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Two aquatic bioregions proposed for the South Coast Region, Western Australia

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Abstract

A need for the development of a bioregionalisation for Australian rivers using aquatic fauna has been recognised. This study was aimed at delineating and describing interim aquatic bioregions for the South Coast region in Western Australia. Macroinvertebrates were collected from 33 waterways located across the region, and data were analysed using cluster analysis. Two broad aquatic bioregions were identified, the Western South Coast bioregion, consisting of rivers lying from Gardner River in the west to the Bluff River, and the Eastern South Coast bioregion, consisting of the Pallinup River through to the Thomas River in the east. Rivers located in the latter bioregion were significantly more saline, slightly more alkaline, and had higher levels of total nitrogen than those located in the Western South Coast bioregion. Many species proved significant in distinguishing the two bioregions. The successful implementation of a biotic classification method to delineate aquatic bioregions for the South Coast Region indicates that the approach may be easily instituted and adapted for other regions within Western Australia, and could be undertaken using macroinvertebrate data generated by past sampling programs.

Keywords: Aquatic bioregions, aquatic fauna, macroinvertebrates, South Coast Region, Western Australia

Introduction

Bioregionalisation is a form of spatial classification which delineates areas of relatively homogeneous features that are distinct from other regions (Omernik 1987; Jenerette *et al*. 2002; Kingsford *et al*. 2005; Mackey *et al*. 2008). The recognition of such areas aids the assessment of rivers based on ecological values, as it allows the scoring of criteria such as 'naturalness', 'representativeness', 'rarity' and 'diversity' relative to a particular river type (Dunn 2000; Bennett *et al*. 2002). The Interim Biogeographic Regionalisation of Australia (IBRA) is a continent-wide regionalisation of landscape patterns, based on climate, geomorphology, landform, and terrestrial biota (Thackway & Cresswell 1995). However, this regionalisation has been shown to have significant limitations for describing the distribution of riverine biota (Turak *et al*. 1999; Marchant *et al*. 2000; Turak & Koop 2008), as has been the case for other landscape classifications (Hawkins *et al*. 2000; Hawkins & Vinson 2000; Heino & Mykra 2006). This has led to a recommendation for the development of a national classification for Australian rivers using aquatic taxa (Hart & Campbell 1994; Kingsford *et al*. 2005). However, such a national riverine classification has yet to be developed, although there have been some regional and State-wide river classification initiatives, with Victoria and New South Wales (NSW) receiving the most attention. Newall & Wells (2000) produced both a physicochemical regionalisation and a macroinvertebrate regionalisation for Victoria, while Turak *et al*. (1999) classified river sites in New South Wales using a predictive model approach, mapping their 'site groups', and Turak & Koop (2008) suggested that the large-scale spatial patterns they observed in their study provided some indication of what appropriate freshwater ecoregions of NSW may look like. In another recent study, Growns & West (2008) defined six aquatic bioregions within NSW based on the theoretical natural distributions of native fish species. The delineation of aquatic bioregions for the South Coast region in Western Australia has yet to be attempted, while the only riverine bioregionalisation existing for Western Australia is the scheme of proposed freshwater fish biogeographic provinces suggested by Unmack (2001).

The overall objective of this project was to delineate and describe interim 'aquatic bioregions' for the South Coast region. This region is one of six recognised for Western Australia, all of which were established by the Commonwealth Government of Australia to facilitate the integrated delivery of natural resource management across Australia. The South Coast covers more than 5.4 million hectares, and includes all southerly-flowing rivers from near Walpole in the west to beyond Cape Arid in the east. Of the approximately 107 rivers or major tributaries occurring in the region, the Frankland River (about 200,000 ML annual average flow) is the largest. Three IBRA bioregions (incorporating four 'sub-regions') occur in the South Coast Region: the Fitzgerald (ESP1) and Recherche (ESP2) sub-regions which together make up the Esperance Plains (ESP) bioregion, the Warren (WAR) bioregion and the Jarrah Forest (JF) bioregion (Thackway & Cresswell 1995).

A universally accepted methodology for the identification and mapping of biogeographical regions is still to be developed (Mackey *et al*. 2008). A classification of rivers could be based on either biological or biophysical (*e.g*., geomorphic or hydrological) data, or a combination of these to define different bioregional types. Since previous testing of the Interim Biogeographic Regionalisation of Australia (IBRA) for representing aquatic ecosystems in Victoria found that this largely biophysical regionalisation was ineffective in characterizing macro-invertebrate assemblage distributions across that State (Marchant *et al.* 2000), an approach was adopted to delineate interim aquatic bioregions for the South Coast region based on macroinvertebrate community composition. Such an approach defined empirically-based bioregions for use in managing (and assessing ecological values) of aquatic ecosystems, rather than highlighting the causal factors behind the regionalisation. Geographical patterns were generated by agglomerating a number of spatial units (catchments) into groups based on a measure of biological similarity. This approach recognises that the resulting bioregions could be spatially disjunct, adjacent or nested, depending on the measured similarity (Mackey *et al*. 2008). Wells *et al.* (2002) used similar methodology to define aquatic bioregions for Victoria (see also Newall & Wells 2000). More specifically, this study aimed to (i) delineate aquatic bioregions for the South Coast region by grouping catchments using macro-invertebrate data, and (ii) examine the relevance of the existing IBRA regionalisation for in-stream biodiversity in the South Coast region at the catchment scale.

Methods

Study sites

Of a total of 183 sites from 33 waterways (Figure 1), sampled as part of an investigation of the ecological values of rivers in the region during 2006–2008, 146 sites were found to have relatively intact riparian zones, with minimal disturbance, and were thus deemed suitable for use in the present study (Table 1). These rivers represented a variety of systems from across the whole South Coast Region. As the western boundary of the South Coast Region has been under discussion, the Gardner, Shannon and Deep Rivers, all presently designated as South West Region systems, were also included the study. The location of each sampling site was recorded using a hand-held Magellan Meridian GPS using datum GDA 1984.

Table 1

River systems and sites used for determining aquatic bioregions in the South Coast Region. Rivers are listed from west to east.

River system	No. sites sampled
Gardner River	5
Shannon River	5
Deep River	5
Walpole River	2
Frankland Gordon	11
Bow River	2
Kent River	5
Kordabup River	1
Denmark River	4
Hay River	12
Sleeman River	2
Marbellup Brook	15
Seven Mile Creek	1
Bluff Creek	1
Goodga River	2
Limeburners Creek	1
Kalgan River	3
Waychinicup River	3
Pallinup River	7
Bremer River	6
Gairdner River	5
Fitzgerald River	9
Phillips West River	8
Steer River	1
Jerdacuttup River	4
Oldfield River	7
Young River	5
Coobidge Creek	2
Dalyup River	4
Bandy River	2
Coromup River	2
Dailey River	3
Thomas River	1

Macroinvertebrate sampling

For the sampling of macroinvertebrates, a 10 m stretch of stream located at the centre of a study reach was selected. This did not have to be contiguous, but was chosen to include all the in-stream habitats within the study reach. After disturbing the benthos using a combination of kick sampling and loosening of stones and large woody debris (if present) by hand, a 250–μm mesh net was used to sweep over 10 m^2 of streambed. After rinsing off the leaves, twigs and other debris, these were discarded. Each sample was sieved through three grades of sieves (2000 μm, 500 μm and 250 μm) and the contents placed in white trays to facilitate live picking. Using tweezers and plastic pipettes, as many as possible of the macroinvertebrates observed were picked out by two observers in a 30 minute period, placed into labelled containers with 70% ethanol, and returned to the laboratory for further processing, when all macroinvertebrate specimens were identified to the lowest level possible and counted. Consistency of identification with previous studies was achieved by examination of a voucher collection based within the Department of Environment and Conservation (DEC). Species codes for undescribed species were used as per this voucher collection. Debris from the three sieves was also placed in labelled sampling containers with 70% ethanol, and returned to the laboratory for further processing. In particular, macroinvertebrates that had been missed in the live pick were removed, identified and counted.

Measurement of water quality

Selected water quality variables were measured at all sites sampled for fauna. Electrical conductivity (mS/cm), salinity (ppt), pH, temperature (°C), dissolved oxygen content (mg/l and % saturation), oxidation reduction potential (mV) and turbidity (NTU) was measured, in-

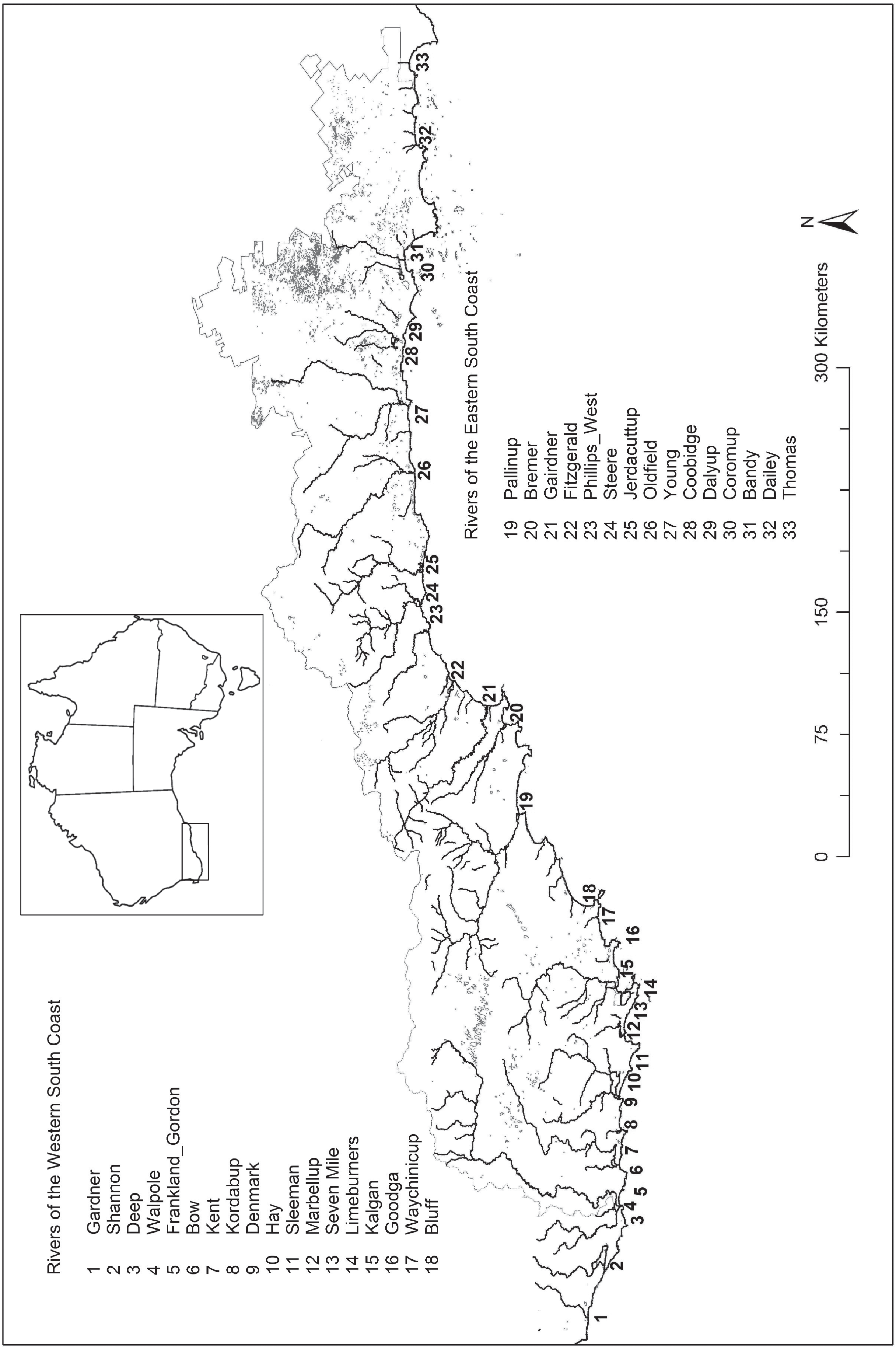

Figure 1. Map of South Coast Region showing location of waterways sampled.

situ, using a Yeo-Kal 611 multi-parameter water analyser. For analysis of total nitrogen and total phosphorus, unfiltered water samples were placed in appropriate containers, kept in a cool, dark place while in the field, and frozen immediately (– 20 °C) upon return to the laboratory. Nutrient analyses were conducted using a Lachat Automated Flow Injection Analyser operated by the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University, Western Australia.

Data analysis

Multivariate analyses were conducted to characterise the waterways based on invertebrate composition using the software package PRIMER v 6 (Primer-E Ltd). This software package consists of a range of univariate, graphical and multivariate routines for analysing matrices of species by samples (Clarke & Warwick 1994). Macroinvertebrate and environmental data were obtained from the 'least impacted' sites sampled for each waterway. These 'least impacted' sites were selected based on scores calculated for the 'width of riparian vegetation' and the occurrence and extent of degradation processes such as erosion, sedimentation, and weed infestation. Width of riparian zone was scored as follows: 0 = riparian vegetation absent, 1 = < 5m in width, 2 = 5–20m, 3 = 20–100m and 4 = > 100m. The presence of erosion, sedimentation and weed infestation in a given area was scored as follows: 0 = covering 0–5% of area assessed, 1 = 5–20%, 2 = 20–50% and 3 = >50%. Scores for the three degradation processes were added together to obtain an overall score for environmental degradation. Sites which had relatively intact riparian vegetation (scores of 3 or 4 for riparian width), and low levels of environmental degradation (overall score of 5 or less) were considered as being least impacted by threatening processes, and thus were used for the analyses. Data from all sites for each river system (catchment) were combined, and macro-invertebrate data was converted to presence/absence data before analysis (see Higgins *et al.* 2005). Following the calculation of Bray-Curtis dissimilarity measures, a cluster analysis was conducted using unweighted pair groups with mean averaging (UPGMA), and the result plotted as a dendrogram. Characteristic macroinvertebrate species (referred to as 'indicator' species) were determined for each of the

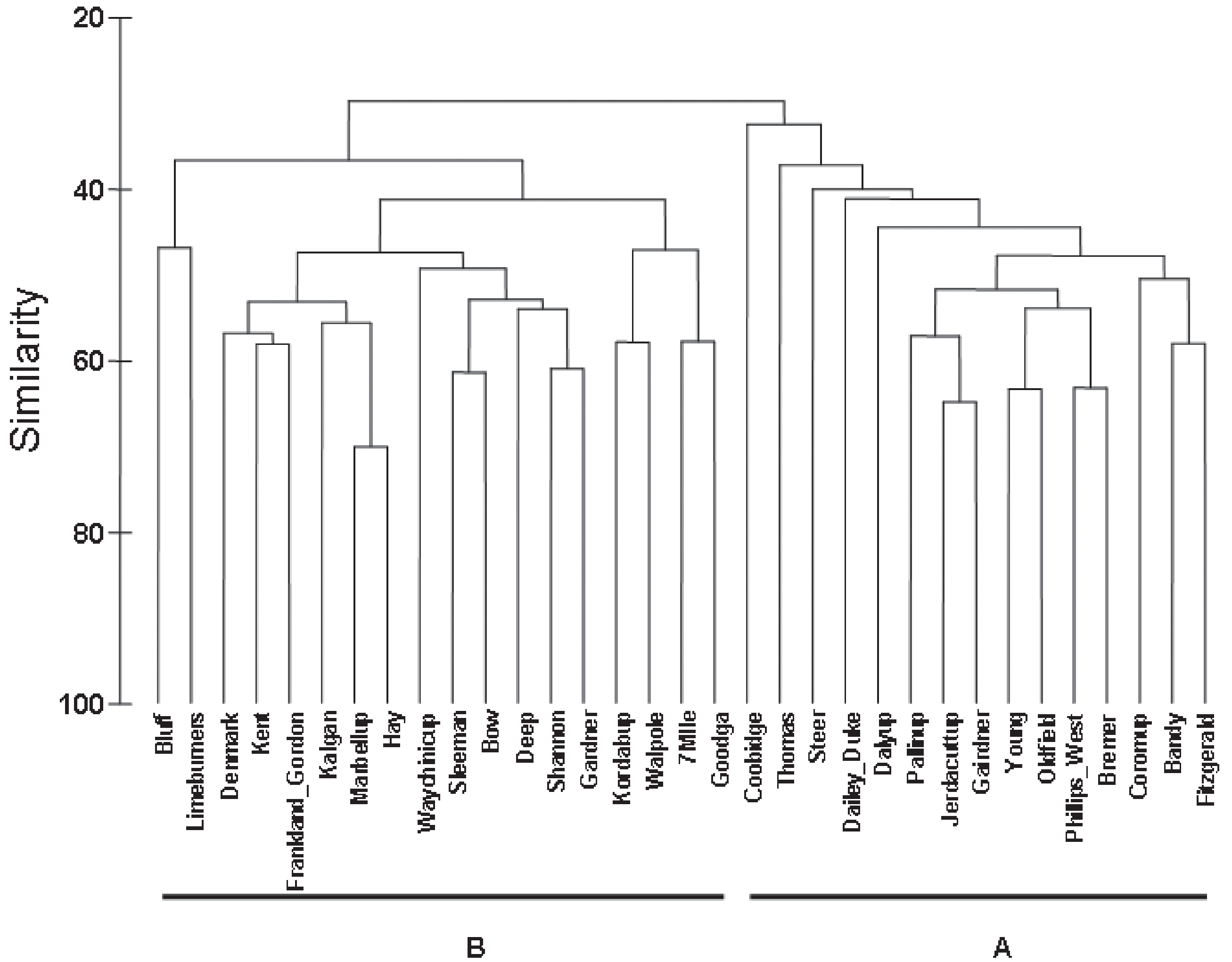

Figure 2. Dendrogram resulting from a hierarchical classification of rivers of the South Coast Region using macroinvertebrate data, showing the existence of two broad aquatic bioregions, (A) Eastern South Coast and (B) Western South Coast. Symbols indicate IBRA bioregions or subregions as follows: closed triangles, Recherche subregion; open triangles, Fitzgerald subregion; closed squares, Jarrah Forest bioregion; open squares, Warren bioregion.

bioregions using the SIMPER subroutine in PRIMER. In order to test the null hypothesis that there were no assemblage differences between the IBRA subregions, an analysis of similarities (ANOSIM) was conducted. Pairwise R values resulting from these analyses give an absolute measure of how well separated the groups are, ranging from a value of 0 for groups which are indistinguishable, to a value of 1, where all similarities within groups are less than any similarity between groups. For cases of few replicates, these pairwise R values can be interpreted as follows: R > 0.75, groups well separated; R > 0.50, groups overlapping but clearly different, and R < 0.25, groups poorly differentiated (Clarke & Warwick 1994).

After delineating bioregions using macroinvertebrate data, water quality data measured at the time of biological sampling (pH, salinity, turbidity, total nitrogen, total phosphorus and dissolved oxygen) were used to provide general descriptions of each bioregion. The mean total number of species (referred to as 'species richness' in the text) collected in a river system, as well as the mean numbers of mayfly, stonefly and caddisfly species (orders Ephemeroptera, Plecoptera and Trichoptera, the so-called 'EPT' taxa), macrocrustaceans (orders Decapoda, Amphipoda and Isopoda), microcrustaceans (classes Copepoda, Ostracoda and Branchiopoda), mites (order Acarina), beetles (order Coeloptera), true flies (order Diptera), bugs (order Hemiptera), dragonflies and damselflies (order Odonata) and snails, limpets and mussels (phylum Mollusca) were also determined for each bioregion. In order to test for significant differences between the two bioregions for water quality and biological variables, t-tests were conducted using the software statistical package GenStat.

Results

Delineation of bioregions

Based on a hierarchical classification using macroinvertebrate data, two distinct aquatic bioregions were recognized for the South Coast region: (i) Western South Coast, consisting of river systems lying from Gardner River in the west to Bluff River, and (ii) Eastern South Coast, consisting of the Pallinup River through to the Thomas River in the east (Figure 2). The two aquatic bioregions coincided with the geographical location of the river systems analysed (Figure 3).

Alignment of the two proposed aquatic bioregions with the IBRA bioregions was variable. The Eastern South Coast aquatic bioregion proposed in this study largely coincided with the Esperance Plains IBRA bioregion, with 15 of 17 rivers located in the IBRA Esperance Plains (ESP) bioregion clustering together. However, the grouping of rivers within the Eastern South Coast aquatic bioregion did not align with the two IBRA

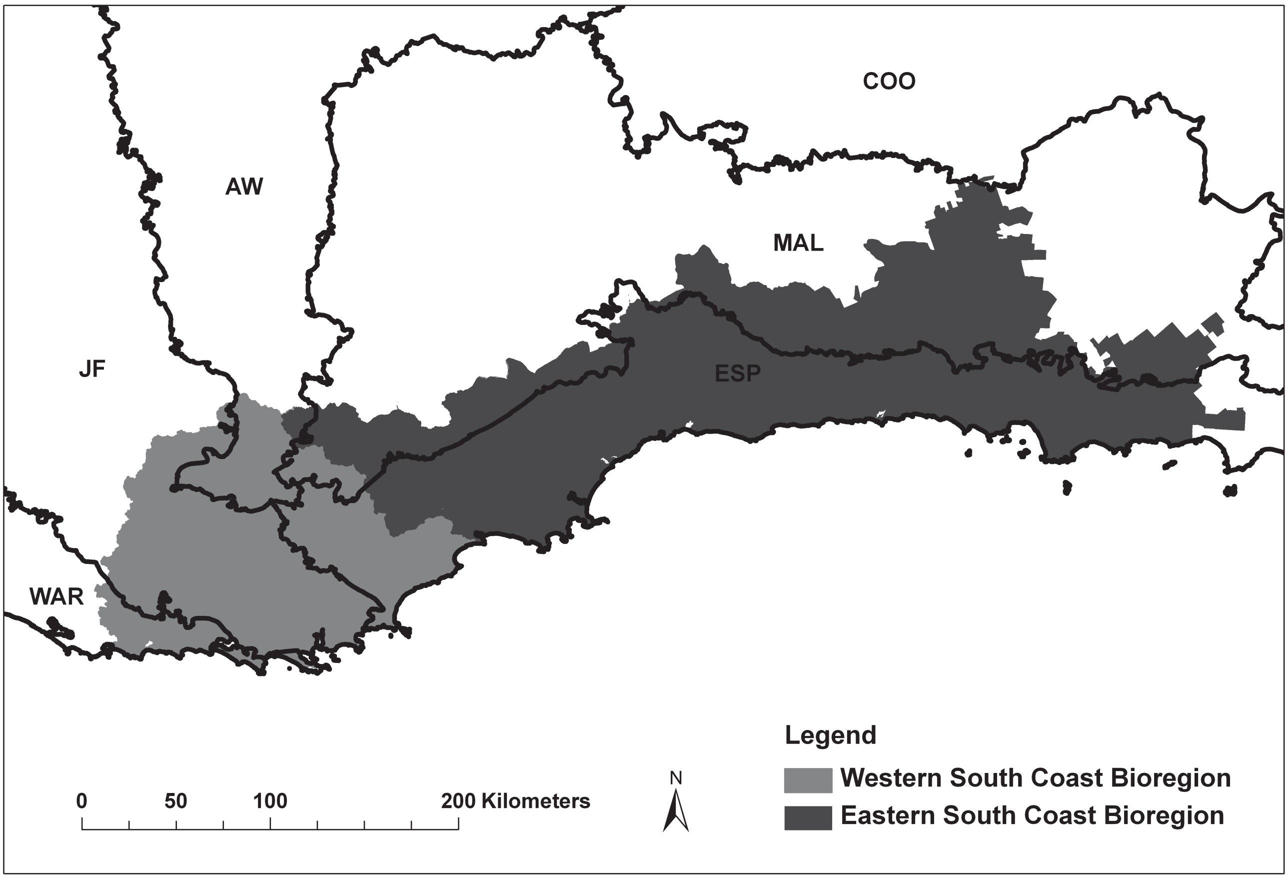

Figure 3. Map of South Coast Region showing location of aquatic bioregions, and boundaries of IBRA bioregions. ESP = Esperance Plains; WAR = Warren; JF = Jarrah Forest.

sub-regions that make up the Esperance Plains bioregion (Table 2). Rivers located in the Recherche sub-region (ESP2) were not more similar to each other than to systems located in the Fitzgerald sub-region (ESP1), and thus these two sub-regions were poorly differentiated (ANOSIM, R = 0.001, p = 0.4). In addition, the Bluff and Waychinicup Rivers (which fall into the Esperance Plains IBRA bioregion) grouped together with rivers located in the Warren and Jarrah Forest IBRA bioregions. All of the 16 rivers that fell into either the IBRA Warren or Jarrah Forest bioregions formed a single cluster which did not subdivide according to IBRA bioregions (R = 0.155, p = 0.06 for pairwise comparison of Jarrah Forest and Warren bioregions).

Water quality

Table 3 summarizes selected water quality parameters associated with each of the two aquatic bioregions defined using macroinvertebrate data. Rivers belonging to the Eastern South Coast aquatic bioregion were significantly more saline, slightly more alkaline, and had higher levels of total nitrogen than those belonging to the Western South Coast aquatic bioregion (t-test, $p < 0.05$). Rivers of both aquatic bioregions had similar levels of turbidity, dissolved oxygen and total phosphorus levels (t-test, $p > 0.05$). The bioregionalisation resulting from the use of invertebrate data was associated with a strong salinity gradient (Figure 4), with river systems falling into the Eastern South Coast region being naturally more saline than those falling into the Western South Coast aquatic bioregion.

Table 2

Results of pairwise comparisons using ANOSIM, showing R-values and significance levels. ESP1 = Fitzgerald sub-region; ESP2 = Recherche sub-region; JF2 = Southern Jarrah Forest sub-region; WAR = Warren bioregion.

Pairwise comparison	R-value	Significance level
ESP2, ESP1	0.001	40%
ESP2, JF2	0.830	0.1%
ESP2, WAR	0.854	0.1%
ESP1, JF2	0.327	1.0%
ESP1, WAR	0.441	0.6%
JF2, WAR	0.155	5.7%

Table 3

Water quality parameters associated with each of the two aquatic bioregions defined using macroinvertebrate data.

Parameter	Eastern South Coast bioregion	Western South Coast bioregion
Salinity (ppt)		
Minimum-maximum	6.45–43.84	0.17–10.52
Mean	23.29	1.50
Standard deviation	10.67	2.60
pH		
Minimum-maximum	4.39–8.74	4.35–8.04
Mean	7.38	6.07
Standard deviation	1.07	0.87
Turbidity (NTU)		
Minimum-maximum	0.0–167.6	0.65–32.17
Mean	24.7	13.83
Standard deviation	41.2	9.77
Total nitrogen (μg/l)		
Minimum-maximum	460–2833	195–1800
Mean	1483	935
Standard deviation	753	457
Total phosphorus (μg/l		
Minimum-maximum	7.0–140.9	9–430
Mean	54.3	85
Standard deviation	42.5	118
Dissolved oxygen (mg/l)		
Minimum-maximum	7.01–13.1	6.44–10.4
Mean	9.26	8.97
Standard deviation	1.97	1.13

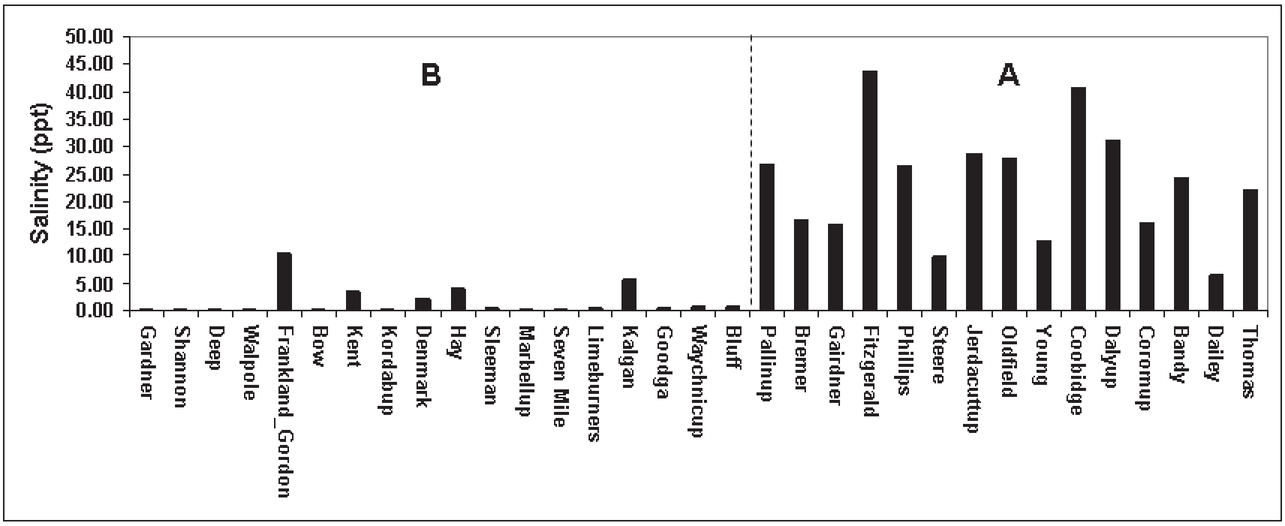

Figure 4. Plot of average salinity recorded for minimally impacted sites sampled from 33 river systems in the South Coast Region. Rivers have been plotted in geographical order from west to east.

In-stream biodiversity

Total species richness ranged from 15 to 79 taxa for river systems in the Eastern South Coast bioregion, and values ranged from 29 to 134 taxa for rivers in the Western South Coast bioregion (Table 4). Average total species richness (69.7) was significantly higher for the Western South Coast aquatic bioregion than for the Eastern South Coast bioregion (45.0) (t-test, $p < 0.05$).

A commonly used biotic index in the assessment of river health is the EPT index. This index is obtained by summing the total number of mayfly (order Ephemeroptera), stonefly (Plecoptera) and caddisfly species (Trichoptera). A significant proportion of the species that make up this index for the South Coast Region are endemic to southwestern Australia. The number of EPT taxa ranged from 0 to 6 for river systems in the Eastern South Coast bioregion, while values ranged from 2 to 25 for rivers in the Western South Coast bioregion (Table 3). Average EPT species richness (12.4) was significantly higher for the Western South Coast aquatic bioregion than for the Eastern South Coast bioregion (2.5) (t-test, $p < 0.05$). Rivers with particularly high numbers of EPT taxa for the Western South Coast bioregion were the Gardner, Shannon and Hay Rivers and Marbellup Brook.

Significant taxa

Many taxa were significant in terms of distinguishing the two aquatic bioregions (Table 5). For example, the amphipod *Perthia branchialis* was common in rivers of the Western South Coast bioregion (occurring in 88.9% of rivers sampled), but was absent in rivers in the Eastern South Coast bioregion. An undescribed paramelitid species was absent in rivers of the Western South Coast bioregion, but occurred in seven (46.7%) rivers in the Eastern South Coast bioregion. The distribution of several species of caddisfly (Order Trichoptera) also proved significant in terms of distinguishing the two aquatic bioregions. Forty-three species of caddisflies (order Trichoptera), from nine families have been recorded in southwestern Australia (Sutcliffe 2003), with about 70% of these being endemic to the region. These regionally endemic species generally coincide with the higher rainfall areas of the region, and a certain proportion of these species show further restriction within the high rainfall area (Sutcliffe 2003). A total of 35 species (in seven families) of caddisflies were collected in the present study, all of which occurred in the Western South Coast bioregion, while only six caddisfly species (all in the Family Leptoceridae) occurred in the Eastern South Coast bioregion. The most common of the 22 species in the family Leptoceridae found in the South Coast region were the southwestern Australian endemics, *Condocerus aptus* (72.2% of rivers in the Western South Coast bioregion), and *Lectrides paralis* (77.8%). Three species were found more frequently in the Eastern South Coast region than in rivers of the Western South Coast bioregion. *Symphitoneuria wheeleri*, known from South Australia and southwestern Australia and thought to be closely associated with saline waters (St Clair 2000) was found in 73.3% of rivers sampled in the Eastern South Coast bioregion, and only 11.1% (the Kalgan and Frankland Gordon River systems) of rivers in the Western South Coast bioregion. Similarly, *Notolina spira*, known to occur widely in Australia (St Clair 2000), was found in more Eastern South Coast bioregion rivers (40%) than in Western South Coast bioregion rivers (22.2%). Two species of the family Hydropsychidae were found in the Western South Coast bioregion, one of which is the southwestern Australian endemic, *Smicrophylax australis.* This species occurred in 44.4% of rivers, from the Gardner River through to the Kalgan River, and was absent in Eastern South Coast rivers.

Table 4

Total species richness, and species richness for selected groups for the two aquatic bioregions in the South Coast Region. Means that are significantly different are indicated by different letters, means that are not significantly different share the same letter.

Parameter	Eastern South Coast bioregion	Western South Coast bioregion
Total species richness		
Minimum-maximum	15 – 79	29 – 134
Mean	45[a]	69.7[b]
Standard deviation	20.2	31.4
EPT (mayflies, stoneflies, caddisflies)		
Minimum-maximum	0 – 6	2 – 25
Mean	2.47 [a]	12.44 [b]
Standard deviation	1.69	6.45
Macrocrustaceans (decapods, amphipods and isopods)		
Minimum-maximum	1 – 5	1 – 8
Mean	3.00 [a]	4.22 [b]
Standard deviation	1.20	1.96
Microcrustaceans (copepods, ostracods and branchiopods)		
Minimum-maximum	1 – 14	2 – 15
Mean	7.20 [a]	7.22 [a]
Standard deviation	3.78	3.61
Acarina (mites)		
Minimum-maximum	0 – 5	0 – 13
Mean	2.07 [a]	7.61[b]
Standard deviation	1.49	3.63
Coleoptera (beetles)		
Minimum-maximum	1 – 25	1 – 31
Mean	8.7 [a]	11.7 [a]
Standard deviation	6.63	9.22
Diptera (true flies)		
Minimum-maximum	5 – 13	6 – 22
Mean	8.80 [a]	11.22 [a]
Standard deviation	2.34	4.32
Hemiptera (bugs)		
Minimum-maximum	0 – 7	0 – 6
Mean	2.87 [a]	2.06 [a]
Standard deviation	2.39	2.01
Odonata (dragonflies and damselflies)		
Minimum-maximum	0 – 8	1 – 13
Mean	2.87 [a]	5.28[b]
Standard deviation	2.53	3.48
Mollusca (snails, limpets and mussels)		
Minimum-maximum	0 – 5	0 – 5
Mean	1.93 [a]	2.11 [a]
Standard deviation	1.39	1.68

Table 5

Role of individual species in contributing to the separation between the aquatic bioregions, listed in decreasing order of contributions.

Taxa	Eastern South Coast: Average abundance	Western South Coast: Average abundance	% contribution	Cumulative %
Perthia branchialis (Nicholls, 1974)	0	0.89	1.22	1.22
Hygrobatidae spp	0	0.89	1.17	2.39
Oxus spp	0	0.83	1.11	3.5
Lectrides parilis Neboiss, 1982	0	0.78	1.05	4.56
Stratiomyidae sp	0.93	0.28	1.03	5.59
Simuliidae spp.	0.13	0.83	1.02	6.6
Necterosoma penicillatus Clark, 1862	0.87	0.28	0.98	7.58
Tipulidae spp.	0.13	0.83	0.97	8.55
Tasmanocoenus tillyardi (Lestage, 1938)	0	0.72	0.96	9.52
Condocerus aptus Neboiss, 1982	0	0.72	0.94	10.46
Symphitoneuria wheeleri Banks, 1939	0.73	0.11	0.93	11.39
Newmanoperla exigua (Kimmins, 1951)	0	0.67	0.93	12.31
Coxiella spp.	0.73	0.11	0.91	13.22
Austroaeshna anacantha (Tillyard)	0	0.67	0.9	14.12
Unionicolidae spp	0.13	0.72	0.83	14.95
Cladocera spp.	0.4	0.89	0.83	15.78
Nematoda sp.	0.33	0.78	0.82	16.6
Empididae sp.	0.13	0.67	0.82	17.42
Scirtidae sp.	0.13	0.67	0.81	18.24
Ostracoda sp.1	0.13	0.67	0.8	19.04
Bibulmena kadjina Dean, 1987	0	0.56	0.8	19.83
Laccobius zietzi (Blackburn, 1895)	0.6	0	0.76	20.6
Calanoida spp	0.87	0.5	0.76	21.36
Hemicordulia tau (Selys, 1871)	0.13	0.61	0.76	22.11
Cherax pressii (Erichson, 1846)	0.13	0.61	0.75	22.86
Sternopriscus marginatus Watts, 1978	0	0.61	0.75	23.61
Miniargiolestes minimus (Tillyard, 1908)	0	0.56	0.73	24.34
Austrolestes annulosus (Selys)	0.6	0.17	0.73	25.07
Nyungara bunni Dean, 1987	0	0.56	0.72	25.79
Austragrion cyane (Selys, 1876)	0.6	0.28	0.71	26.5
Ferrissia sp	0	0.5	0.7	27.19
Ephidridae sp2	0.53	0.06	0.69	27.89
Trombidioidea spp	0.53	0.61	0.69	28.58
Ocetis sp.	0.47	0.61	0.69	29.26
Gomphodella spp	0	0.5	0.69	29.95
Palaemonetes australis Dakin, 1915	0.47	0.56	0.68	30.63
Isotomidae sp.	0.33	0.56	0.68	31.31
Veliidae/Hebridae spp.	0.6	0.67	0.67	31.98
Westralunio spp.	0.53	0.17	0.67	32.65
Orbatididae spp	0.6	0.78	0.65	33.3
Mytilocypris tasmanica chapmani McKenzie	0.53	0.17	0.65	33.95
Limbodessus inornatus (Sharp, 1882)	0.13	0.56	0.64	34.59
Limnoxenus zelandicus (Broun)	0.4	0.44	0.64	35.23
Paramelitidae sp.	0.47	0	0.62	35.85
Austrogomphus lateralis (Selys, 1873)	0.13	0.44	0.62	36.48
Micronecta robusta Hale, 1922	0.47	0.33	0.62	37.1
Ilyocypris australiensis Sars, 1889	0.47	0.22	0.61	37.7
Mesostigmata spp	0.13	0.44	0.6	38.31
Mytilocypris ambiguosa De Deckker, 1978	0.47	0.11	0.6	38.9
Harpacticoida spp	0.8	0.72	0.58	39.48
Hypogastruridae sp.	0.87	0.67	0.58	40.06
Orthocladinae spp	0.6	1	0.57	40.63
Paracymus pygmaeus (MacLeay, 1871)	0.13	0.5	0.57	41.2
Lepidoptera spp.	0.27	0.44	0.56	41.76
Sphaeromatidae sp	0.4	0	0.56	42.32
Culicidae Aedes spp.	0.4	0.11	0.56	42.88
Smicrophylax australis (Ulmer, 1908)	0	0.44	0.56	43.43
Ephidridae sp1	0.4	0	0.55	43.98
Sminthuridae sp.	0.27	0.33	0.55	44.53
Notalina spira St Clair, 1991	0.4	0.22	0.54	45.07
Aeshna brevistyla (Rambur)	0.27	0.33	0.54	45.61
Tanyderidae sp	0	0.39	0.54	46.16
Necterosoma regulare Sharp, 1882	0.4	0.11	0.54	46.7
Tabanidae sp	0.33	0.22	0.54	47.23
Chrysomelidae spp	0.13	0.39	0.53	47.76
Notodromadidae spp.	0.33	0.33	0.53	48.29
Triplectides australicus Banks, 1939	0.13	0.44	0.53	48.81
Arrenurus sp	0.2	0.33	0.52	49.34
Sternopriscus multimaculatus (Clark, 1862)	0.27	0.33	0.52	49.86
Curculionidae spp.	0.13	0.39	0.52	50.37
Notoperata tenax Neboiss, 1982	0	0.39	0.51	50.88

Mayflies (Order Ephemeroptera) and stoneflies (Order Plecoptera) were collected from a number of Western South Coast rivers, but were absent in rivers of the Eastern South Coast bioregion. Nine mayfly species were collected from the South Coast, seven of which belonged to the family Leptophlebiidae, the most diverse of the Australian mayfly families. Of these, six are known to be endemic to southwestern Australia. The endemic species *Bibulmena kadjina* was collected from more than half of the rivers sampled in the Western South Coast bioregion (55.6%). *Tasmanocoenus tillyardi* was also relatively common, occurring in 72% of rivers sampled. Despite high diversity in eastern Australia, only four species of stoneflies are known from Western Australia (Hynes & Bunn 1984). All of these are regionally endemic. The stonefly species *Newmanoperla exigua* occurred in 66.7% of the rivers of the Western South Coast bioregion and *Leptoperla australica* was found in 38.9% of rivers in this bioregion. Both species were absent in rivers of the Eastern South Coast bioregion.

Discussion

Classification of rivers based on macroinvertebrate data revealed two distinct aquatic bioregions in the South Coast region – the Western South Coast aquatic bioregion stretching from the Gardner River in the west to the Bluff River in the east, and the Eastern South Coast aquatic bioregion stretching from the Pallinup River in the west to the Thomas River in the east. These two site groups support the notion of large, relatively homogeneous regional patterns for aquatic biodiversity distribution in the South Coast Region of southwestern Australia. This is despite the fact that classifications based on numeric agglomerative approaches can often be characterised by groups with complex spatial patterns, where a group can have more than one geographical occurrence (Mackey *et al*. 2008). In order to determine whether these aquatic bioregions relate to the 'aquatic zoogeographic units' or the 'ecological drainage units' suggested by Higgins *et al*. (2005), a bioregionalisation for the whole of Western Australia would need to be conducted. Higgins *et al*. (2005) have suggested a hierarchical classification framework of four spatial levels for freshwater classification and biodiversity conservation planning – an aquatic zoogeographic unit; ecological drainage units within one aquatic zoogeographic unit; aquatic ecological systems within one ecological drainage unit; and macrohabitats within one aquatic ecological system. Aquatic zoogeographic units (generally 10,000–100,000 km^2) are distinguished by regional patterns of zoogeography, while ecological drainage units delineate areas with similar biotic patterns, but on a finer scale (1,000–10,000 km^2). The recognition of the latter through multivariate analysis of common species presence/absence data, as was adopted in this study, is a recommended approach (Higgins *et al*. 2005).

The recognition of aquatic bioregions is important for a number of reasons. For example, the relatively low Observed/Expected (O/E) scores (thus implying poor condition) obtained by Halse *et al*. (2007) for naturally saline, 'reference' (minimally disturbed) sites on the South Coast highlights the importance of assessing the condition (and ecological value) of rivers relative to their type. The AusRivAS (Australian River Assessment System) models used by these authors contained mainly freshwater reference site groups. These are clearly inappropriate for assessing naturally saline systems belonging to the Eastern South Coast aquatic bioregion, suggesting that the AusRivAS models for Western Australia should be refined to account for bioregional differences. Halse *et al*. (2002) have suggested that a regionally-based AusRivAS model needs to be developed to assess rivers located in the eastern part of the South Coast region, and that this model should use salinity as a predictor variable to assign sites to reference groups. These authors attributed the poor O/E scores for reference sites in their results for this region to the occurrence of high salinities in the area. The development of 'bioregion-specific' AusRivAS models for the whole of Western Australia could improve the sensitivity of this approach, enabling the detection of low to moderate levels of disturbance. Use of biotic indices such as the SIGNAL (Stream Invertebrate grade Number Average Level) index (Chessman 1995) and the Ephemeroptera-Plecoptera-Trichoptera (EPT) index would also be further enhanced if natural regional differences were to be incorporated into their use.

The results of this study suggest that the IBRA bioregions and sub-regions need to be further tested for applicability for describing aquatic biodiversity. As the present study was aimed at producing a broad, regional-scale classification, resulting in the recognition of homogeneous geographical regions, it was conducted at the catchment scale, rather than at the sub-catchment scale. While the Eastern South Coast aquatic bioregion proposed in this study aligns well with the Esperance Plains bioregion defined by IBRA, the catchment level analysis conducted in this study was not of a fine enough resolution to test the validity of using the Warren and Jarrah Forest IBRA bioregions for explaining in-stream biodiversity patterns. Although there are 13 rivers located in the Warren bioregion, only six of these (Gardner, Shannon, Deep, Walpole, Scott and Inlet Rivers) have their main catchments within the bioregion. Although assigned to this bioregion in the catchment-level analysis, the Kent, Frankland Gordon and Bow Rivers have only their lower reaches in the bioregion. The catchment scale approach, however, could be successfully used to test the applicability of the two IBRA sub-regions defined for the Esperance Plains bioregion, as the catchments of rivers in this bioregion fell largely in either one or other of these two sub-regions. This analysis showed that the existence of the two terrestrially derived IBRA sub-regions (Fitzgerald and Recherche) was not supported by the aquatic fauna.

Many species proved significant in distinguishing the two bioregions, including two species of amphipods, the perthiid *P. branchialis* and an undescribed paramelitid species. The families Perthiiidae and Paramelitidae are members of the Superfamily Crangonyctoidea, the most widespread and significant of Australian freshwater groups (Bradbury & Williams 1999). There is only one known genus in the family Perthiidae, with two species (*Perthia branchialis* and *P. acutitelson*), both of which are confined to southwestern Western Australia. To date, 10 paramelitid species (five species in the genus *Uroctena*, one species each in the genera *Hurleya*, *Protocrangonyx*, *Toulrabia*, *Totgammarus* and *Pilbarus*) have been described from Western Australia (Bradbury & Williams 1999). The species collected from the rivers of the Eastern South Coast bioregion was not one of these species. This amphipod was generally collected from sites along the lower reaches of rivers, and has a distribution ranging from the Jerdacuttup River through to the Thomas River, in the eastern part of the Eastern South Coast bioregion. This species requires taxonomic description.

Conclusions

The successful implementation of a biotic classification to delineate aquatic bioregions for the South Coast Region indicates that the method may be easily instituted and adapted for other regions within Western Australia. It certainly would be beneficial to extend the hierarchical classification approach adopted in the present study to the whole of the State of Western Australia. Such an approach would recognise larger biogeographical regions, subdivided into subregions, which are further characterised by variation among sites within subregions. Such a classification would be an essential first step in a larger process of conservation planning for freshwater biodiversity in Western Australia. The aquatic bioregionalisation would facilitate the assessment of river health and conservation through the setting of meaningful regional water quality guidelines, it would allow the selection of 'representative' river systems and monitoring sites within the context of a larger classification system of river types, and would also facilitate the development of broadly applicable management strategies and frameworks by water resource managers.

Although using biotic attributes to classify and define groups of waterways is likely to lead to the recognition of ecological meaningful classifications, this approach is data intensive, and can be hampered by the time and resources needed to collect biotic data. Past sampling program, such as the Australian-wide 'Australian River Assessment System' (AusRivAS) program have generated large macroinvertebrate datasets, and these have been used by some authors to define interim aquatic bioregions in other parts of Australia (*e.g.*, Turak *et al*. 1999). Once specimens have been identified to species level to improve resolution, these datasets could be used to define, and refine aquatic bioregions for other parts of Western Australia. The AusRivAS program in Western Australia sampled 477 sites in 1997–2000 and a further 188 sites in 2004 (Halse *et al.* 2007), thus generating a potentially useful database for delineating bioregions across Western Australia. Newall & Wells (2000) undertook a similar approach when they sourced large data sets for Victoria that had been gathered for State and national water quality monitoring programs (e.g., the Victorian component of the Monitoring River Health Initiative), and defined bioregions for the State.

Additional sampling would better define the boundary between two aquatic bioregions proposed for the South Coast region. A 'grey' area still exists in the area lying between the Bluff and Pallinup Rivers, as systems lying in this area (Wongerup Creek, Mulloculllop Creek, Cordinup River, Willyun Creek and Eyre River) were not included in this study. Inclusion of these systems in future analyses will further refine the exact location of bioregion boundaries, and will also confirm whether a transitional zone exists between the two broad aquatic bioregions. More data analyses at the subcatchment scale would also be required to test whether the two broad aquatic bioregions can be divided into aquatic sub-regions. It is probable that at the finer subregional scale, groupings will reflect the longitudinal nature of rivers, with upper reaches of adjacent systems being more similar to each other than the upper and lower reaches of a single system.

In addition, it is possible that the bioregionalisation produced here based on macro-invertebrates may not reflect differences in other aquatic biotic groups such as fish or plants, leading to the recommendation that the potential commonality in regionalisations of different groups of aquatic biota needs to be established (Growns & West 2008). Future research projects can thus treat the bioregionalisation proposed here as a working hypothesis (see Mackey *et al*. 2008) that can be tested for applicability to other aquatic groups as well as other types of waterbodies such as wetlands and lakes.

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