (e.g. upper catchment of Duck Creek in the Ashburton system) also have extensively inundated areas following major rains. This is in contrast to most other large Australian dryland river systems which occur in areas of more subdued topography, permeable substrates and very extensive floodplains, creating more gently rising floods which move down the lengths of rivers much more slowly: e.g. northern Murray Darling and Lake Eyre systems (Costelloe 2004; Marshall *et al.* 2006; Sheldon *et al.* 2002).

Most of the existing studies of dryland river ecology in Australia have been conducted in these more inland and eastern systems, including studies of the ecological water requirements of dryland rivers (Boulton 1999; Boulton *et al.* 2006; Costelloe *et al.* 2004; Jenkins and Boulton 2007; Sheldon *et al.* 2002), although van Dam *et al.* (2005) reported on aspects of the ecological requirements of river pool ecosystems on the De Grey River in the Pilbara. Braided systems (multiple river channels) are also much more widespread in these other arid catchments, so that the size of the flood has a stronger influence on which anabranches (and thus which pools) receive water compared to at least the more inland parts of the Pilbara. Strongly braided channels in the Pilbara are largely restricted to the Roebourne Plains along the coast, but also some inland areas such as the middle Fortescue Valley upstream of Millstream National Park. Although there is extensive braiding and meandering flow paths within inland reaches of Pilbara rivers, these are generally contained within a single main channel in the

relatively confined valleys and are subject to ongoing change as floods regularly shift sediments around (Sambrook-Smith 2007). In these reaches river pools are likely to be flooded more consistently than where there is extensive braiding of the channels.

Major floods in Pilbara rivers are largely restricted to mid-late summer rainfall events (Gentilli 1993), especially those associated with cyclones, although minor flows can occur at other times of the year (Figure 1). Periods of no flow can also occur at any time of year but are more likely to occur in spring and early summer. Cyclones affect the Pilbara every one or two years on average (nine approached or crossed the Pilbara between 1998 and 2008) and some flow occurs in most rivers in most years (Figure 1). The major summer rainfall events generally each only bring rains to a part of the region, leading to uneven flood patterns between rivers. For example, tropical cyclones George and Jacob passed over the eastern Pilbara in March 2007 causing flows of up to 89 000 ML/day in the lower Yule (lasting six weeks) and up to 277 000 ML/day in the lower De Grey (lasting three months) but no flow in the lower Fortescue (Figure 1).

River pools are present along the lengths of the major rivers in the Pilbara and are the dominant wetland type in the region. Despite the region's aridity (mostly < 350 mm annual rainfall), many of the pools are near permanent or permanent. Analysis of remotely sensed inundation data suggests that about a quarter of river pools are semi-permanent to permanent. Van Dam *et al.* (2005) suggested that there are well over 100 semi-permanent to permanent pools in the De Grey catchment alone. This abundance of permanent fresh and clear surface water is in contrast to many other dryland areas in Australia. For instance, Hamilton *et al.* (2005) suggest that waterholes maintained by fresh groundwater would be 'exceptionally important' refugia in the Cooper Creek system of the Lake Eyre Basin. The longevity of many Pilbara pools reflects a combination of regular flooding, depth, shading by gorge cliffs (in inland areas), groundwater discharge via springs or seepage through porous sediments and impedance of hyporheic flow by bedrock structures at the downstream ends of pools. In this sense many river pools in the Pilbara are groundwater dependant ecosystems (Boulton and Hancock 2006). Furthermore, while some Pilbara river pools increase in salinity between flood events, discharge of fresh groundwater generally maintains water quality (especially low salinity) in many of the permanent pools during drought periods. In some other Australian arid zones, even where pools have long hydroperiods, water quality frequently declines during non-flow periods due to evapoconcentration and/or intrusion of saline groundwater (Costelloe *et al.* 2005; Hamilton *et al.* 2005).

River pools sampled for this project were all on the Fortescue, Yule and De Grey Rivers mostly on the Roebourne Plains (Figure 2).

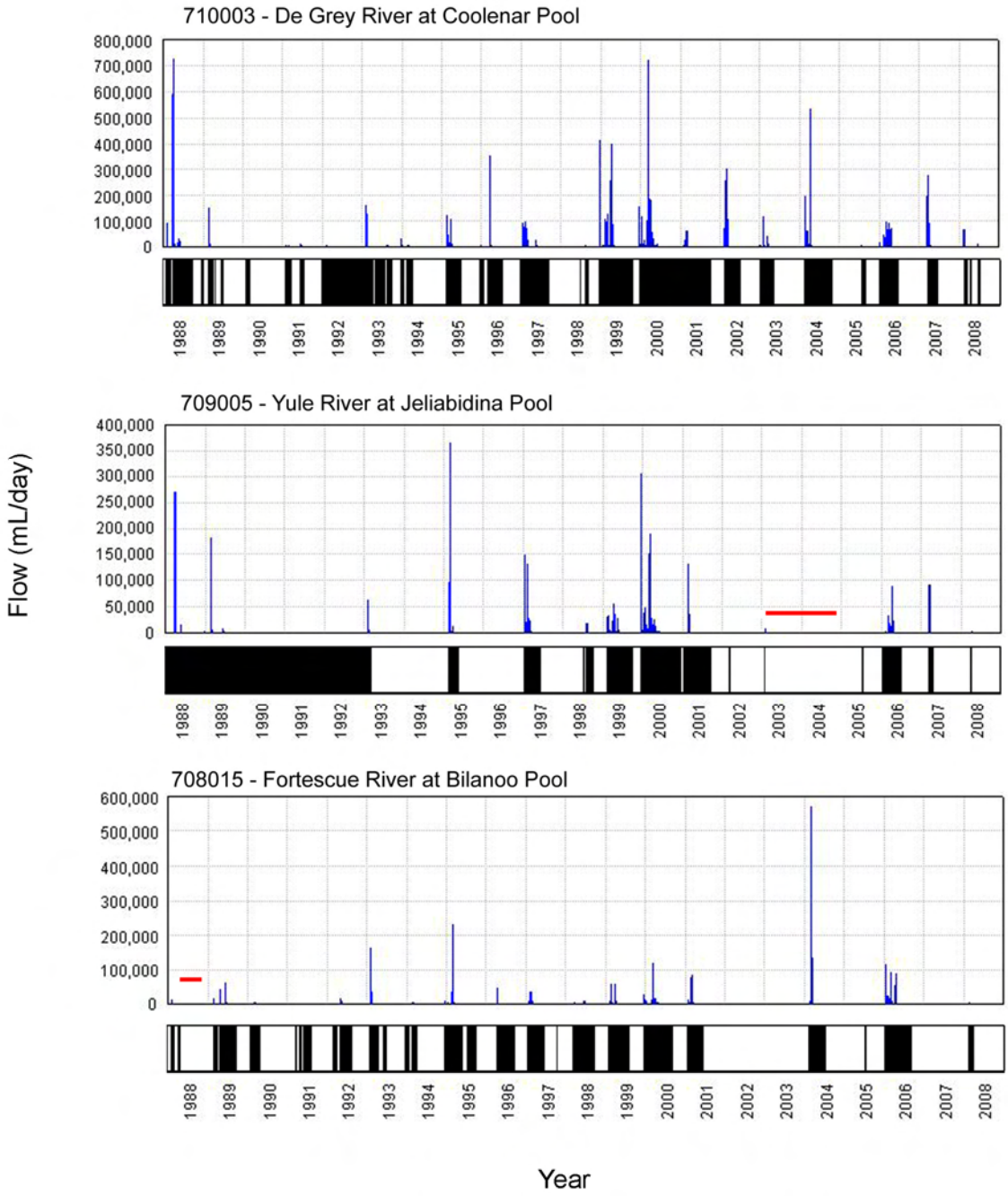


Figure 1. Daily discharge for three gauging stations on the lower De Grey, Yule and Fortescue Rivers. In the upper plots, horizontal red lines indicate periods of missing data. Black blocks in the lower part of each graph indicate periods with flow > 0 ML/day.

Fortescue River

The 700 km long Fortescue River (Figure 2) has few significant tributaries and drains the southern slopes of the Chichester Range and the northern and far eastern slopes of the Hamersley Range. The upper Fortescue, which drains the eastern Hamersley Range is essentially endorheic, terminating at the large brackish to mesosaline Fortescue Marsh which rarely overflows. The Fortescue thus arises anew from tributaries flowing off the slopes of the

middle Hamersley and Chichester Ranges. These creeks flow into a valley that contains a number of claypans and flats and the start of the poorly defined braided middle Fortescue River. Downstream, the river receives perennial flow from springs and groundwater input into deep permanent pools (such as Deep Reach, pool 19 of this study) as it passes through the south-western tip of Millstream National Park, after which the lower Fortescue is again a well defined single channel until it reaches the Roebourne Plains and becomes more braided.

De Grey River

The large De Grey River Basin occupies most of the eastern third of the Pilbara and includes several major subcatchments (Oakover, Shaw, Coongan and Nullagine, Figure 2); only known as the De Grey after the Oakover-Nullagine confluence. These rivers drain the eastern Chichester Range, numerous minor ranges within the basin and ranges bounding the Pilbara top the east (e.g. Gregory Range). Few off-channel wetlands occur in most of this catchment because of the generally rugged topography, other than near the lower De Grey, so springs and river pools predominate in the more inland areas. Coastal reaches of the De Grey, Coongan, Shaw and Strelley Rivers are more braided and have many permanent pools, especially on the De Grey River. Some flow has occurred in this river every year for the past 21 years, primarily in late summer and extending through to winter or spring, though in exceptional years flow has been perennial.

The Yule River

The Yule River is one of a number of short catchments originating on the northern slopes of the Chichester Range (Figure 2) and which constitute the Port Hedland Coast Basin. The Yule begins as dozens of smaller creeks that join to traverse the coastal Roebourne Plain as a moderately braided channel before splitting into a number of channels with separate outlets to the ocean. There are numerous pools in its lowland sections.

Pilbara river pools and their habitats

Pilbara river pools vary in morphology from very small and shallow through to some that are kilometres long and several metres deep. Pool position is largely determined by the geomorphology and geology of the river bed and adjacent landscapes and how this affects water flow and sediment deposition (Gordon *et al.* 1992; Sambrook-Smith 2007). Pools are frequently located on the convex side of a bend in the river, adjacent to an embankment where flood waters have scoured away sediment, leaving a depression in the bed, but also sometimes where

there is a bedrock impediment to flow (normally in more upland confined channels), where cliffs create erosive forces or at channel confluences. Pools located near the river bank, like most of those surveyed for this study, are typically deepest near the river bank and become shallower towards the dry river bed within the channel. The steep bank may also contain undercut areas due to the erosive action of floods, especially where riparian trees are present, sometimes exposing tree roots or causing trees to fall into the river and become submerged logs. River pools may also be located in narrow sections of the river, where both banks are quite steep (as in the Millstream section of the Fortescue River or the pool at Running Waters on the Davis River) or in the middle of river channels, the latter especially where there is a spring or bedrock present. The dimensions of most pools vary in response to recent flows, but some of those that are strongly influenced by groundwater can be quite stable in size between flows. Large flood events can alter the shape and location of a pool through altered sediment deposition, although local geomorphology and geology often constrain pools to certain general locations in the long term if the banks remain stable.

Pilbara river pools often contain several structural habitat components, including bare sediment (of various grades and heterogeneity), macrophyte beds (of various species composition and density), undercut banks, tree roots, logs and organic detritus. In more upland areas there may also be flowing surface water from spring discharge into the pool and this may flow out the downstream end of the pool for some distance. In general, however, coastal river pools in the Pilbara are fairly simple, with few functional habitats (sensu Buffagni *et al.* 2000; Storey and Lynas 2007, for example): essentially just submerged macrophyte beds and bare sediment (of various particle size composition), with small patches of emergent macrophytes at some pools. During the dry season there are few backwater areas or flooded riparian zones and usually no visibly flowing water. Even organic debris tends to be sparsely scattered rather than forming a discrete functional habitat (though it is undoubtedly important for some invertebrate species).

Sediments in Pilbara river pools vary from clay dominated to cobble dominated, sometimes with boulders and/or bedrock present. Coastal pools tend to be dominated either by clay sediments (turbid pools in smaller creeks and anabranches) or sand and gravel (clear water pools) and have little bedrock and boulder. The river channel banks are frequently lined with clay whereas the beds have coarser sediments. Boulders usually occur where they have tumbled from nearby slopes and cliffs or where there is exposed underlying geology so are rare in pools on the flat alluvial Roebourne Plains.

Most clear water pools have extensive beds of submerged macrophytes and sometimes also have emergent macrophytes in the shallows. Common submerged macrophytes in the Pilbara are *Najas*, *Potamogeton*, *Myriophyllum* and the charophytes *Nitella* and *Chara.* Macrophyte beds normally include a mixture of these occurring together and several combinations can occur

in the same pool along with monospecific beds, especially of the Characeae. Highest macrophyte biomass tends to occur along the steeper bank edges where the greater depth allows greater biomass per unit area. Emergent vegetation around Pilbara river pools is dominated by *Schoenoplectus subulatus* and *Typha domingensis* (M. Lyons, DEC, pers. comm.). These are normally also at their greatest extent on the edge of the pools near the river bank. They are not commonly found in turbid river pools due to light limitation, but sometimes form very dense and extensive beds in clear Pilbara river pools, especially those that are spring fed. However, few of the coastal pools have extensive emergent macrophyte stands.

Riparian vegetation along the banks of river pools provides a variety of habitats. Leaf litter is important for some groups of invertebrates, particularly where these accumulate to form 'packs'. Masses of fine tree roots projecting from the bank provide another sheltered habitat for some invertebrates, as do larger woody roots and semi-submerged tree limbs, especially for some hemipterans such as belostomatids, nepids and *Caridina* shrimp.

The mix of these habitat variables, plus water chemistry (especially salinity and turbidity) and hydrology are the major determinants of aquatic invertebrate community composition in arid zone river pools.

Pilbara river pool invertebrate faunas

Dryland rivers were neglected by researchers for many years because they were thought to have little of biological interest (Williams 1998). This has changed in the last couple of decades, with recognition that inland rivers have significant conservation values and that maintenance of functioning ecosystems requires knowledge of their ecological water requirements (e.g. Sheldon *et al.* 2002; Timms and Boulton 2001; Williams 2000). The focus of the majority of these studies has been the ecology of rivers in eastern Australia, especially the Murray Darling, Cooper Creek, Paroo and Lake Eyre systems (e.g. Hamilton *et al.* 2005; Marshall *et al.* 2006; Sheldon *et al.* 2002). The biodiversity and ecology of Pilbara rivers are not so well documented, though several studies in the last two decades have made significant progress.

A survey of Pilbara wetlands by Masini (1988) aimed to describe wetlands in the region, assess anthropogenic pressures on them and establish priorities and guidelines for their conservation. This survey surveyed riparian and aquatic vegetation, algae, aquatic invertebrates, fish and physico-chemical water quality of 76 surface water pools, but invertebrates were collected from only 10 of these and identifications were mostly to family and genus level (only 24 taxa were identified). Biological richness was highest in wetlands with permanent water supplies and/or high integral habitat diversity, primarily springs and river pools. At about the same time, Ponder (1987) undertook a small survey of springs (Millstream, Fortescue Falls, Running Waters and

Skull Springs) to determine their conservation values. He concluded that these contained rare and/or restricted species, confirmed during the Pilbara Biological Survey (see below), but sampling effort was low at each pool, focussing on taxa likely to be endemic.

Macroinvertebrate faunas of 51 river pools and spring pools in the Kimberley, Gascoyne and Pilbara regions were sampled by Kay *et al*. (1999) as part of the national AusRivAS river biomonitoring program (Halse *et al.* 2006). The focus of Kay's paper was the spatial and temporal patterns of distribution of aquatic invertebrates in north-western Australia. Macroinvertebrate richness (at the family level) differed between regions (richest in the Kimberley, lowest in the Gascoyne, intermediate in the Pilbara) and wetlands with greater habitat diversity (riffle, bare sediment, macrophyte, pool rocks were sampled) supported more families. Significantly differences in species richness were found between habitats, with macrophytes having greatest diversity (20.2 species/10 metre sweep sample compared to only 15 for bare sediment in the Pilbara). Pilbara communities appeared to be somewhat intermediate in composition between those of the Gascoyne and Kimberley regions. Springs and spring-fed pools supported significantly greater aquatic invertebrate diversity than other river pools and supported a number of taxa largely restricted to springs.

In a precursor to the stygofauna component of the Pilbara Biological Survey Halse *et al.* (2002) examined the extent to which five springs in the Pilbara provided habitat for groundwater and surface water invertebrates. They recorded 159 species but only 18 were considered to be groundwater species.

A study by van Dam *et al*. (2005) assessed the sensitivity of riverine communities to changes in hydrologic regime within the Bulgarene borefield area of the lower the De Grey River. Eight of the 12 river pools sampled were also sampled in the present survey. Aquatic macroinvertebrates, fish, phytoplankton and macrophytes were included in the biological component of the study. Physico-chemical water quality and bathymetric measurements were also recorded at each pool. These authors identified invertebrates to family level only, recording 46 families. Results of this study are compared to our in this report.

To date, the most comprehensive study of aquatic invertebrates in the Pilbara is the Pilbara Biological Survey (herein often referred to as 'PBS') conducted by DEC between 2003 and 2006. That survey of water chemistry, invertebrates, waterbirds, algae and aquatic and riparian vascular flora at 100 sampling sites (at 98 wetlands) aimed to describe the region's aquatic biodiversity and examine patterns in its distribution as a contribution to regional conservation planning. The PBS included most types of wetlands present in the region, including river pools, claypans, rock pools and springs. The survey is being published as a series of papers, including Pinder *et al*. (in review) on the invertebrates. Just over 1000 species of aquatic invertebrate

were collected, with an average of 94 species/sample and a maximum 226. There was little evidence of subregional patterning other than that caused by uneven distribution of wetland habitats (e.g. more claypans along the coast and in broad valleys and more permanently flowing waters in upland areas). Overall, the fauna is quite widespread in the region, although a small mesic element is restricted to a subset of the springs, as suggested by Masini (1988) and Kay *et al.* (1999). There was some association between invertebrate community composition and gross wetland type (clear water pool, turbid pool, spring, claypan, salt marsh), but with significant overlap in composition between some wetland types. Stream order was not a strong predictor of composition, with differences in composition mainly between 1st and 2nd order streams and between those and some higher orders. Community composition (relative richness of different species assemblages) was associated with flow, estimated permanence, water chemistry, macrophytes and sediments.

About half of the Pilbara invertebrate fauna is widespread in Australia or their known distributions are patchy. About a quarter have northern Australian and/or inland distributions and around 19% comprise a 'north-west' component consisting of species known only from the north-west (essentially the Pilbara) to date. The remaining 7% have either broader Western Australian distributions or southern Australian distributions, with the Pilbara representing the northern boundary of their distributions in Western Australia.

Forty one of the one hundred wetlands sampled during the PBS were river pools with mostly clear water and sediments ranging from sand to cobble dominated (as in the present project) and an additional nine were turbid pools in small creeks with finer sediments. However, few pools were sampled on the coastal reaches of the major rivers (on the Roebourne Plains), so the current project helps to fill that gap. A total of 782 invertebrate species were collected in the 41 clear river pools. Of these, 268 were microinvertebrates (protozoans, rotifers, copepods, ostracods and cladocerans) and 514 were macroinvertebrates (other taxa). The number of macroinvertebrate species found in each pool ranged from 10 to 164 species (mostly 50 to 100) with an average of 80.

Variables influencing dryland river pool invertebrates

River pool invertebrate communities are influenced by a range of interacting components of the physical and chemical environment. These components include water chemistry, the cover, density and composition of macrophytes, sediment composition, pool morphology, organic material and many aspects of hydrological regimes.

Macrophytes and organic debris. Macrophytes influence richness and composition of invertebrate communities for a host of reasons, including effects on micro-flow environments,

water chemistry, protection from predators (especially fish), shading of the river bed, provision of egg laying surfaces, provision of material for species that construct cases, sites for dragonflies to emerge from the water and food resources, including epiphytic algae and entrapped organic matter (Boulton and Lloyd 1991; Cyr and Downing 1988; Dodds and Biggs 1998; Gregg and Rose 1985; Schramm HL and Jirka KJ 1989; Stansfield *et al.* 1997; Wollheim and Lovvorn 1996). Some physical and chemical variables may influence invertebrates indirectly through their effects on macrophytes (Ali *et al.* 2007). Macrophyte diversity is frequently correlated with invertebrate diversity because of the greater range of surfaces provided by more diverse plant stems and leaves (e.g. Brown *et al.* 1988). In the Pilbara, Kay *et al.* (1999) found that macrophyte habitats in river pools had higher average species richness than bare sediment, riffle or cobble habitats. Pinder *et al.* (in review) found strong correlations between macrophyte biomass and/or cover with richness of some aquatic invertebrate assemblages in the Pilbara. These were mostly positive correlations, although richness of assemblages with a preference for turbid waters was negatively correlated with macrophyte cover.

Undercut banks, logs and protruding roots of riparian trees are important refuges for species such as shrimps and belostomatid and nepid hemipterans (Everett and Ruiz 1993). Fallen debris such as logs, sticks, tree branches and organic debris provide material for cases of some caddisflies and some dipterans (including wood boring species) and hemipterans (Haden *et al.* 1999) and a food source for detritivores.

Sediments. Sediment composition is also a significant influence on aquatic invertebrate communities (Boyero 2003; Flecker and David 1984; Reice 1980; Williams and Mundie 1978). Cobbles and boulders create spaces within which invertebrates can take refuge from predators and feed on epilithic algae and where organic material can accumulate, providing food for detritivores. Fine sediments are required for burrowing species such as bivalves, chironomid larvae and oligochaetes, though species of these differ in their preferences for different grades of fine sediment. Medium to coarse-grained sediments allow hyporheic flow and movement of stygal and hyporheic species, such as phreodrilid oligochaetes and harpacticoid copepods, into pools. Some pools have more uniform sediments (especially clay-lined turbid pools in smaller channels), whereas others have a mixture of sediment types, often sorted by hydrological processes, so that different areas of the pool have different sediments. Sediments can also influence water chemistry variables such as nutrient dynamics and ionic composition.

Water chemistry. Numerous elements of water chemistry affect aquatic invertebrate assemblages. The responses of aquatic invertebrates to salinity have been well documented (Hart *et al.* 1990; Kefford *et al.* 2006; Pinder *et al.* 2005; Shiel *et al.* 2006). In freshwater, even small changes in salinity can alter species composition. Above about 2 to 4 g/L richness starts

to decline and above 20 g/L halophilic species tend to become dominant. (Pinder *et al.* 2005). Most river pools in the Pilbara are fresh most of the time, partly due to the input of fresh groundwater via springs or the hyporheic zone, although there is sufficient variation to expect some mild effect of salinity. Of the 100 water samples collected from 50 river pools during the PBS only 8% were above 3 g/L (the generally recognised ecological upper limit for 'freshwater') and only two were above 10 g/L. One of latter two samples one was from Catfish Pool on the Ashburton River, which became saline as water levels declined, and one was the tidally influenced Mundabullangana Homestead Pool on the Yule River. Both of these pools had particularly low richness.

Increasing turbidity also tends to reduce invertebrate richness, although naturally turbid water is associated with a distinct suite of species; often regionally endemic and including some that are largely restricted to turbid waters (Timms 2002, 2008; Timms and Boulton 2001). Suspended particles in turbid water reduce visibility for visual predators, clog filter-feeding apparatus of some macroinvertebrates and affect the efficiency of fine gill structures in others. For these reasons species like mayflies and mosquitoes tend to be reduced in number and diversity as turbidity increases. (Aldridge *et al.* 1987; Bogan 1993; Box and Mossa 1999). Turbidity also reduces light penetration, with consequences for productivity of phytoplankton and macrophytes ((ANZECC and ARMCANZ 2000)) and for invertebrates that are associated with them.

Invertebrate species assemblages are also influenced by pH, especially in the acidic to neutral range (e.g. Collier *et al.* 1990; Courtney and Clements 1998; Morris and Taylor 1989). However, Pilbara waters are very rarely acidic: 10^{th} and 90^{th} percentiles for pH recorded during the PBS were 7.55 and 9.13 and only 3 measurements out of 189 for the PBS were below 7 (6.5 to 6.9). pH was not a strong influence on Pilbara aquatic invertebrate assemblages in analyses of the PBS data (Pinder *et al.* in review).

Nutrients influence aquatic communities through their effects on algal and macrophyte primary production, with flow on effects via oxygenation of the water (or deoxygenation when algal blooms collapse). The influence of nutrients in arid zones wetlands of Australia has received relatively little attention compared to more urban and intensively farmed areas (Bunn *et al.* 2006). In the Pilbara, nutrient concentrations in river pools are generally low: mostly < 1.0 mg/L total filterable nitrogen and < 0.03 mg/L total filterable phosphorus in the PBS). High nutrient concentrations usually indicate heavy stock use of a static river pool in between flood events, except in turbid waters where nutrients adhered to fine sediment particles inflate nutrient concentrations in the water column. Algal blooms in Pilbara rivers are normally mild and largely restricted to river pools where there is excessive cattle use and little or no flow, unlike the extensive blooms that have occurred in some dryland rivers of eastern Australia

(Oliver *et al.* 2000). Chlorophyll concentrations were very low in most of the wetlands sampled for the PBS (generally < 0.01 mg/L) other than in a small number of claypans, springs and a couple of small river pools (including Wodgina Pool on the upper Yule River). In some pools heavily utilised by cattle there was extensive growth of filamentous algae which would not have been reflected in chlorophyll values.

Hydrology and ecological water requirements. Hydrology partly influences all of the above variables and is therefore considered to be an overarching driver of aquatic invertebrate community composition and ecosystem functioning, including in arid zones (Boulton and Jenkins 1998; Boulton *et al.* 2006; Bunn and Arthington 2002; Monk *et al.* 2007; Poff 1997; Wood and Armitage 2004). That altered hydrological regimes affect riverine and floodplain communities is well recognised, though better understood for permanently flowing temperate systems. Arid zone rivers have highly variable flow regimes on multiple temporal scales (from days to decades) and patterns in the distribution of species is known to be strongly related to these, both in river channels and in associated floodplains (Costelloe *et al.* 2004; Jenkins and Boulton 2007; Puckridge 1999; Ward and Blaustein 1994). This underlying natural variability means that the biological effects of water resource developments are particularly difficult to predict and measure in arid systems. Nonetheless, there has been significant progress over the last 20 years, at least in the understanding of the responses of biota to natural hydrological regimes in semi-arid and arid aquatic systems, albeit with a focus on floodplain wetlands rather than river channels (Boulton 2003; Capon and Brock 2006; Costelloe *et al.* 2004; Jenkins and Boulton 2007; Kingsford and Johnson 1998; Lake PS 2003; Marshall *et al.* 2006; Sheldon *et al.* 2002; Timms 1999).

Hydrological regimes are described by timing, frequency, amount, duration and variability of water flow and any or all of these can be affected by various water resource developments, with invertebrates and other biota responding differently to changes in each. In the Pilbara region surface flows in the rivers and their floodplains are driven by rainfall in the middle to upper catchments where there are no significant impediments to water moving downstream to the areas of concern reported on here. Rather, it is the low flow periods, during which pools are maintained by groundwater inflows, which are of concern.

Many river pools in the Pilbara are permanent to near permanent, largely due to inflows from shallow groundwater aquifers. Reduced flows from aquifers to pools could compromise pool ecosystems directly by reducing pool size, longevity, connectivity between pools, linkages between pools and riparian zones (e.g. where pools contract away from the river bank), as well as affecting riverine ecosystem processes (see review by Boulton and Hancock 2006). Potential indirect effects flowing from these changes include declining water quality, increasing water temperature, altered patterns of aquatic plant growth, increased intensity of disturbance by

stock, reduced habitat diversity and altered community interactions (e.g. changes to predatory fish populations). The effects of drought are not well understood in riverine systems, whether natural or not. In a review of the effects of drought as a perturbation in rivers Lake *et al.* (2003) contrasted two types of drought: seasonal and supra-seasonal. He suggested that seasonal drought (reduced flow and/or water levels as part of a natural and regular hydrological cycle) is tolerated very well by riverine biotas. Biotas have both high resistance (populations can survive *in situ*) and resilience (populations are able to re-establish when the drought ends) to seasonal drought. By contrast, supra-seasonal droughts (those that are unpredictable in timing and duration) are more difficult for fauna to deal with. In the Pilbara there is an underlying seasonal pattern to flow, with flow most likely to be absent in winter and spring, but there is substantial variability between years and between rivers, with some periods of supraseasonal drought. An example of the latter is the period of no flow in the Fortescue River between mid 2001 and early 2004 following reliable summer/autumn flows in the previous 14 years. Reduced groundwater inputs to Pilbara river pools may exacerbate the ecological effects of both seasonal and supra-seasonal droughts, but may have greater effects during the latter. However, as Boulton (2003) points out, there is insufficient long-term data to "indicate persistent effects of drought or predict the impacts of excessive surface water or groundwater abstraction". Drought generally has negative consequences for invertebrate diversity in desert rivers (Boulton 2003; Boulton *et al.* 2006; Lake P.S. 2003), but effect of drought on the fauna of individual pools depends on whether pools dry completely or at least cause conditions in pools to cross some threshold that eliminates elements of the biota (Boulton 2003, 2006, Lake 2003). For a subregion or river reach the effects of drought (or the enhancement of drought by reduced groundwater inflows) would depend on what proportion of pools was negatively affected. Where there are sufficient pools to act as refugia (or not impacted by groundwater drawdown) the long term effects on a reach are probably minimal since these refugia act as sources of colonisers once the drought ends. In the Pilbara, given the extreme nature of many floods (Figure 1) large proportions of the entire catchments of some rivers are sources of recolonisation, so negative effects of drought on a small proportion of pools probably have few system-wide consequences.

METHODS

Selection of pools and sampling locations.

Twenty river pools on the De Grey, Yule and Fortescue Rivers were selected by Department of Water (Figure 2, Appendix 1 and Plates 1 to 3). Pools were selected based on permanence and to be spatially representative across the study sub-areas. These were mostly permanent to near permanent pools within existing or potential groundwater abstraction areas. Ten of these were selected for sampling aquatic invertebrates and ten were sampled for environmental variables only, with the aim of using predictive models derived from the Pilbara Biological Survey (Pinder *et al.*, in review) to predict relative richness in the latter.

Pools 1 to 8 were in the De Grey River, pools 9 to 14 were in the Yule River and pools 15 to 20 were in the Fortescue River. All of these were located on the Roebourne Plains except for pools 19 (Deep Reach) and 20 (Livistonia Pool) in Millstream National Park.

At each of the ten pools sampled for invertebrates three sampling locations were selected to represent the dominant macrohabitats. Macrohabitat diversity was usually low within a pool and samples were normally taken from bare sediment and from macrophytes, with the latter usually in deep or shallow water or in dense or sparse beds or within beds of different species of dominant macrophyte. At each of these macrohabitats an invertebrate samples was collected, macrophyte cover was estimated, sediments sampled and depth, pH, turbidity, water temperature and conductivity were measured. At each of the 10 pools not sampled for invertebrates three dominant macrohabitats were also chosen and the above features (except for invertebrates) were taken or measured.

All field work was undertaken between 12 Oct and 20 Oct 2008.

Determination of pool size and persistence from remotely sensed inundation extent

The Department of Water undertook a trial remote sensing project with the objective of mapping and assessing the permanency of river pools and wetlands within the Pilbara. They were particularly interested in identifying permanent or semi-permanent pools because their permanence is likely to be groundwater dependent. Landsat TM imagery was used to provide replication. ‘Epochs’ available free of charge from the Australian Greenhouse Office (AGO) were supplemented with additional epochs from the Department of Environment and Conservation and some purchased for the project. Landsat imagery has the benefits of multiple

replicates, is readily available and allows separation of all spectral bands. It does, however, have relatively low resolution with 25m pixels.

Replicates or epochs were chosen to maximise time since rainfall or river flow, to give the greatest chance of a water body drying if it was going to. However, the timing of the AGO Landsat imagery was problematic, with the majority of the available scenes available from wet season months. Years were selected from the available replicates when surface water flows were absent using the record from surface water gauging stations and rainfall records (Table 1). However, due to the patchy nature of both the available flow and rainfall record and thunderstorm activity in the Pilbara during the wet season some rainfall and stream flow is present in the imagery.

A supervised classification methodology was chosen to map surface water features across the Pilbara study area. The supervised classification required operator driven selection of suitable surface water features to build a profile typical of similar surface water features contained in the remainder of the image under analysis. Training pools were selected using a 432 pseudo colour image and available high-resolution photography when required. After training pool selection a parallel piped classifier was used to extract like image pixels. Parallel piped classification has the benefit of speed and was chosen due to the large size of the study area and number of images and epochs to be classified.

Table 1. Landsat imagery used to determine pool extent.

Imagery Processed	**Year**	**Image Capture**
AGO Landsat TM5	2000	Oct. 99 - Dec. 99
AGO Landsat TM5	2002	Dec. 01 – Apr. 02
Landsat TM5	2003	Sept. 03 - Oct. 03
DEC Landsat TM5	2003	Jan. 03 – Mar. 03
AGO Landsat TM5	2004	Sept. 03 – Jun. 04
AGO Landsat TM5	2005	Jan. 05 – Mar. 05
Landsat TM5	2007	Sep. 07

Once all image epochs across the study area were classified and surface water features extracted a manual process of determining recurring pools was conducted by GIS officers. Pool locations were mapped using a set of rules developed to maintain consistency when placing a marker for pool permanency.

This derived data was available for 18 of the pools sampled for this project; the exceptions being PRP015 and PRP016 which were narrower than the 25 m pixel size of the data (see pool photos below). Data was also available for some of the pools sampled for the Pilbara Biological Survey. From this inundation extent data the minimum and maximum pool size was calculated, with the latter excluding any epochs where adjacent pools were connected (as indicated by identical (and very large) pool size estimates. 'Permanency' was defined as the proportion of epochs in which water was detected.

Water Chemistry

Samples of water were collected at one location per pool (generally from open water) just prior to sampling for aquatic invertebrates. From these samples alkalinity, total dissolved solids, colour, total filterable and unfiltered nitrogen and phosphorus, chlorophyll and ionic composition were determined by the Chemistry Centre of WA. Note that calcium was mistakenly left out of the analyses requested so percentage cations are calculated without calcium. Chlorophyll is the sum of chlorophyll a, b, c and phaeophytin a.

Submerged macrophytes

Where present, submerged macrophyte samples were collected from six 25 x 25 cm quadrats within each macrohabitat. Macrophyte samples were air dried in the field, dried at 100ºC for 48 hours in an oven and weighed to the nearest 0.1g.

Sediment

The percent occurrence of bedrock + boulder, cobble + pebble and finer sediments (gravels to clays) on the surface of the river bed was estimated for each macrohabitat in the field. For analyses involving data from whole pools (not separate samples) these field estimates were averaged. From within each macrohabitat a 500 ml sample of the fine sediments was collected for analyses of particle size composition (% gravel, % sand, % silt and %clay). Due to budget constraints these three samples of finer sediments were combined prior to analysis, so the laboratory analyses represent an average across the three macrohabitats. Percentage gravel sometimes included small pebbles. The values of these laboratory fractions were multiplied by the average estimated proportion of 'fine' sediments at each sampling locations to give a value for the pool. These variables are not absolute representations of sediment composition, which would require much more thorough methods, but provide an estimate of relative sediment composition and are consistent with methods used by Pinder *et al*. (in review).

Invertebrates

At the 10 odd numbered pools a 15 m sweep net sample of invertebrates was collected from each of the three macrohabitats. Where possible, these were from different macrohabitats (generally different combinations of aquatic plant density and/or community type, sediment and depth – since these were the main habitat variables that varied within the pools). Sweep net samples were collected by stirring up the sediment and vegetation with feet and/or the net frame and then sweeping through the stirred up material. Sediment was removed from samples in the field by elutriation. Coarse plant matter was discarded after it was washed in clean pool water and the washing water passed back through the net. Samples were preserved in 100% ethanol. Zooplankton samples were not collected and this may have slightly reduced macroinvertebrate species richness compared to PBS samples since some additional macroinvertebrates are usually collected in zooplankton samples.

Other habitat variables

Flow would have been recorded but all pools were still when visited. The maximum depth at which each invertebrate sample was collected (or would have been collected for other pools) was recorded and a sketch made of the pool to indicate where samples were taken. Presence of leaf litter, small woody debris (sticks), logs, and exposed fine and coarse roots were scored as subjective categories (1 = none, 2 = sparse, 3 = moderate and 4 = abundant) within each macro habitat as per Table 2.

Table 2. Scoring system for habitat variables.

Habitat variable	1	2	3	4
Large riparian roots in water	none	little (<10% of area)	moderate (10-50% of area)	abundant (>50% of area)
Fine riparian roots in water	none	little (<10% of area)	moderate (10-50% of area)	abundant (>50% of area)
Small woody debris (<5cm diameter)	none	sparse (only a few scattered sticks)	moderate (few accumulations and/or numerous sticks but distributed)	abundant (numerous accumulations or distributed and common)
Logs (>5cm diameter)	none	sparse (1 or 2 in sampling area)	numerous (3-10 in sampling area)	abundant (>10 in sampling area)
Leaf litter	none	sparse or only very small patches (< 0.5 m)	moderate (several packs, most > 0.5 m or with more even or scattered distribution	abundant (numerous packs > 0.5 m or over continuous large areas of bed)

Invertebrate sample processing

Invertebrate samples were processed in the laboratory by separating each sample into 3 fractions using sieves of 2 mm, 500 µm and 250 µm mesh size. Each size fraction was transferred into several petri dishes and examined under a stereo microscope. Representative invertebrates were removed from the sample for identification. All animals were identified to species except where specimens were in poor condition, too juvenile, the wrong sex or from a taxonomic group that is poorly known.

Data management

All data were entered into an Access database maintained by the wetland fauna group within DEC's Science Division.

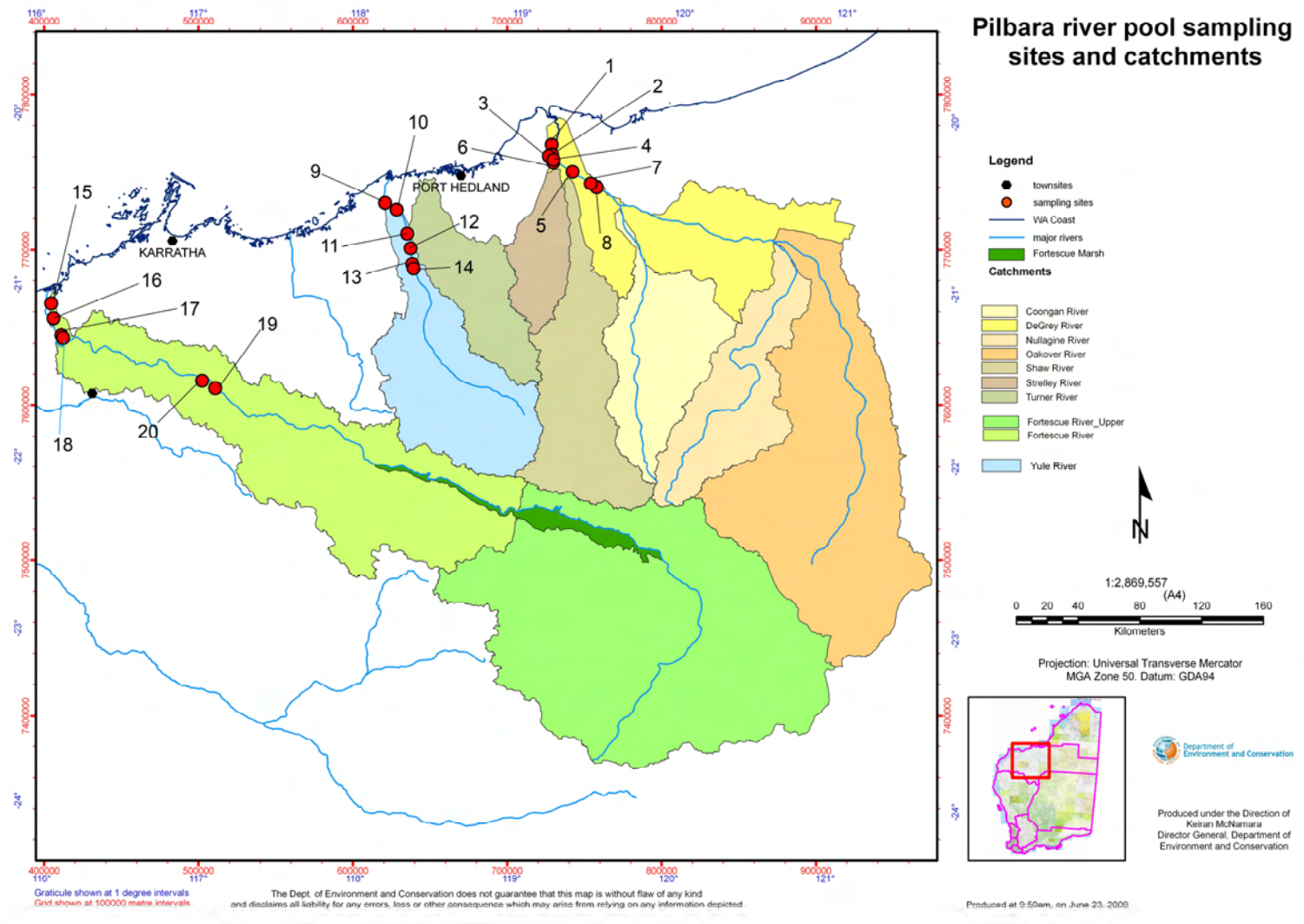
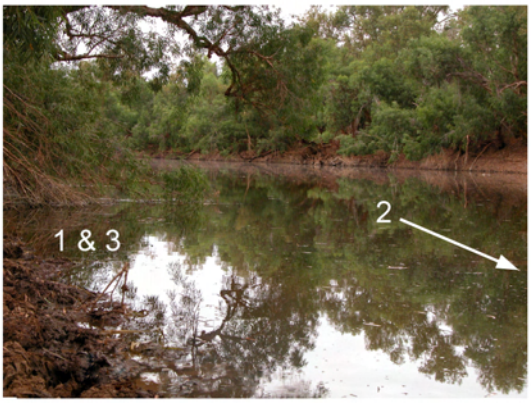


Figure 2. Map showing locations of sampled river pools (1 to 20) in the Fortescue, Yule and De Grey rivers.

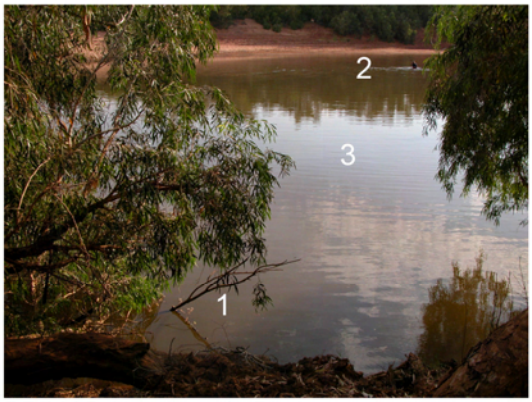
PRP001: Homestead Pool

PRP002: Pool J96



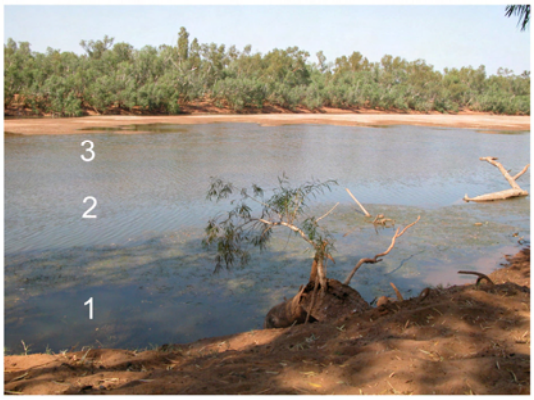
PRP003: Muccangarra Pool

PRP004: Junction Pool



PRP005: Namagoorie Pool

PRP006: Marloo Pool



PRP007: Coongeenariner Pool

PRP008: Wardoomoondene Pool

Plate 1. River pools sampled on the De Grey River with sampling locations 1 to 3 indicated.

PRP009: Li Lin Pool

PRP010: Un-named pool

PRP011: Highway Pool

PRP012: Un-named pool

PRP013: Jelliabidina Pool

PRP014: Un-named Pool

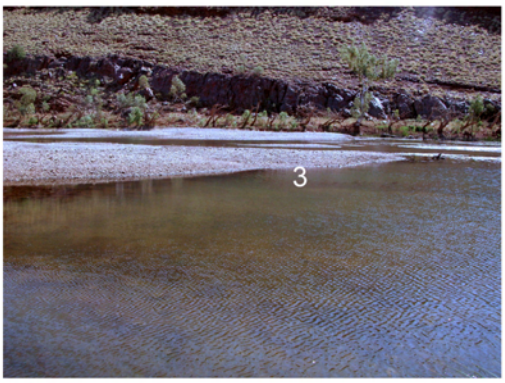
Plate 2. River pools sampled on the Yule River with sampling locations 1 to 3 indicated where visible. Sampling locations off photo indicated with an arrow.

PRP015: Mungajee Pool

PRP016: Stewart Pool

PRP017: Bilanoo Pool

PRP017: Bilanoo Pool



PRP017: Bilanoo Pool

PRP018: Tarda Pool

PRP019: Deep Reach


PRP020: Livistonia Pool, site 2

Plate 3: River pools sampled on the Fortescue River with sampling locations 1 to 3 indicated where visible. Sampling locations off photo indicated with an arrow.

Data analysis

Species richness within a sample and for entire pools was calculated from the whole dataset (i.e. including juveniles where there were no adults of the taxon present). For multivariate analyses partly identified specimens (juveniles and females of some groups) were removed where they would have tended to inflate similarity between samples. The same applies to some whole groups where finer resolution was not possible (nematodes and some dipteran families for instance). Singleton taxa (those occurring in just one sample or pool) were also removed from datasets prior to multivariate analysis.

Multivariate analyses were performed using either Primer (Primer-E Ltd. 2008) or PATN (Belbin 2006), with the latter used only for some cluster analysis where the Primer algorithm led to chaining (i.e. large numbers of small groups each sequentially separating from all remaining samples). Environmental data were range standardised and ionic concentrations were converted to percentage milliequivalents. The Bray-Curtis index (similarity in Primer or dissimilarity in PATN) was used to produce similarity matrices of samples and pools based on their invertebrate faunas. The two-step index (in PATN) was used as a measure of similarity for species based on their patterns of occurrence across pools and Euclidean distance was used for environmental data. Ordinations were non-metric multidimensional scaling (nMDS) performed in Primer using 50 restarts and were 2-dimensional except where stress was considered unacceptable (> ~ 0.15) in which case a 3-dimensional ordination was used.

Univariate analyses of variance were used to assess differences in species richness between classes of some environmental variables. Distance-based linear modeling (DistLM) in Primer was used to relate environmental variables to community composition (as represented by a similarity matrix). Environmental data were transformed as necessary to approach normality.

Pinder *et al.* (in review) identified a number of invertebrate species assemblages with differing patterns of distribution (Appendix 4) and used multivariate adaptive regression spline (MARS) modeling to relate richness of these to environmental variables. The various assemblages were modelled separately since they were each likely to be responding differently to environmental variables. Assemblages were recognised from a two-way table of invertebrate occurrences ordered by cluster analyses of species and samples. The value of these models for predicting invertebrate richness in coastal river pools was investigated as part of the current project. However, since these models have not yet been published we here repeat the methods used in their construction.

The MARS models were constructed using the (Leathwick *et al.* 2005) MARS script for R (R 2.7.0, The R Foundation 2008). This method, described by Hastie *et al.* (2001), identifies sub-ranges of explanatory variables, each of which has a linear relationship (determined using generalized linear models) with a dependant variable (Friedman 1991) and creates a basis function (essentially a linear model with a threshold) for each. The Leathwick and Elith routine uses forward stepwise addition of basis functions and backwards pruning using generalized cross validation to assess model error at each step (with a penalty [K], as per

Hastie *et al.* (2001), adjusted as necessary to produce a parsimonious model). Independent variables were allowed into the model provided they showed an ecologically tenable relationship to richness in univariate plots that did not reflect outliers or gaps in sampling that would lead to over-fitting. After an initial run, variables whose basis functions seemed to reflect gaps or outliers in the independent data, or which had a non-significant relationship to richness ($p < 0.05$), were removed from the pool of variables available and the model selection process re-run. Next, to produce more parsimonious models, variables that contributed less than about 1% to explained deviance were removed from consideration if their removal did not reduce adjusted r^2 by more than a similar proportion. Where more than one variable was removed, all were individually allowed back into the model selection process (and the model re-assessed) before a final model was produced. A Poisson error distribution was assumed for richness and frequency plots of model residuals showed that errors did approximate Poisson distributions, albeit with greater right skew than expected. Models were assessed by calculating adjusted r^2 values and 10-fold cross-validation to provide mean and standard error estimates of the regression intercept and slope between predicted and observed richness.

RESULTS AND DISCUSSION

Environmental Parameters

Pool size and permanence

Table 3 shows minimum and maximum remotely sensed pool size and permanence (see Methods). For the 18 pools where remotely sensed inundation area was available, 12 were inundated on all six remote sensing events, five were inundated for five of the six events (83%) and one was inundated for four of the six events (67%). Of the 10 pools sampled for invertebrates only two (Highway Pool on the Yule and Bilanoo Pool on the Fortescue) were not inundated on all events. Minimum pool size varied from 0 (i.e. pools that dried) or 1270 m^2 (for pools that did not dry) to 164249 m^2. Maximum pool size varied from 25119 m^2 (Jelliabidina Pool on the Yule River) to 3274101 m^2 (for Namagoorie Pool on the De Grey River).

Water chemistry

Water chemistry data is provided in Table 4 and Table 5. All river pools were fresh (< 3000 mg/L). Salinity ranged from 230 to 1300 mg/L (mean = 750) in the De Grey, 160 to 1500 mg/L (mean = 490) in the Yule, and 690 to 1400 mg/L (mean = 1000) in the Fortescue. All pools had alkaline water (as is typical in the Pilbara), with pH between 7.4 and 9.15. Pools in the De Grey tended to be slightly more alkaline (mean pH = 8.74) than those in the Yule (mean = 8.24) and Fortescue (mean = 7.81). Within a pool, pH varied by an average of 0.3 between sample locations (maximum 1.22).

Most river pools were clear, with turbidity < 10 NTU. Pools with highest turbidity were Junction Pool (pool 4) with turbidity up to 86.8 NTU, the clay-lined Mungajee Pool (pool 15) with turbidity up to 22.1 NTU and Highway Pool (pool 11) with 22.5 NTU. None of these values are particularly high compared to many arid zone wetlands. For example, some turbid creek pools sampled by Pinder *et al.* (in review) were up to 56000 NTU and frequently exceeded 150. The relatively high turbidity in Mungajee Pool was natural and caused by suspension of the clay sediment, but in Junction Pool and Highway Pool cattle may have caused elevated turbidity, either through physical disturbance of sediments or elevated phytoplankton.

Table 3. Summary of remotely sensed inundation. "Non-zero" minimum pool size is the size of a pool at its minimum recorded extent other than when it was dry.

Pool	Catchment	Percentage of 'epochs' where water retained between flood events	Minimum pool size (m^2) (non-zero pool size in brackets)	Maximum pool size (m^2)
1	De Grey	100%	164249	279374
2	De Grey	100%	5050	39510
3	De Grey	100%	8215	157689
4	De Grey	100%	27029	33934
5	De Grey	100%	43954	3274101
6	De Grey	83%	0 (20115)	31380
7	De Grey	100%	63369	170534
8	De Grey	83%	0 (2525)	101094
9	Yule	100%	1270	412834
10	Yule	100%	1895	63409
11	Yule	83%	0 (33274)	241094
12	Yule	83%	0 (5680)	67684
13	Yule	100%	5055	25119
14	Yule	67%	0 (3155)	203234
15	Fortescue	-	-	-
16	Fortescue	-	-	-
17	Fortescue	83%	0 (1895)	105404
18	Fortescue	100%	8180	248254
19	Fortescue	100%	157529	203174
20	Fortescue	100%	9455	31434

Total nitrogen (TN) concentration ranged from 0.14 to 0.81 mg/L (mean = 0.35) in the De Grey, 0.3 to 5.9 mg/L (mean = 1.5) in the Yule, and 0.17 to 0.79 mg/L (mean = 0.4) in the Fortescue. The un-named pool 10 on the Yule had the highest TN (5.9 mg/L). Nutrient concentrations indicating enrichment have not been derived for the Pilbara or for other arid zones, but for tropical Australian rivers ANZECC/ARMCANZ

(2000) suggests a TN default trigger range of 0.2-0.3 mg/L. Only six river pools recorded TN values lower than 0.3 mg/L. Three of these were in the De Grey and three were in the Fortescue. In 12 De Grey River pools van Dam *et al.* (2005) recorded TN between 0.07 and 0.36 mg/L, so our measurements for the De Grey were generally higher. The average for Pilbara river pools sampled by Kay *et al.* (1999) was 0.52 mg/L.

Total filterable nitrogen (TFN) ranged from 0.11 to 0.68 mg/L (mean = 0.29) in De Grey pools, 0.28 to 2.5 mg/L (mean = 0.78) in Yule pools and 0.08 to 0.71 mg/L (mean = 0.32) in Fortescue pools. The two highest concentrations were in pool 10 (2.5 mg/L) and Jelliabidina Pool (pool 13, 0.76 mg/L), both on the Yule. The mean TFN recorded in the 50 pools sampled for the PBS was 0.83 mg/L, which is higher than in all but three of the pools sampled for the present project, but only seven PBS pools had TFN exceeding the maximum recorded in the present survey. These figures suggest that most pools sampled for this project had relatively low TFN in the context of the Pilbara, but that TFN in pool 10 was particularly high.

Total phosphorus (TP) concentrations ranged from 0.01-0.04 mg/L (mean = 0.013) in the De Grey, 0.01-0.49 mg/L (mean = 0.11) in the Yule and were at or below the detectable limit (0.01 mg/L) in the Fortescue. ANZECC/ARMCANZ (2000) suggest a TP trigger value for tropical lowland rivers of 0.01 mg/L. Of the 20 pools, one on the De Grey River (pool 4, Junction Pool) and four on the Yule (pools 9, 10, 11 & 13) were above this trigger value. Van Dam *et al.* (2005) recorded TP concentrations of <0.005 to 0.01 mg/L in the De Grey River while Kay *et al.* (1999) recorded an average of 0.015 mg/L across the region. This suggests that some total phosphorus concentrations in the Yule River are unusually high for the region.

Total filterable phosphorus (TFP) was below detectable limits at all but two De Grey pools (0.01 mg/L at Wardoomoondene Pool and Junction Pool) and one Fortescue pool (0.01 mg/L at Deep Reach) and undetectable to 0.05 mg/L in Yule River Pools (maximum of 0.05 at pool 10). The mean TFP recorded in the 50 pools sampled for the PBS was 0.03 mg/L, higher than in all but one of the pools sampled for the present project, but only seven PBS pools had TFP exceeding the maximum recorded in the present survey. As for TFN, these figures suggest that most pools sampled for this project had relatively low TFP but that TFP in pool 10 was particularly high.

Table 4. Water chemistry variables measured at one sampling location per pool.

		Pool									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Colour	**TCU**	9	9	10	18	8	7	10	19	8	49
Alkalinity	**mg/L**	180	220	135	150	255	200	225	225	105	230
Nitrogen (total)	**mg/L**	0.37	0.38	0.35	0.81	0.32	0.18	0.28	0.14	0.3	5.9
Nitrogen (total filterable)	**mg/L**	0.35	0.27	0.27	0.68	0.19	0.15	0.32	0.11	0.28	2.5
Phosphorus (total)	**mg/L**	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.02	0.49
Phosphorus (total filterable)	**mg/L**	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.05
Total chlorophyll	**mg/L**	0.012	0.004	0.007	0.013	0.004	0.003	0.004	<0.002	0.012	0.22
Na^+	**mg/L**	167	249	79.8	44	274	188	367	278	38.9	89.4
K^+	**mg/L**	4.1	6.3	3.9	4.2	6.2	5.2	5.8	4.4	2	48.4
Mg^{2+}	**mg/L**	25.5	37.9	17.5	14.2	40.1	26.9	70.1	48.6	4.4	12.9
Cl^-	**mg/L**	242	368	144	45	395	244	602	443	28	112
SO_4^{2-}	**mg/L**	51.7	77.1	21.5	10.6	87.3	60.6	127	63.6	5.3	14.6
HCO_3^-	**mg/L**	171	183	165	183	311	244	275	189	128	281
CO_3^{2-}	**mg/L**	24	42	<1	<1	<1	<1	<1	42	<1	<1
SiO_2	**mg/L**	13	4.6	9.9	15	16	14	20	38	21	21
Total dissolved solids	**mg/L**	580	880	370	230	940	670	1300	1000	160	480

		Pool									
		11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Colour	**TCU**	9	15	36	32	37	3	9	5	3	9
Alkalinity	**mg/L**	160	175	730	190	240	140	80	150	310	350
Nitrogen (total)	**mg/L**	0.84	0.69	0.83	0.41	0.37	0.79	0.28	0.25	0.57	0.17
Nitrogen (total filterable)	**mg/L**	0.28	0.53	0.76	0.36	0.19	0.71	0.26	0.16	0.55	0.08
Phosphorus (total)	**mg/L**	0.06	0.01	0.05	0.01	0.01	0.01	<0.01	0.01	0.01	0.01
Phosphorus (total filterable)	**mg/L**	0.02	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Total chlorophyll	**mg/L**	0.056	0.011	0.057	0.009	0.012	0.005	0.003	<0.002	<0.002	0
Na^+	**mg/L**	53.9	76.4	468	89.8	87.3	89.6	147	136	232	228
K^+	**mg/L**	4.6	4.8	6.9	3.9	9	8.6	11.1	9.4	23.3	22.6
Mg^{2+}	**mg/L**	9.1	14.3	68.3	15	44.1	40.7	54.8	53	90.7	93.8
Cl^-	**mg/L**	44	60	481	79	217	247	377	341	456	447
SO_4^{2-}	**mg/L**	4.4	3.6	32.2	2.3	56	76.4	101	87.2	222	204
HCO_3^-	**mg/L**	195	140	817	171	293	171	37	183	378	427
CO_3^{2-}	**mg/L**	<1	36	36	30	<1	<1	30	<1	<1	<1
SiO_2	**mg/L**	25	6.2	37	4.5	28	23	15	20	65	56
Total dissolved solids	**mg/L**	240	270	1500	310	690	710	880	900	1400	1400

Table 5. Environmental data measured for each sampling location. * = samples combined in field for pools where invertebrates not collected, so that figure applies to whole pool. # = missing data. Sediment data provided in Table 6.

Pool	Sample	Submerged macrophyte cover (%)	Submerged macrophyte biomass (g/m^2) *	Emergent macrophyte cover (%)	Depth of invertebrate sample (cm)	pH	Water temperature (ºC)	Turbidity (NTU)
1	1	95	253.33	0	65	8.98	29.4	0
1	2	25	66.67	0	65	9	28.5	1.6
1	3	20	53.33	0	94	9.04	28.4	0.8
2	1	100		0	73	8.85	27.1	6
2	2	90	266.67	0	120	8.81	27.7	1
2	3	50		0	34	8.85	28.7	3
3	1	50	133.33	0	61	8.03	29.3	9.4
3	2	100	266.67	0	54	8.47	29.1	5.1
3	3	0	0.00	0	54	7.99	29.4	10.6
4	1	0		0	#	7.6	29.1	51
4	2	0	0.00	0	#	7.6	29.1	86.8
4	3	100		0	#	7.84	29.7	86.8
5	1	0	0.00	0	50	8.59	30.1	11.8
5	2	70	186.67	0	31	8.47	30.9	19.2
5	3	0	0.00	0	91	8.54	30.1	11.8
6	1	100		0	121	8.61	29.2	1.1
6	2	0	266.67	0	120	8.48	28	3.2
6	3	0		0	33	8.45	27.9	3.4
7	1	90	240.00	0	105	8.41	27	4.3
7	2	50	133.33	0	78	8.52	27.6	2.9
7	3	10	26.67	0	29	7.3	28	7.3
8	1	0		0	74	8.67	28	1.2
8	2	100	0.00	0	86	8.49	28.4	0
8	3	20		80	54	8.3	27.7	0
9	1	80	213.33	0	41	7.9	27.9	4.5
9	2	80	213.33	0	40	8.69	27.6	19.6
9	3	5	13.33	0	76	8.93	28	14.8
10	1	#		#	#	#	#	#
10	2	#	#	#	#	#	#	#
10	3	#		#	#	#	#	#
11	1	0	0.00	0	25	8.78	32.1	22
11	2	0	0.00	0	120	8.76	31.6	20.2
11	3	60	160.00	0	15	8.79	32.4	22.5
12	1	75		0	33	9.15	30.9	1.9
12	2	75	200.00	0	33	9.15	30.9	1.9
12	3	75		0	33	9.15	30.9	1.9
13	1	95	253.33	0	40	8.48	30.8	7.5
13	2	80	213.33	50	55	8.54	30.1	8.1
13	3	100	266.67	0	40	8.48	30.8	7.5
14	1	70		70	49	8.82	30.9	0
14	2	100	186.67	0	40	8.71	30.4	0
14	3	100		0	83	8.71	30.4	0
15	1	0	0.00	0	20	7.39	28.3	22
15	2	0	0.00	0	125	7.41	28.2	22.1
15	3	0	0.00	0	20	7.39	28.3	22
16	1	5		0	20	7.99	31.4	0
16	2	5	13.33	0	60	7.89	32.1	0
16	3	60		0	65	7.94	32.1	0
17	1	100	266.67	0	50	8.2	30.1	0.4
17	2	75	200.00	0	50	7.96	31.8	0
17	3	5	13.33	0	98	7.96	30.8	0
18	1	90		0	40	8.39	31.1	0.8
18	2	20	240.00	60	75	8.18	30.1	0.8
18	3	10		0	65	7.83	30.4	0
19	1	10	26.67	90	120	7.53	28.6	1.5
19	2	10	26.67	90	150	7.48	28.7	2.5
19	3	0	0.00	90	142	7.75	28.9	0
20	1	0		100	130	7.8	32	0
20	2	0	0.00	100	>150	7.78	30.4	0
20	3	0		100	>150	7.8	31	0

Chlorophyll tended to be highest in river pools along the Yule River, where values ranged from 0.0085 to 0.217 mg/L (mean = 0.061). Chlorophyll in the De Grey River pools ranged from < 0.002 (below detectable limits) to 0.0065 mg/L (mean = 0.0046) and on the Fortescue chlorophyll ranged from < 0.002 to 0.011 mg/L (mean = 0.0043). Total chlorophyll in the PBS ranged from below detectable limits to 0.201 mg/L. The mean value of 0.007 mg/L recorded during the PBS is much lower than the average recorded during the present survey (0.025) but none of the 50 PBS pools had chlorophyll higher than that recorded at pool 10 of the present survey (0.217 mg/L). Default trigger values suggested by ANZECC/ARMCANZ (2000) for chlorophyll in tropical lowland rivers is 0.005 mg/L. Chlorophyll-a was higher than this benchmark for all of the pools in the Yule River, three pools on the De Grey River and one pool on the Fortescue River.

The higher nutrient and chlorophyll concentrations at some pools, especially along the Yule River, probably reflect their very heavy use by cattle prior to sampling. These pools and surrounds had many faeces, heavy pugging and, in some cases, obvious algal blooms.

Sediments

Most pools were dominated by fine sediments, primarily in the sand and gravel fractions (normally > 40% and 15% respectively) (Table 6). The De Grey and Yule Rivers consistently had a high proportion of fine sediments (mostly sand and gravel) compared to some of the Fortescue pools. Yule River pools tended to have a greater proportion of gravel (11-36%) than De Grey pools (8-26%) whereas the De Grey pools were sandier. Some pools had particularly fine sediments, with Mungajee Pool (pool 15) on the Fortescue River having nearly 25% clay and silt and Livistonia Pool in Millstream National Park having 31% clay and silt but also 32% gravel (along the vertical banks). Three of the lower Fortescue River pools (Tarda, Stewart and Bilanoo Pools) had particularly coarse sediments. Sediments of Tarda Pool (pool 18) were dominated by cobble and pebble (53%) with significant bedrock, boulder and gravel. Stewart Pool (pool 16) had mostly cobble and pebble (78%) with some bedrock and boulders (17%) and Bilanoo Pool (Pool 17) had mostly cobble and pebble (30%) and gravel (68%). Deep Reach and Livistonia Pool (pool 19 and 20) would have had high organic content in sediments but this was not measured.

Macrophytes

All pools except for the turbid Mungajee Pool (pool 15) and Livistonia Pool at Millstream (pool 20) had some submerged macrophytes (Table 5). The latter would have had macrophytes on the deep bed but none were present where invertebrate sampling with a sweep net would have been possible. Most pools had areas of macrophyte and areas of bare sediment, though the beds of some pools were entirely covered in macrophyte, albeit sparse in patches. Estimated cover of submerged macrophytes within each sampling location varied from zero to complete (100%, no bare sediment visible). Where macrophytes were present

dry biomass ranged from 12 to 358 g/m^2, the latter from sample location 1 in Coongeenariner Pool on the De Grey (see Plate 1). Few pools had emergent macrophytes. Deep Reach and Livistonia Pool in Millstream National Park had dense emergent macrophytes along their shorelines but only four other pools had any emergent macrophytes (and then only in small stands).

Table 6. Sediment particle size composition.

Catchment	Pool	% Bedrock+boulder	% Cobble+pebble	% Gravel	% Sand	% Clay	% Silt
De Grey	1	0.0	6.7	25.9	63.3	1.7	2.4
De Grey	2	0.0	1.7	14.5	81.4	0.8	1.7
De Grey	3	0.0	0.0	17.1	58.9	9.9	14.1
De Grey	4	0.0	1.7	14.8	77.6	2.1	3.8
De Grey	5	0.0	3.3	6.8	85.0	1.8	3.1
De Grey	6	0.0	0.0	16.4	80.3	1.3	2.1
De Grey	7	0.0	0.3	18.1	79.1	0.8	1.6
De Grey	8	3.3	0.0	8.8	83.5	1.8	2.6
Yule	9	0.0	0.0	24.3	73.8	0.8	1.1
Yule	10	0.0	0.0	10.9	86.0	1.8	1.3
Yule	11	0.0	0.0	20.6	76.6	1.6	1.2
Yule	12	0.0	1.0	30.7	65.6	1.4	1.4
Yule	13	6.7	0.0	36.0	45.3	8.0	4.0
Yule	14	20.0	0.0	26.1	48.5	2.7	2.7
Fortescue	15	0.0	0.0	26.7	48.7	10.6	13.9
Fortescue	16	16.7	78.3	4.5	0.4	0.0	0.0
Fortescue	17	0.0	30.0	68.2	1.1	0.3	0.4
Fortescue	18	25.0	53.3	19.8	1.5	0.1	0.2
Fortescue	19	0.0	0.0	62.9	25.2	4.8	7.0
Fortescue	20	0.0	0.0	32.2	36.6	11.9	19.3

Multivariate analyses of pools based on their environmental variables.

An nMDS ordination of 19 of the river pools (pool 10 excluded due to missing data) based on their environmental characteristics (without the pool inundation extent data) is shown in Figure 3. This shows that the pools from different catchments largely separated from each other; except that pools 19 and 20 (Deep Reach and Livistonia Pool on the Fortescue River) separated from other pools and pool 4 (Junction Pool on the De Grey) was dissimilar to other De Grey pools. An anosim analysis suggested that there were strong and significant differences in environmental characteristics between catchments ($R = 0.454$, $p<0.001$). A similar result was obtained when the remotely sensed inundation variables were included (and pools 15 and 16 excluded), but with even more significant separation of pools by catchment ($R = 0.655$, $p<0.001$), probably driven by smaller pool size and lower permanency in the Yule River compared to the De Grey and Fortescue.

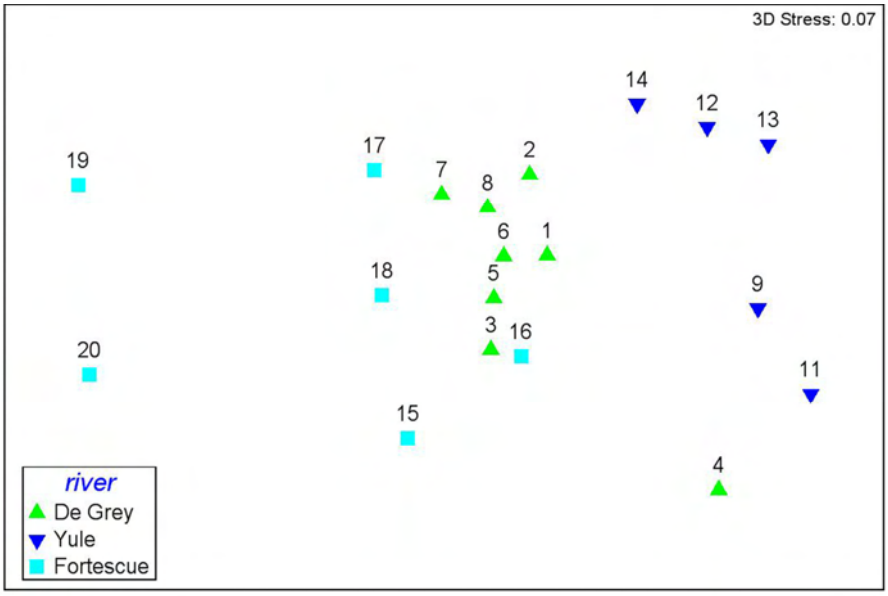


Figure 3. Axes 1 versus 3 of an nMDS ordination of river pools according to their environmental characteristics.

Aquatic invertebrate diversity and composition

Diversity

A total of 253 species of macroinvertebrate from 57 families (or subfamilies for chironomid Diptera) were collected from the 10 sampled pools (Appendix 2). This is 25% the aquatic invertebrate fauna known from the Pilbara, 41% of the known macroinvertebrates and 49% of the macroinvertebrates known from clear river pools (as mostly sampled for this project). Richness in individual samples ranged from 15 to 79 (median 30) and total richness within a pool (i.e. from 3 samples) ranged from 53 to 105 (median 70). This is a narrower range than recorded in clear fresh water pools during the PBS (20 to 164) and the median and 75th percentiles are slightly lower than for the PBS (Figure 4). This level of difference is almost certainly due to the PBS samples each consisting of a 50 m benthic sample and a 50 m plankton sample, whereas for the present project the samples were 3 x 15 m benthic samples only. Nonetheless, only eleven PBS river pool samples had higher macroinvertebrate richness than the maximum recorded during the present survey.

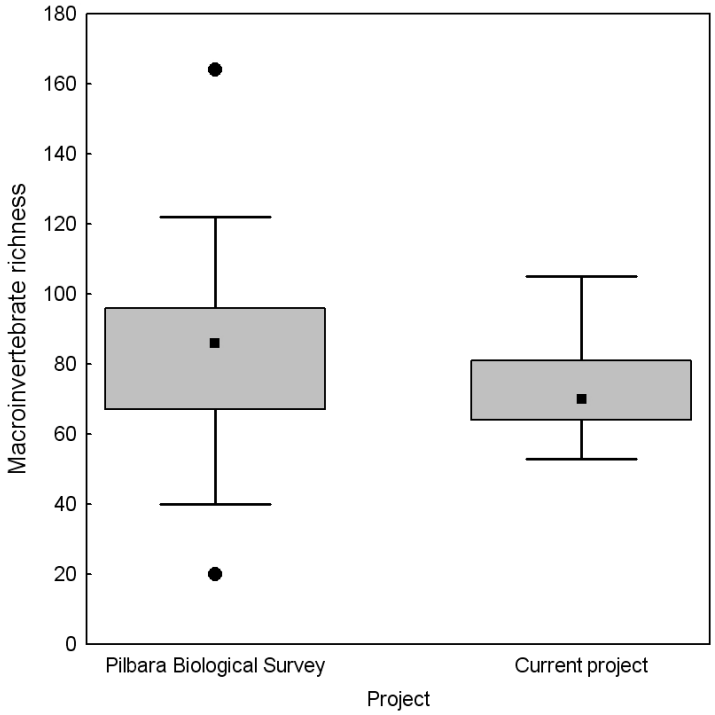


Figure 4. Box blots of macroinvertebrate richness for pools sampled for the Pilbara Biological Survey and for the present project, showing median, 25th and 75th percentiles, one standard deviation and values outside of one standard deviation.

Comparison of richness and composition between rivers and pools

Figure 5 shows total species richness and composition at the major group level for each of the three rivers. The De Grey, Yule and Fortescue rivers had 133, 151 and 156 species respectively. Notably, the De Grey River had the lowest number of species despite invertebrates being sampled at four pools, rather than three as in the Yule and Fortescue. All three rivers had similar invertebrate composition at this level of taxonomic discrimination, although the De Grey River contained comparatively depauperate assemblages of hemipterans and water mites. Figure 6, Figure 7 and Figure 8 provide similar comparisons for pools within each catchment.

Richness was fairly consistent across pools in the De Grey (Figure 6) except for slightly lower richness in Namagoorie Pool (pool 5). Composition was also fairly consistent, with the exception of high coleopteran richness and virtual lack of water mites in Muccangarra Pool (pool 3) and greater number of dipterans in Coongeenariner Pool (pool 7).

In the Yule River, Jelliabidina Pool (pool 13) had highest total richness and higher richness of most groups except for water mites (Figure 7). Li Lin Pool (pool 9), which was a very small pool when sampled and highly disturbed by cattle, had lowest richness, although it still had more species than any pool from the De Grey River.

Fortescue River pools were particularly variable in their invertebrate richness and composition (Figure 8). Deep Reach at Millstream (pool 19) contained the highest species richness of all pools sampled in the project. Coleopterans, dipterans and water mites accounted for the most of the higher species richness in that pool. Pool 15 (the mildly turbid Mungajee Pool on an anabranch of the Fortescue) contained the least number of species (53) but had very simple habitat: clay sediments and no macrophytes.

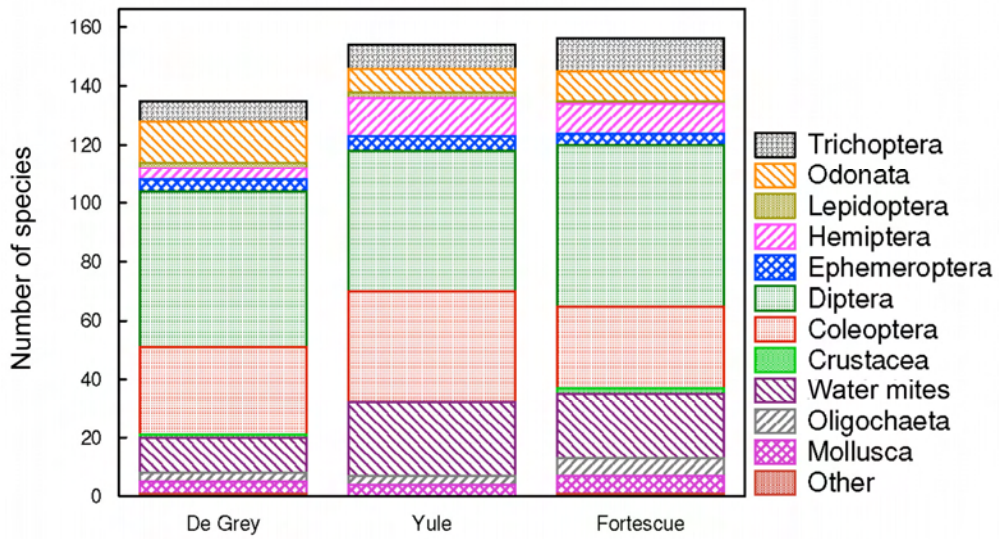


Figure 5. Total species richness of each catchment and composition by major group.

The proportion of species recorded in only one of the three or four pools within a river was 45% for the De Grey River, 55% for the Yule River and 64% for the Fortescue, although the latter is high mostly because of the high number of species unique to Deep Reach, which was a very different pool to those sampled near the coast. This means that species composition was very different between the pools within a catchment. None of these rarer species would be genuinely restricted to the particular pools in which they were collected, but the high proportions involved demonstrate how heterogeneous the fauna is on any one sampling occasion. Pinder *et al.* (in review) found only very weak evidence of seasonality within the region's river pool community composition. This is not to say that communities did not change between seasonal sampling events in individual wetlands – merely that change was not consistent across pools. In fact, on average, only 30% of a river pool's fauna were present in both occasions on which a pool was sampled during the PBS. Thus, over time, a pool (or a series of pools) will be inhabited by a much larger range of species than would be recorded on a single sampling occasion, subject to limits imposed by habitat availability. Observed differences in composition between pools in this project should be considered in this context.

Almost all of the species recorded during this project have been recorded in the Pilbara before, but 16 have not (Table 7). These were water mites, dipterans or beetles and, while they were evenly distributed across the three rivers, most were collected from only one pool. It should be noted that the identification of some of these is uncertain but is the best that can be achieved with current taxonomic knowledge.

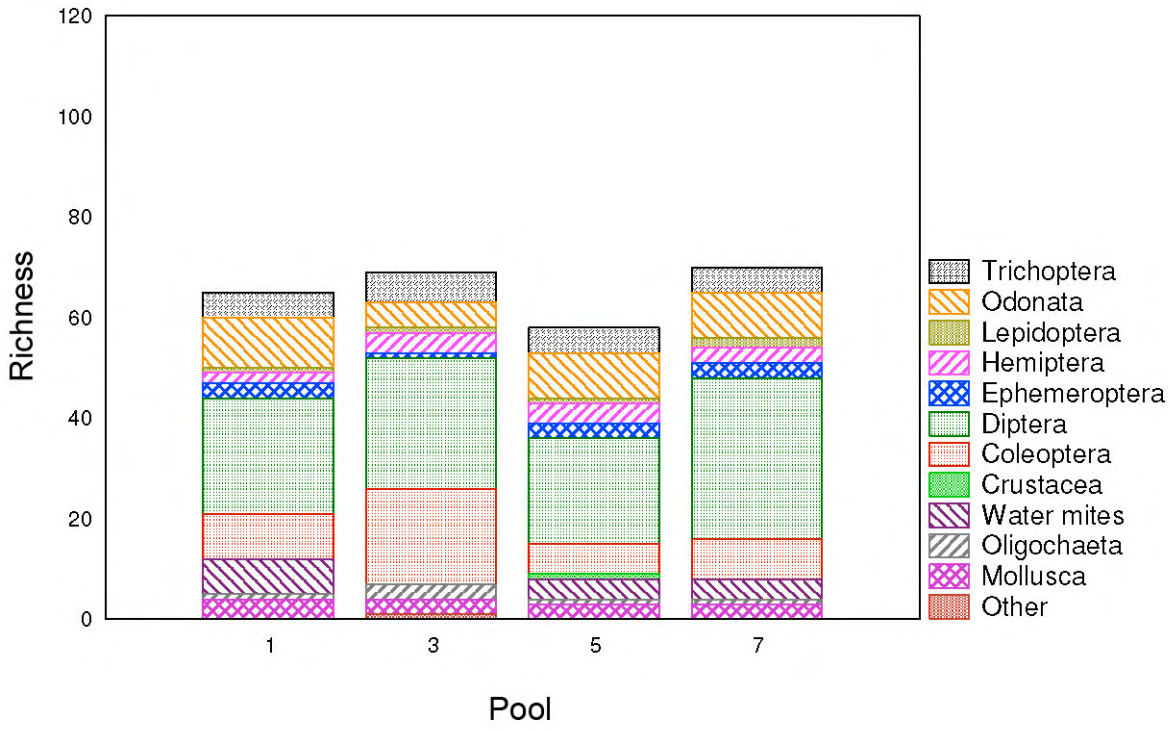


Figure 6. Richness and species composition in pools on the De Grey River.

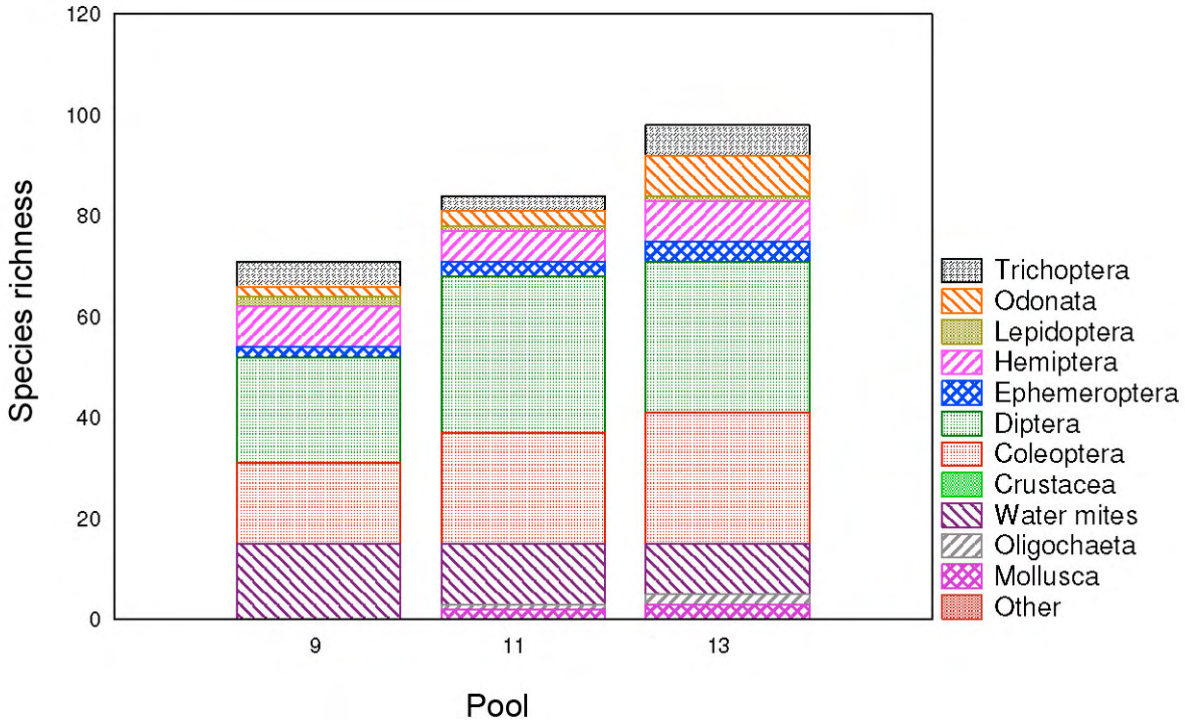


Figure 7. Richness and species composition in pools on the Yule River

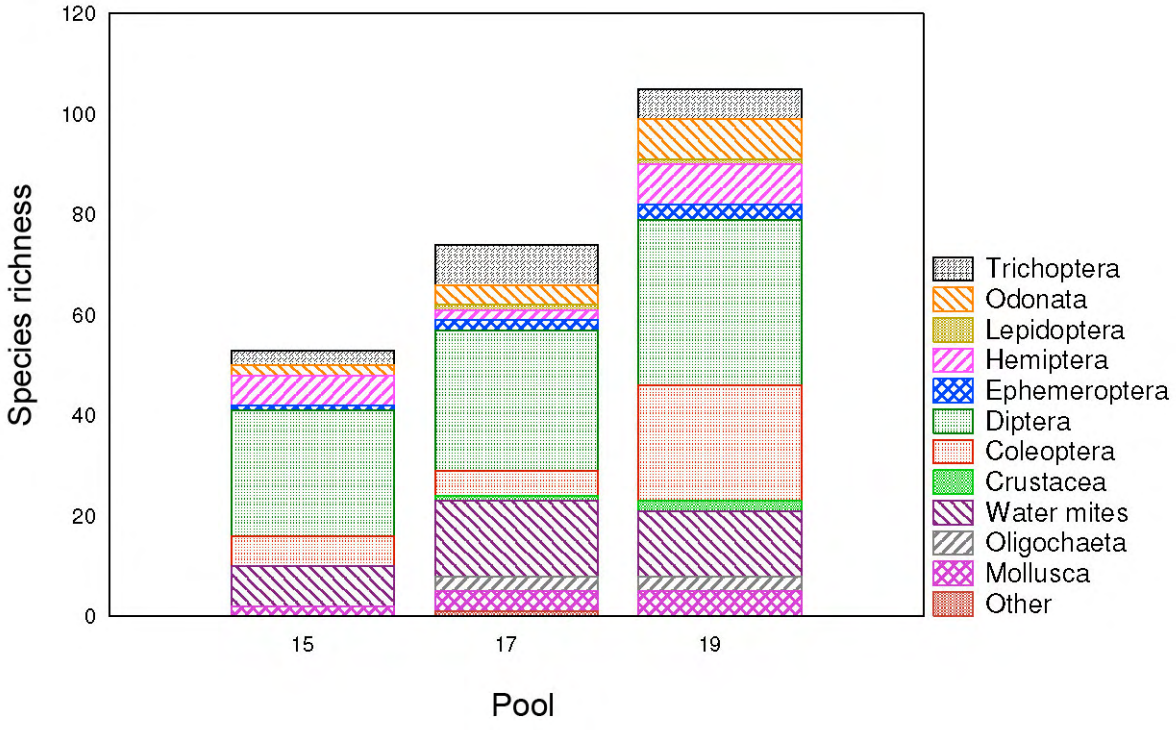


Figure 8. Richness and species composition in pools on the Fortescue River.

Table 7. Aquatic invertebrates collected during this survey but not collected previously in the Pilbara.

Species	Group	Pools	Comments
Arrenurus sp. 22	Acarina	9	
Austraturus sp. P3	Acarina	1	
Koenikea branacha	Acarina	19	northern Australian
Koenikea distans	Acarina	13	northern Australian
Koenikea setosa	Acarina	9, 13 and 15	northern Australian
Unionicola nr *alpa*	Acarina	11, 17 and 19	
Unionicola nr *vidrinei*	Acarina	1 and 17	
Unionicola sp P1	Acarina	5	
Hydrochus sp. P5	Coleoptera	3	
Ochthebius sp. P5	Coleoptera	19	
Paranacaena sp. P1	Coleoptera	3	
Forcypomyia sp. P5	Diptera	19	
Muscidae sp. N	Diptera	5	
Polypedilum griseoguttatum	Diptera	5	northern Australian
Skusella nr "V12 ex-WA"	Diptera	5, 7, 9 and 11	
Stilobezzia sp P2	Diptera	19	

Multivariate analysis of samples by invertebrate composition

A cluster analysis of the 30 samples according to the similarity of their invertebrate communities resulted in five main groups (Figure 9). These all separated from each other at a low level of similarity (Bray-Curtis similarity <30) indicating that this grouping reflected strong differences between pools. In general, the grouping structure reflected differences between the three catchments. One sample from the De Grey River clustered in group 3 with pools 15 and 17 of the Fortescue River but as a separate single pool subgroup. Also, two Yule River samples and a De Grey sample clustered apart from all other samples as group 1.

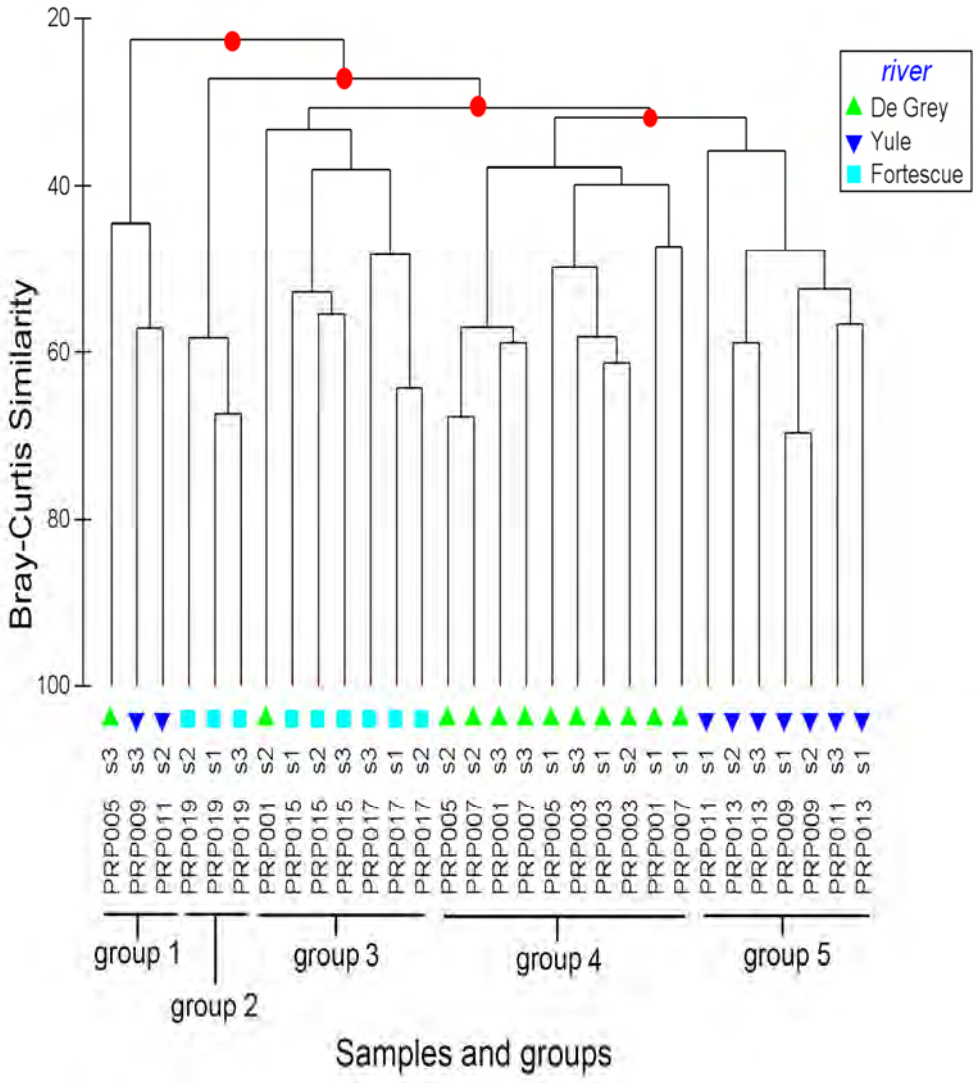


Figure 9. Dendrogram from cluster analysis of all 30 aquatic invertebrate samples. Red dots indicate nodes at which sub-grouping was recognised.

Figure 10 shows all three axis combinations from 3D ordinations of the 30 invertebrate samples according to their community composition and of the 30 sampling locations according to their environmental characteristics. Sampling locations tended to cluster together according to catchment for both the invertebrate and environmental data, although this was more pronounced for the invertebrate communities. The spread of samples within a pool is much greater in the invertebrate ordination than in the ordination of the abiotic data because the same water chemistry data was used for each of the three sampling locations within a pool. Jelliabidina Pool (pool 13), which grouped apart in the environmental ordination, had particularly high nutrient concentrations, high chlorophyll concentration and higher colour than most pools. It also had the highest concentration of total dissolved solids of all pools and was the only pool to have any

bedrock (albeit a very small proportion of the substrate). Anosim analyses indicated strong and significant differences in invertebrate community composition and environmental characteristics between all three rivers (global R = 0.48 and 0.68 respectively, $p<0.001$).

An equivalent analysis was undertaken to examine patterns at the pool level by combining invertebrates up to the pool level and averaging environmental variables within a pool. Data from all three samples per pool were combined for a whole pool analysis. The resulting ordinations (Figure 11) show clear separation of catchments according to their invertebrate communities and, to a lesser extent, by their environmental characteristics. In the latter, the De Grey and Yule river pools separated from each other, but the Fortescue pools were very variable so did not form a distinct group of pools. Anosim analyses suggested very strong and significant differences between catchments for invertebrates ($R = 0.992$, $p < 0.001$) and lesser but still significant differences for environmental data ($R = 0.374$, $p < 0.01$).

These cluster and ordination analyses suggest that there are significant differences in both abiotic conditions and invertebrate communities between the three catchments. Results from the PBS suggested little differentiation between river pool faunas of different drainage basins, but differences in macroinvertebrates may have been masked by the inclusion of microinvertebrates. Also the PBS included very few Roebourne Plains river pools, so perhaps the higher order pools are more differentiated by catchment than are lower order pools. Differences between the catchments imply that for invertebrate faunas the rivers are not surrogates for one another on the Roebourne Plains. This also implies that protection of pools in one river will not protect the communities present in another river. However, this should be viewed with caution because 1) only three or four pools were sampled for invertebrates out of numerous other pools present along each river and 2) the rivers had different recent hydrological history, which may have made the sampled communities appear more different at that point in time than they are in the long term.

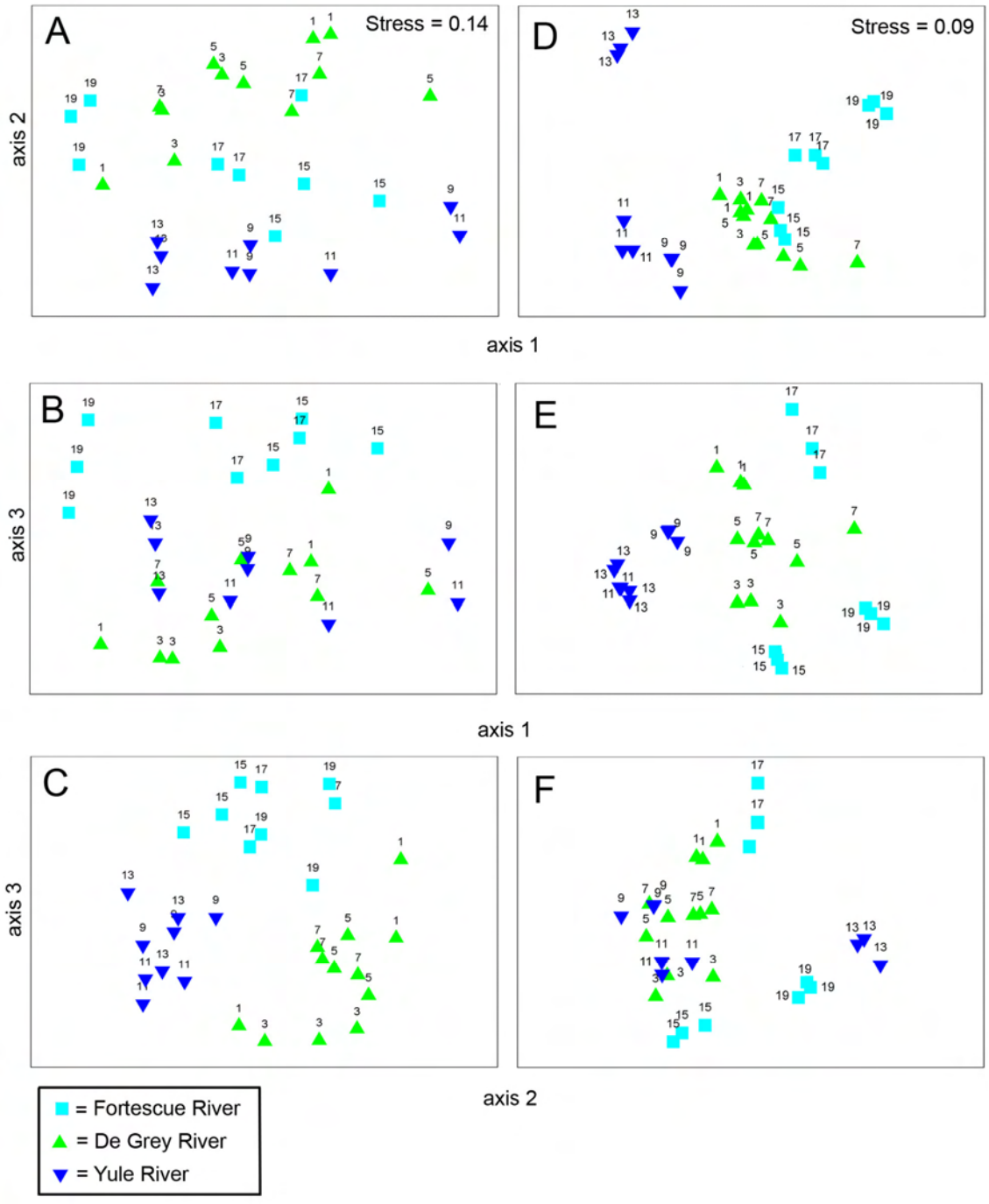


Figure 10. All three axis combinations for 3D nMDS ordinations of samples according to their invertebrate community composition (A-C) and the environmental characteristics of the sampling locations (D-F). Numbers are pools and colours and symbols represented catchment.

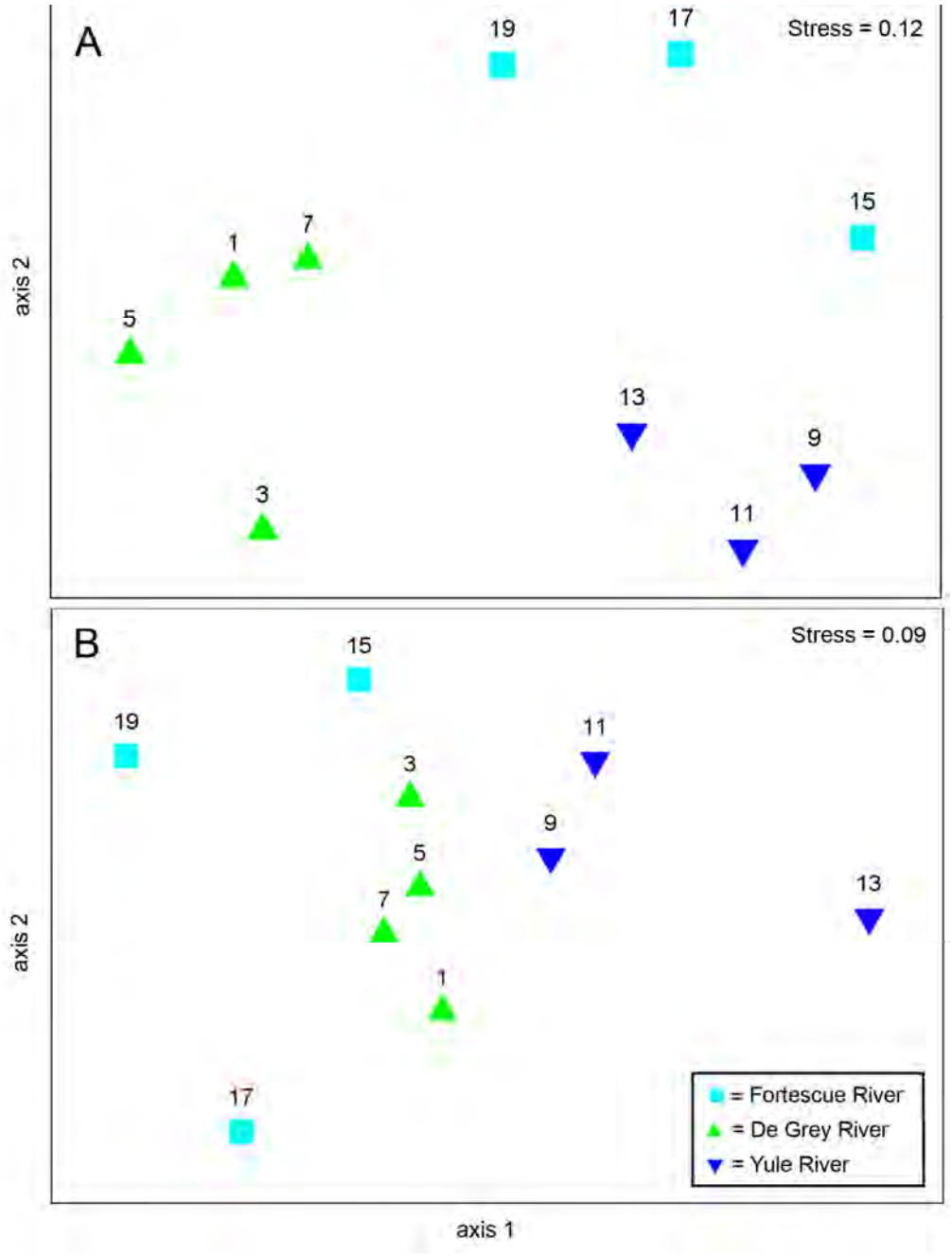


Figure 11. 2D nMDS ordinations of river pools according to their invertebrate community composition (A) and their environmental characteristics (B). Numbers are pools and colours and symbols represented catchment.

Relative conservation values of coastal river pools

If communities in the higher order reaches of rivers on the coastal plain have invertebrate communities that are different to those occurring in more inland pools then they have unique conservation values that require consideration when planning water resource developments. To investigate this proposition, communities of pools in the coastal reaches of Pilbara rivers were compared to those in pools of more inland reaches.

In an nMDS ordination turbid and clear river pools were separated because they are known to have different faunas and saline pools were excluded. Seventeen samples from 13 coastal pools (nine for this project and four sampled during the PBS) were compared to 71 samples from 36 inland pools (70 from the PBS plus Deep Reach sampled for this project). Figure 12 indicates that turbid and clear river pools have very different faunas irrespective of their location and that coastal and inland turbid pools did not have different faunas. The clear coastal pools were located around part of the periphery of the large group of clear inland pools. This suggests that invertebrate communities from coastal pools were more heterogeneous than the inland pools (as also suggested by their separation by catchment, above). An anosim analysis indicated that turbid and clear river pools had significantly different community composition (R = 0.46 to 0.62 for the four combinations of inland/coastal – turbid/clear, $p < 0.001$), but that coastal and inland river pools (whether clear or turbid) did not ($p > 0.1$).

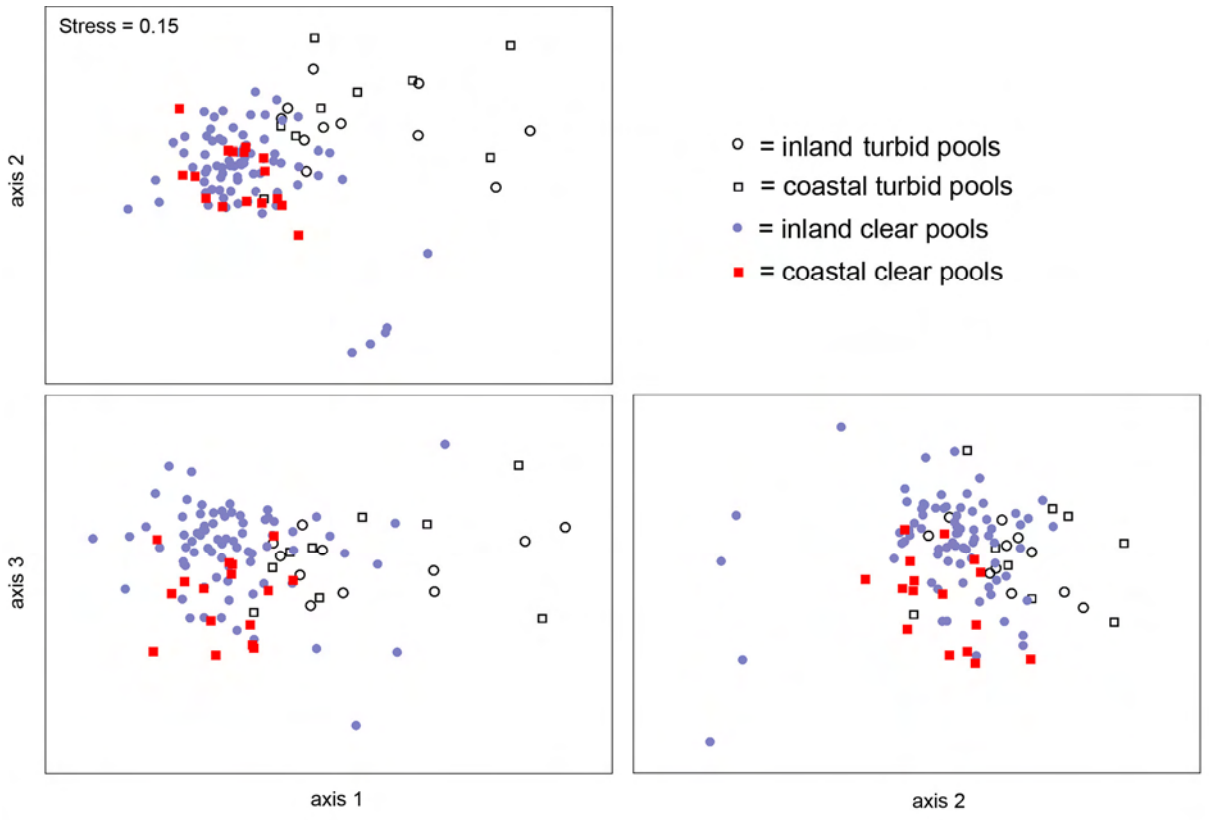


Figure 12. Results of a 3D nMDS ordination of inland and coastal river pools.

Relationships between inland and coastal pools are easier to visualise in a cluster analysis dendrogram (Figure 14). In this analysis the coastal river pools sampled for the present project tended to separate out by catchment as small subgroups. However, these were set within larger groups composed of both inland and coastal pools from various catchments, again suggesting greater differentiation of coastal pools by catchment

than is seen in more inland pools. Turbid and clear pools also tended to form separate groups, as in the ordination.

There is no suggestion from these multivariate analyses that coastal pools on the Roebourne Plains had substantially different invertebrate communities to those located further inland. However, we also looked at the combined data matrix to see if there were individual species that were more common in coastal pools than in inland pools. Species that only occurred once in the combined dataset were excluded from this analysis because they could not have occurred in both inland and coastal pools in this dataset. Thirty-six taxa that occurred at least three times as frequently in the 17 samples from coastal pools as they did in the 71 samples from inland pools are listed in Appendix 3. Most of these species were also recorded in Pilbara wetlands other than river pools (springs, claypans etc.), but rarely as frequently as in coastal river pools. Five species have been collected only in coastal river pools in the Pilbara but at least two of these occur across northern Australia.

The number of these species per pool was variable, with pool 11 (Highway Pool on the Yule River) having highest representation, despite its very small and highly degraded nature (Figure 13).

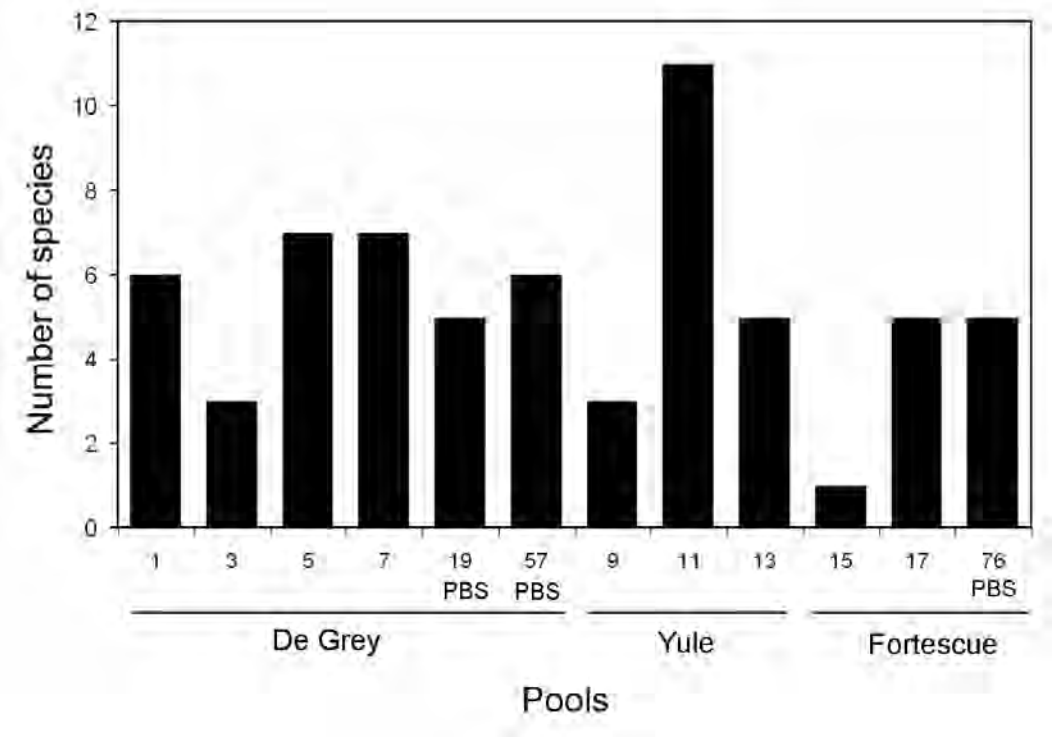


Figure 13. Number of species occurring more frequently in coastal river pools than in more inland pools for each of the coastal pools. 'PBS' indicates pools sampled during the Pilbara Biological Survey.

The singleton species that were excluded from this analysis were most of those in Table 7 that were not collected at all during the PBS, plus palaemonid prawns. The prawns were first collected in the Pilbara by van Dam *et al.* (2005) from Homestead Pool on De Grey River and were collected by us from the nearby

Namagoorie Pool. These are probably restricted to the De Grey River within the Pilbara, but are most likely one of the five species listed from the Kimberley by Short (2004).

Most of those species that have been collected more frequently in the coastal river pools in the Pilbara have widespread distributions, at least across northern Australia, although a few may be endemic to the region. The latter include the water mite *Gretacarus bifalcisetus* and the gelastocorid hemipteran *Nerthra* n. sp. (neither of which are restricted to coastal pools), but possibly also some of the informally identified dipterans and water mites. Some of the singleton species in Table 7 may also be Pilbara endemics and may be more common in (or even restricted to) coastal river pools. Unfortunately, limited species level identifications in northern Australia and taxonomic impediments prevent a more rigorous analysis of their distributions.

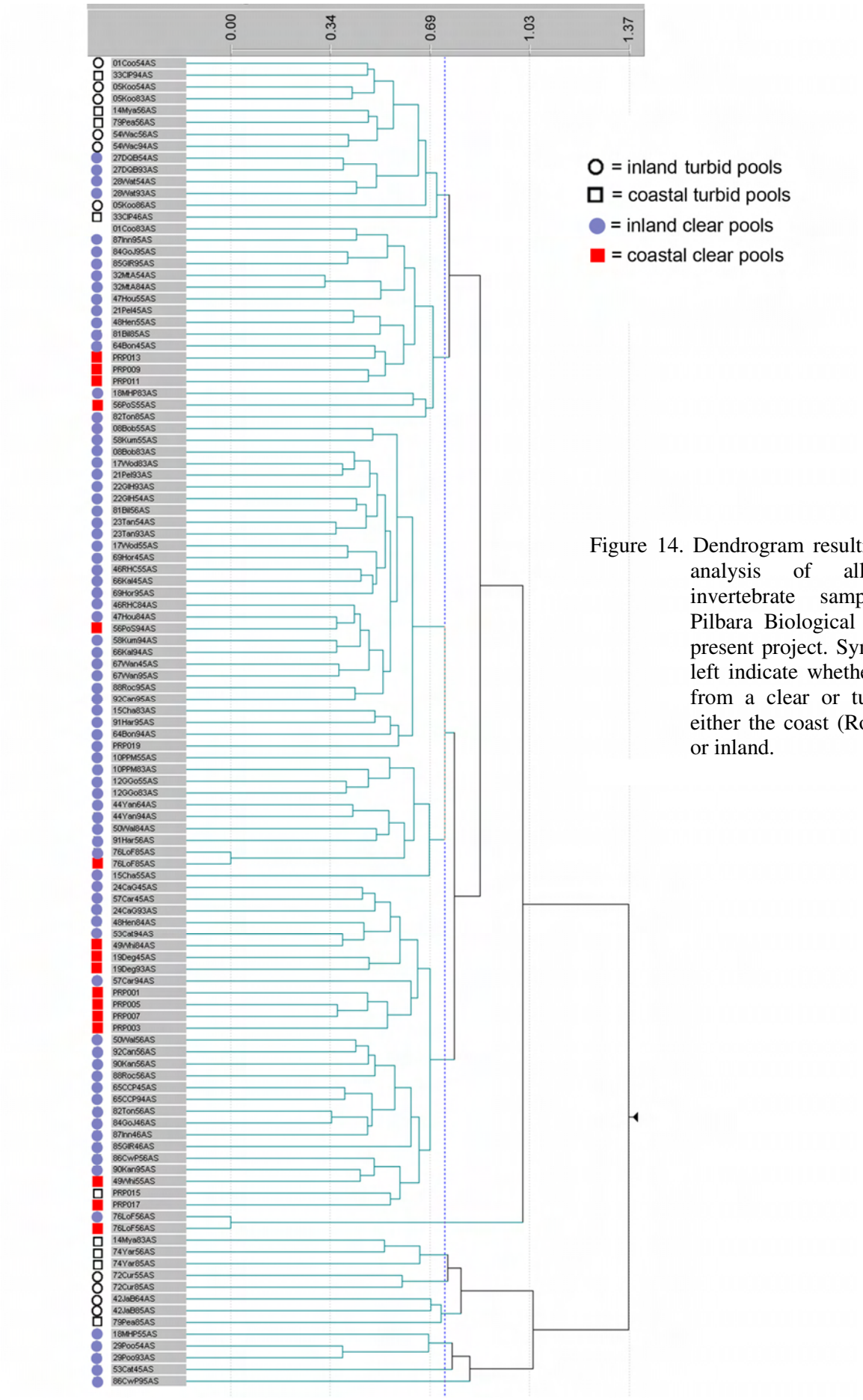


Figure 14. Dendrogram resulting from cluster analysis of all river pool invertebrate samples from the Pilbara Biological Survey and the present project. Symbols on the far left indicate whether a sample was from a clear or turbid pool from either the coast (Roebourne Plains) or inland.

Associations between environmental variables and richness and composition of aquatic invertebrate communities

Richness and environmental variables

Figure 15 to Figure 18 show univariate plots of species richness in the 30 invertebrate samples versus environmental variables. Also, habitat variables (macrophytes, sediment fractions, and sample depth) were divided into three equal percentile categories and differences in species richness between categories contrasted using analysis of variance (Table 8). Few of the measured environmental variables were strongly associated with species richness in samples.

Macrophytes and organic detritus. Species richness increased with increasing submerged macrophyte biomass (to about 100g/m²) and with increasing submerged macrophyte cover (Figure 15). Richness was also high where there were emergent macrophytes, but too few wetlands had this habitat to suggest that is a general relationship. Emergent macrophytes are important as sites of emergence for dragonfly nymphs but generally do not support as many invertebrates as submerged macrophytes. Presence of macrophytes has frequently been associated with higher invertebrate richness compared to bare substrate and the type, density and diversity of macrophytes is also important (Ali *et al.* 2007; Boulton and Lloyd 1991; Collier *et al.* 1999; Cyr and Downing 1988; Gregg and Rose 1985; Schramm H.L. and Jirka K.J. 1989; Thomaz *et al.* 2008). Aquatic invertebrate richness was also positively associated with increasing cover and/or biomass of macrophytes in the Pilbara Biological survey data. Two of the PBS assemblages most closely associated with river pools increased in richness with submerged macrophyte biomass up to about 80 g/m^2, which is similar to the threshold noted above. There were also positive relationships between richness and emergent macrophytes, though most notably for assemblages preferring springs rather than river pools. Macrophytes provide physical habitat, food (especially periphytic algae growing on macrophytes) and protection from predators for invertebrates.

Depth. The apparently bimodal relationship of richness with depth in Figure 15 is probably artefactual: the high richness (79 taxa) in the one of the samples from Deep Reach at Millstream makes it look like there is a rise in richness after 100 cm. There was no overall tendency for richness to increase with depth at the sampling location, although the deepest sections of some river pools were not sampled. Van Dam *et al*. (2005) recorded average macroinvertebrate family richness values of 30, 27.8 and 25.8 in samples taken from the shallower parts of De Grey River pools classed as deep (> 3 m), intermediate (1 – 3 m) and shallow (< 1 m) respectively. They concluded that there was a difference in richness between deep and shallow pools but any difference was small (see their Fig. 15). They suggested that the reduced richness in shallow pools might be associated with increased cattle disturbance in shallow pools rather than depth (and presumably longevity) *per se*. Nonetheless, severity of cattle impact is at least partly an indirect effect of shallow depth and is a consideration in determining ecological water requirements. Our measured depth values are the depths at which invertebrates were collected rather than the maximum depth of the pools. For most pools one of the 3 samples was taken at about the maximum depth, but for a few pools maximum depth would have

been greater than we could have sampled with a sweep net. Figure 19 and Figure 20 are attempts to allocate the 10 pools sampled for invertebrates in this project into the same maximum depth classes as were used by van Dam *et al.* (2005), based on measured or likely maximum depths when sampled. Only one pool (pool 9, Li Lin Pool) had a maximum depth < 1 m and only Homestead Pool and Muccangarra Pool (pools 1 and 3 on the De Grey) and Deep Reach (pool 19 on the Fortescue) are likely to have had maximum depths > 3 m. Figure 19 shows richness summed for the 3 samples per pool whereas Figure 20 shows species and family richness per 15 metre sweep net sample, so the family richness is roughly equivalent to the richness per 10 metre sample collected by van Dam *et al.* (2005). No relationship between maximum depth and species or family richness is evident in either of these figures. In Figure 20 the samples from deep pools appear to have higher average richness than those in the shallow Jelliabidina Pool, but this is due to very high richness in pool 19 (Deep Reach). This pool is of a very different nature to all remaining pools and high richness may be due to the particular habitats present (especially the dense emergent macrophytes). It is interesting to note that pool 13 (Jelliabidina Pool), which was nutrient enriched and heavily disturbed by cattle, has the second highest species and family richness, in contrast to the suggestion in van Dam *et al.* (2005) that pools disturbed by cattle have lower richness.

Another point to make about the van Dam *et al.* (2005) invertebrate data is that richness of families and richness of species are not always correlated. It can be seen in our Figure 19 that family richness is not strongly correlated with species richness for our total pool richness data. This suggests that the family richness values in van Dam *et al.* (2005) cannot be relied upon to indicate the number of species inhabiting each of the pools. Given the very small difference in family richness between the deep and shallow pools in the van Dam *et al.* study, this is significant.

Van Dam *et al.* (2005) list a number of taxa that their data suggested might be unique to pools of one or more depth category. Of the six families absent from shallow pools, only one (Nepidae) did occur in the single pool (Li Lin Pool) from this project that would be classes as shallow. Of the seven families recorded only from deep pools by van Dam *et al.* (2005), two were not recorded by us at all, but three (Palaemonidae, Hydroptilidae and Elmidae) were recorded in pools of intermediate depth but not in the shallow pool. Hydroptilids and elmids did occur in shallow pools sampled during for the PBS. Since we sampled only one pool classed as shallow we will not add taxa to these lists.

Remotely detected pool size and permanency. These variables were not strongly related to richness of individual samples (Figure 18). When viewed on a log scale (to better resolve the patterns in the smaller pools) it can be seen that the pools with smallest maximum pool size had high richness and the pools with largest maximum pool size had low richness, but there was little relationship evident in between these extremes (Figure 18). Richness in samples did not appear to be related to minimum pool size. Pools that dried in some years did not have lower or higher richness than those that did not dry within the same time frame, though there were few examples of the former. Graphs of total pool richness versus these pool size

and permanence variables are presented in Figure 21. These show that there is no relationship between total macroinvertebrate richness and pool permanence and size.

Inclusion of a wider range of pools with different hydroperiods, rather than a focus on more permanent pools, may have revealed some effect of longevity. In the PBS, there was a strong relationship between both composition and richness of invertebrate communities and permanence. However, this relationship was for all wetlands (from ephemeral claypans to permanent springs) so much of the relationship would have reflected other characteristics of the various wetland types. In that dataset permanence was the estimated likelihood of water persisting in a wetland after inundation in four classes (ephemeral, seasonal, near permanent and permanent). In the PBS, those species assemblages that showed greatest affinity for river pools (as opposed to other types of wetlands) tended to have greater richness as permanence class increased but, again, those analyses included richness at all wetlands (i.e. including ephemeral and seasonal floodplain wetlands, not just river pools) and there was frequently little difference between wetlands deemed to be near permanent and permanent. Most of the pools sampled for the present survey would have been classed as near permanent to permanent. Invertebrate community composition showed a gradient of change as estimated hydroperiod increased from ephemeral through to permanent in the PBS, but this also included all wetland types so is not directly comparable with the current analyses.

Remotely sensed pool size and permanence data was also available for 14 freshwater river pools sampled (twice each) for the Pilbara Biological Survey (Pinder *et al.* in review). As above, this remotely sensed data was from six epochs between 2000 and 2005. Invertebrates for the PBS pools were all sampled between 2003 and 2006. Macroinvertebrate richness and total invertebrate richness are plotted against permanence and minimum and maximum pool size in Figure 22 to Figure 24. Carleecarleethong Pool on the De Grey River had a maximum pool size of more than 26 x 10^6 and was excluded from Figure 24 so that the rest of the data points can be seen on a reasonable scale. This wetland had 65 and 83 macroinvertebrates and 117 and 110 invertebrates in total for the two sampling dates. Furthermore, a DistLM analysis indicated that permanency and minimum and maximum pool size were only marginally correlated with community composition in the PBS pools: permanency and minimum pool size explaining only 12% of variation in community composition. This should be viewed with caution, however, as there may be a closer relationship between composition and these variables if there was a consistent temporal gap between the remote sensed data and the invertebrate data, and the size of the gap may be important. For example, whether or not a pool dried may only be important if the drying was in the previous hydrological cycle. There is some evidence from arid zone floodplain studies (e.g. Boulton and Jenkins 1998) that the frequency of flooding during a series of hydrological cycles may be more important than the probability of drying if flooding occurs. In other words, providing that there is a flooding event and a wetland remains flooded for long enough for invertebrates to reproduce, whether or not the wetland subsequently dries is less important.

There was little evidence of relationships between invertebrate richness and permanence or pool size from these analyses. Some pools with minimum (non-zero) pool size <10000 m^2 had higher richness than the

pools with highest minimum pool size, but overall there was no significant trend. Spearman's rank correlations between richness and permanence or pool size were all non-significant.

One of the difficulties with trying to determine effects of pool size on biotic richness in this study and in the PBS is that equal sampling effort per pool means that larger pools are relatively under-sampled compared to small pools. If sufficient sampling was undertaken to collect all species present in a pool (and thus obtain the true richness value) then more samples might be required in a larger pool. A larger pool might have more species turnover across its area and possibly more habitats, though in the coastal reaches of Pilbara rivers the latter is probably not the case as habitat diversity is generally low. Our data are richness per sample (or series of samples) not absolute richness per pool, so if the same habitats are sampled with the same effort then richness may not differ between a small pool and a large pool even if the larger pool in fact supports more species in total. An analogy would be sampling invertebrates in a square metre of bush in a small nature reserve and a square metre of bush in a large reserve. This provides information on species density but not total richness of either reserve.

Large flood events are known to largely reset invertebrate communities in river pools. Thus, after a flood a new community develops from 1) what was not removed in a flood, 2) what hatches from the sediment propagule bank (some of which may have survived in situ during the flood but much of which would have been brought in by the flood), 3) what else was deposited by the flood (e.g. some of the more robust animals like beetles and molluscs) and 4) what colonises the pools from elsewhere. While a pool that had remained inundated between floods may have had a higher starting point for invertebrate richness (if any resident fauna survived), both pools that dried and pools that did not dry would develop a diverse fauna that partly reflects the vagaries of flood survival and colonisation and partly what habitats and conditions are present. This resetting of pool communities is probably why there is little difference in richness observed between pools of differing permanence. Furthermore, most members of the Pilbara river pool fauna would be very adapted to cycles of drought and flooding, so few would be eliminated from reaches of rivers in the long term by drying and shallow depths providing that not all pools are affected. Frequency of flooding and time since flooding are certainly more of an influence in floodplain wetlands where sediments remain largely in-situ and therefore retain their own propagule banks, especially in areas where floods are highly variable in extent and frequency (Boulton and Jenkins 1998; Boulton and Lloyd 1991; Jenkins and Buikema 1998).

Water chemistry. Richness was relatively high in the two pools with highest filterable nitrogen (pool 13, Jelliabidina Pool and pool 19, Deep Reach). These two pools also had high filterable phosphorus and total nitrogen, and Jelliabidina Pool had high total phosphorus, but so did pool 11 (Highway Pool), which had more moderate richness. The relatively high richness in some of the more nutrient enriched pools may be associated with higher primary productivity, though this is not evident in the chlorophyll data. Alternatively, the small size of these pools when sampled may have increased richness due to the pool's fauna being concentrated into a smaller area (and thus greater likelihood of more species being captured). Jelliabidina

Pool had particularly even cover of submerged macrophyte and high macrophyte biomass, which may have reflected the nutrient concentrations and caused the high invertebrate richness.

There was no relationship between salinity and richness. All pools were fresh (< 1 g/L) and therefore below the salinity threshold (< ~3 g/L) above which richness is frequently observed to decline (Pinder *et al.* 2005 and PBS data). Invertebrate richness often frequently responds negatively to increasing turbidity. This is usually assumed to be result from lower primary productivity in turbid waters, low habitat diversity (no macrophytes, uniform clay sediments) and, for claypans if not turbid river pools, short hydroperiods. During the Pilbara Biological Survey some pools in creeks and rivers had turbidity exceeding 100 NTU (maximum 317). In the present survey maximum turbidity at pools sampled for invertebrates was 22.5 NTU at the highly degraded Highway Pool (pool 11) on the Yule River and 22.1 in Mungajee Pool (pool 15) on the Fortescue. Invertebrate richness would not be expected to respond to these relatively low turbidities.

Analyses of variance. Habitat variables (depth, macrophytes, sediment fractions, organic debris and position in the pool) were each divided into 2 or 3 categories based on percentiles (50^{th} or 33^{rd}) or pre-defined qualitative categories (for organic debris). Richness was compared between categories using univariate analysis of variance. Position in the pool refers to whether the sample was taken from 1) along the edge of the river bank, 2) in the middle of the pool or 3) the edge of the pool within the river channel. Invertebrate richness was significantly different between levels of some of these variables (Table 8). In particular, species richness was higher where macrophytes were present and where more than about 25% of sediment was gravel. Species richness was not significantly different between the three depth categories (< 47 cm, 48 to 77 cm and >77 cm. Of the organic debris classes only the presence of abundant leaf litter was a significant factor. Richness was also higher on the edges of pools than in the middle, probably because the pool edges tended to have more significant macrophyte beds.

Table 8. Results of analyses of variance comparing species richness between habitat variables divided into categories based on 30th or 50th percentiles.

Variable	# categories	F	p	signif.	Post hoc tests
Submerged macrophyte cover	3	4.350	0.023	**	richness lower in low cover category (<5% cover)
Emergent macrophyte cover	2	10.110	0.004	***	richness higher when emergent macrophytes present
Submerged macrophyte biomass	3	4.450	0.021	**	richness higher where macrophyte biomass high
Depth	3	0.655	0.527	n.s.	
% Cobble + pebble	2	1.184	0.256	n.s.	
% Gravel	3	5.662	0.009	***	richness higher in highest category (>26.7%) than otherwise
% Sand	3	0.666	0.522	n.s.	
% Silt	3	0.081	0.922	n.s.	
% Clay	3	0.395	0.678	n.s.	
Logs (present or absent)	2	1.858	0.184	n.s.	
Small woody debris (present or abse	2	0.050	0.824	n.s.	
Coarse roots (none or sparse)	2	0.065	0.8	n.s.	
Fine roots (none, moderate or abund	3	2.857	0.075	n.s.	
Litter category	3	3.526	0.047	*	richness higher where litter 'abundant'
Position of sample site in pool	3	4.479	0.021	**	richness lower in middle of pool and higher on the edges.

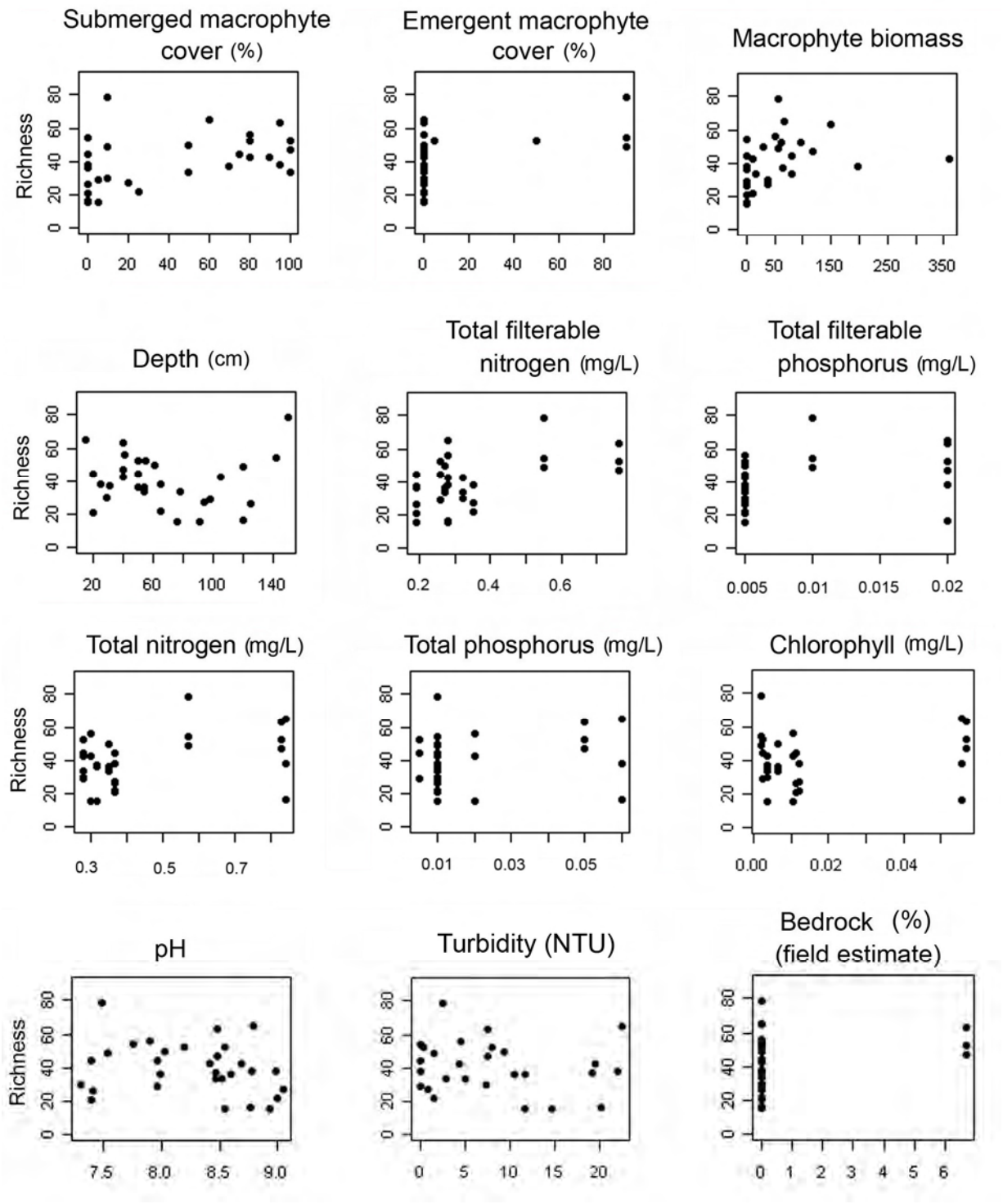


Figure 15. Environmental variables versus sample invertebrate richness.

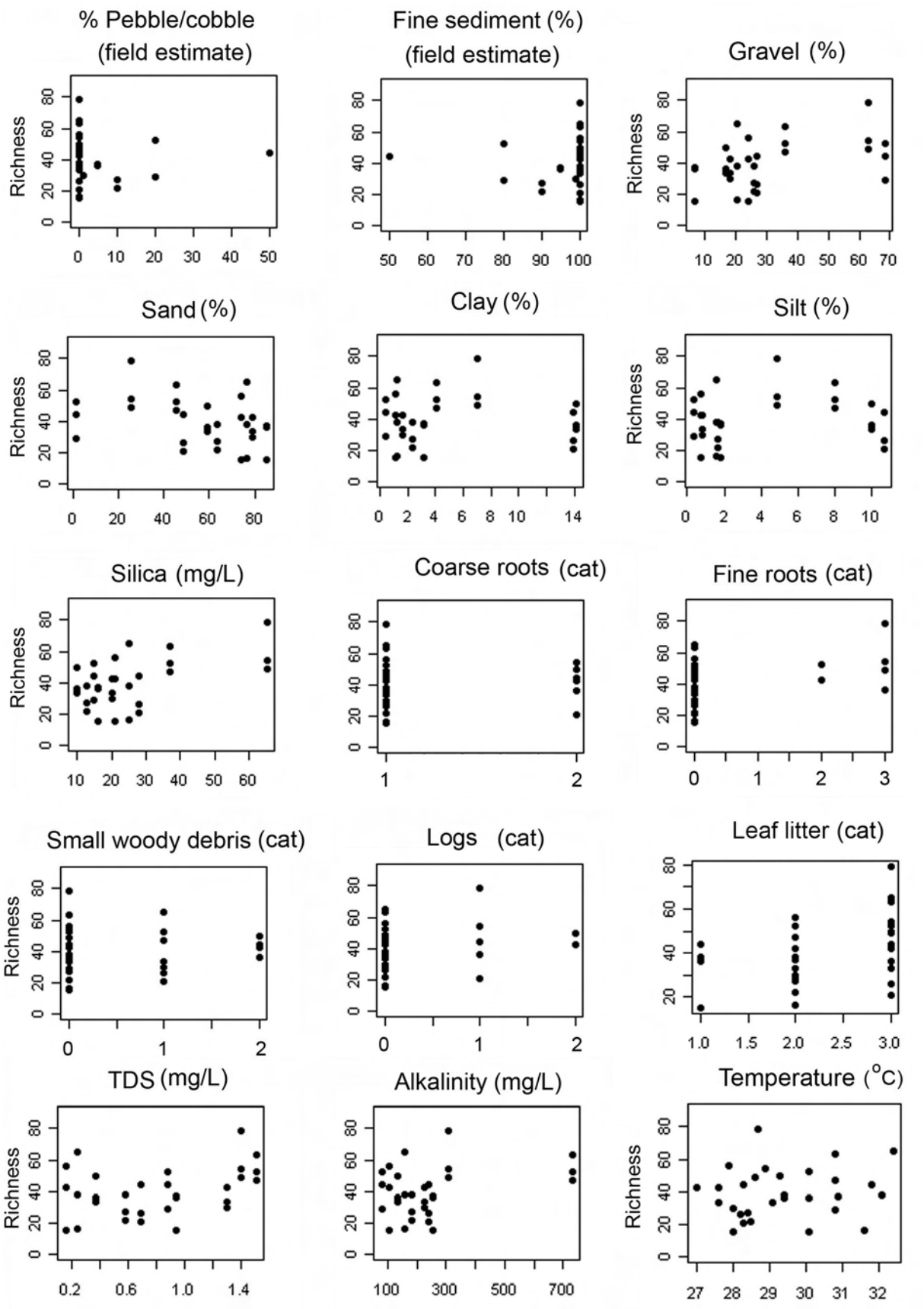


Figure 16. Environmental variables versus sample richness for the 30 sampling. Cat = categorical variables. See methods for explanations of other variables.

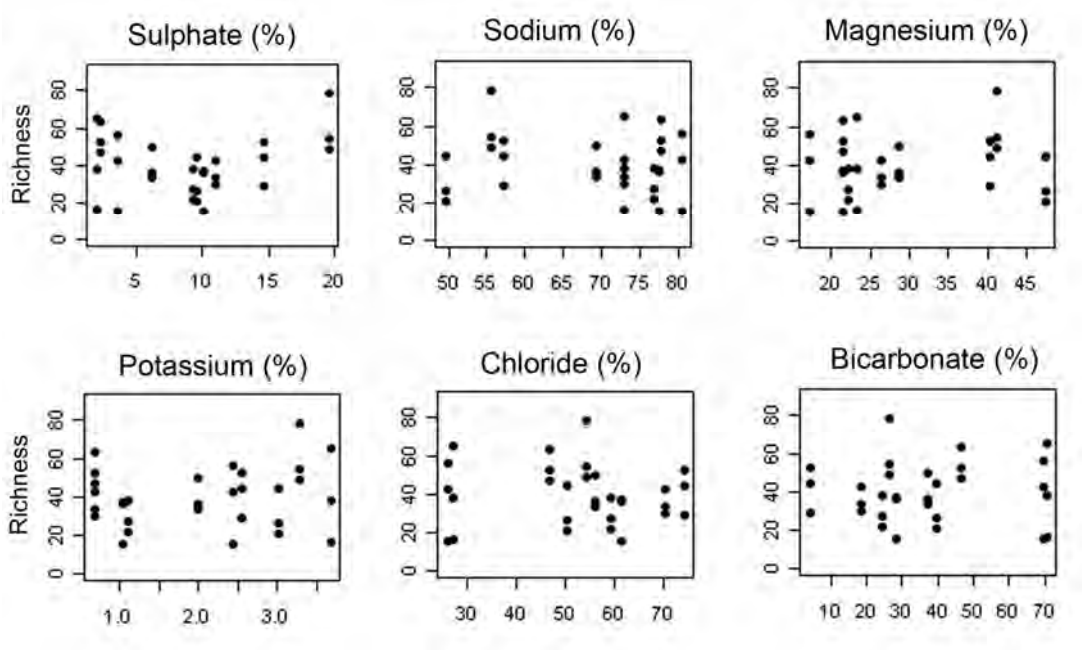


Figure 17. Percent ionic composition versus sample invertebrate richness.

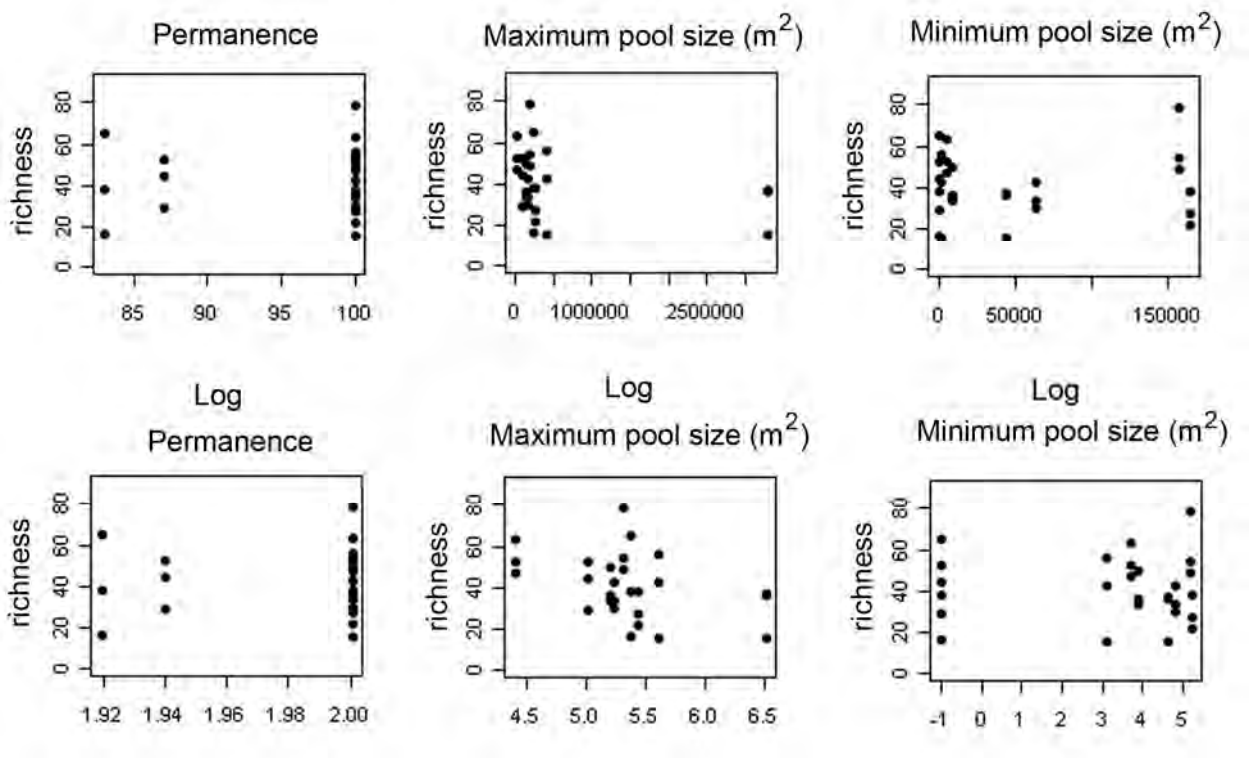


Figure 18. Pool permanence and inundation variables on linear scale (top row) and log10 scale (bottom row) versus sample invertebrate richness. Pool 15 (Mungajee Pool excluded).

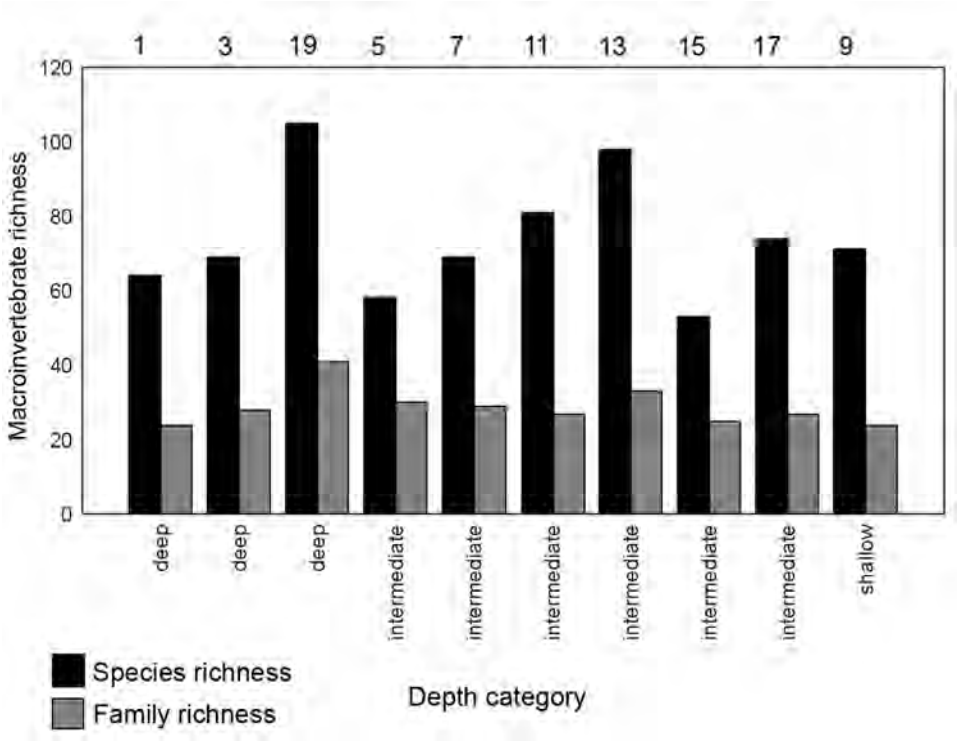


Figure 19. Total macroinvertebrate species and family richness in pools shown according to depth categories used by van Dam *et al.* (2005). Pool number shown at the top of the graph.

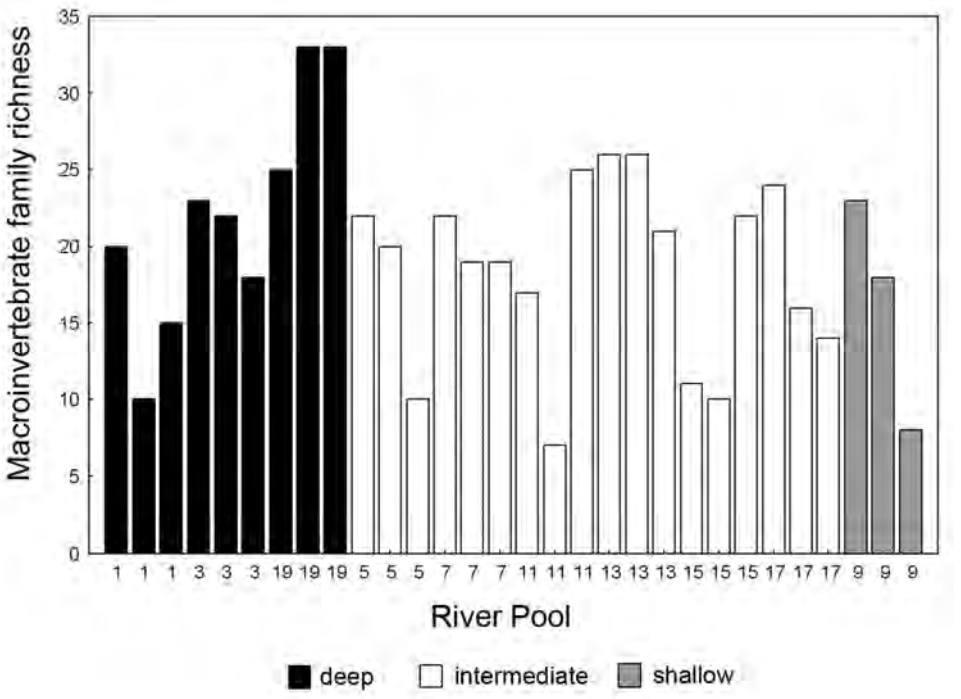


Figure 20. Macroinvertebrate richness per sample according to depth categories used by van Dam *et al.* (2005).

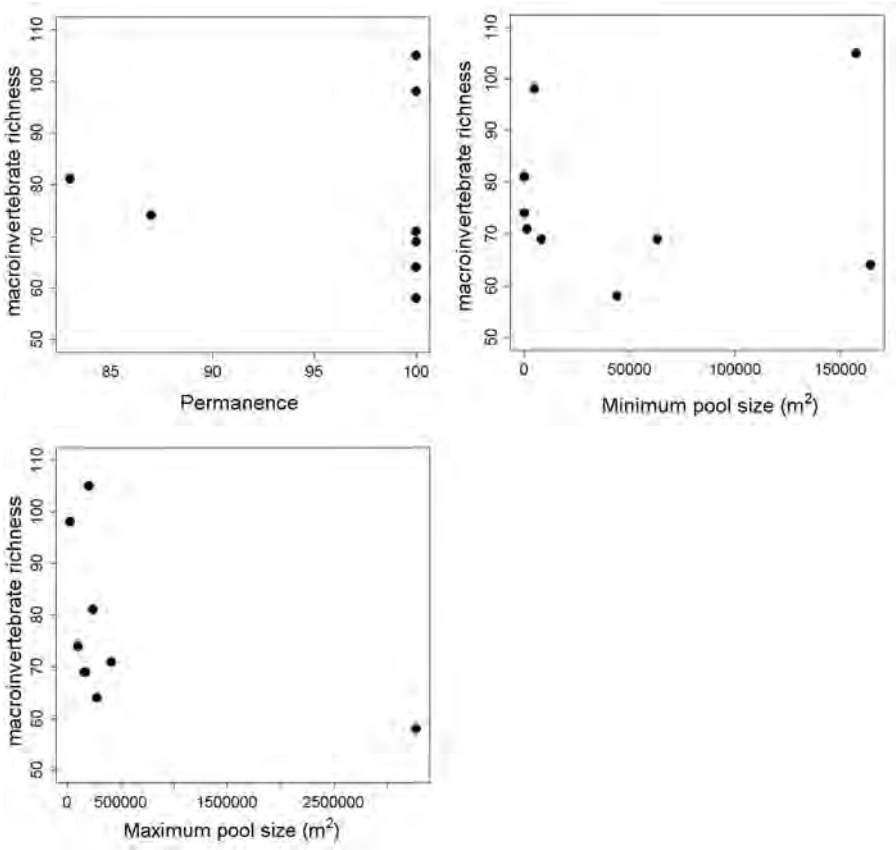


Figure 21. Remotely sensed pool permanence and size (see Methods) versus total pool invertebrate richness (combined across samples).

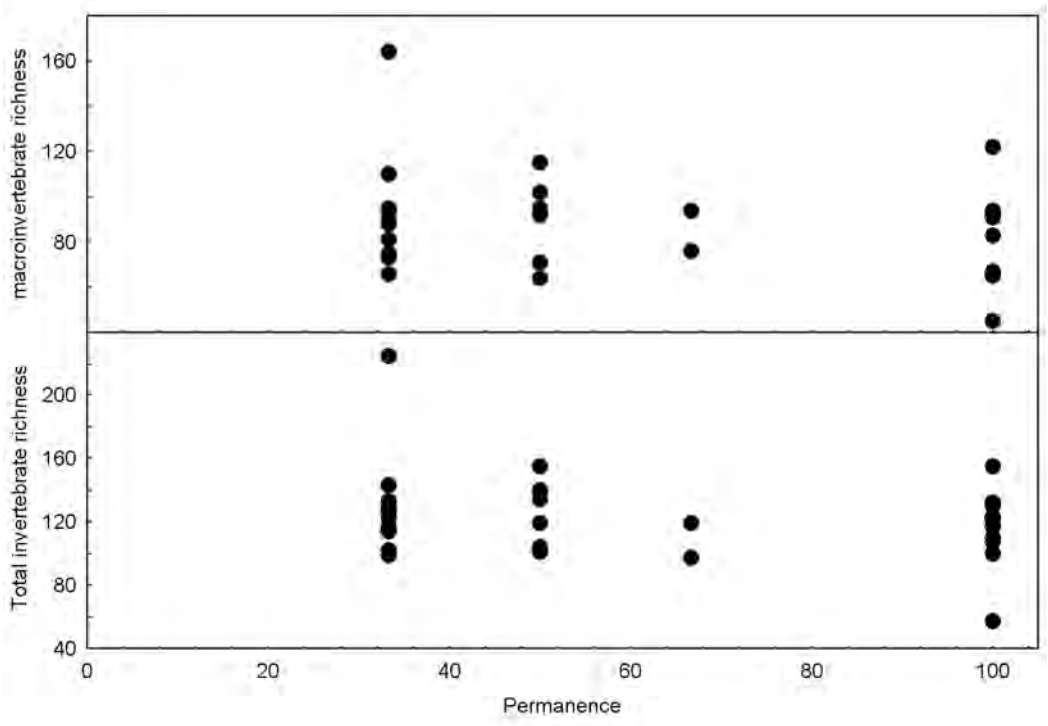


Figure 22. Permanence (as a percentage of remotely sensed epochs in which water detected) versus richness of macroinvertebrates and all invertebrates in pools sampled for the Pilbara Biological Survey.

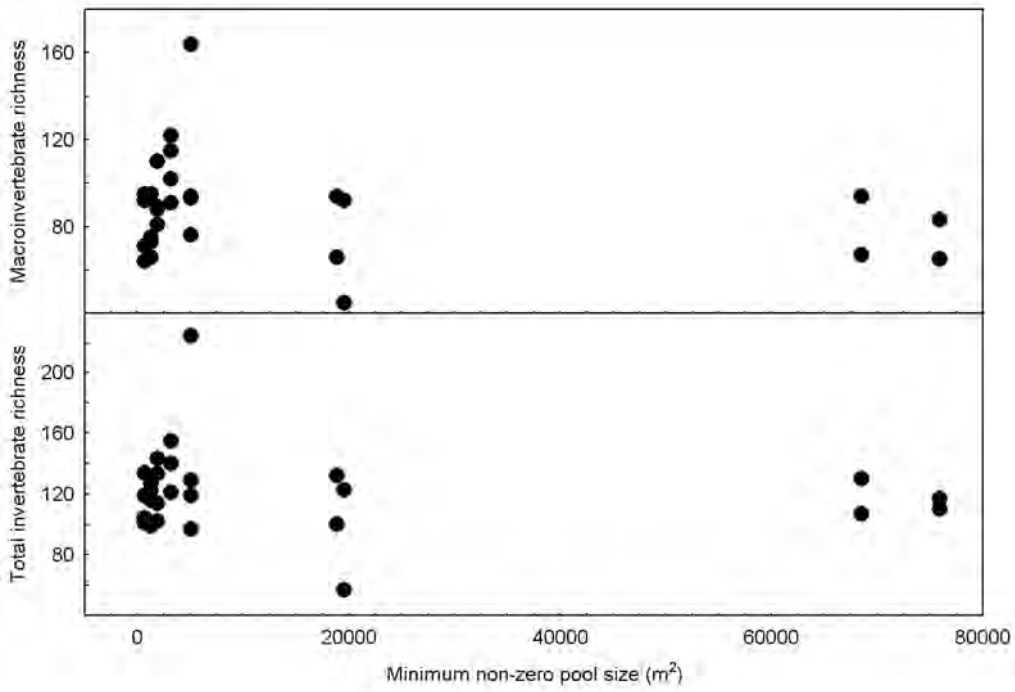


Figure 23. Minimum remotely sensed pool size versus richness of macroinvertebrates and all invertebrates in pools sampled for the Pilbara Biological Survey.

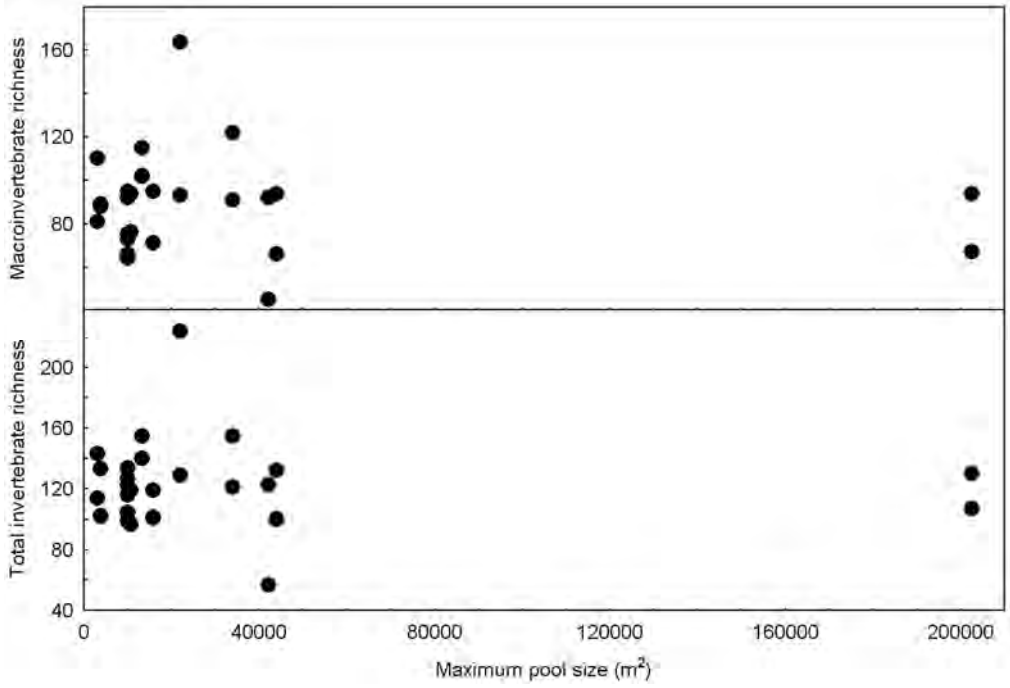


Figure 24. Maximum remotely sensed pool size versus richness of macroinvertebrates and all invertebrates in pools sampled for the Pilbara Biological Survey.

Community composition and environmental variables

Two methods are used to examine associations between measured environmental variables and community composition. Firstly, symbols representing invertebrate samples in the nMDS ordination (from

Figure 10) are scaled in proportion to the value of selected environmental variables. This allows a visual examination of the degree to which patterns in community composition are related to environmental variables. Secondly, distance-based linear modelling is used to quantitatively relate environmental variables and community composition (or more strictly community similarity). It should be kept in mind that these relationships are not necessarily causative.

In the nMDS ordinations (Figure 25 and Figure 26), only those environmental variables that showed an obvious pattern in relation to the invertebrate ordination are presented. Each variable is shown on the pair of axes that showed the strongest gradients (mostly axes 2 v 3). Several trends can be seen in these plots. Those invertebrate samples from pools with higher nutrients and chlorophyll clustered together (Figure 25). The same pools had highest alkalinity, which is often associated with high primary production. These pools were all on the Yule River and had higher chlorophyll than in the remaining pools. Invertebrates from the two more coloured pools (Jelliabidina Pool on the Yule River and Mungajee Pool on the Fortescue) occurred towards the left of the ordination (in the view of axes 2 versus 3). In the same view the communities in samples from pools with coarser sediments (high gravel and cobble) and sulphate also tended to cluster together (Bilanoo Pool and Deep Reach on the Fortescue River: Figure 25 and Figure 26) and there was a slight tendency for samples collected in deeper parts of pools to occur more towards the upper right (Figure 25). There was also a tendency for invertebrate communities from pools that have larger minimum sizes to group together in the right of the ordination when viewed on axes 2 v 3, though maximum pool size did not show much pattern. The pools with larger minimum size were largely on the De Grey River plus Deep Reach on the Fortescue River. Since almost all pools were inundated for all of the remotely sensed periods the permanence variable is not shown.

When viewed as axes 1 v 2 those invertebrate samples collected where there were more macrophytes and fine roots tended to occur more towards the left of the ordination. Since all pools were essentially fresh (mostly <1000 mg/L) a strong salinity effect would not be expected and the relationship between community composition and TDS is weak, with lower salinity samples tending to occur together near the centre and bottom left on axis 1 v 2.

Figure 25 and Figure 26 indicate that there are some associations between community composition and environmental variables. Distance-based linear models (DistLM) and constrained ordination plots were used to investigate these relationships more quantitatively. This method performs multiple multivariate regression to find linear relationships between community composition (as represented by axes from a principal coordinates analysis) and environmental variables (Anderson *et al.* 2008; Legendre and Anderson 1999). The regression is then used to predict the positions of samples along each axis from the environmental data,

producing a constrained ordination that shows only that proportion of variation in community composition that is associated with the model parameters. Each environmental variable selected by the model is also represented by a vector on the ordination whose length and orientation indicates the strength and direction of the variable's correlation with the axes shown.

An initial analysis was run to determine whether river catchment explained any of the variation in invertebrate community composition not explainable by the environmental variables alone. In this analysis, which included all pools but excluded remotely sensed pool size and permanence data, catchment did not explain a significant amount of variation in community composition in addition to that explained by the environmental variables. When the remotely sensed data were included (and pool 15 excluded) the result was about the same. This suggests that the differences in community composition between catchments (as indicated in Figure 10 A-C) are largely due to differences in environmental characteristics of pools between catchments rather than a biogeographic effect. This is not surprising considering the degree of separation of the pools by catchment in the ordination of the environmental data (Figure 10 D-F).

Further DistLM analyses were performed on the dataset with remotely sensed data (i.e. again without Mungajee Pool) but using a stepwise model building procedure and Primer's modified Akaike Information Criterion (AICc) as a measure of model performance. This procedure selects a model that is a tradeoff between performance and parsimomy by penalising larger models). In this analysis catchment was the best individual predictor of community composition and was selected in a model with submerged macrophyte cover, %clay, SO_4^{2-} and silica, which together explained 55% of variation in community composition. In this case, catchment is probably acting as a surrogate of a range of environmental variables, as indicated by the initial analysis above. When catchment was excluded then a model explaining 47.5% of variation in community composition was produced using cover of submerged and emergent macrophytes, %clay and total phosphorus (Table 9). Numerous other environmental variables individually explained similar proportions of variation in community composition (> 10%, Table 10) as that explained individually by the four variables included in the model. This suggests that many other combinations of variables would have provided models of similar performance. It also means that small changes in the data or a slightly different selection pools is likely to have produced a different model and that, therefore, the variables selected in the model are not of particular significance as explanatory variables.

Finally, since pool size and permanence were of particular interest, a model just using the remotely sensed minimum and maximum pool size and permanence produced a model with all three variables explaining only 24% of variation in community composition.

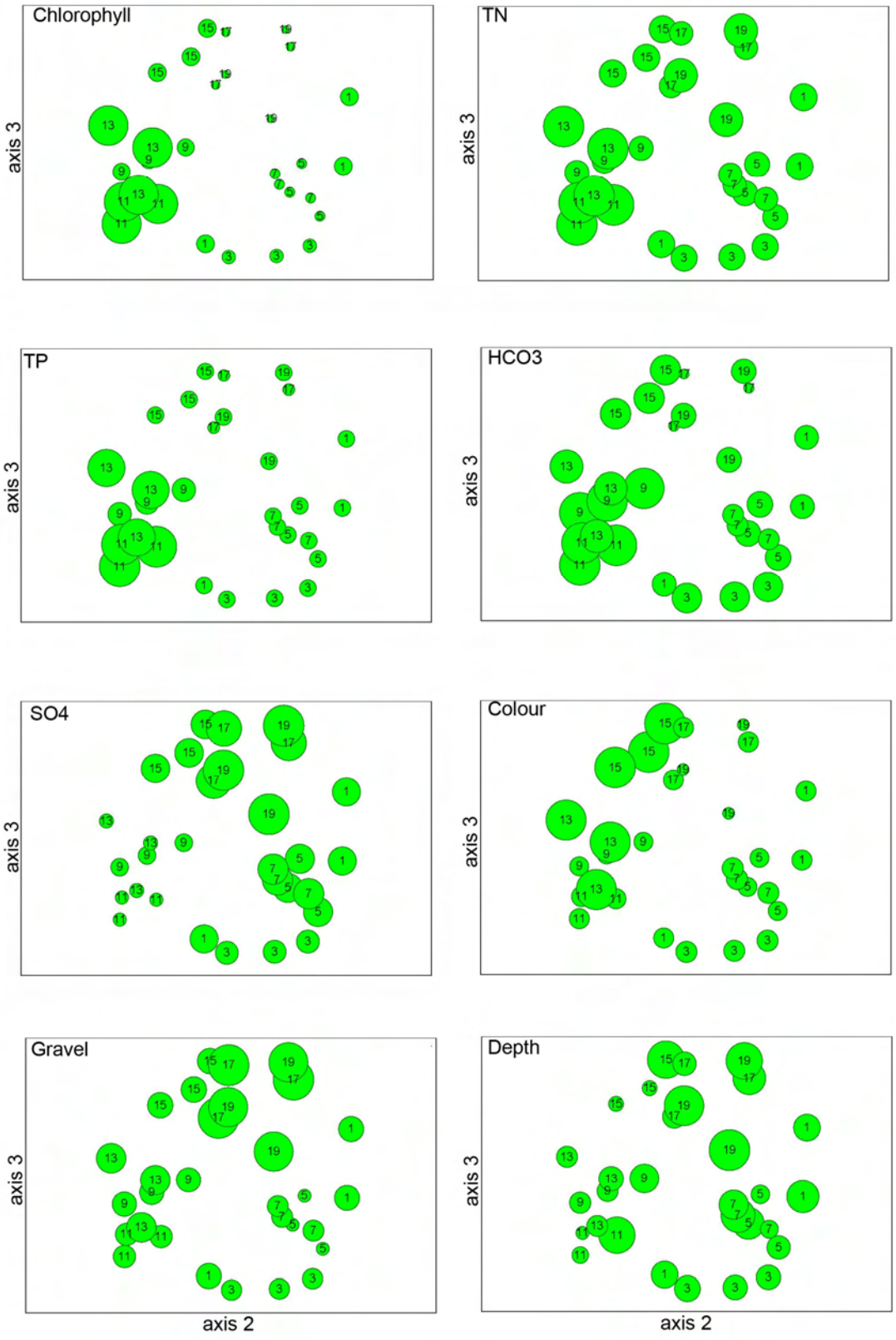


Figure 25. Relative values of environmental variables (as indicated by symbol size) superimposed on axes 2 versus 3 of the nMDS ordination of sample invertebrate community composition (i.e. the ordination shown in Fig.10).

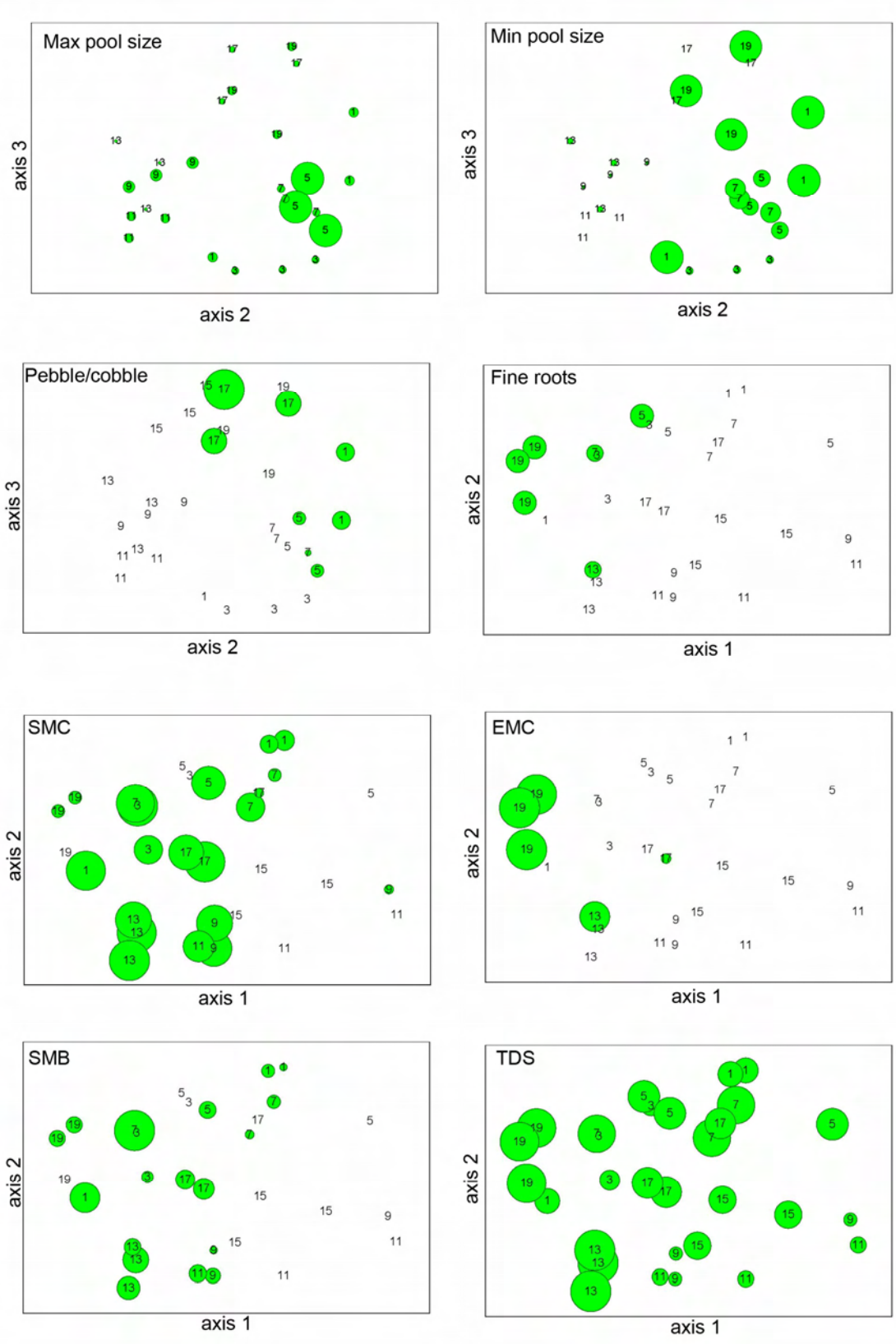


Figure 26. Relative values of environmental variables (as indicated by symbol size) superimposed on axes 1 versus 2 or 2 versus 3 of the nMDS ordination of sample invertebrate community composition (i.e. the ordination shown in Fig. 10). Pool 15 excluded for pool size and permanence variables.

Table 9. Variables selected in the DistLM model built without 'catchment' and their contribution to the model.

variable	sequential additional proportion of variance explained	cumulative proportion of variation explained in model	significance (p)	residual degrees of freedom
Emergent macrophyte cover	0.127	0.127	<0.001	25
Submerged macrophyte cover	0.136	0.263	<0.001	24
Total phosphorus	0.107	0.370	<0.001	23
% Clay	0.105	0.475	<0.001	22

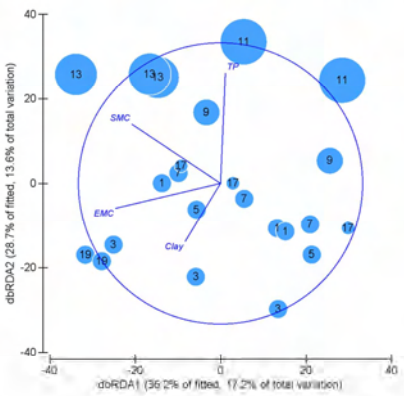
Table 10. Significance and marginal proportions of variation in community composition explained by individual environmental variables. Shaded variables are those included in the DistLM model excluding catchment (see Table 9). Only variables significantly correlated with community composition are shown.

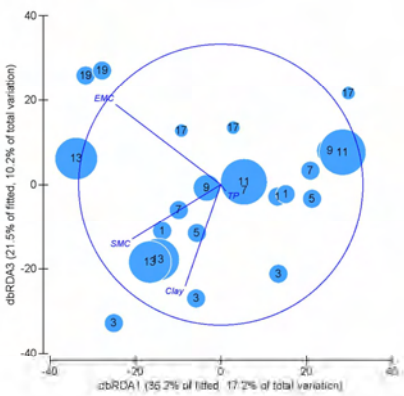
Variable	p	Proportion of variation explained
% Emergent macrophyte cover	0.001	0.127
% Sand	0.002	0.126
SO_4^{2-}	0.001	0.123
K^+	0.001	0.123
% Gravel	0.002	0.121
% Submerged macrophyte cover	0.001	0.117
Silica	0.001	0.114
Total phosphorus	0.002	0.113
% Clay	0.001	0.110
Total filterable nitrogen	0.001	0.107
Mg^{2+}	0.003	0.107
Chlorophyll	0.004	0.105
Fine roots	0.002	0.104
% Silt	0.001	0.102
Submerged macrophyte biomass	0.002	0.101
Minimum pool size (2000-2005)	0.006	0.101
Litter	0.002	0.098
Total filterable phosphorus	0.004	0.098
Total nitrogen	0.008	0.090
pH	0.01	0.087
Permanence	0.016	0.083
Total dissolved solids	0.011	0.083
Maximum pool size (2000-2005)	0.015	0.080
Colour	0.022	0.077
Cl^-	0.03	0.075
% Pebble + Cobble	0.011	0.072
Turbidity	0.038	0.071
CO_3^{2-}	0.039	0.069
Na^+	0.044	0.069
Depth	0.041	0.065

The constrained ordination reflecting the four variable model is shown in Figure 27, with lines representing the direction of the environmental gradients and size of symbols representing values of the model variables. Unlike Figure 25 and Figure 26, which indicate total variation in community composition, the relative position of the samples in the constrained ordination plots indicate only that proportion of their community variation that can be explained by the environmental variables included in the models. For this reason, bubble plots like these will usually show strong spatial patterns, even if those patterns represent weak relationships. These plots show the vector for total phosphorus pointing towards the nutrient enriched Yule River pools (pool 11, Highway Pool and pool 13, Jelliabidina Pool); the emergent macrophyte cover vector pointing towards samples from Deep Reach (pool 19), which had highest emergent macrophyte cover; the vector for submerged macrophyte pointing away from the few samples with lower macrophyte cover (from numerous pools) and the % clay vector pointing towards samples from Muccangarra Pool and deep Reach (pools 3 and 19) with higher clay content in sediments.

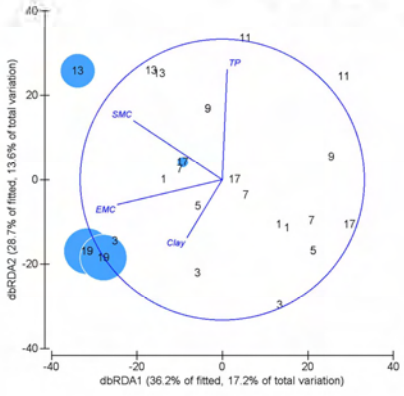
Figure 27 (following page). db-RDA ordination of invertebrate community composition as predicted by the DistLM model. Circles represent invertebrate samples and are scaled according the values of the four variables as indicated. Plots on the left are axes 1 v 2 and plots on the right are axes 1 v 3 (from an ordination with 4 axes). These three axes accounted for 86.4% of the variation in community composition explained by the model and are therefore adequate to visually represent the model. Pool numbers are shown for each sample and where there is no symbol this represents a zero value for the variable.

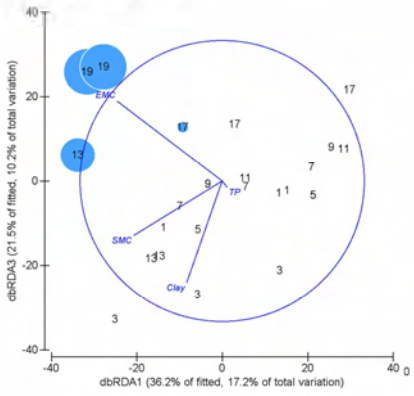
total phosphorus



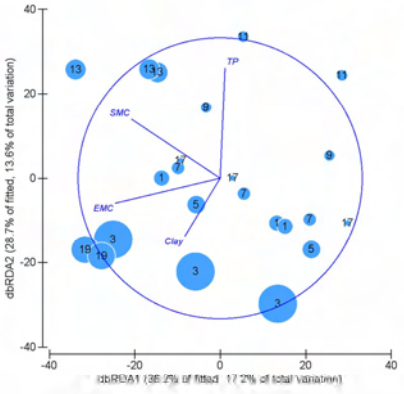


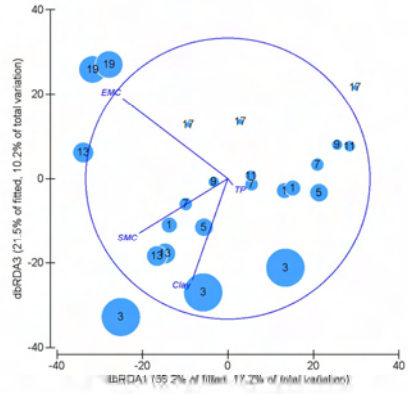
emergent macrophyte cover



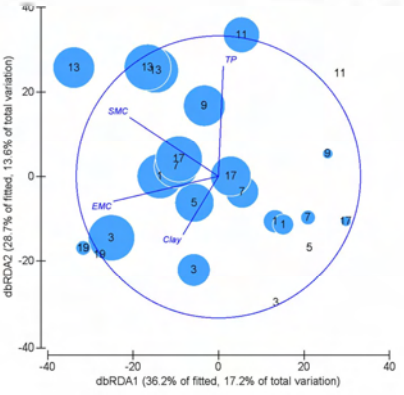


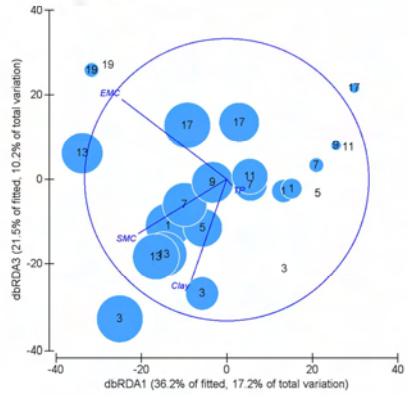
% clay in sediments





submerged macrophyte cover





The above analyses of relationships between richness and composition of macroinvertebrate communities and environmental variables suggest that:

1) Macroinvertebrate species richness is not strongly related to most of the measured environmental variables. Some relationships are evident between richness and macrophyte cover and biomass, nutrients and sediment variables but these are not strong.

2) Macroinvertebrate richness does not appear to be correlated with depth (at the point where the sample was collected), remotely sensed pool size and permanence data. The latter may be a determinant of richness in coastal river pools, but the pools sampled for this project did not span a broad enough range of the hydroperiod gradient to enable such a relationship to be detected (i.e. most were permanent). Richness was as high in samples collected at a depth of 20 cm as those collected from depths greater than 100 cm, but this is collection depth not maximum depth of the pool. Estimated maximum depth within a pool when sampled also appears to be unrelated to macroinvertebrate richness. The minimum pool depth recorded during this survey was at pool 9 (Li Lin Pool on the Yule: 0.76 m) but this pool had richness as high as or higher than most other pools (5^{th} highest richness overall). This suggests that if pools are maintained at this depth or higher then macroinvertebrate richness and composition should not be negatively affected. However, this should not be seen as a definitive threshold as it represents just one point in time at one pool. Notably, although Li Lin was the shallowest pool the remote sensing data suggested it was not more likely to dry compared to other pools. Analysis of a subset of the PBS data similarly found no evidence of a relationship between richness and any of the pool size and permanence data.

3) Community composition is weakly related to a broad range of environmental variables, including macrophyte biomass and cover, sediment type and water chemistry (especially nutrients), but also to pool size and permanence, though the latter two were not amongst the best predictors of community composition. Invertebrate richness can remain constant even as composition changes substantially and so is usually a less sensitive indicator of environmental change than composition. However, composition is a multivariate measure and difficult to use for setting targets, especially in environments that are as variable and unpredictable as Pilbara rivers.

4) Nutrient enrichment caused by cattle may be affecting community composition in Pilbara river pools. Enrichment does not seem to have negatively affected richness of invertebrate communities but does appear be correlated with altered community composition.

River pools not sampled for invertebrates

Ordination

A nMDS ordination (Figure 28) of all river pools (except pool 10 for which we were missing some data) showed that abiotic conditions within the pools sampled for invertebrates were not significantly different from those in which we did not (anosim R = -0.043, p>0.05). There is, therefore, no reason to expect that the aquatic invertebrate communities in the pools where they were not sampled would be substantially different, overall, from communities recorded in pools where they were sampled. This analysis excluded remotely sensed pool size and permanence data because this data was not available for two pools (15 and 16). Including these variables (but excluding pools 15 and 16) did not lead to greater separation of the two sets of pools.

There is also no individual aspect of the water chemistry and habitat data that would suggest that any of the pools not sampled for invertebrates would have particularly different richness or composition to those where we did sample invertebrates.

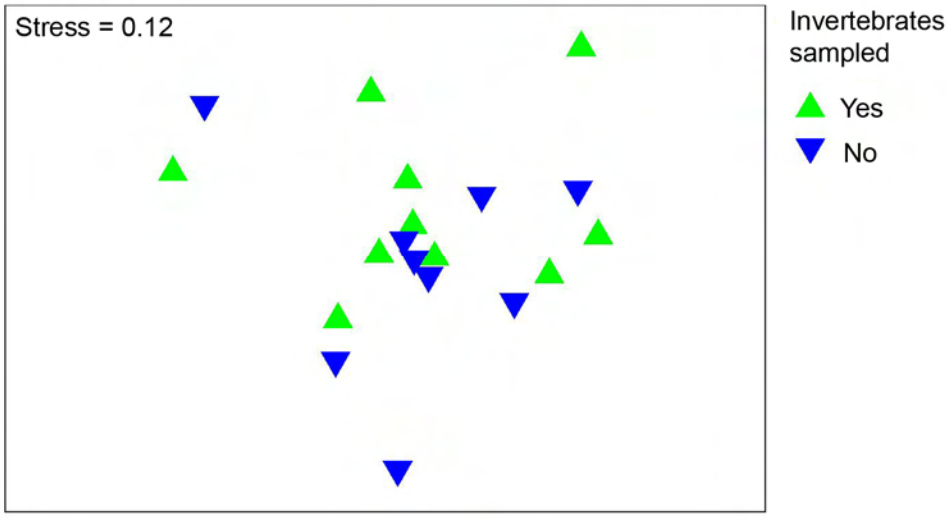


Figure 28. Two dimensional nMDS ordination of all pools based on environmental variables

MARS models

Pinder *et al.* (in review) identified thirteen assemblages of species from the Pilbara Biological Survey invertebrate data, each comprising a set of non-singleton species of micro- and macroinvertebrates with common patterns of distribution (as described in the Methods). These assemblages and their occurrence in Pilbara wetlands are described in Appendix 4. For nine of these assemblages Pinder *et al.* (in review)

produced models that relate richness in a sample to measured physical, chemical, climatic and geographic variables. These models were constructed using "multivariate adaptive regression splines" (MARS) using the Elith and Leathwick (2005) script for R (R 2.7.0, The R Foundation 2008). The nine models varied in performance, with r^2 values between 0.25 and 0.73 for predicted versus observed richness. We have tested these models by predicting macroinvertebrate richness at the 10 pools sampled for this project and comparing these predicted values to observed richness. The aim of this exercise was to assess whether the models could be used to predict richness at the 10 pools where we did not sample invertebrates. For the following discussion the pools sampled for this project are termed 'PRP' pools, in contrast to the PBS pools. We could not assess the actual numeric predictions of richness because we did not collect and identify microinvertebrates, but we can test whether there is a correlation between predicted total richness and observed macroinvertebrate richness and see if the predicted richness values are at least in the same rank order as the observed values. Figure 29 and Figure 30 are graphs of predicted versus observed richness for all nine modelled assemblages. Samples in these plots are shown with symbols representing i) river pools sampled during the PBS; ii) river pools sampled during the present project (PRP) and iii) other types of wetlands (turbid creek pools, claypans, springs etc) sampled during the PBS. Points representing PRP pools are predicted total richness versus observed macroinvertebrate richness, whereas the points representing PBS pools are predicted and observed total richness. From these it can be seen that some assemblages (1 and 2) are more likely to be richer in river pools than in other types of wetlands, while other assemblages are unlikely to reach highest richness in river pools (e.g. assemblages 6, 10 and 11).

Predicted richness in PRP pools is generally low to average compared to river pools sampled during the PBS. This would initially suggest that the mostly coastal PRP pools are suboptimal for most assemblages compared to those sampled for the PBS, which were mostly inland river pools. However, surprisingly, the ranges of observed PRP macroinvertebrate richness values are close to range of predicted total richness. This would suggest that the assemblages sampled in PRP pools were sufficiently rich in macroinvertebrates to have largely made up for the lack of microinvertebrates. By corollary, this also suggests that the models grossly underestimated the richness in PRP pools that would have been observed had microinvertebrates been sampled. One reason for this may be that very few fresh coastal river pools were included in the PBS dataset used to construct the models.

While the models predicted the ballpark range of assemblage richness values in the 10 PRP pools reasonable well, they were poor at discriminating comparatively high richness PRP pools from ones that were more depauperate. This is probably because the PRP pools are relatively homogeneous in their chemical and physical characteristics compared to the much wider range of pools and other wetlands on which the models were based. Linear correlations between observed and predicted PRP assemblage richness had r^2 values that varied between 0.0004 and 0.84 (but the higher value was due to one outlier, otherwise the maximum r^2 was 0.13) and, moreover, some of these correlations were negative. This very low correlation between observed macroinvertebrate richness and predicted total richness for the 10 PRP pools means that the models cannot

be used to predict macroinvertebrate richness at the 10 pools not sampled for invertebrates. However, for our purposes it would be sufficient that the predicted total richness values are at least in the same rank order as the observed macroinvertebrate richness values. This would allow us to suggest which of the pools not sampled for invertebrates might have had higher richness. Unfortunately, the Spearman rank correlation coefficients between predicted and observed richness varied from 0.24 to 0.76 (mean 0.42) so the models did not adequately place pools in the correct rank order.

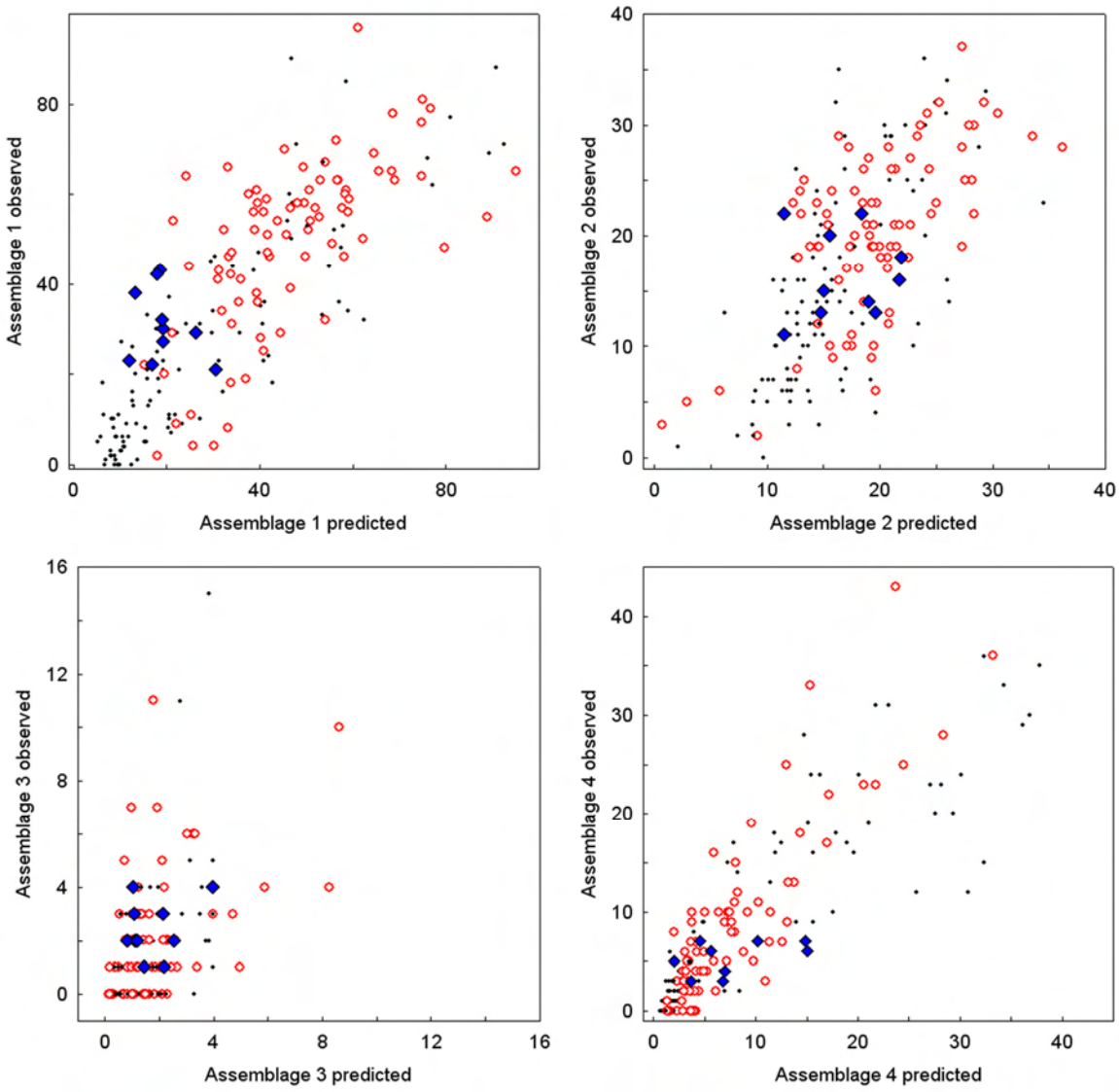


Figure 29. Richness of invertebrate assemblages 1 to 4 predicted by MARS models versus observed richness. Red open circles are PBS river pools, black dots are other types of PBS wetlands and blue closed diamonds are PRP pools.

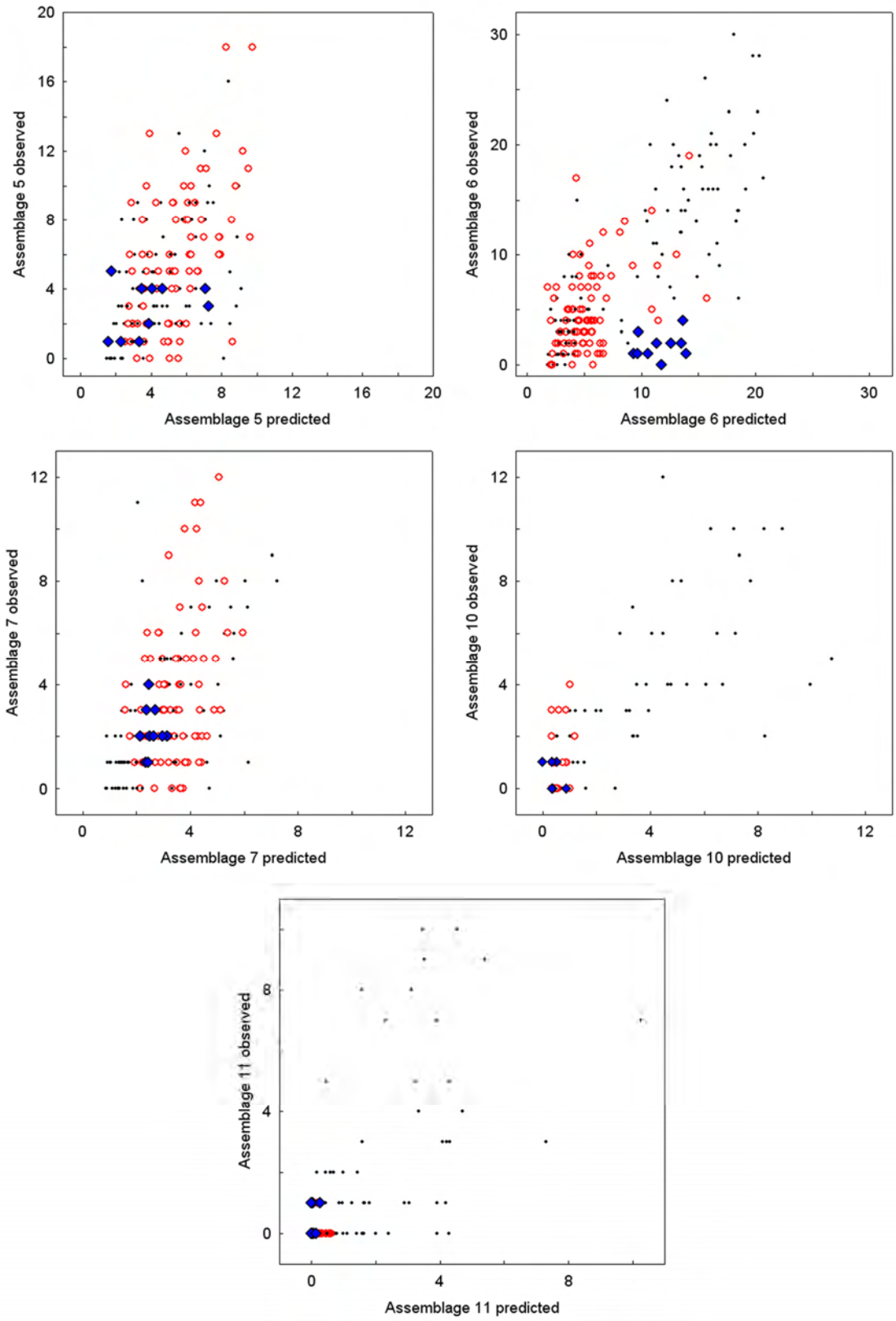


Figure 30. Richness of invertebrate assemblages 5 to 7 and 10 and 11 predicted by MARS models versus observed richness. Red circles are PBS river pools, black dots are other types of wetlands and blue diamonds are pools sampled for the present project.

New river pool macroinvertebrate only model

A final approach was to produce a new model (or models) using just the PBS macroinvertebrate data from river pools, so that the predictive data set more closely matches the type of data collected during this project. Cluster analysis suggested that the macroinvertebrate species constituted a single assemblage and a MARS model was produced that predicted macroinvertebrate richness using water temperature, alkalinity, permanence (as estimated by Pinder *et al.* (in review)), total dissolved solids and emergent macrophyte cover. This model had an adjusted r^2 of 0.52. Figure 31 is a graph of predicted versus observed richness for this model. While this model explains about half of the overall variation in macroinvertebrate richness it can be seen that for any individual sample there is considerable error in the predicted richness. Predicted richness is mostly 10 to 20 species higher or lower than observed richness. The richness of PRP samples (and even their rank order) was poorly predicted, so this model is also of little use for predicting richness in those pools not sampled for invertebrates.

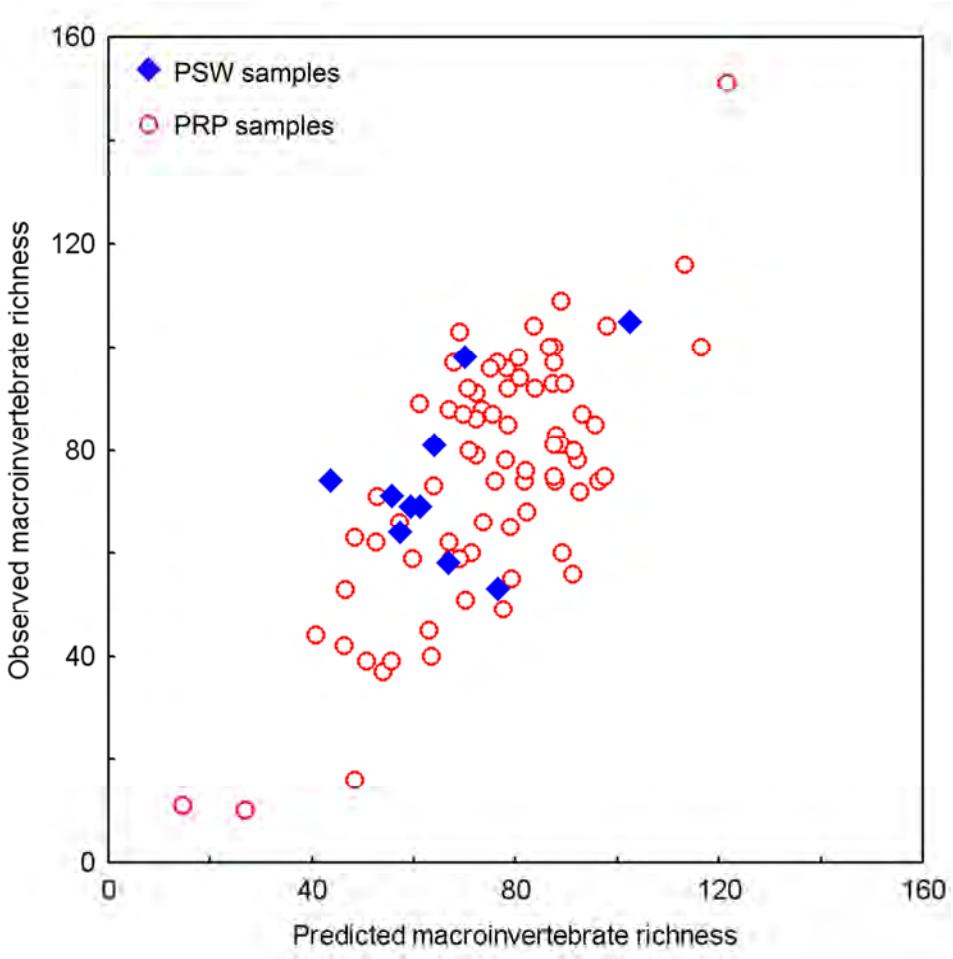


Figure 31. Richness predicted by the river pool macroinvertebrate only MARS model versus observed richness for river pools sampled for the Pilbara Biological Survey (red circles) and the current project (blue diamonds).

SUMMARY

Hypothesis 1: River pools within potential groundwater extraction areas are essentially uniform with respect to their physical, chemical and biological characteristics.

In a broad sense, river pools in the coastal reaches of Pilbara rivers are fairly similar to one another: they tend to have sandy to gravely sediments, depth less than a few metres, clear fresh water, and extensive beds of submerged macrophytes but little emergent macrophyte. Compared with many pools in the more inland reaches of the Pilbara they have relatively little habitat diversity in that they are generally not associated with permanently flowing springs, they lack backwater areas and have relatively uniform sediments (notably a lack of bedrock and boulders). Habitats present are simply combinations of macrophyte density and type, depth and sediment composition. However, there were subtle (and some not so subtle) differences between the 20 pools sampled. Most were sand and gravel dominated but some on the Fortescue River were dominated by coarser sediments and those of the Yule tended to have proportionally more gravel than sand compared to the De Grey. Nutrient concentrations varied greatly, with some pools, especially some of those on the Yule River, having elevated nutrient and chlorophyll concentrations, probably as a result of cattle using the pools. Most pools had clear water but some were mildly turbid, either due to naturally high clay content in sediments (Mungajee Pool on the Fortescue) or due to nutrient enrichment and subsequent algal concentrations or physical disturbance of sediments by cattle, especially on the Yule River. Macrophyte cover and biomass also varied greatly within a pool and between pools, with macrophytes absent from some pools but covering almost the entire bed in others. Multivariate analyses showed that there were significant differences between catchments in terms of their environmental variables and that pools within the Fortescue River were more variable than those within the Yule and De Grey Rivers.

There were some differences in macroinvertebrate richness between pools, with the richest pool (Deep Reach on the Yule at Millstream) having twice the number of species as the pool with lowest richness (Mungajee Pool, also on the Fortescue). However, the range of richness values recorded (53 to 105) was relatively narrow compared to river pools across the broader Pilbara and there was no significant difference in pool invertebrate richness between catchments. There were significant differences in invertebrate species community composition between pools and catchments, with over half the species recorded from just one catchment and 45% recorded only from one pool (i.e. most of the species recorded in just one catchment were singletons at the pool level). The individual pools within a catchment were certainly not uniform either, with half to two-thirds of each catchment's species pool collected from only one river pool.

The Millstream river pools and associated springs (including Deep Reach) have distinctive aquatic invertebrate communities and are certainly different from those inhabiting more lowland pools on the

Fortescue and other rivers. The three samples from Deep Reach collected in this project separated from other samples in the ordination and cluster analyses, forming one of the five major groups in the latter. In cluster analysis of the Pilbara Biological Survey the Millstream wetlands also tended to form small separate groups in a cluster analysis (DEC, unpublished data). While most individual species in these wetlands do occur widely in the Pilbara their faunas include a geographically and/or environmentally restricted group of species, as discussed under the following hypothesis.

Analysis of the data collected during this study suggests that there is sufficient environmental and biological heterogeneity between catchments that they cannot be considered surrogates for one another for conservation purposes. The same can be said for pools within a catchment, suggesting that it will be important to maintain adequate conditions in a variety of pools within the coastal reaches of these major rivers in order to ensure the persistence of the present pool of invertebrate species. However, over time (during a single hydrological cycle and between cycles) any individual pool or series of pools in a stretch of river will have a much larger fauna than would be recorded on a single sampling occasion. Floods will tend to reset pool invertebrate communities and analysis of data from the Pilbara Biological Survey suggests that pools will develop a very diverse community after flooding even if they do lose species during the dry periods. Following floods individual pools will have faunas that are as rich as they were prior to the flood but with a somewhat different composition. Where there are numerous pools along the reach of a river it is unlikely that the loss of a small proportion of these will have significant consequences for the river's fauna overall. Exceptions would be some of the smaller spring fed pools, such as Running Waters on the Oakover, and the Millstream pools, whose faunas include a more restricted element.

Hypothesis 1 is rejected on the basis of moderate differences in environmental and biological characteristics between the catchments and pools. However, species lists accumulated over time would undoubtedly reveal that the suite of species occurring in a series of pools will occur in most of the individual pools at some stage, so any one pool is probably not critical for the river's fauna.

Hypothesis 2. That river pools within potential groundwater extraction areas do not have ecological values that are not well represented elsewhere, i.e. they do not have particularly high conservation significance in a regional context.

Richness of macroinvertebrate communities in the pools sampled for this project are slightly below the average recorded in freshwater pools during the Pilbara Biological Survey, almost all of which were in more inland parts of the Pilbara. However, this difference can be accounted for by the lower sampling effort used

during the present project. The majority of the aquatic invertebrates collected during this project were regularly collected in the more inland pools sampled for the Pilbara Biological Survey and communities in the coastal reaches of the major rivers do not have significantly different composition to those in more inland pools. However, about 1 in 7 species in Appendix 2 appear to be far more likely to occur in river pools on the Roebourne Plains than in river pools elsewhere in the Pilbara and, of these, five have only been found in coastal pools. This is not to say that most of these species are rare in inland parts of the Pilbara, just that they appear to be especially common in coastal pools and that maintenance of these pools is therefore particularly likely to ensure the persistence of regional populations. Moreover, a few of these species are also common in other types of wetlands in the Pilbara. A few additional species, collected only once in this project and not all during the PBS, may also be more common in the coastal pools than elsewhere. None of the three rivers were more or less likely to support these coastal species and about half of the species were collected in more than one river. In fact, most of these species have ranges that extend into the Kimberley and Northern Territory or more widely, so are probably also widespread along the Pilbara coast. Palaemonid prawns are a possible exception and are probably restricted to the lower De Grey River.

As mentioned above, the Millstream wetlands support a range of rare and/or restricted species. Pinder *et al.* (in review), building on work by Masini (1988) and Ponder (1987), identified an assemblage of species that is restricted to a small number of springs and spring fed pools. Most members of this assemblage are widely distributed but only found in selected permanently flowing springs (and some associated pools), including those at Millstream and Karijini National Parks plus Weeli Wolli Spring (Fortescue catchment), Nyeetbury Spring (Robe catchment) and Running Waters and Skull Springs (on the Oakover River). However, a small number of species, including some from this assemblage, are known only from the surface water wetlands at Millstream within the Pilbara. These include the locally endemic damselfly *Nososticta pilbara*, the dragonfly *Nannophlebia injibandi*, assimineid snails, a pyralid moth (tentatively identified as *Margarosticha euprepialis*), a *Thraulus* mayfly, a *Notalina* caddisfly plus several water mites and dipterans. We collected some of these from Deep Reach during this project. While some of these are known from elsewhere in Northern Australia, populations in the Pilbara appear to be dependant on Millstream wetlands. This is in addition to the well recognised Millstream stygofauna community, some species of which occasionally occur in surface waters.

Hypothesis 2 is supported to a large extent. There is a very small component of the Pilbara fauna that is more common in river pools on the Roebourne Plains than in pools along more inland reaches of the same rivers. However, most these are unlikely to be restricted to particular pools or even to particular rivers, most are not restricted to the coastal reaches and most are not even endemic to the Pilbara.

Hypothesis 3. That there are no relationships between aquatic invertebrate communities and pool characteristics such as size, permanence, depth and habitat characteristics that may be affected by groundwater extraction.

Few relationships between macroinvertebrate richness and measured environmental variables were evident. The presence of macrophytes is frequently associated with increased richness compared to bare sediment and this appears to be the case in these pools. Abundance of leaf litter was also associated with higher richness of invertebrates. Our data suggest that there are no relationships between richness and depth at which a sample was taken, maximum depth category of the pool or remotely sensed pool size and permanence data. There were also no relationships between pool invertebrate richness and these variables for river pools sampled during the Pilbara Biological Survey. There are some limits to these interpretations. The depth and permanence gradients were not well sampled at their lower extents. Thus, almost all of the pools sampled for invertebrates are permanent and those that are not permanent do not dry very frequently. Likewise with depth, only one pool was less than one metre deep when sampled. Had these gradients been more thoroughly sampled we may have been able to detect more of a relationship between them and richness, at least in terms of a threshold response. Since there are no obvious relationships between richness and pool size, permanence or depth within the sampled ranges of these gradients, an interim conclusion might be that the extremes of values of these variables can be used as default ecological water requirement thresholds. For example, the minimum pool depth recorded during the survey was 76 cm, but there was no evidence that this pool had lower invertebrate richness than many of the deeper pools. As a default, this depth (or 1 metre to include a buffer) could be used as a minimum required depth in the absence of more information on the faunas of shallower pools.

However, evidence presented above would suggest that even regular drying of Pilbara river pools seems to have little effect on the richness and composition of invertebrate communities observed during later filling events. Analysis of data from the Pilbara Biological Survey suggests that pools that dried during one in three of the remotely sensed hydrological cycles have invertebrate communities that are at least as rich as pools that did not dry at all. Neither was frequency of drying strongly related to community composition in the PBS dataset or in the present study. If pools occasionally dry this should not have very much of an influence on the invertebrate communities that develop after a subsequent flood event, providing that refuges from drought occur further upstream so that there are sources of colonisation.

Community composition was weakly correlated with a large range of variables, which, in combination, explained a substantial proportion of community variation. Pool size and permanence were among these significantly correlated variables but were not as strongly correlated with composition as were a range of water chemistry and habitat variables.

Pools along the Yule River were particularly nutrient enriched and some had elevated chlorophyll concentrations, almost certainly as a result of intensive cattle disturbance. Richness of invertebrates does not appear to have been negatively affected by this enrichment (in fact there was relatively high richness in some of these pools) but nutrients and chlorophyll were weakly associated with community composition.

Hypothesis 3 is accepted with provisos. To the extent that the data allows, we can conclude that depth, permanency and pool size are not correlated with invertebrate communities to an extent that would allow thresholds to be recognised that are of relevance for developing rules for ecological water requirements. There was no relationship with pool depth above 76 cm (the minimum pool depth sampled) so this could be considered an interim minimum depth target for pools that currently maintain a depth greater than this throughout a hydrological cycle. Further work in shallower pools may reveal an even lower threshold. Pilbara river pool invertebrate faunas appear to be highly adapted to variable water regimes, including regular drying, providing that there are sufficient refuges in the system to allow reestablishment of populations following flood events.

Implications for managing groundwater resources

- There were significant differences between the invertebrate communities of the De Grey, Yule and Fortescue rivers, reflecting, at least in part, differences in the abiotic characteristics of pools. This means that none of the three catchments are redundant in terms of their ecological values and each river needs to be managed for its own values. However, part of the reason that the Yule river pools had communities that differed in composition from the rest may be that they were more heavily disturbed by cattle than were pools in the other two rivers. This impact had not reduced richness.

- River pools within each of the catchments contained a heterogenous array of aquatic invertebrates. None of these pools had redundant ecological values, in that a large proportion of species within each catchment were collected from single pools. It is a combination of pools that make up the fauna of the river. However, composition within any particular pool is unstable through time and most species would inhabit most of the pools within a section of a river at some stage over several hydrological cycles. This implies that there would not be a substantial impact on a river's fauna should a small proportion of pools be negatively affected by groundwater drawdown.

- Only a very small proportion of the Pilbara aquatic invertebrate fauna occurs more commonly in the higher order pools sampled during this project than in more upstream pools, and only 18 are known only from these pools to date. As a group these species are evenly distributed across the three rivers and, although most species are currently only known from one or two pools, most are unlikely to

have restricted distributions. The *Macrobrachium* prawn is likely to be an exception here and perhaps restricted to the most downstream pools on the De Grey. Most of these species are not even Pilbara endemics but the lowland pools may be particularly important for their persistence in the Pilbara.

- We have not identified any thresholds of pool characteristics that provide firm criteria for ecological water requirements. A depth of one metre is suggested as an interim threshold based on the observation that there was no effect of depth on invertebrate communities above about 75 cm. Many pools would become shallower than this under natural hydrological regimes, but such a threshold could be applied to pools that presently do not become as shallow as this. Even this threshold is likely to be conservative as there appears to be little difference in invertebrate richness or composition between river pools that are near permanent to permanent and those that regularly dry out towards the end of a hydrological cycle.

ACKNOWLEDGEMENTS

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APPENDIX 1: Locations and descriptions of sampled pools and data types collected

Pool	Pool name	Catchment	Date sampled	Site descirption	Latitude	Longitude	sample	sample description	Invertebrates	Physico-chemical	Macrophyte biomass	Ionic composition	Sediment composition
1	Homestead Pool	De Grey	18 Oct 2008	Large permanent pool at Station Homestead on the De Grey River. Moderately impacted by cattle.	-20.1754	119.1900	1	Dense macrophyte in shallow water	✓	✓	✓		
							2	Sparse macrophyte in shallow water	✓	✓	✓	✓	✓
							3	Sparse macrophyte in deep water	✓	✓	✓		
2	J96	De Grey	19 Oct 2008	Heavily impacted by cattle. Small permanent pool adjacent to proposed borefield.	-20.2318	119.1933	1	Dense macrophyte (Vallisnera/Ruppia/Potamogeton)		✓			
							2	Dense Chara in deep water		✓	✓	✓	✓
							3	Sparse macrophytes in shallow water (Niais/Chara/Ruppia/Nitella)		✓			
3	Muccang-arra Pool	De Grey	19 Oct 2008	Large permanent pool on the Ridley River. Moderately impacted by cattle.	-20.2405	119.1734	1	Moderate macrophyte (Vallisnera). Leaf litter abundant. Moderate small woody debris and logs	✓	✓	✓		
							2	Dense macrophyte (Vallisnera). Moderate leaf litter	✓	✓	✓	✓	✓
							3	Bare sediment	✓	✓			
4	Junction Pool	De Grey	19 Oct 2008	Medium permanent pool at confluence of Shaw and De Grey River	-20.2790	119.2007	1	Bare sediment		✓			
							2	Bare sediment. Moderate Large roots, fine roots and leaf litter in water		✓	✓	✓	✓
							3	Dense macrophytes (Niais)		✓			
5	Namagoorie Pool	De Grey	18 Oct 2008	Large permanent pool adjacent to existing borefield	-20.3309	119.3205	1	Bare sediment. Fine roots abundant. Moderate small woody debris and leaf litter	✓	✓			
							2	Dense macrophytes in shallow water	✓	✓	✓	✓	✓
							3	Bare sediment in deep water	✓	✓			
6	Marloo Pool	De Grey	18 Oct 2008	Medium sixzed permanent pool	-20.2629	119.2011	1	Dense macrophyte in deep water (Ruppia/Potamogeton)		✓			
							2	Bare sediment deep water		✓	✓	✓	✓
							3	Bare sediment shallow water		✓			
7	Coongeena-riner Pool	De Grey	20 Oct 2008	large permanent pool	-20.4212	119.4721	1	Dense macrophyte in deep water. Moderate fine roots, small woody debris, logs and leaf litter	✓	✓	✓		
							2	Moderate macrophyte	✓	✓	✓	✓	✓
							3	Sparse macrophyte in shallow water	✓	✓	✓		

Pool	Pool name	Catchment		Site descirption	Latitude	Longitude	sample	sample description	Invertebrates	Physico-chemical	Macrophyte biomass	Ionic composition	Sediment composition
8	Wardoom-oondene Pool	De Grey	20 Oct 2008	Medium sized pool	########	#########	1	Bare sediment		✓	✓	✓	✓
							2	Dense macrophyte. Moderate leaf litter		✓			
							3	Dense emergent vegetation (Eleocharis). Moderate leaf litter		✓			
9	Li Lin Pool	Yule	17 Oct 2008	Small permanent pool within borefield. Poor condition due to cattle	########	#########	1	Dense macrophytes in shallow water (Niais & Myriophyllum)	✓	✓	✓	✓	✓
							2	Dense macrophyte in shallow water (Myriophyllum)	✓	✓	✓		
							3	Bare sediment	✓	✓			
10		Yule	17 Oct 2008	Small permanent pool within borefield. Poor condition due to cattle	########	#########	1	Macrophyte		✓	✓	✓	✓
							2						
							3						
11	Highway Pool	Yule	16 Oct 2008	large pool at highway that can dry out during drought periods. Largely impacted by cattle.	########	#########	1	Bare sediment shallow water	✓	✓		✓	✓
							2	Bare sediment deep water	✓	✓			
							3	Moderate macrophyte in shallow water. Moderate leaf litter	✓	✓	✓		
12		Yule	17 Oct 2008	Medium pool. Not permanent. Only one habitat present	########	#########	1	Dense macrophyte in shallow water (Chara)		✓	✓	✓	✓
							2						
							3						
13	Jelliabidina Pool	Yule	17 Oct 2008	Small deep permanent pool with some rocky substrate	########	#########	1	Dense macrophyte in moderately deep water. Moderate leaf litter	✓	✓	✓	✓	✓
							2	Dense emergent vegetation close to bank. Moderate fine roots	✓	✓	✓		
							3	Dense macrophyte in moderately deep water (same as sample 1)	✓	✓	✓		
14		Yule	17 Oct 2008	medium sized semi permanent pool.	########	#########	1	Dense emergent vegetation (Typha). Moderate fine roots		✓	✓	✓	✓
							2	Dense macrophytes in deep water(Myriophyllum/Potamogeton). Moderate fine roots		✓			
							3						

Pool	Pool name	Catchment		Site descirption	Latitude	Longitude	sample	sample description	Invertebrates	Physico-chemical	Macrophyte biomass	Ionic composition	Sediment composition
15	Mungajee Pool	Fortescue	14 Oct 2008	Narrow possibly permanent pool. Western anabranch of the Fortescue River. Moderately impacted by cattle	########	#########	1	Bare sediment in shallow water. Moderate leaf litter	✓	✓			
							2	Bare sediment in deep water. Moderate leaf litter	✓	✓		✓	✓
							3	Bare sediment in shallow water. Moderate leaf litter and small woody debris	✓	✓			
16	Stewart Pool	Fortescue	13 Oct 2008	semi permanent pool	########	#########	1	Bare sediment in shallow water		✓			
							2	Bare sediment in deep water		✓	✓	✓	✓
							3	Moderate macrophyte in deep water		✓			
17	Bilanoo Pool	Fortescue	12 Oct 2008	medium sized semi permanent pool. Beneath highway near roadhouse	########	#########	1	Dense macrophyte (mixed Chara/Myriophyllum/ Eleocharis) in deep water. Moderate leaf litter	✓	✓	✓		
							2	Dense macrophyte (mixed Niais/Myriophyllum/Eleocharis/niais) in shallow water	✓	✓	✓	✓	✓
							3	Bare sediment in shallow water	✓	✓			
18	Tarda Pool	Fortescue	14 Oct 2008	Large permanent pool	########	#########	1	Dense macrophyte in shallow water		✓			
							2	Emergent vegetation in deep water		✓	✓	✓	✓
							3	Sparse macrophyte in deep water		✓			
19	Deep Reach	Fortescue	15 Oct 2008	Large deep permanent pool in Millstream National Park. Launched boat from picnic site and travelled about 1km downstream. Sediment is 100% organic (fine roots)	########	#########	1	Dense emergent vegetation on western bank (Eleocharis/Typha). Abundant fine roots. Moderate leaf litter	✓	✓	✓		
							2	Dense emergent vegetation (mixed) on southern end of pool. Abundant fine roots. Moderate leaf litter	✓	✓	✓	✓	✓
							3	Dense emergent vegetation (mixed) on eastern edge of bank. Abundant fine roots. Moderate leaf litter	✓	✓	✓		
20	Livistona Pool	Fortescue	15 Oct 2008	Medium sized deep permanent pool in Millstream National Park. Surrounded by dense emergent vegetation	########	#########	1	Dense emergent vegetation (Typha) on steep southern bank. Abundant fine roots		✓			
							2	Dense emergent vegetation (Typha and mixed species) on steep bank. Abundant fine roots		✓		✓	✓
							3			✓			

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
1	Nemertini	-	-	IH999999	Nemertini
2	Nematoda	-	-	II999999	Nematoda
3	Molluscs	Snails	Thiaridae	KG040102	*Plotiopsis australis*
4	Molluscs	Snails	Lymnaeidae	KG050103	*Austropeplea vinosa*
5	Molluscs	Snails	Planorbidae	KG070705	*Gyraulus hesperus*
6	Molluscs	Snails	Planorbidae	KG0711A0	*Ameriana* sp. P1
7	Molluscs	Snails	Planorbidae	KG0711A2	*Ameriana* sp. P3 (cf *bonushenricus*)
8	Molluscs	Snails	Assiminaeidae	KG210201	*Aviassiminea palitans*
9	Molluscs	Bivalves	Corbiculidae	KP020199	*Corbicula* sp.
10	Annelids	Tubificida	Naididae	LO050104	*Nais variabilis*
11	Annelids	Tubificida	Naididae	LO050201	*Dero digitata*
12	Annelids	Tubificida	Naididae	LO050202	*Dero nivea*
13	Annelids	Tubificida	Naididae	LO050203	*Dero furcata*
14	Annelids	Tubificida	Naididae	LO050401	*Allonais pectinata*
15	Annelids	Tubificida	Naididae	LO050403	*Allonais paraguayensis*
16	Annelids	Tubificida	Naididae	LO050501	*Pristina longiseta*
17	Annelids	Tubificida	Naididae	LO051701	*Aulodrilus pigueti*
18	Annelids	Tubificida	Naididae	LO052201	*Branchiura sowerbyi*
19	Annelids	Tubificida	Naididae	LO059999	Naididae (ex Tubificidae)
20	Annelids	Tubificida	Enchytraeidae	LO089999	Enchytraeidae
21	Mites	Water mites	Hydrachnidae	MM010199	*Hydrachna* sp.
22	Mites	Water mites	Limnocharidae	MM020101	*Limnochares australica*
23	Mites	Water mites	Eylaidae	MM030199	*Eylais* sp.
24	Mites	Water mites	Hydrodromidae	MM070199	*Hydrodroma* sp.
25	Mites	Water mites	Oxidae	MM090201	*Frontipoda spinosa*
26	Mites	Water mites	Oxidae	MM090302	*Oxus orientalis*
27	Mites	Water mites	Limnesiidae	MM120103	*Limnesia maceripalpis*
28	Mites	Water mites	Limnesiidae	MM120104	*Limnesia parasolida*
29	Mites	Water mites	Limnesiidae	MM120199	*Limnesia* sp.
30	Mites	Water mites	Limnesiidae	MM1201A5	*Limnesia sp. 4*
31	Mites	Water mites	Hygrobatidae	MM150303	*Australiobates vertriscutatus*
32	Mites	Water mites	Hygrobatidae	MM1503A4	*Australiobates queenslandensis*
33	Mites	Water mites	Hygrobatidae	MM1503A5	*Australiobates sp. P3 (nr crassisetus)*
34	Mites	Water mites	Hygrobatidae	MM150601	*Coaustraliobates minor*
35	Mites	Water mites	Unionicolidae	MM160399	*Neumania sp.*
36	Mites	Water mites	Unionicolidae	MM160501	*Recifella doomba*
37	Mites	Water mites	Unionicolidae	MM160502	*Recifella tinka*
38	Mites	Water mites	Unionicolidae	MM160599	*Recifella sp.*
39	Mites	Water mites	Unionicolidae	MM160602	*Unionicola crassipalpis*

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
40	Mites	Water mites	Unionicolidae	MM160604	*Unionicola neoaffinis*
41	Mites	Water mites	Unionicolidae	MM160699	*Unionicola sp.*
42	Mites	Water mites	Unionicolidae	MM1606A2	*Unionicola nr alpa*
43	Mites	Water mites	Unionicolidae	MM1606A3	*Unionicola nr vidrinei*
44	Mites	Water mites	Unionicolidae	MM1606A4	*Unionicola sp P1*
45	Mites	Water mites	Unionicolidae	XX000005	*Koenikea distans*
46	Mites	Water mites	Unionicolidae	XX000018	*Koenikea setosa*
47	Mites	Water mites	Unionicolidae	XX000019	*Koenikea branacha*
48	Mites	Water mites	Pionidae	MM170302	*Piona cumberlandensis*
49	Mites	Water mites	Aturidae	MM190102	*Albia rectifrons*
50	Mites	Water mites	Aturidae	MM1902A4	*Austraturus* sp. P3
51	Mites	Water mites	Aturidae	MM190399	*Axonopsella* sp.
52	Mites	Water mites	Aturidae	MM1903A1	*Axonopsella* nr *truza*
53	Mites	Water mites	Momoniidae	MM200101	*Momoniella nr australica*
54	Mites	Water mites	Mideopsidae	MM2101A0	*Gretacarus* n. sp. P1
55	Mites	Water mites	Arrenuridae	MM230104	*Arrenurus ensifer*
56	Mites	Water mites	Arrenuridae	MM230106	*Arrenurus tripartitus*
57	Mites	Water mites	Arrenuridae	MM230107	*Arrenurus vanderpalae*
58	Mites	Water mites	Arrenuridae	MM230113	*Arrenurus tricornutus*
59	Mites	Water mites	Arrenuridae	MM2301B0	*Arrenurus* sp. 9 (nr *pseudaffinis*)
60	Mites	Water mites	Arrenuridae	MM2301D7	*Arrenurus* sp. 22
61	Mites	Oribatids	-	MM9999A3	Oribatida group 1
62	Mites	Oribatids	-	MM9999C0	Oribatida group 5
63	Mites	Trombidioids	-	MM9999A6	Trombidioidea
64	Crustaceans	Shrimps	Atyidae	OT010303	*Caridina indistincta*
65	Crustaceans	Prawns	Palaemonidae	OT0201A1	*Macrobrachium* sp.
66	Insects	Beetles	Dytiscidae	QC090101	*Laccophilus sharpi*
67	Insects	Beetles	Dytiscidae	QC090308	*Hydrovatus weiri*
68	Insects	Beetles	Dytiscidae	QC090399	*Hydrovatus* sp.
69	Insects	Beetles	Dytiscidae	QC090401	*Hyphydrus elegans*
70	Insects	Beetles	Dytiscidae	QC090402	*Hyphydrus lyratus*
71	Insects	Beetles	Dytiscidae	QC090604	*Bidessodes denticulatus*
72	Insects	Beetles	Dytiscidae	QC090902	*Hydroglyphus orthogrammus*
73	Insects	Beetles	Dytiscidae	QC090907	*Hydroglyphus leai*
74	Insects	Beetles	Dytiscidae	QC090910	*Hydroglyphus grammopterus*
75	Insects	Beetles	Dytiscidae	QC091001	*Limbodessus compactus*
76	Insects	Beetles	Dytiscidae	QC091101	*Allodessus bistrigatus*
77	Insects	Beetles	Dytiscidae	QC091703	*Tiporus tambreyi*
78	Insects	Beetles	Dytiscidae	QC091815	*Sternopriscus pilbarensis*

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
79	Insects	Beetles	Dytiscidae	QC091899	*Sternopriscus* sp.
80	Insects	Beetles	Dytiscidae	QC092009	*Necterosoma regulare*
81	Insects	Beetles	Dytiscidae	QC092210	*Platynectes decempunctatus var decempunctatus*
82	Insects	Beetles	Dytiscidae	QC092602	*Batrachomatus wingi*
83	Insects	Beetles	Dytiscidae	QC092704	*Copelatus nigrolineatus*
84	Insects	Beetles	Dytiscidae	QC093602	*Cybister tripunctatus*
85	Insects	Beetles	Dytiscidae	QC093699	*Cybister* sp.
86	Insects	Beetles	Hydrophilidae	QC110199	*Georissus* sp.
87	Insects	Beetles	Hydrophilidae	QC110401	*Berosus australiae*
88	Insects	Beetles	Hydrophilidae	QC110406	*Berosus dallasi*
89	Insects	Beetles	Hydrophilidae	QC110413	*Berosus josephenae*
90	Insects	Beetles	Hydrophilidae	QC110422	*Berosus pulchellus*
91	Insects	Beetles	Hydrophilidae	QC110499	*Berosus* sp.
92	Insects	Beetles	Hydrophilidae	QC1104A2	*Berosus* nr *josephenae*
93	Insects	Beetles	Hydrophilidae	QC110605	*Laccobius matthewsi*
95	Insects	Beetles	Hydrophilidae	QC110701	*Regimbartia attenuata*
96	Insects	Beetles	Hydrophilidae	QC110902	*Paranacaena horni*
97	Insects	Beetles	Hydrophillidae	QC1109A0	*Paranacaena* sp. P1
98	Insects	Beetles	Hydrophilidae	QC111001	*Chaetarthria nigerrimus*
99	Insects	Beetles	Hydrophilidae	QC111101	*Enochrus elongatus*
100	Insects	Beetles	Hydrophilidae	QC111105	*Enochrus deserticola*
101	Insects	Beetles	Hydrophilidae	QC111199	*Enochrus* sp.
102	Insects	Beetles	Hydrophilidae	QC111204	*Helochares tatei*
103	Insects	Beetles	Hydrophilidae	QC111299	*Helochares* sp.
104	Insects	Beetles	Hydrophilidae	QC111601	*Paracymus pygmaeus*
105	Insects	Beetles	Hydrophilidae	QC111603	*Paracymus spenceri*
106	Insects	Beetles	Hydrophilidae	QC111901	*Sternolophus marginicollis*
107	Insects	Beetles	Hydrophilidae	QC111999	*Sternolophus* sp.
108	Insects	Beetles	Hydrophilidae	QC119999	*Hydrophilidae*
109	Insects	Beetles	Hydrophilidae	QC1199A0	Unknown hydrophillid P1
110	Insects	Beetles	Hydraenidae	QC130107	*Hydraena barbipes*
111	Insects	Beetles	Hydraenidae	QC130123	*Hydraena brittoni*
112	Insects	Beetles	Hydraenidae	QC1301a1	*Hydraena* nr. *rudallensis*
113	Insects	Beetles	Hydraenidae	QC130299	*Limnebius* sp.
114	Insects	Beetles	Hydraenidae	QC1303A0	*Ochthebius* sp. P1
115	Insects	Beetles	Hydraenidae	QC1303A1	*Ochthebius* sp. P2
116	Insects	Beetles	Hydraenidae	QC1303A3	*Ochthebius* sp. P4
117	Insects	Beetles	Hydraenidae	QC1303A5	*Ochthebius* sp. P5
118	Insects	Beetles	Scirtidae	QC209999	Scirtidae sp.

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
119		Beetles	Elmidae	QC3401A0	*Austrolimnius* WA sp. 1 (larvae)
120	Insects	Beetles	Elmidae	QC3401A1	*Austrolimnius* WA sp. 2
121	Insects	Beetles	Elmidae	QC340503	*Coxelmis* v.*fasciatus*
122	Insects	Beetles	Hydrochidae	QCA00107	*Hydrochus burdekinensis*
123	Insects	Beetles	Hydrochidae	QCA00110	*Hydrochus eurypleuron*
124	Insects	Beetles	Hydrochidae	QCA00121	*Hydrochus obscuroaeneus*
125	Insects	Beetles	Hydrochidae	QCA001A5	*Hydrochus* sp. P1
126	Insects	Beetles	Hydrochidae	QCA001A6	*Hydrochus* group 3 "black"
127	Insects	Beetles	Hydrochidae	QCA001A7	*Hydrochus* nr *burdekinensis*
128	Insects	Beetles	Hydrochidae	QCA001B1	*Hydrochus* sp. P5
129	Insects	Fly larvae	Tipulidae	QD019999	Tipulidae
130	Insects	Fly larvae	Tipulidae	QD0199A4	*Tipulidae* type E
131	Insects	Fly larvae	Tipulidae	QD0199B2	*Tipulidae* type P3
132	Insects	Fly larvae	Chaoboridae	QD050303	*Chaoborus punctilliger*
133	Insects	Fly larvae	Culicidae	QD070101	*Anopheles annulipes* s.l.
134	Insects	Fly larvae	Culicidae	QD070401	*Aedeomyia catasticta*
135	Insects	Fly larvae	Culicidae	QD070709	*Culex (Culex) annulirostris*
136	Insects	Fly larvae	Culicidae	QD070713	*Culex crinicauda*
137	Insects	Fly larvae	Culicidae	QD0707A5	*Culex* nr. *crinicauda*
138	Insects	Fly larvae	Culicidae	QD079999	Culicidae
139	Insects	Fly larvae	Ceratopogonidae	QD0904A3	*Bezzia* sp. P1
140	Insects	Fly larvae	Ceratopogonidae	QD0904A4	*Bezzia* sp. P2
141	Insects	Fly larvae	Ceratopogonidae	QD0904A7	*Bezzia* sp. P5
142	Insects	Fly larvae	Ceratopogonidae	QD0908A1	*Culicoides* sp. P2
143	Insects	Fly larvae	Ceratopogonidae	QD091399	*Lanatomyia* sp.
144	Insects	Fly larvae	Ceratopogonidae	QD0919A1	*Monohelea* sp. P2
145	Insects	Fly larvae	Ceratopogonidae	QD0919A4	*Monohelea* sp. P1
146	Insects	Fly larvae	Ceratopogonidae	QD0920A3	*Nilobezzia* sp. P1
147	Insects	Fly larvae	Ceratopogonidae	QD0920A4	*Nilobezzia* sp. P2
148	Insects	Fly larvae	Ceratopogonidae	QD0926A0	*Stilobezzia* sp P1
149	Insects	Fly larvae	Ceratopogonidae	QD0926A1	*Stilobezzia* sp P2
150	Insects	Fly larvae	Ceratopogonidae	QD0927A2	*Atrichopogon* sp. P1
151	Insects	Fly larvae	Ceratopogonidae	QD0928B2	*Forcypomyia* sp. P5
152	Insects	Fly larvae	Ceratopogonidae	QD0999A9	Dasyheleinae sp. P1
153	Insects	Fly larvae	Ceratopogonidae	QD0999B0	Dasyheleinae sp. P2
154	Insects	Fly larvae	Tabanidae	QD239999	Tabanidae
155	Insects	Fly larvae	Stratiomyidae	QD249999	Stratiomyidae
156	Insects	Fly larvae	Dolichopodidae	QD369999	Dolichopodidae
157	Insects	Fly larvae	Dolichopodidae	QD3699A0	Dolichopodidae sp. A

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
158	Insects	Fly larvae	Sciomyzidae	QD459999	Sciomyzidae
159	Insects	Fly larvae	Ephydridae	QD7899A6	Ephydridae sp. 2
160	Insects	Fly larvae	Ephydridae	QD7899B0	Ephydridae sp. 6
161	Insects	Fly larvae	Muscidae	QD8999A0	Muscidae sp. A
162	Insects	Fly larvae	Muscidae	QD8999B4	Muscidae sp. N
163	Insects	Fly larvae	Chironomidae	QDAE0101	*Clinotanypus crux*
164	Insects	Fly larvae	Chironomidae	QDAE0201	*Coelopynia pruinosa*
165	Insects	Fly larvae	Chironomidae	QDAE0401	*Fittkauimyia disparipes*
166	Insects	Fly larvae	Chironomidae	QDAE08A0	*Procladius* Pilbara sp. 1
167	Insects	Fly larvae	Chironomidae	QDAE1101	*Ablabesmyia hilli*
168	Insects	Fly larvae	Chironomidae	QDAE1102	*Ablabesmyia notabilis*
169	Insects	Fly larvae	Chironomidae	QDAE12A0	*Paramerina* sp.A (*parva*?)
170	Insects	Fly larvae	Chironomidae	QDAE12A3	*Paramerina* sp C
171	Insects	Fly larvae	Chironomidae	QDAE12A4	*Paramerina* sp D
172	Insects	Fly larvae	Chironomidae	QDAE1701	*Larsia albiceps*
173	Insects	Fly larvae	Chironomidae	QDAE99A8	*Pentaneurini* sp. P1
174	Insects	Fly larvae	Chironomidae	QDAE99B0	*Pentaneurini* sp. P3
175	Insects	Fly larvae	Chironomidae	QDAE99B1	*Pentaneurini* sp. P6
176	Insects	Fly larvae	Chironomidae	QDAF04A0	*Nanocladius* sp. 1 (VCD7)
177	Insects	Fly larvae	Chironomidae	QDAF0699	*Corynoneura* sp.
178	Insects	Fly larvae	Chironomidae	QDAF06A0	*Corynoneura* sp. P1
179	Insects	Fly larvae	Chironomidae	QDAF19A2	*Compterosmittia* sp. P1
180	Insects	Fly larvae	Chironomidae	QDAH03A3	*Cladotanytarsus* aff K4
181	Insects	Fly larvae	Chironomidae	QDAH0410	*Tanytarsus fuscithorax/semibarbitarsus*
182	Insects	Fly larvae	Chironomidae	QDAH0499	*Tanytarsus* sp.
183	Insects	Fly larvae	Chironomidae	QDAH04A7	*Tanytarsus* sp. H
184	Insects	Fly larvae	Chironomidae	QDAH04B2	*Tanytarsus* sp. P1
185	Insects	Fly larvae	Chironomidae	QDAH04B3	*Tanytarsus* sp. P4
186	Insects	Fly larvae	Chironomidae	QDAH04B4	*Tanytarsus* 'K12'
187	Insects	Fly larvae	Chironomidae	QDAH04B5	*Tanytarsus* sp. P5
188	Insects	Fly larvae	Chironomidae	QDAH04B6	*Tanytarsus* sp. P6
189	Insects	Fly larvae	Chironomidae	QDAH04B8	*Tanytarsus* sp. P7
190	Insects	Fly larvae	Chironomidae	QDAH04C0	*Tanytarsus* sp. P8
191	Insects	Fly larvae	Chironomidae	QDAH04C1	*Tanytarsus* sp. P9
192	Insects	Fly larvae	Chironomidae	QDAH04C2	*Tanytarsus* sp. P10
193	Insects	Fly larvae	Chironomidae	QDAH04C5	*Tanytarsus* sp. P12
194	Insects	Fly larvae	Chironomidae	QDAH06A2	*Paratanytarsus* sp. P1
195	Insects	Fly larvae	Chironomidae	QDAH06A3	*Paratanytarsus* sp. P2
196	Insects	Fly larvae	Chironomidae	QDAI0201	*Stenochironomus watsoni*

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
197	Insects	Fly larvae	Chironomidae	QDAI04A0	*Chironomus aff. alternans* (V24)
198	Insects	Fly larvae	Chironomidae	QDAI05A2	*Xenochironomus* sp P2
199	Insects	Fly larvae	Chironomidae	QDAI0606	*Dicrotendipes jobetus*
200	Insects	Fly larvae	Chironomidae	QDAI06A7	*Dicrotendipes* 'CA1' type 3
201	Insects	Fly larvae	Chironomidae	QDAI06B3	*Dicrotendipes* P5
202	Insects	Fly larvae	Chironomidae	QDAI06B4	*Dicrotendipes* 'CA1' Pilbara type 1
203	Insects	Fly larvae	Chironomidae	QDAI0701	*Kiefferulus intertinctus*
204	Insects	Fly larvae	Chironomidae	QDAI0706	*Kiefferulus tumidus*
205	Insects	Fly larvae	Chironomidae	QDAI0801	*Polypedilum leei*
206	Insects	Fly larvae	Chironomidae	QDAI0803	*Polypedilum griseoguttatum*
207	Insects	Fly larvae	Chironomidae	QDAI0804	*Polypedilum nubifer*
208	Insects	Fly larvae	Chironomidae	XX000004	*Polypedilum convexum*
209	Insects	Fly larvae	Chironomidae	QDAI0810	*Polypedilum watsoni*
210	Insects	Fly larvae	Chironomidae	QDAI08A4	*Polypedilum* sp. S1
211	Insects	Fly larvae	Chironomidae	QDAI08A5	*Polypedilum* sp. K1
212	Insects	Fly larvae	Chironomidae	QDAI13A1	*Skusella* nr "V12 ex-WA"
213	Insects	Fly larvae	Chironomidae	QDAI1901	*Cryptochironomus griseidorsum*
214	Insects	Fly larvae	Chironomidae	QDAI19A0	*Cryptochironomus aff griseidorsum*
215	Insects	Fly larvae	Chironomidae	QDAI20A0	*Demicryptochironomus* sp. P1
216	Insects	Fly larvae	Chironomidae	QDAI21A0	*Microchironomus* K1
217	Insects	Fly larvae	Chironomidae	QDAI23A0	*Harnischia* K1
218	Insects	Fly larvae	Chironomidae	QDAI25A1	*Parachironomus* K2
219	Insects	Fly larvae	Chironomidae	QDAI25A2	*Parachironomus* K1
220	Insects	Fly larvae	Chironomidae	QDAI99A1	Chironomini genus K2 sp. 1
221	Insects	Mayflies	Baetidae	QE020299	*Cloeon* sp.
222	Insects	Mayflies	Baetidae	QE0299A2	*Pseudocloeon hypodelum*
223	Insects	Mayflies	Leptophlebiidae	QE0615A1	*Thraulus* sp AV 1
224	Insects	Mayflies	Caenidae	QE080106	*Tasmanocoenis arcuata*
225	Insects	Mayflies	Caenidae	QE0801A1	*Tasmanocoenis* sp. M
226	Insects	Mayflies	Caenidae	QE0801A2	*Tasmanocoenis* sp. P
227	Insects	Mayflies	Caenidae	QE080202	*Wundacaenis dostini*
228	Insects	Water bugs	Mesoveliidae	QH520101	*Mesovelia hungerfordi*
229	Insects	Water bugs	Mesoveliidae	QH520104	*Mesovelia horvathi*
230	Insects	Water bugs	Mesoveliidae	QH520199	*Mesovelia* sp.
231	Insects	Water bugs	Hebridae	QH530101	*Hebrus axillaris*
232	Insects	Water bugs	Veliidae	QH560103	*Microvelia (Austromicrovelia) peramoena*
233	Insects	Water bugs	Gerridae	QH570101	*Rhagadotarsus anomalus*
234	Insects	Water bugs	Gerridae	QH570301	*Limnogonus fossarum gilguy*
235	Insects	Water bugs	Nepidae	QH610202	*Ranatra diminuta*

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
236	Insects	Water bugs	Belostomatidae	QH620201	*Diplonychus eques*
237	Insects	Water bugs	Gelastocoridae	QH6401A0	*Nerthra* n. sp. (nr *luteovaria*)
238	Insects	Water bugs	Corixidae	QH650505	*Micronecta annae illiesi*
239	Insects	Water bugs	Corixidae	QH650513	*Micronecta micra*
240	Insects	Water bugs	Corixidae	QH650516	*Micronecta virgata*
241	Insects	Water bugs	Corixidae	QH650599	*Micronecta* sp.
242	Insects	Water bugs	Corixidae	QH6505A4	*Micronecta* n. sp. P3
243	Insects	Water bugs	Corixidae	QH659999	Corixidae
244	Insects	Water bugs	Naucoridae	QH660105	*Naucoris subaureus*
245	Insects	Water bugs	Notonectidae	QH670405	*Anisops hackeri*
246	Insects	Water bugs	Notonectidae	QH670417	*Anisops nabillus*
247	Insects	Water bugs	Notonectidae	QH670499	*Anisops* sp.
248	Insects	Water bugs	Pleidae	QH6801A1	*Paraplea* n. sp. (ANIC 6)
249	Insects	Moth larvae	Pyralidae	QL019999	Pyralidae
250	Insects	Moth larvae	Pyralidae	QL0199A0	Pyralidae nr. sp. 39/40 of JHH (SAP)
251	Insects	Moth larvae	Pyralidae	QL0199A4	Pyralidae Pilbara sp 2
252	Insects	Moth larvae	Pyralidae	QL0199A6	Pyralidae Pilbara sp 4
253	Insects	Damselflies	Coenagrionidae	QO020401	*Argiocnemis rubescens*
254	Insects	Damselflies	Coenagrionidae	QO021001	*Ischnura aurora aurora*
255	Insects	Damselflies	Coenagrionidae	QO021101	*Pseudagrion aureofrons*
256	Insects	Damselflies	Coenagrionidae	QO021104	*Pseudagrion microcephalum*
257	Insects	Damselflies	Coenagrionidae	QO021199	*Pseudagrion* sp.
258	Insects	Damselflies	Coenagrionidae	QO021301	*Xanthagrion erythroneurum*
259	Insects	Damselflies	Coenagrionidae	QO029999	Coenagrionidae
260	Insects	Damselflies	Isostictidae	QO030201	*Eurysticta coolawanyah*
261	Insects	Dragonflies	Gomphidae	QO130302	*Austroepigomphus (Xerogomphus) gordoni*
262	Insects	Dragonflies	Gomphidae	QO130413	*Austrogomphus mjobergi*
263	Insects	Dragonflies	Libellulidae	QO170601	*Crocothemis nigrifrons*
264	Insects	Dragonflies	Libellulidae	QO170702	*Diplacodes haematodes*
265	Insects	Dragonflies	Libellulidae	QO171601	*Orthetrum caledonicum*
266	Insects	Dragonflies	Libellulidae	QO172601	*Zyxomma elgneri*
267	Insects	Dragonflies	Lindeniidae	QO220102	*Ictinogomphus dobsoni*
268	Insects	Dragonflies	Hemicorduliidae	QO300105	*Hemicordulia koomina*
269	Insects	Dragonflies	Urothemistidae	QO310201	*Macrodiplax cora*
270	Insects	Caddisflies	Hydroptilidae	QT030499	*Hellyethira* sp.
271	Insects	Caddisflies	Hydroptilidae	QT030999	*Orthotrichia* sp.
272	Insects	Caddisflies	Ecnomidae	QT080430	*Ecnomus pilbarensis*
273	Insects	Caddisflies	Ecnomidae	QT0804A1	*Ecnomus* sp. AV16
274	Insects	Caddisflies	Leptoceridae	QT2503A0	*Leptocerus* sp. AV2 (*atsou*?)

APPENDIX 2: Invertebrates recorded in the 30 sweep net samples

row #	Higher taxonomic groups		Family	LowestIDNC	*Taxon*
275	Insects	Caddisflies	Leptoceridae	QT250799	*Oecetis* sp.
276	Insects	Caddisflies	Leptoceridae	QT2507A2	*Oecetis* sp. Pilbara 4
277	Insects	Caddisflies	Leptoceridae	QT2507A3	*Oecetis* sp. Pilbara 5
278	Insects	Caddisflies	Leptoceridae	QT2507A4	*Oecetis* sp. Pilbara 2
279	Insects	Caddisflies	Leptoceridae	QT2507A5	*Oecetis* sp. Pilbara 1
280	Insects	Caddisflies	Leptoceridae	QT251099	*Triaenodes* sp.
281	Insects	Caddisflies	Leptoceridae	QT2510A0	*Triaenodes* sp. P1/P2
282	Insects	Caddisflies	Leptoceridae	QT251103	*Triplectides australis*
283	Insects	Caddisflies	Leptoceridae	QT251126	*Triplectides ciuskus seductus*
284	Insects	Caddisflies	Leptoceridae	QT259999	Leptoceridae

	Pool and sample																												
	Pool 1			Pool 3			Pool 5			Pool 7			Pool 9			Pool 11			Pool 13			Pool 15			Pool 17			Pool 19		
row #	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1																										1				
2				1	1																									
3	1		1	1	1	1	1	1	1	1	1	1													1	1			1	1
4																	1	1	1	1	1	1	1	1	1	1		1		1
5	1		1	1	1	1	1	1		1	1	1							1	1	1					1	1	1	1	1
6	1		1																	1		1	1			1				
7																	1													
8																												1	1	1
9			1		1			1		1	1	1																1	1	1
10																													1	
11																													1	
12																				1										
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16																									1	1				
17				1		1	1			1																				
18																									1	1				
19	1	1	1		1				1			1				1														
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24													1			1							1				1	1	1	1
25																												1	1	
26																1									1					
27													1	1								1	1	1	1					
28												1	1		1	1	1	1	1				1	1	1	1				1
29																						1								
30													1																1	1
31																1														
32																										1				
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34															1								1		1	1		1	1	
35													1	1		1	1	1			1									
36													1					1												
37														1		1							1	1	1	1				
38			1																		1	1	1							
39			1							1						1						1	1	1		1	1		1	

	Pool and sample																													
	Pool 1			Pool 3			Pool 5			Pool 7			Pool 9			Pool 11			Pool 13			Pool 15			Pool 17			Pool 19		
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APPENDIX 3: Invertebrates with greater representation in coastal river pools than in inland river pools

Group	Species	percentage of samples from coastal freshwater river pools with species	percentage of samples from inland clear freshwater river pools with species	percentage of samples from other wetland types with species (#)	Number of times more likely to occur in coastal river pools than in inland river pools	Catchments with presence of species in coastal sites	Comments
Water mite	*Koenikea setosa*	16.7	0.0*	0.0	only from coastal pools	Yule and Fortescue	northern Australian (Pilbara to NT)
Dipteran	Muscidae sp. A	22.2	0.0	0.0	only from coastal pools	De Grey and Fortescue	
Lepidopteran	Pyralidae nr sp. 39	11.1	0.0	0.0	only from coastal pools	De Grey	
Dipteran	*Skusella* nr "V12 ex-WA" (Cranston)	22.2	0.0	0.0	only from coastal pools	De Grey and Yule	
Water mite	*Unionicola* nr *vidrinei*	11.1	0.0	0.0	only from coastal pools	De Grey and Fortescue	
Trichopteran	*Cheumatopsyche dostinei*	11.1	0.0	2.5	only from coastal pools	De Grey	northern Australian, inhabits riffles
Oligochaete	*Aulodrilus pigueti*	23.5	1.4	0.0	16.5	De Grey	cosmopolitan
Coleopteran	*Copelatus nigrolineatus*	27.8	2.9	13.3	9.7	De Grey, Yule and Fortescue	northern Australian
Mollusc	*Ameriana* sp. P1	22.2	2.9	0.0	7.8	De Grey, Yule and Fortescue	
Water mite	*Encentridophorus sarasini*	11.1	1.4	12.5	7.8	De Grey	northern Australian
Hemipteran	*Georissus* sp.	11.1	1.4	2.5	7.8	De Grey and Yule	northern Australian
Water mite	*Unionicola* nr *alpa*	11.1	1.4	0.0	7.8	Yule and Fortescue	
Dipteran	*Culicoides* sp. P2	16.7	2.9	0.8	5.8	De Grey and Yule	
Hemipteran	*Micronecta robusta*	16.7	2.9	6.7	5.8	De Grey and Fortescue	pan continental
Dragonfly	*Macrodiplax cora*	22.2	4.3	0.8	5.2	De Grey	peripheral distribution in Australia, except south-east
Mollusc	*Ameriana* sp. P3 (cf *bonushenricus*)	5.6	1.4	0.8	3.9	Yule	
Water mite	*Arrenurus tricornutus*	5.6	1.4	2.5	3.9	De Grey	northern Australian
Water mite	*Australiobates vertriscutatus*	5.6	1.4	4.2	3.9	Yule	pan continental
Dragonfly	*Austrogomphus mjobergi*	22.2	5.7	2.5	3.9	De Grey	northern Australian
Mollusc	*Corbicula* sp.	22.2	5.7	1.7	3.9	De Grey	
Dipteran	*Dicrotendipes* sp. P5 (=*balciunasi*?)	11.1	2.9	4.2	3.9	De Grey and Fortescue	
Coleopteran	*Enochrus elongatus*	5.6	1.4	5.0	3.9	Yule	pan continental
Water mite	*Gretacarus bifalcisetus*	5.6	1.4	2.5	3.9	Fortescue	Pilbara endemic
Dragonfly	*Hemicordulia australiae*	5.6	1.4	2.5	3.9	Fortescue	southern Australian
Coleopteran	*Hydroglyphus basalis*	5.6	1.4	3.3	3.9	De Grey	northern Australian
Hemipteran	*Mesovelia horvathi*	5.6	1.4	0.8	3.9	Yule	northern Australian
Hemipteran	*Nerthra* n. sp. (nr *luteovaria*)	5.6	1.4	1.7	3.9	Yule	Pilbara endemic?
Dipteran	Pentaneurini sp. P3	11.1	2.9	0.0	3.9	De Grey and Yule	
Dipteran	*Tanytarsus* sp. P4	11.1	2.9	2.5	3.9	De Grey	
Dipteran	Tipulidae type P3 (nr SAP type D)	11.1	2.9	0.8	3.9	Yule and Fortescue	
Water mite	*Unionicola vidrinei*	5.6	1.4	1.7	3.9	De Grey	northern Australian
Water mite	*Australiobates* sp. P3	16.7	4.3	2.5	3.9	De Grey and Ashburton	
Trichopteran	*Triaenodes* sp. P1	50.0	14.3	10.8	3.5	De Grey, Yule, Fortescue and Ashburton	
Dipteran	*Cnephia tonnoiri*	22.2	7.1	5.0	3.1	De Grey, Fortescue and Ashburton	Western Australian
Dipteran	*Parachironomus* sp. 'K1'	22.2	7.1	10.0	3.1	De Grey and Yule	

* = recorded in inland pools in other studies

including saline and highly turbid pools

APPENDIX 4: Species assemblage descriptions from Pinder *et al.* (in review). Actual models provided in same publication

		Adjusted r^2 of Pinder *et al.* models
Assemblage 1	153 species occurring in deeper wetlands with flowing water and longer hydroperiods. The assemblage was under represented in the Fortescue and Roebourne Plains subregions, which have few springs, but was otherwise geographically widespread	0.67
Assemblage 2	52 common species, less speciose at springs and in highly turbid and/or ephemeral claypans than in other wetlands, richness was generally high in most wetlands	0.45
Assemblage 3	42 sparsely distributed assemblage with low richness other than in a few mostly permanent inland river pools	0.34
Assemblage 4	97 species occurring mostly in springs but also groundwater/hyporheic fed pools	0.73
Assemblage 5	69 species occurring mostly in large claypans and non-flowing river pools	0.28
Assemblage 6	56 species mostly ocurring in seasonal fresh to subsaline lentic waters, including moderately turbid claypans and pools, most of which were in the Fortescue and Roebourne Plains subregions, and in Fortescue Marsh when salinity was low	0.6
Assemblage 7	148 uncommon species occurring in a wide range of wetlands, though generally richer in springs and clear river pools than in claypans and turbid river pools	0.25
Assemblage 8	24 species mostly occurring in Millstream National Park wetlands plus a few other springs	-
Assemblage 9	21 species mostly occurring in rockpools and mildly turbid claypans and river pools	-
Assemblage 10	39 species tending to occur in mildly turbid waters	0.63
Assemblage 11	40 species of ephemeral wetlands, including highly turbid claypans, rock pools and creeks	0.62
Assemblage 12	20 species with a preference for saline waters	-
Assemblage 13	10 rare species occurring primarily in claypans	-