ECOLOGICAL VALUES OF WATERWAYS IN THE SOUTH COAST REGION, WESTERN AUSTRALIA

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FINAL REPORT
CENRM Report No CENRM079

Centre of Excellence in Natural Resource Management

The University of Western Australia

TITLE: **Ecological Values of Waterways in the South Coast Region, Western Australia**

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PRODUCED FOR: **DEPARTMENT OF WATER**
Albany

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DATE: **NOVEMBER 2008**

PUBLICATION DATA: **Cook, B. A., Janicke, G. & Maughan, J. 2008. Ecological values of waterways in the South Coast Region, Western Australia. Report No CENRM079, Centre of Excellence in Natural Resource Management, University of Western Australia. Report prepared for the Department of Water.**

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Executive summary

Background and objectives

- The South Coast Region in Western Australia contains approximately 107 rivers and major tributaries, ranging from larger, perennial systems, to smaller, often ephemeral streams. The ecological values of many of these systems are poorly understood. The overall objective of this project was thus to conduct a comparative assessment of the ecological values of selected river systems in the South Coast region. To achieve this objective, an "ecological" snapshot of selected rivers, covering the diverse range of aquatic environments found on the South Coast was undertaken.

- Activities included (i) the collation of existing ecological information on South Coast rivers using both published and unpublished sources, (ii) additional surveys of fauna and flora, habitat and water quality at 183 sites in 33 river catchments, covering a range of habitats, including river pools, (iii) the delineation and description of interim 'aquatic bioregions' for the South Coast region using macroinvertebrate data, (iv) the identification of 'hotspots' for species richness, and endemism using appropriate multivariate analyses, (v) the assessment of 'ecological values' of selected rivers systems using a recently developed Framework of criteria, indicators and measures, (vi) the exploration of the use of 'surrogate' taxa for tracking and mapping aquatic biodiversity in South Coast waterways, and, (vii) mapping of the presence of biodiversity and endemism 'hotspots' using the GIS software package ArcView.

Methods

- The presence and relative abundance of macro-invertebrates, fish, macrophytes (submerged and emergent vegetation) and macroalgae was recorded for each site.

In addition, the presence and relative abundance and condition of dominant foreshore plant species (trees, shrubs and groundcovers, sedges, grasses, herbs and weeds) was also recorded.

- Selected water quality variables were measured at all sites sampled for fauna and flora. These included total nitrogen, total phosphorus, electrical conductivity, salinity, pH, temperature, dissolved oxygen content, oxidation reduction potential and turbidity.

- Various habitat variables relating to the streambed and riparian condition were also recorded. These included relative abundance of submerged and emergent vegetation, filamentous algae, overhanging vegetation, leaf litter, small and large woody debris, snag piles, root masses substrate and open water, as well as the relative abundance of various substratum types (clay, mud, silt, sand, gravel, cobble, rock and bedrock). In addition to recording the proportion cover of foreshore vegetation, bank steepness, and evidence of erosion, slumping and sedimentation were also noted.

- For the bioregionalisation, an *a posteriori* approach was adopted to delineate interim aquatic bioregions for the South Coast region based on macroinvertebrate community composition. Macroinvertebrate and environmental data were obtained from the 'least impacted' sites sampled for each waterway. Data from all sites for each river system were combined, and converted to presence/absence data before analysis. 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. After delineating bioregions using macroinvertebrate data, environmental data were used to provide general descriptions of each bioregion.

- The 33 river systems were ranked according to their ecological values, as determined by three criteria (naturalness, diversity and rarity) using 12 indicators and 19 measures.

Results

- Based on a hierarchical classification using macroinvertebrate data, two broad 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. 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. Rivers of both aquatic bioregions had similar levels of turbidity, dissolved oxygen and total phosphorus levels.

- Total macroinvertebrate species richness ranged from 15 to 79 species for river systems in the Eastern South Coast bioregion, while values ranged from 29 to 134 species for rivers in the Western South Coast bioregion. Average total species richness (69.7) was significantly higher for the Western South Coast aquatic bioregion than for the Eastern South Coast bioregion (45). Species richness 'hotspots' in the Eastern South Coast bioregion were the Bremer and Phillips West Rivers. The Frankland Gordon, Kent, Hay and Marbellup systems appeared to be 'hotspots' for total species richness in the Western South Coast bioregion.

- The number of EPT taxa (mayflies - Order Ephemeroptera, stoneflies – Order Plecoptera and caddisflies – Order Trichoptera) 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. 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). Endemism 'hotspots' for the Western South Coast bioregion were the Gardner, Shannon and Hay Rivers and Marbellup Brook. All of the species recorded for the Eastern South Coast bioregion were either not endemic, or their endemism status was unknown.

- A number of species can be considered to be characteristic of the two bioregions. For example, of the five species of amphipods collected, two species (*Perthia branchialis* and *P. acutitelson*) were only found in rivers in the Western South Coast bioregion, while an undescribed species of Paramelitidae was only found in the eastern part of the Eastern South Coast bioregion. All nine mayfly species and both stonefly species collected only occurred in rivers of the Western South Coast bioregion. Similarly, 29 of the 35 species of caddisflies collected were only found in rivers of the Western South Coast bioregion. However, three species were found more frequently in the Eastern South Coast bioregion, and can thus be considered to be characteristic of that bioregion. These included *Symphitoneuria wheeleri*, also known from saline waters in South Australia. A similar pattern of distribution is also found for the dragonflies, with all of the 29 species collected occurring in the Western South Coast bioregion. Many of these species, such as the common *Austroaeschna anacantha*, were either absent, or rare in the rivers of the Eastern South Coast bioregion, despite being very common in western rivers. The Eastern South Coast bioregion did, however, contain one species of dragonfly (*Procordulia affinis*) and two species of damselflies (*Austroagrion cyane* and *Austrolestes annulosus*) of significance for the bioregion; with all three species being more common in eastern rivers than in the western rivers.

- A number of undescribed species were found in this study. These included an amphipod in the Family Paramelitidae, an isopod species in the Family Amphisopodidae, and a caddisfly species in the Family Hydroptilidae. An undescribed bivalve in the family Sphaeriidae was also found in rivers of the Eastern South Coast bioregion.

- The known ranges of a number of species were also extended. For example, the distribution of the Western Swamp Emerald dragonfly, *Procordulia affinis*, known previously from the Frankland Gordon catchment, was shown to include several Eastern rivers. Similarly, the koonac *Cherax preissi*, thought previously to occur only as far east as the Kalgan River, was found in the Gairdner and Bremer Rivers in the Eastern South Coast bioregion.

- Based on five indicators, rivers with the highest ranking for degree of 'naturalness' in the Western South Coast bioregion were the Shannon, Deep and Denmark Rivers. The lowest ranked waterway in this bioregion was the Sleeman River. The top three ranked rivers in the Eastern South Coast bioregion were the Oldfield, Jerdacuttup and Gairdner Rivers. The lowest ranked waterway was Coobidge Creek.

- Based on the scoring of four indicators, the most diverse of the waterways in the Western South Coast bioregion were the Shannon, Frankland Gordon and Gardner Rivers. Seven Mile Creek, Bluff Creek and Goodga River were least diverse in terms of the substrata, in-stream habitat and faunal diversity found in these systems. The Oldfield, Bremer and Jerdacuttup Rivers were the most diverse of the Eastern South Coast systems, while Coobidge Creek was the least diverse system.

- The criterion 'rarity' was scored using three indicators. River systems in the Western South Coast bioregion that ranked highest for rarity were the Shannon and Deep Rivers and Marbellup Brook. Rivers in the Eastern South Coast bioregion ranked highly for rarity were the Bremer, Gairdner, Fitzgerald and Phillips West Rivers.

- When naturalness, diversity and rarity were considered together to obtain an overall assessment of ecological value, the top three ranked rivers in the Western South Coast bioregion were the Shannon, Deep and Gardner Rivers. The top

three ranked rivers in the Eastern South Coast bioregion were the Bremer, Oldfield and Jerdacuttup Rivers.

Discussion

- The successful implementation of an *a posteriori* method 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. Additional sampling is also needed to clarify the delineation of bioregions in 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 were not included in the analysis. 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.

- There are a number of taxa which could be used as 'indicators' of river health for rivers in the Western South Coast bioregion, as they are generally widespread across the bioregion. These include the 46 species of mayflies, stoneflies and caddisflies collected from these rivers, as well as some macrocrustacean species which were also well represented in the bioregion. Similarly, the unidentified paramelitid amphipod species, caddisflies, damselflies, bivalves, snails and the Common Jollytail fish, *Galaxias maculatus* could be used as indicators of river health in rivers of the Eastern South Coast bioregion.

- By applying a consistent set of criteria and indicators that provided measures of naturalness, diversity and rarity, this project was able to successfully identify systems that could be considered as 'high conservation value aquatic ecosystems' (HCVAEs) in the South Coast Region.

- A number of other key waterways were not sampled as part of this project. These systems include the Lort and Hamersley Rivers in the Eastern South Coast bioregion, and the King Creek, Angove River, and the King River in the Western South Coast bioregion. A number of smaller systems also remain unsampled. Inclusion of these systems in future sampling aimed at determining the ecological values of South Coast Region would greatly enhance our knowledge of the area, and would provide a more complete picture of the ecological values of waterways in the Region.

Introduction

Background

Australian waterways are characterized by variable flows, both seasonally and from year to year, a divergence from the typical chemical composition for freshwaters worldwide, with sodium and chloride often dominant, and a high level of endemicity of its animals and plants (Williams, 1981). In addition, several animal groups have undergone an adaptive radiation, whilst other groups found commonly in waters worldwide are poorly represented, or even absent in waterways of Australia. For example, the fish fauna is characterized by low diversity, high endemicity, and the absence of 'primary' freshwater groups such as salmonids, percids and cyprinids. All of these characteristics play a role in defining the ecological values of Australian waterways.

The South Coast region contains approximately 107 rivers and major tributaries, ranging from larger to smaller systems, either perennial or ephemeral in nature. A comparative assessment of the ecological values of these systems has yet to be undertaken. To date, the focus of most data and information collection has been on water quality and riparian condition, although some data do exist on selected components of the biota as a result of published and unpublished surveys of fish and invertebrates across a number of systems. For example, a major undertaking of the Western Australian Salinity Action Plan was a biological survey of the Wheatbelt, and included the sampling of some waterways in the South Coast Region (Pinder et al., 2004). A recent University of Western Australia funded project on the distribution, genetics and conservation status of freshwater crayfish has led to a better understanding of this charismatic fauna in the region (Gouws et al., 2006). Although aimed at assessing water quality, the National River Health Program's AusRivAS biomonitoring system has also contributed to our understanding of in-stream biodiversity in South Coast rivers. Although this program gave only a superficial understanding of macroinvertebrate diversity, based on an

analysis to family level for a limited number of rivers across the south coast, subsequent further processing of samples by Karen Sutcliffe, a PhD candidate from Murdoch University has yielded more information on the distribution of three important macroinvertebrate groups (dragonflies, stoneflies and caddisflies) (Sutcliffe, 2003).

Ecological studies on selected waterways also exist in the literature. For example, Storey et al. (1993) examined the aquatic invertebrate fauna of the Goodga and Angove Rivers, and measured selected physical and chemical parameters such as salinity and pH.

Ecological values

Ecological value includes aquatic and riparian biota, river habitats and geomorphology, physical and biological river processes, and the role that rivers may play in sustaining other systems such as karst, estuaries, floodplains and wetlands (Dunn, 2000). Bennett et al. (2002) defined ecological values as "the natural significance of ecosystem structures and functions, expressed in terms of their quality, rarity and diversity. Significance can arise from individual biological, physical or chemical features or a combination of features." Based on broad scale support at both the national (Dunn, 2000; Bennett et al., 2002) and State level, a Framework is presently being developed by the Centre of Excellence in Natural Resource Management (CENRM) and the Department of Water (DOW), using the following five criteria to identify ecological values:

- Naturalness/condition,
- Representativeness,
- Diversity or richness,
- Rarity and
- Special features

There are a number of indicators (sometimes called attributes) and measures that could be used to assess each criterion, the choice of which will depend on the availability of data.

Naturalness

The ‘naturalness’ criterion assesses to what extent the waterway’s structures and functions are similar to natural, where the latter is assumed to mean a lack of human-induced disturbance. This criterion is thus a measure of the condition of a waterway. Condition assessments provide a measure of how much a system has changed relative to a nominated ‘benchmark’ or ‘reference’ condition. These assessments thus measure the level of disturbance or stress. Reference sites are usually ‘undisturbed’, or ‘least-disturbed’ waterways of a similar type. The proposed Framework uses six broad indicators to assess the ‘naturalness’ of a waterway unit (Appendix B). These are:

- Level of catchment disturbance
- Level of riparian zone disturbance
- Level of river channel disturbance
- Level of flow modification
- Variation from natural state of water chemistry
- Variation from natural state of in-stream biota

A comprehensive assessment would seek to rate the waterway unit for all of these indicators. Assessments based on limited data would seek to use as many of these indicators as is feasible.

Representativeness

The ‘representativeness’ criterion assesses to what extent a waterway has features typical of a type or class of waterways. This criterion can only be scored following a classification of waterways or waterway management units.

This Framework uses three broad indicators to assess the ‘representativeness’ of a waterway unit (Appendix B). These are:

- Hydrological regime

- Water quality characteristics
- Biotic characteristics

Diversity

The ‘diversity or richness’ criterion assesses to what extent a waterway has a range of biota and geomorphic features. Although biotic diversity can be measured at a range of scales (e.g. genetic, species, community and regional levels), it is most commonly measured for species or communities. Levels of diversity need to be assessed relative to values which could be expected for a particular river type.

This Framework uses six broad indicators to assess the ‘diversity or richness’ of a waterway unit (Appendix B). These are:

- Hydrological diversity
- Channel heterogeneity
- In-stream habitat heterogeneity
- Invertebrate diversity
- Vertebrate diversity
- Floral diversity

Rarity

The ‘rarity’ criterion assesses to what extent a waterway has an uncommon feature, or combination of features, such as unusual natural water chemistry, hydrology, geology or landscape features, or the presence of rare and threatened species.

This Framework uses six broad indicators to assess the ‘rarity’ of a waterway unit (Appendix B). These are:

- Unusual hydrological regimes

- Unusual water quality types
- Rare geomorphological and habitat features
- Presence of threatened and priority species and communities
- Presence of ‘flagship’ species
- Presence of rare or endemic species

Special features

The ‘special features’ criterion assesses to what extent a waterway has features which are uncommon within the landscape generally, or to what extent the waterway sustains other important ecosystems such as karst, estuary or floodplain wetlands, or to what extent the waterway might have other functions such as acting as a drought refuge, biodiversity corridor or environment for keystone or flagship species.

This Framework uses seven broad indicators to assess ‘special features’ of a waterway unit (Appendix B). These are:

- Drought refuge
- Maintenance of hydrological features
- Special biotic features
- Significant areas
- Refuge habitats
- Habitat for species of ‘special’ interest
- Significant scientific sites

A systematic assessment of the ecological values of the river systems of the South Coast Region has yet to be undertaken.

Bioregionalisation

Bioregionalisation is a form of spatial classification which delineates areas of relatively homogeneous features (Kingsford et al., 2005). The recognition of such areas is needed to assess 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. For example, classification of river types is essential for defining a reference condition against which existing 'naturalness' can be compared. It also provides a basis for assessing the relative 'rarity' and 'representativeness' of particular river types. The Interim Biogeographic Regionalisation of Australia (IBRA) is a continent-wide regionalization of landscape patterns, based on data on climate, geomorphology, landform, and terrestrial biota (Thackway & Cresswell, 1995). However, this regionalization has been shown to have significant limitations for riverine biota, and is thus a poor predictor of aquatic biodiversity (Turak et al., 1999; Marchant et al., 2000; Turak & Koop, 2008). This has led to a recommendation for the development of a national landscape classification for Australian rivers using aquatic taxa (Kingsford et al., 2005). However, such a national classification has yet to be developed, although there have been some regional and State-wide river classification initiatives, with Victoria receiving the most attention. Newall & Wells (2000) produced both a physicochemical regionalization and a macroinvertebrate regionalization for Victoria, while Doeg (2001) proposed aquatic bioregions for the State using a combination of landform, climate, geology, hydrology and macroinvertebrate and fish community structure. Turak et al. (1999) classified river sites in New South Wales using a predictive model approach, but did not define freshwater ecoregions for this State. Turak & Koop (2008) did, however, suggest that the large-scale spatial patterns they observed in their study provided some indication of what appropriate freshwater ecoregions of NSW may look like. The delineation of aquatic bioregions for the South Coast region has yet to be attempted.

This classification of rivers can be based on either biological or biophysical (e.g. geomorphic or hydrological) data to define different bioregional types. Use of data such

as climate zones or other physical criteria represents a 'top-down', or '*a priori*' classification. On the other hand, use of biological assemblage data represents a 'bottom-up', or '*a posteriori*' approach. Unmack's (2001) recognition of 'fish provinces' is an example of such a 'bottom-up' approach for delineating bioregions.

Objectives

The overall objective of this project was to conduct a comparative assessment of the ecological values of selected river systems in the South Coast region. To achieve this objective, an "ecological" snapshot of selected rivers, covering the diverse range of aquatic environments found on the South Coast was undertaken. More specifically, the project:

- Collated existing ecological information on South Coast rivers using both published and unpublished sources,
- Conducted additional surveys of fauna and flora, habitat and water quality at 183 sites along 33 river systems, covering a range of habitats, including river pools
- Delineated and described interim 'aquatic bioregions' for the South Coast region, using macroinvertebrate data,
- Identified the presence and location of special biodiversity hotspots, rare species, and areas of high endemism using appropriate multivariate analyses,
- Assessed the 'ecological values' of selected rivers systems using a recently developed Framework of criteria, indicators and measures,
- Explored the use of 'surrogate' taxa for tracking and mapping aquatic biodiversity in South Coast waterways, and,
- Mapped the presence of biodiversity and endemism 'hotspots' using the GIS software package ArcView.

Materials and methods

Site selection

Following preliminary analysis of existing data, and consultation with staff of the Department of Water, 183 sites from 33 waterways, representing a variety of systems from across the whole South Coast Region were selected for sampling (Table 1; Fig. 1). 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 study also included data from 28 sites from Marbellup Brook and 22 sites from the Hay River which were sampled as part of an investigation of the impacts of various land-uses on water quality and biodiversity of local waterways. The location of each sampling site was determined using a hand-held Garmin GPS using datum GDA 1984 (see Appendix A).

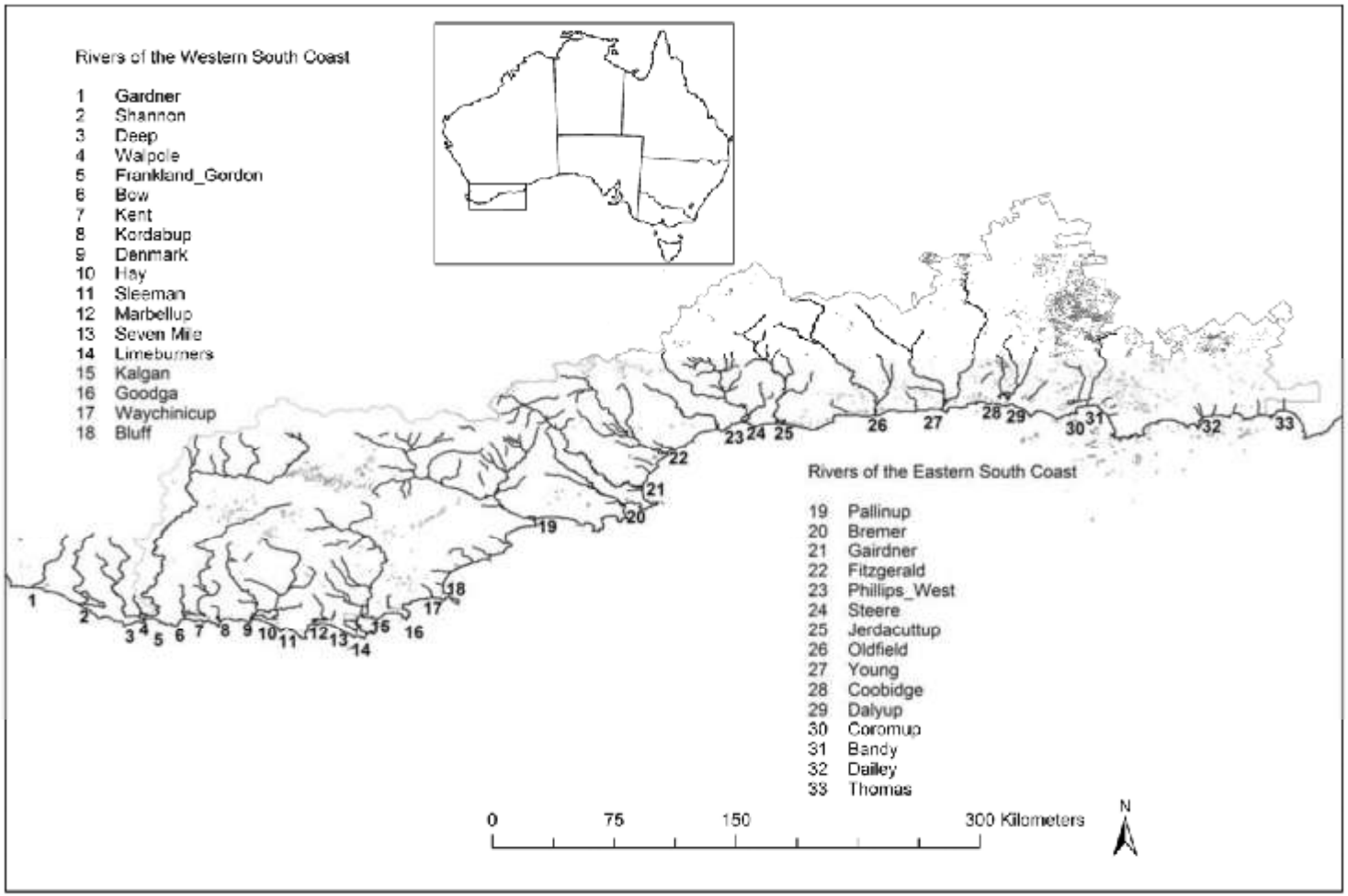

Figure 1: Map of South Coast Region showing location of river systems sampled.

Table 1: River systems and sites sampled in the South Coast Region.

River system	No. sites sampled	Date sampled
Gardner River	5	Nov 2007
Shannon River	5	Nov 2007
Deep River	5	Oct 2007
Walpole River	2	Oct 2007
Frankland Gordon	11	Oct, Nov 2007
Bow River	2	Oct 2007
Kent River	5	Oct 2007
Kordabup River	1	Oct 2007
Denmark River	7	Jun, Oct, Sep 2007
Hay River	22	Jun-Sep 2007
Sleeman River	2	Sep 2007
Marbellup Brook	28	Feb, May, Aug, Nov, Dec 2006; Jul 2007
Seven Mile Creek	1	Sep 2007
Bluff Creek	1	Aug 2007
Goodga River	2	Aug 2007
Limeburners Creek	1	Sep 2007
Kalgan River	11	Jan 2006; Dec 2007
Waychinicup River	3	Oct 2006
Pallinup River	8	Aug 2007
Bremer River	7	May 2006; Sep 2007
Gairdner River	5	Oct 2006
Fitzgerald River	9	Mar, Sep, Nov 2006
Phillips West River	8	Oct 2006
Steer River	1	Oct 2006
Jerdacuttup River	4	Oct 2006
Oldfield River	7	Aug 2006
Young River	5	Sep 2006
Coobidge Creek	2	Sep 2006
Dalyup River	4	Sep 2006
Bandy River	2	Sep 2006
Coromup River	2	Sep 2006
Dailey River	3	Sep 2006
Thomas River	1	Sep 2006

Sampling of fauna

For the sampling of macroinvertebrates, a 10m 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 $10m^2$ of streambed. After rinsing off the leaves, twigs and other debris, these were discarded. Each sample was sieved through three grades of sieves (2 mm, 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 in a 30 minute period, placed into labeled containers with 70% ethanol, and returned to the laboratory for further processing, when all macroinvertebrate specimens were identified to species level and counted. Exceptions to this were the taxa Oligochaeta, Hirudinea and Nematoda which were not identified further. 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 labeled sampling containers with 70% ethanol, and returned to the laboratory for further processing. In particular, macro-invertebrates that had been missed in the live pick were removed, identified and counted.

Fish were collected using a combination of netting techniques to maximise the likelihood of collecting a representative sample of fish. Baited fish traps with commercial cat food biscuits as bait and fyke nets were left overnight at each site. The fyke net was fitted with a polystyrene ball inside at the cod end to enable access to air for any air breathing fauna trapped in the net. All fish netting was conducted in accordance with the Fisheries Exemption Research Permit number 2007-5. Specimens were identified, counted and returned live to the waterway.

Voucher specimen collection

Specimens were used to prepare an identified voucher collection. All species were photographed using a digital camera attached to a dissecting microscope. These photos formed the basis of a photographic voucher collection which accompanies the voucher specimen collection.

Sampling of flora

The presence and relative abundance of macrophytes (submerged and emergent vegetation) and macroalgae was recorded for each site. In addition, the presence and relative abundance and condition of dominant foreshore plant species (trees, shrubs and groundcovers, sedges, grasses, herbs and weeds) was also recorded.

As a measure of planktonic algal activity, chlorophyll *a* and phaeophyton content in the water column was determined using the 90% acetone extraction, acid correction method, and the 100% acetone extraction, acid correction method, respectively (Clesceri et al., 1998). Analyses was undertaken by the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University, Western Australia.

Water quality and habitat variables

Selected water quality variables were measured at all sites sampled for fauna and flora. Electrical conductivity (mS/cm), salinity (parts per thousand), pH, temperature (degrees Celsius), dissolved oxygen content (mg/l and % saturation), oxidation reduction potential (mV) and turbidity (NTU) were measured, in-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 ^{0}C) upon return to the laboratory. Nutrient analyses was conducted using a nutrient autoanalyser operated by The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University, Western Australia.(NATA accredited).

Various habitat variables relating to the streambed and riparian condition were recorded. These included relative abundance of submerged and emergent vegetation, filamentous algae, overhanging vegetation, leaf litter, small and large woody debris, snag

piles, root masses substrate and open water. The relative abundance of various substratum types (clay, mud, silt, sand, gravel, cobble, rock and bedrock) was also recorded. In addition to recording the proportion cover of foreshore vegetation, bank steepness, and evidence of erosion, slumping and sedimentation were also noted.

A DVD outlining the main sampling methods used in this project has been produced. Entitled "Ecological Monitoring Methods Illustrated", a copy of this DVD has been attached to the final report.

Data analysis

Appropriate multivariate analyses were conducted using the software package PRIMER (similar attributes to PATN) to characterise the waterways based on invertebrate and fish composition and abundance. The software package PRIMER (Plymouth Routines in Multivariate Ecological Research) consists of a range of univariate, graphical and multivariate routines for analysing matrices of species by samples. Since the methods make few, if any assumptions about the form of the data, they are 'robust', leading to greater confidence in interpretation of community patterns. PRIMER has been used extensively worldwide, particularly in marine science, but increasingly in freshwater and terrestrial studies.

Delineation of bioregions

Previous testing of the Interim Biogeographic Regionalisation of Australia (IBRA) for representing aquatic ecosystems in Victoria found that this regionalization was ineffective in characterizing macroinvertebrate assemblage distributions across that State (Marchant et al., 2000). Thus, an *a posteriori* approach was adopted to delineate interim aquatic bioregions for the South Coast region based on macroinvertebrate community composition. Such an approach defines empirically-based bioregions for use

in managing (and assessing ecological values) of aquatic ecosystems, rather than highlighting the causal factors behind the regionalization. Wells et al. (2002) used similar methodology to define aquatic bioregions for Victoria (see also Newall & Wells, 2000). 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. Data from these selected sites for each river system were combined, and converted to presence/absence data before analysis. 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. After delineating bioregions using macroinvertebrate data, environmental data were used to provide general descriptions of each bioregion. Characteristic macroinvertebrate species were determined for each of the bioregions using the SIMPER subroutine in PRIMER.

Assessment of ecological values

The 33 river systems were ranked according to their ecological value, as determined by three criteria (naturalness, diversity and rarity) using 12 indicators and 19 measures (Appendix B; Table 2). The criteria and indicators used were a subset of those proposed in a draft framework for the management of waterways in Western Australia (Macgregor et al., 2008). When more than one measure was used for a particular indicator, a mean score was obtained for that indicator, and all the mean indicator scores were summed to obtain a total ecological value score. Mean scores for each of the three criteria were adjusted to give each an equal weighting for each criterion in the calculation of the overall total score. Bioregional differences were taken into account by modifying the scoring to account for the river type being assessed. All measures were scored on a scale of three, where a score of 1 indicated a lower ecological value, and a value of 3, a higher ecological value.

Table 2: Criteria, indicators and measures used to assess the ecological values of river systems in the South Coast region. Bioregion A: Eastern South Coast, Bioregion B: Western South Coast.

Criteria	Indicator	Measures used	Scoring
Naturalness	Level of catchment disturbance	% of natural vegetation cover remaining	1 = 0% - 32.99% 2 = 33% - 66.99% 3 = > 67%
	Level of riparian zone disturbance	Width of intact, native riparian zone	1 = < 5m in width 2 = 5-20 m 3 = > 20 m in width
		Canopy cover of native vegetation	1 = absent to < 25% 2 = 25-50% 3 = > 50%
		Presence of understorey weeds	1 = > 50% cover 2 = 20-50% 3 = < 20% cover
	Level of river channel disturbance	Presence and extent of bank erosion	1 = > 50% 2 = 20-50% 3 = < 20%
		Presence and extent of sedimentation	1 = > 50% 2 = 20-50% 3 = < 20%
	Variation from natural state of water chemistry	Extent to which salinity varies from natural	Bioregion A: 1 = > 35 ppt 2 = 25-35 ppt 3 = < 25 ppt Bioregion B 1 = > 5 ppt 2 = 2-5 ppt 3 = < 2 ppt
		Extent to which TP varies from natural	1 = > 100 µg/l 2 = 50-100 µg/l 3 = < 50 µg/l
		Extent to which TN varies from natural	1 = > 1500 µg/l 2 = 1000-1500 µg/ 3 = < 1000 µg/l
	Variation from natural state of biota	Species richness	Bioregion A 1 = < 30 spp 2 = 30-45 spp 3 = >45 spp Bioregion B 1 = < 45 spp 2 = 45-70 spp 3 = > 70 spp

		EPT	Bioregion A: 1 = < 2 spp 2 = 2-3 spp 3 = > 3 spp Bioregion B: 1 = < 8 spp 2 = 8-12 spp 3 = > 12 spp
Diversity	In-stream habitat heterogeneity	Index of in-stream habitat diversity based on total % cover of submerged, emergent & overhanging vegetation, leaf litter, woody debris & snags	Bioregion A: 1 = 0-4 points 2 = 5-8 points 3 = > 8 points Bioregion B: 1 = 0-7 points 2 = 8-14 points 3 = > 14 points
	Channel heterogeneity	Index of substrata diversity based on total % cover of clay, mud, peat, sand, gravel, cobble & rock	1 = 1 point 2 = 2-3 points 3 = > 3 points
	Invertebrate diversity	Total macro-invertebrate species richness	Bioregion A: 1 = < 26 2 = 26-53 3 = > 53 Bioregion B: 1 = <45 2 = 45-90 3 = >90
	Vertebrate diversity	Total fish species richness (Bioregion A: native freshwater and estuarine species; Bioregion B: native freshwater fish species only)	Bioregion A: 1 = 0-1 spp 2 = 2-3 spp 3 = > 3 spp Bioregion B: 1 =0-2 spp 2 =3-4 spp 3 => 4 spp
Rarity	Flagship species	Number of endemic decapod species	Bioregion A: 1 = no endemic decapods 2 = shrimps, but no koonacs present

			3 = koonacs present Bioregion B: 1 = < 2 spp of endemic crayfish 2 = 2-3 spp of endemic crayfish 3 = 4 spp of endemic crayfish
	Endemic or rare species	Number of endemic mayfly species (Bioregion B only)	Bioregion B: 1 = 0 -1 sp 2 = 2 spp 3 = 3-4 spp
		Number of caddisfly species (Bioregion A: all species; Bioregion B: species endemic to southwestern Australia only)	Bioregion A: 1 = < 2 spp 2 = 2-3 spp 3 = 4-6 spp Bioregion B: 1 = 0 – 3 spp 2 = 4 -7 spp 3 = 8 – 12 spp
	Threatened species	Number of listed fish species	1 = No threatened species 2 = Either *L. salamandroides* or *N. balstoni* present 3 = *G. truttaceus* present

The 'level of catchment disturbance' indicator was scored by measuring the % of natural vegetation cover remaining in a given catchment , as inferred from GIS shapefiles for remnant vegetation. The remaining indicators were scored using data collected from each site.

Results

Delineation of bioregions

Macroinvertebrate bioregionalisation

Based on a hierarchical classification using macroinvertebrate data, two broad 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 (Fig. 2). Although these aquatic bioregions coincided with the geographical location of the river systems analysed (Fig. 3), they did not align strongly with the IBRA sub-regions. For example, rivers located in the Recherche sub-region were not more similar to each other than to systems located in the Fitzgerald sub-region. However, alignment with IBRA bioregions was better, with 15 of 17 rivers located in the Esperance Plains bioregion clustering together. The Bluff and Waychinicup Rivers (which fall into the Esperance Plains IBRA bioregion) grouped together with rivers located in the Warren and Jarrah bioregions. All of the latter rivers formed a single cluster which did not subdivide according to IBRA bioregions.

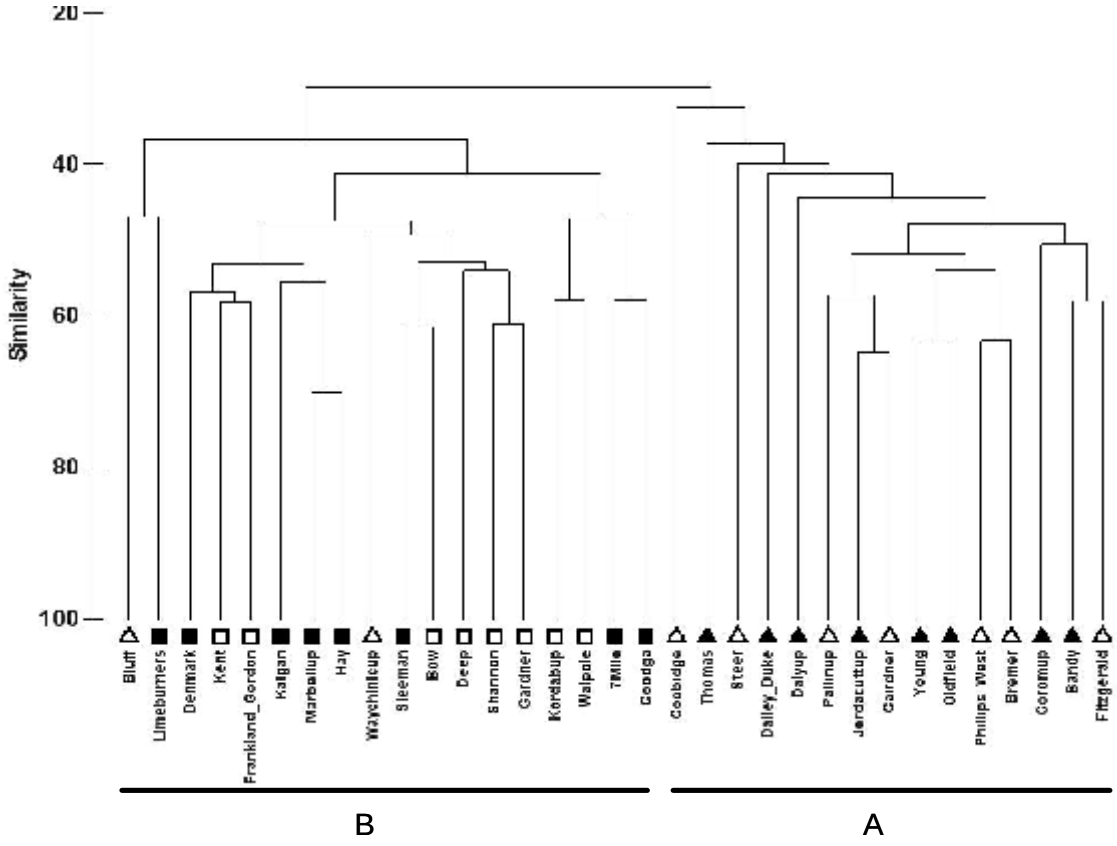

Figure 2: Dendrogram resulting from a hierarchical classification of rivers of the South Coast region using macroinvertebrate data, showing the existence of two broad aquatic bioregions, (A) Eastern South Coast and (B) Western South Coast. Symbols indicate IBRA subregions; open triangle = Esperance 1, closed triangle = Esperance 2, open squares = Warren bioregion, closed squares = Souther Jarrah Forest bioregion.

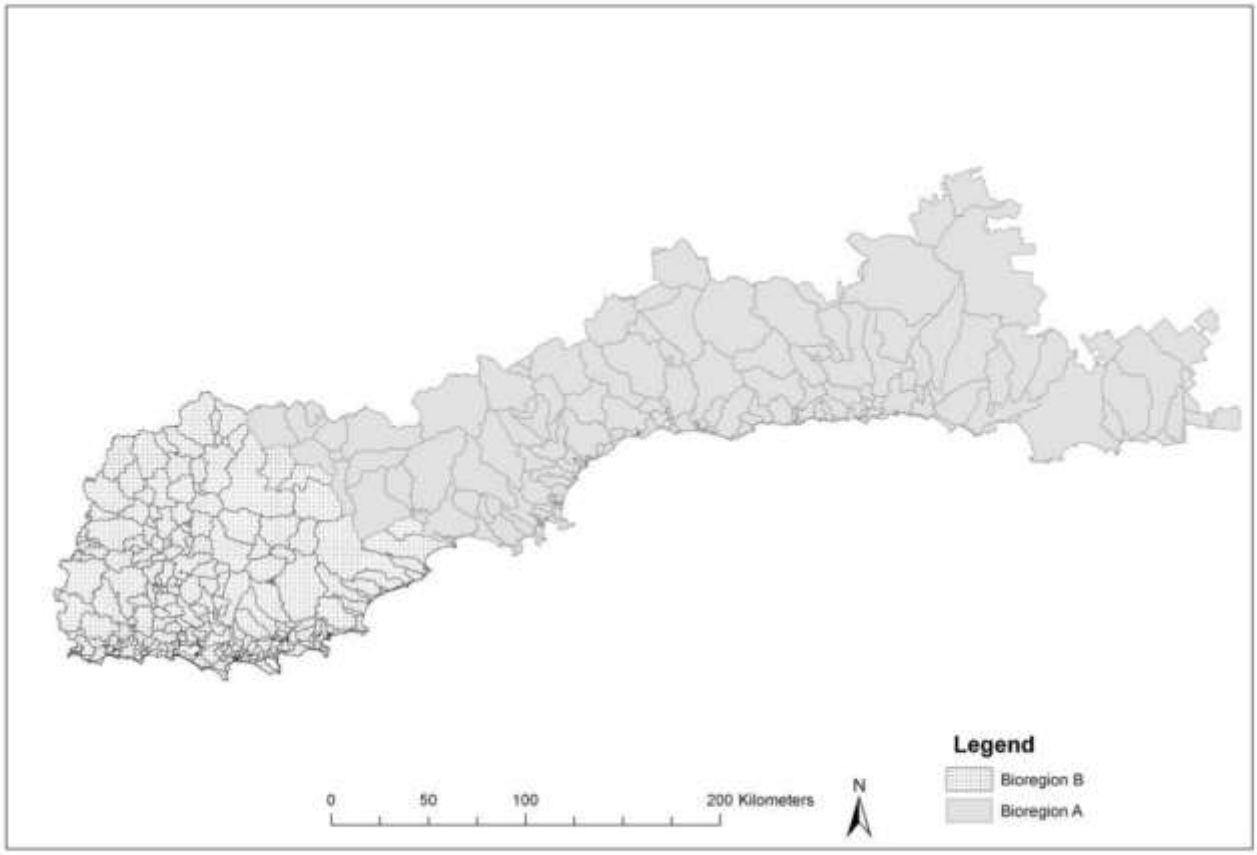

Figure 3: Map of South Coast region showing location of Western South Coast bioregion (Bioregion B) and Eastern South Coast bioregion (Bioregion A).

Physicochemical bioregionalisation

When six water quality parameters (salinity, pH, turbidity, dissolved oxygen, total nitrogen and total phosphorus) were used to define aquatic bioregions, patterns were not as clear-cut as for the macroinvertebrate data, and did not coincide with the geographical location of the river systems. However, some concordance with the biological data was observed. For example, eight of 15 river systems grouped together by the biological classification into the 'Eastern South Coast region' did cluster together, albeit with the addition of the Frankland Gordon River system to this grouping (Fig. 4). Similarly, 12 of

18 ‘Western South Coast region’ rivers did cluster together, while four of these rivers fell into another separate cluster.

The Coobidge River was found to be the most dissimilar river to the other river systems investigated. Water in this river was highly saline, acidic, and very turbid. Along with the Sleeman River and Seven Mile Creek, sampling of this river system revealed a shortage of suitable minimally-disturbed sites, and thus more degraded reaches had to be used for the physicochemical bioregionalisation.

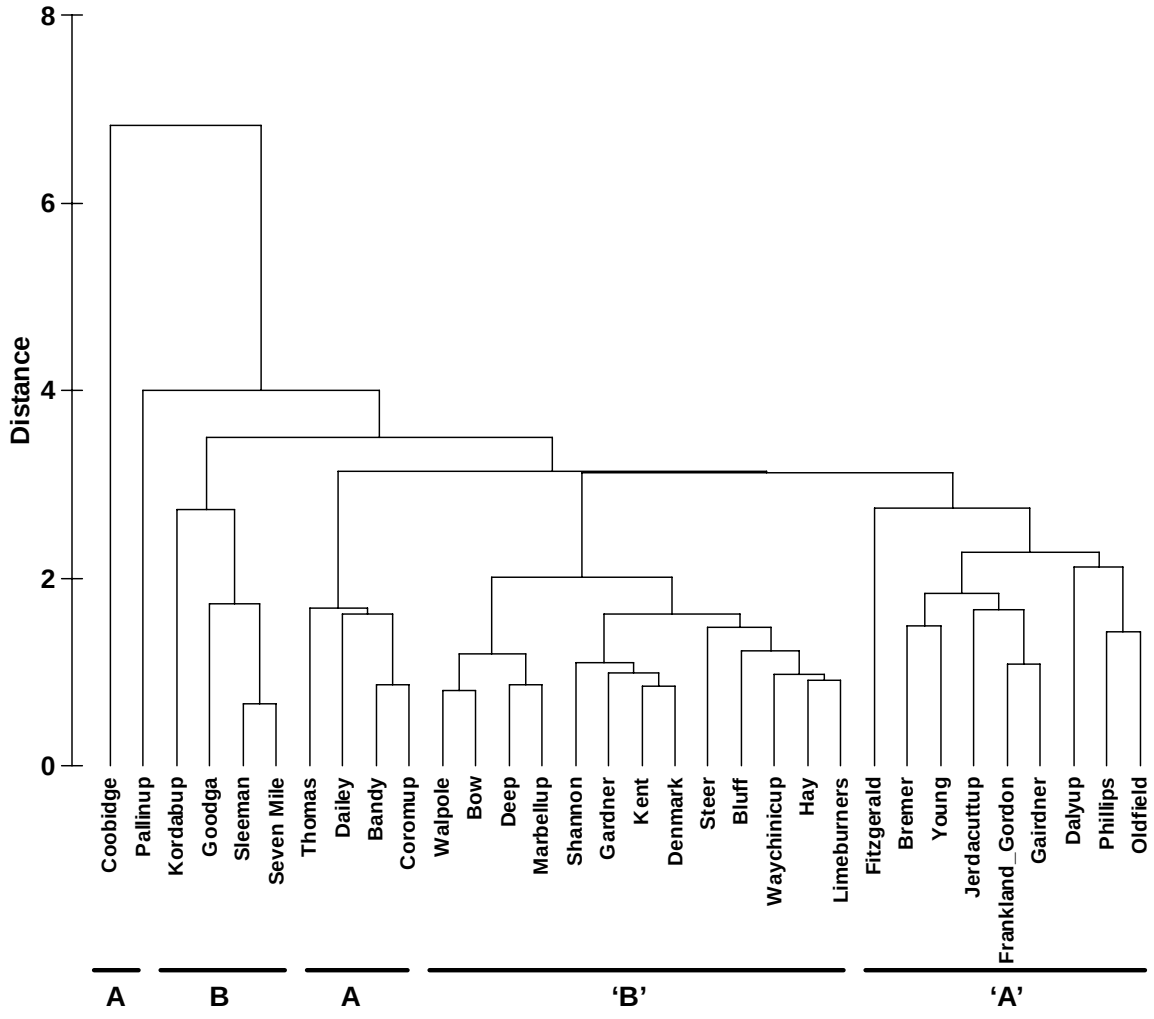

Figure 4: Dendrogram resulting from a hierarchical classification of rivers of the South Coast region using selected water quality variables. The existence of groupings concordant with the two main bioregions (A and B) defined using macroinvertebrate data is also shown.

Descriptions of invertebrate 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 (ANOVA, $p < 0.05$). Rivers of both aquatic bioregions had similar levels of turbidity, dissolved oxygen and total phosphorus levels (ANOVA, $p > 0.05$).

Table 3: Water quality parameters associated with each of the two aquatic bioregions defined using macroinvertebrate data.

Parameter	Western South Coast	Eastern South Coast
Salinity (ppt)		
Minimum-maximum	0.17-10.52	6.45-43.84
Mean	1.50	23.29
Standard deviation	2.60	10.67
pH		
Minimum-maximum	4.35-8.04	4.39-8.74
Mean	6.07	7.38
Standard deviation	0.87	1.07
Turbidity (NTU)		
Minimum-maximum	0.65-32.17	0.0-167.6
Mean	13.83	24.7
Standard deviation	9.77	41.2
Total nitrogen (µg/l)		
Minimum-maximum	195-1800	460-2833
Mean	935	1483
Standard deviation	457	753
Total phosphorus (µg/l)		
Minimum-maximum	9-430	7.0-140.9

Mean	85	54.3
Standard deviation	118	42.5
Dissolved oxygen (mg/l)		
Minimum-maximum	6.44-10.4	7.01-13.1
Mean	8.97	9.26
Standard deviation	1.13	1.97

The bioregionalisation resulting from the use of invertebrate data was associated with a strong salinity gradient (Fig. 5), with river systems falling into the Eastern South Coast region being naturally more saline than those falling into the Western South Coast aquatic bioregion.

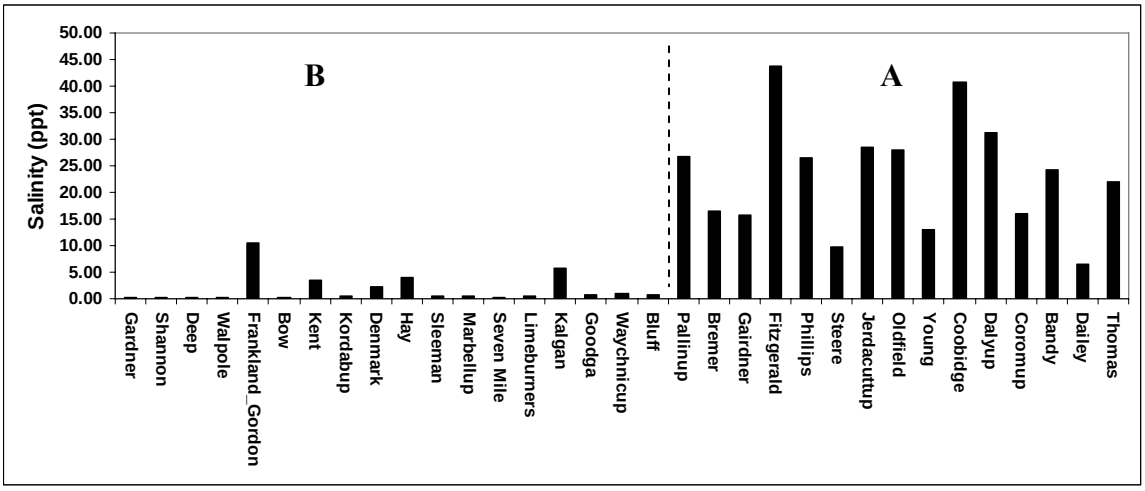

Figure 5: Plot of average salinity recorded for minimally impacted sites sampled from 33 river systems in the South Coast Region. Rivers have been plotted in geographical order from west to east. Dashed line indicates boundary between aquatic bioregions. A = Eastern South Coast bioregion, B = Western South Coast bioregion.

Biodiversity

Total macroinvertebrate species richness ranged from 15 to 79 species for river systems in the Eastern South Coast bioregion, while values ranged from 29 to 134 species for rivers in the Western South Coast bioregion (Fig. 6; 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) (ANOVA, $p < 0.05$). Species richness 'hotspots' in the Eastern South Coast bioregion were the Bremer and Phillips West

Rivers. The Frankland Gordon, Kent, Hay and Marbellup systems appeared to be 'hotspots' in the Western South Coast bioregion.

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	Western South Coast	Eastern South Coast
Total species richness		
Minimum-maximum	29 – 134	15 – 79
Mean	69.7[b]	45.0[a]
Standard deviation	31.4	20.2
EPT (mayflies, stoneflies and caddisflies)		
Minimum-maximum	2 – 25	0 – 6
Mean	12.44 [b]	2.47 [a]
Standard deviation	6.45	1.69
Macrocrustaceans (decapods, amphipods and isopods)		
Minimum-maximum	1 – 8	1 – 5
Mean	4.22 [b]	3.00 [a]
Standard deviation	1.96	1.20
Microcrustaceans (copepods, ostracods and branchiopods)		
Minimum-maximum	2 – 15	1 – 14
Mean	7.22 [a]	7.20 [a]
Standard deviation	3.61	3.78
Acarina (mites)		
Minimum-maximum	0 – 13	0 – 5
Mean	7.61 [b]	2.07 [a]
Standard deviation	3.63	1.49
Coleoptera (beetles)		
Minimum-maximum	1 – 31	1 – 25
Mean	11.7 [a]	8.7 [a]
Standard deviation	9.22	6.63
Diptera (true flies)		
Minimum-maximum	6 – 22	5 – 13
Mean	11.22 [a]	8.80 [a]
Standard deviation	4.32	2.34
Hemiptera (bugs)		
Minimum-maximum	0 – 6	0 – 7
Mean	2.06 [a]	2.87 [a]
Standard deviation	2.01	2.39
Odonata (dragonflies and damselflies)		
Minimum-maximum	1 – 13	0 – 8
Mean	5.28 [b]	2.87 [a]
Standard deviation	3.48	2.53

Mollusca (snails, limpets and mussels)		
Minimum-maximum	0 – 5	0 – 5
Mean	2.11 [a]	1.93 [a]
Standard deviation	1.68	1.39

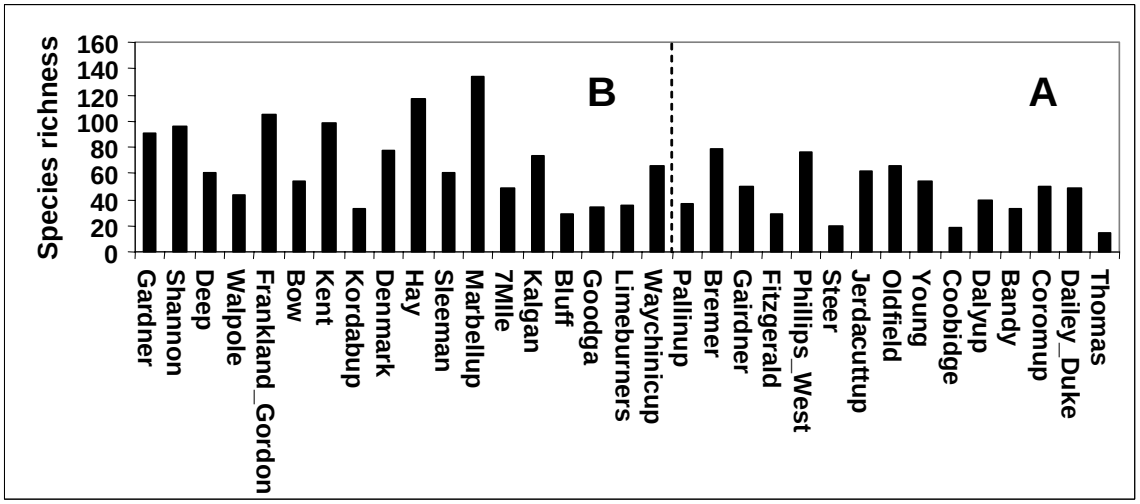

Figure 6: Macroinvertebrate total species richness for 33 river systems in the South Coast Region. Rivers are plotted in geographical order from west to east. A = Eastern South Coast bioregion; B = Western South Coast bioregion.

Figure 7 is a plot of the number of EPT taxa found in each river system. The EPT index is obtained by summing the total number of mayfly (order Ephemeroptera), stonefly (Plecoptera) and caddisfly species (Trichoptera). 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 (Fig. 7; Table 40). 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) (ANOVA, $p < 0.05$). Hotspots for EPT taxa (mostly endemic species) for the Western South Coast bioregion were the Gardner, Shannon and Hay Rivers and Marbellup Brook. All of the species recorded for the Eastern South Coast bioregion were either not endemic, or their endemism status was unknown.

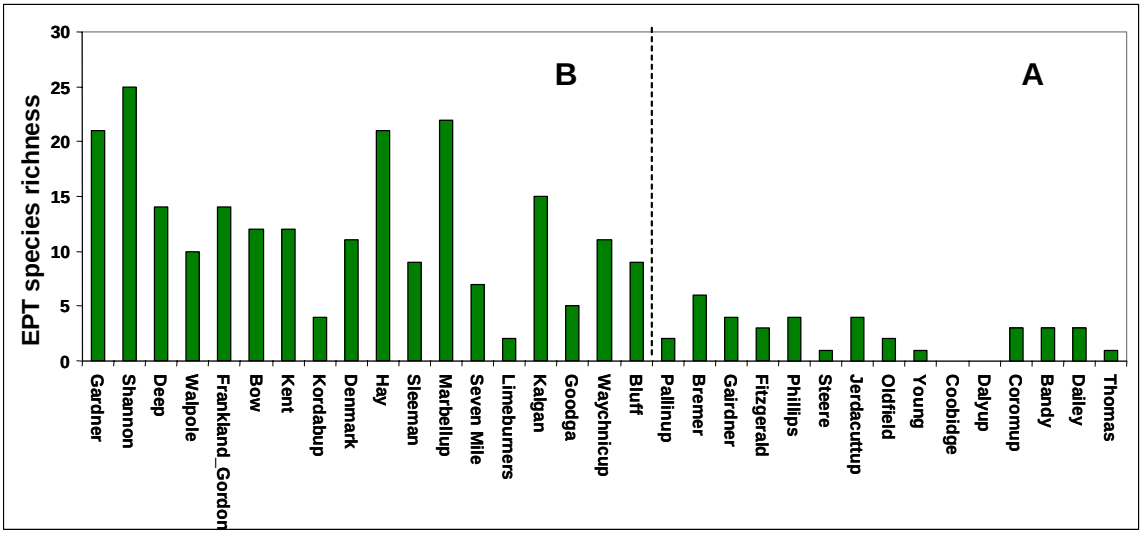

Figure 7: EPT species richness for 33 river systems in the South Coast Region. Rivers are plotted in geographical order from west to east. A = Eastern South Coast bioregion; B = Western South Coast bioregion.

The number of macrocrustacean species, mites (Order Acarina) and dragonflies (Order Odonata) were also significantly higher for the Western South Coast bioregion than for the Eastern South Coast bioregion (ANOVA, $p < 0.05$).

Significant faunal groups

Macrocrustaceans

Five species (belonging to four families) of amphipods occurred in the rivers of the South Coast Region, three of which are of interest because of limited distributions (Table 5).

Table 5: Significant macrocrustacean species collected from waterways in the South Coast region. Values represent the % of rivers sampled which had these species present.

Taxa	Western South Coast	Eastern South Coast
Amphisopus lintoni	27.8%	0%
Perthia branchialis	88.9%	0%
Perthia acutitelson	11.1%	0%
Undescribed Paramelitidae sp.	0%	46.7%
Cherax crassimanus	80.0%	0%
Cherax preissii	80.0%	13.3%
Cherax quinquecarinatus	26.7%	0%

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. *Perthia branchialis* (Fig. 8) was common in rivers of the Western South Coast bioregion (occurring in 88.9% of river systems sampled), whilst *P. acutitelson* was less common (16.7%), having been found in the Shannon River and Gardner Rivers only. Neither of these two species occurred in rivers of the Eastern South Coast bioregion.

Of significance was the discovery of an undescribed species of Paramelitidae from seven (46.7%) rivers in the Eastern South Coast bioregion (Fig. 8). 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). This species does not appear to be any of these. The animal 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. It was not found in any rivers belonging to the Western South Coast bioregion.

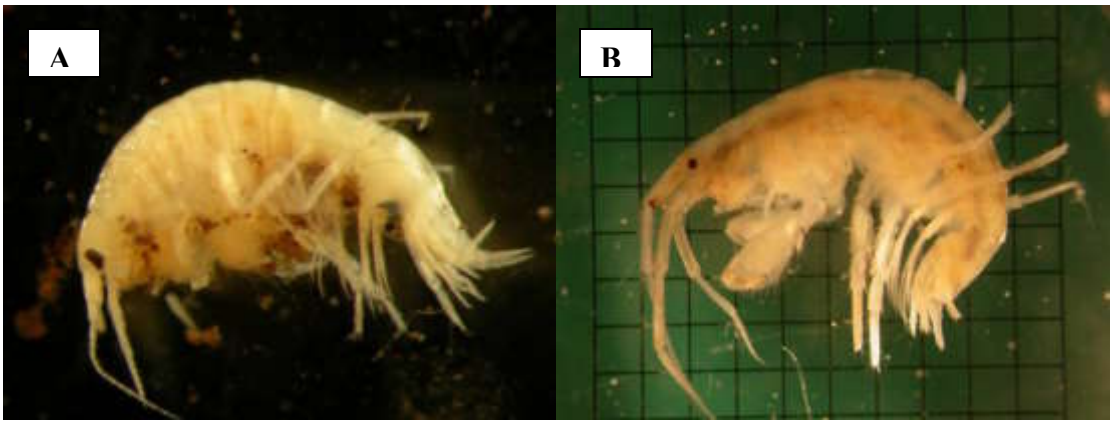

Figure 8: Amphipod species collected from waterways of the South Coast region, (A) *Perthia branchialis,* and (B)undescribed Paramelitidae sp.

Four species of isopods were collected from the South Coast region, one of which is an example of a Gondwanan relictual species. *Amphisopus lintoni* (family Amphisopodidae) is a member of the suborder Phreatoicidea, an ancient group with a typically Gondwanan distribution, having been found in Australia, New Zealand, India and South Africa. There are about 50 described phreatoicid species in 19 nominal genera in Australia, with more species awaiting description (Wilson & Keable, 2001). Eight genera are known from Western Australia, a surprising level of phreatoicidean diversity considering the relative aridity of the State (Wilson & Keable, 2002). The genus *Amphisopus* presently contains two species, both confined to Western Australia - *A. annectan*s to the Warren River system (in the South West region), and *A. lintoni* to the Warren River (in the west) through to the King and Kalgan Rivers (to the east). However, Wilson & Keable (2002) and other (see Horwitz, 1997) suspect that undescribed species-level diversity may be present in the genus *Amphisopus*. This has been confirmed by a recent study of molecular species boundaries within *Amphisopus* (Gouws et al, in prep.) based on 17 populations collected along a rough transect from east of Albany to the western-most of the known *Amphisopus* collection localities (Warren National Park). This investigation has suggested that three distinct species be recognized, (i) *A. lintoni*, distributed from just east of Albany to the Kent River, (ii) *A. annectans*, known from the Warren, Gardner and Shannon Rivers and Doggerup Creek, and (iii) an undescribed species from the Walpole-Nornalup area. This suggests that specimens collected in the present study from Seven Mile Creek, Marbellup Brook and Denmark be

assigned to *A. lintoni* (Fig. 9), and specimens collected from the Shannon and Gardner Rivers be assigned to *A. annectans*. *Amphisopus* specimens were not collected from rivers falling into the Eastern South Coast bioregion.

Figure 9: Specimen of *Amphisopus lintoni* collected from Marbellup Brook.

Six species of decapods were collected from across the South Coast region, including one widespread species of shrimp (*Palaemonetes australis*) and five species of freshwater crayfish belonging to the genus *Cherax* in the family Parastacidae (the introduced 'yabby', the 'marron', the 'gilgie' and two species of 'koonacs'). Of these, three of the crayfish are of significance because of restricted distributions. With the exception of the introduced 'yabby', *Cherax destructor*, all native freshwater crayfish within Western Australia are endemic to the southwestern part of the State. The six species belonging to the genus *Cherax* form a monophyletic group, and constitute one of three distinct centres of *Cherax* diversity in Australia. These southwestern species can be further divided into two distinct subgroups consisting of (i) the three koonac species, *C. crassimanus*, *C. preissii* and *C. glaber*, and (ii) the gilgie, *C. quinquecarinatus* the marron, *C. cainii* and the Margaret River hairy marron, *C. tenuimanus* (Munasinghe et al., 2004). Four of the six *Cherax* species known to be native to southwestern Western

Australia were recorded from the South Coast region. Both *C. crassimanus* and *C. preissii* were found in 80.0% of rivers sampled in the Western South Coast bioregion (Fig. 10). *Cherax preissii* also occurred in the Eastern South Coast region, but was only found in the Gairdner and Bremer Rivers. These records represent a range extension, as this species was previously thought to occur only as far east as the Kalgan River. The gilgie *C. quinquecarinatus* did not occur in the Eastern South Coast region, but was found in the Western South Coast region (26.7%), extending as far east as Marbellup Brook.

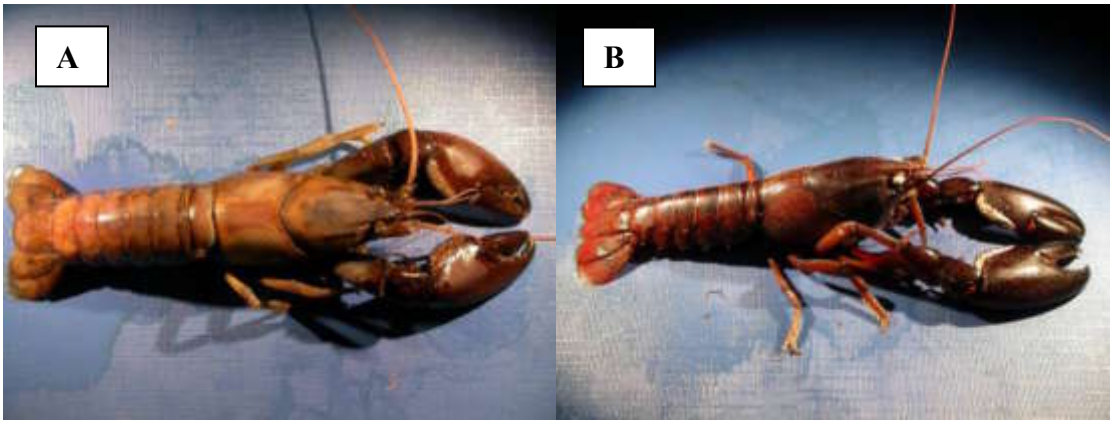

Figure 10: Freshwater crayfish species collected from waterways of the South Coast region, (A) *Cherax preissii* from the Gairdner River, and (B) *Cherax crassimanus* from the Denmark River. Both species are commonly known as 'koonacs'.

EPT

The number of mayflies (order Ephemeroptera), stoneflies (order Plecoptera) and caddisflies (order Trichoptera) together (the so-called 'EPT' index) is often used to assess the 'health' of waterways, both in Australia and further afield. These taxa are generally sensitive to pollution and disturbance gradients, making them useful 'indicators' of degradation processes. A number of these species proved to be significant because of their distribution (Table 6).

Table 6: Significant species of mayflies (Order Ephemeroptera), stoneflies (Order Plecoptera) and caddisflies (OrderTrichoptera) collected from waterways in the South Coast Region.

Taxa	Western South Coast	Eastern South Coast
Bibulmina kadjina	55.6%	0%
Nyungura bunni	55.6%	0%
Neboissophlebia occidentalis	22.4%	0%
Loamaggalangta sp.AV1	27.8%	0%
Kaninga qwabbalitcha	5.6%	0%
Nousia sp.AV16	5.6%	0%
Newmanoperla exigua	72.2%	0%
Leptoperla australica	44.4%	0%
Taschorema pallescens	33.3%	0%
Smicrophylax australis	44.4%	0%
Acritoptila margartetae	11.1%	0%
Acritoptila globosa	11.1%	0%
Hellyethira litua	27.8%	0%
Condocerus aptus	72.2%	0%
Lectrides parilis	77.8%	0%
Leptoc Genus A AV1	27.8%	0%
Notolina sp. AV16	33.3%	0%
Notolina spira	22.2%	40%
Notoperata tenax	38.9%	0%
Symphitoneuria wheeleri	11.1%	73.3%
Triplectides australis	22.2%	33.3%
Triplectides ?australicus	44.4%	13.3%

Nine mayfly species (order Ephemeroptera) were collected from the South Coast, all from the Western South Coast bioregion. Seven of these belong to the family Leptophlebiidae (Dean, 2000), the most diverse of the Australian mayfly families (Dean, 1999). Of these, six are known to be endemic, and are thus confined 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%). The monotypic genus *Bibulmena* was established by Dean (1987) to accommodate the species *B. kadjina.*

Dean (1987) also erected the genus *Nyungara* in this publication to accommodate the southwestern endemic species *N. bunni.* The latter species was also collected from 10 (55.6%) river systems in the Western South Coast bioregion. Dean (1988) has recently described another 'new' genus, *Neboissophlebia*, to accommodate two new species, one of which is *N. occidentalis*, also a southwestern Australian endemic. The latter species

was found in 22.2% of rivers in the Western South Coast bioregion. *Loamaggalangta* sp.AV1, found in 27.8% of the rivers in the Western South Coast bioregion is another endemic, restricted in distribution. Two other endemic species were collected each from a single river system. The ancient and morphologically conservative genus *Nousia*, presently containing 16 nominal species, has been recorded from Australia and South America (Dean, 1999). One southwestern Australian endemic is recognized (*Nousia* sp.AV16, previously genus R), and was collected from the Shannon River. *Kaninga gwabbalitcha* was found in the Gardner River. This species was previously thought to be confined mainly to a single river system in the South West region, having been collected on previous occasions (Dean, 2000) from Carey Brook, Beedelup Brook and Fish Creek, all tributaries of the Donnelly River.

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. Two stonefly species occurred in the rivers of the Western South Coast bioregion, none were found in rivers of the Eastern South Coast bioregion. Both *Newmanoperla exigua* (found in 66.7% of rivers) and *Leptoperla australica* (in 38.9% of rivers) are mostly restricted to regions with greater than 800 mm rainfall per annum, an area generally extending from Perth to Albany along the coast (see also distribution records in Sutcliffe, 2003).

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) were collected in the present study. All of these species occurred in the Western South Coast bioregion, while only six caddisfly species (all in the Family Leptoceridae) occurred in the Eastern South Coast bioregion.

A single species from the family Hydrobiosidae was found in the South Coast Region. Two species of this family have been previously recorded from southwestern Australia (Neboiss, 1982). Hydrobiosid caddisflies are primarily eastern Australian in distribution (Dean, 1997). *Taschorema pallescens* was found in six river systems (33.3%) in the Western South Coast bioregion, stretching from the Denmark River through to the Bluff River (Fig. 11). This species is also known to occur in rivers (e.g. Collie, Harvey and Donnelly Rivers) in the South West region (Nebois, 1982), and has also been described as occurring from "the Upper Canning catchment to Walpole" (Dean & Bunn, 1989). Larvae were thought to be restricted to the jarrah (*Eucalyptus marginata*) forest streams of the Darling Range and karri (*E. diversicolor*) streams of the lower south-west (Dean & Bunn, 1989). Records from the present study extend the known range of this species, as do the records given in Sutcliffe (2003).

Two species of the family Hydropsychidae were found in the Western South Coast bioregion, one of which is the southwestern Australian endemic, *Smicrophylax australis* (Fig. 11). This species occurred in 44.4% of rivers, from the Gardner River through to the Kalgan River.

Figure 11: Trichopteran species collected from waterways of the South Coast Region, (A) *Taschorema pallescens* from Marbellup Brook, (B) *Smicrophylax australis* from Marbellup Brook, and (C) *Acritoptila margaretae* from the Kent River.

The family Hydroptilidae was represented by seven species which occurred in 5.6% to 33.3% of rivers of the Western South Coast bioregion. It is likely that all of these species are endemic to southwestern Australia – certainly *Acritoptila margaretae* (11.1%; Fig. 11), *A. globosa* (11.1%), and *Hellyethira litua* (27.8%) are known to be

confined to the area, while the as yet, unidentified *Oxyethira* species found in six rivers is probably also a southwestern Australian endemic. The *Oxyethira* species collected is likely to be assigned to either *O. brevis* (described from the Cape Leeuwin National Park) or *O. retracta* (known to occur as far east as the Kalgan River) following consultation with taxonomic experts. Both species are southwestern Australian endemics. Of interest was the discovery of a new, and as yet, undescribed hydroptilid species in the upper reaches of the Quickup River (tributary of the Denmark River) (A. Wells, pers. comm.).

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), one of two species belonging to this genus (St Clair, 2000), and *Lectrides paralis* (77.8%) (Fig. 12). Both species are known to occur from Perth to as far east as the Kalgan River (this study, see also Sutcliffe, 2003).

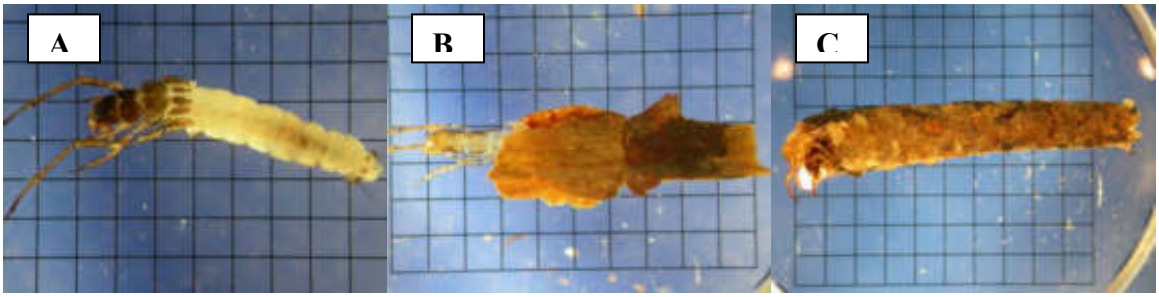

Figure 12: Trichopteran species collected from waterways in the South Coast Region, (A) *Condocerus aptus*, (B) *Lectrides paralis* and (C) *Symphitoneuria wheeleri.*

Taxonomic uncertainty still surrounds the genus *Notalina*, known from Australia and South America (St Clair, 2000). Five described species and a further four undescribed species are known to occur in southwestern Australia, with all but one of these being confined to the region. Five *Notalina* species were collected from the South Coast region in this study. With the exception of *N. spira*, these species were only found in rivers of the Western South Coast bioregion, at a frequency of 5.6% to 33.3%.

Five species of *Notoperata* are currently recognized in Australia, but at least seven species are recognized as larvae, including *Notoperata* sp. AV1 and *Notoperata* sp. AV4,

both confined to southwestern Australia, and recorded from rivers in the Western South Coast bioregion. *Notoperata* species were found in 5.6% (*Notoperata* sp. AV4) to 38.9% (*N. tenax*) of South Coast rivers, and are all southwestern Australian endemics. The leptocerid "Genus Leptoc A", with one known species is possibly an "aberrant species" of *Notoperata* (St Clair, 2000). This species occurred in five rivers (27.8%) in the Western South Coast bioregion.

Approximately 26 species of *Triplectides* are known from Australia, with eight of these probably occurring in southwestern Australia. Five distinct species were found in rivers in the South Coast Region. All of these species were present in the Western South Coast bioregion (16.7% to 44.4% of rivers), while two of these species (*T. australis* and *T. ?australicus*) were found in Eastern South Coast bioregion rivers (13.3% to 33.3%). Sutcliffe (2003) reported that *T. australis* was the most common species in her samples.

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 (Fig. 12). Similarly, *Notolina spira*, known to occur widely in Australia, was found in more Eastern South Coast bioregion rivers (40%) than in Western South Coast bioregion rivers (22.2%).

Dragonflies

Dragonflies and damselflies are well represented in Australia, with a total of 324 species known from the continent (Theischinger & Hawking, 2006). A total of 29 odonate species were collected from waterways of the South Coast region, with 26 of these being assigned to described species.

Table 7: Significant species of dragonflies and damselflies (Order Odonata) collected from waterways in the South Coast region.

Taxa	Western South Coast	Eastern South Coast
Austroagrion cyane	27.8%	60.0%
Austrolestes annulosus	16.7%	60.0%
Hemicordulia tau	61.1%	13.3%
Procordulia affinis	16.7%	40.0%
Zephrogomphus lateralis	44.4%	13.3%
Miniargiolestes minimus	55.6%	0%
Archaeosynthemis occidentalis	22.2%	0%
Austrosynthemis cyanitincta	22.2%	0%
Austroaeshna anacantha	66.7%	0%

Of the 35 species belonging to the family Telephlebiidae occurring in Australia, only one species is known from Western Australia. *Austroaeschna anacantha*, a southwestern Australian endemic, was found in 12 waterways (66.7%) in the Western South Coast region, but was absent in the rivers of the Eastern South Coast bioregion (Table 7; Fig. 13). This study extends the known range of this species to as far east as the Bluff River. Previous records had indicated that the easterly most populations of this species occurred in the Denmark River (Sutcliffe, 2003).

Figure 13: Odonate species collected from waterways of the South Coast region, (A) *Austroaeschna anacantha*, (B) *Austrosynthemis cyanitincta*, and (C) *Zephrogomphus lateralis*.

Twenty-six species of dragonflies, assigned to the family Synthemistidae occur in Australia (Theischinger & Hawking, 2006). Of these, four have been recorded from southwestern Australia, are endemic to the area, and were all collected from the South Coast Region. Two of these species (*Archaeosynthemis occidentalis* and *Austrosynthemis cyanitincta*) were relatively common in waterways of the Western South

Coast bioregion (occurrence of 22.2%), but absent in waterways of the Eastern South Coast subregion. *Austrosynthemis cyanitincta* is the only known species of the genus (Fig. 13), and like *A. occidentalis* and the other synthemistid species, is restricted to southwestern Australia.

The family Gomphidae is represented by 36 species in Australia, with four species known to occur in southwestern Australia. The three gomphid species found in waterways of the South Coast Region are all known to be endemic to southwestern Australia. One of two species known from the genus, *Zephrogomphus lateralis* was rare in waterways on the Eastern South Coast bioregion (13.3%), but relatively common (44.4%) in waters of the Western South Coast bioregion (Fig. 13). This species is also believed to be a southwestern Australian endemic. Sutcliffe (2003) recorded this species from only one locality (Frankland Gordon River) in the South Coast Region, and thus the present study extends the known range of this species.

The family Hemicorduliidae is represented by 11 species in Australia, with three of these known to occur in southwestern Australia. Of these three species, only the Western Swamp Emerald, *Procordulia affinis*, is endemic to the area (Fig. 14). This species was encountered more frequently in waterways of the Eastern South Coast bioregion (40.0%) than in waterways of the Western South Coast bioregion (16.7%). Sutcliffe (2003) recorded this species as occurring in the Frankland Gordon catchment in the South Coast region, and thus the records in this study greatly extend the known range of this species. On the other hand, *Hemicordulia tau*, a species known to be widespread across Australia, appeared to favour the fresher waters of the Western South Coast bioregion (61.1%) over the more saline waters of the Eastern South Coast bioregion (13.3%). However, Sutcliffe (2003) shows several records in the Eastern South Coast bioregion, and reported this species to be widespread across southwestern Australia.

Figure 14: Odonate species collected from waterways of the South Coast Region, (A) *Procordulia affinis*, (B) *Austroagrion cyane* and (C) *Austrolestes annulosus*.

Twenty-two species of damselflies in the family Megapodagrionidae occur in Australia, four of these occur and are endemic to southwestern Australia. Two megapodagrionid species were collected in this study. *Miniargiolestes minimus* was relatively common in waterways of the Western South Coast bioregion (55.6%), but was absent in waters of the Eastern South Coast bioregion, a finding confirmed by the records of Sutcliffe (2003).

Although four of the 31 species known in the family Coenagrionidae occur in southwestern Australia, none of these are endemic to the area. Of interest is the South-Western Billabongfly, *Austroagrion cyane* (Fig. 14) which was more common the eastern rivers (60%) than in the western rivers (27.8%). Sutcliffe (2003) reported this species to be fairly widespread across southwestern Australia. Similarly, the five species (of a total of 14) of Lestidae that occur in southwestern Australia are also not endemic to the area. Of these lestid species, *Austrolestes annulosus* (Fig. 14) occurred more frequently in eastern (60%) than in western rivers (16.7%) in our study, as well as in the study of Sutcliffe (2003).

Molluscs

Four species of 'freshwater' mussels were collected from waterways in the South Coast Region, and these were assigned to two families (Sphaeriidae and Hyriidae). Freshwater mussels are thought to be absent in saline waters, despite their apparently high salinity tolerance (Williams & Campbell, 1987). Seventeen species of bivalves in

the family Sphaeriidae are known from Australia. Only one species, *Musculium kendricki*, is described from Western Australia, and is endemic to this area (Korniushin, 2000). According to Korniushin (2000), this species has been collected from the western part of southwestern Australia. Specimens assigned in this study to *M. kendricki* from the Oldfield and Jerdacuttup Rivers appear to be different from specimens assigned to this species from Marbellup Brook, Seven Mile Creek and Sleeman River, and it is thus possible that there may be an undescribed sphaeriid species in the rivers of the Eastern South Coast bioregion.

Table 8: Significant species of bivalves, limpets and snails (Phylum Mollusca) collected from waterways in the South Coast region.

Taxa	Western South Coast	Eastern South Coast
Musculium kendricki	16.7%	13.3%
Westralunio spp	11.1%	53.3%
Westrapyrgus westralis	5.6%	0%
Coxiella spp	11.1%	73.3%
Pygmanisus sp.	11.1%	26.7%
Physa acuta	22.2%	0%
Glyptophysa sp.	27.8%	6.7%
Ferrissia sp.	50.0%	0%

The remaining three species of freshwater mussels were assigned to the family Hyriidae. Much confusion still surrounds the taxonomy of this family in Australia, with possibly six species known from across Western Australia (Graf & Cummings, 2007). Of the three hyriid species collected, specimens assigned to *Westralunio* spp were most abundant, occurring in 53.3% or rivers in the Eastern South Coast bioregion and 11.1% of rivers in the Western South Coast bioregion (Kalgan and Frankland Gordon) (Table 8; Fig. 15). This species thus appears to favour the more saline waterways. *W. carteri,* known to occur in southwestern Australia is sensitive to high salinities (e.g. Kendrick, 1976), and thus the as yet, unidentified *Westralunio* sp. specimens collected in this study are unlikely to be *W. carteri*.

Figure 15: Molluscan species collected from waterways of the South Coast Region, (A) *Westralunio* sp., (B) *Ferissia* sp. and (C) *Coxiella* sp.

The remaining 12 molluscan species collected from the South Coast region were all members of the Class Gastropoda. One species of freshwater limpet (*Ferissia* sp. in the family Ancylidae) was collected from 50% of waterways in the Western South Coast bioregion, but did not occur in waterways of the Eastern South Coast bioregion (Fig. 15). This species is generally confined to non-saline waters.

Of interest is an unidentified Hydrobiidae species found in the Walpole River. This species is likely to be *Westrapyrgus westralis*, a species known from the South West Region and endemic to southwestern Australia. *Westrapyrgus westralis* has a similar distribution to *Austroassiminea letha* (family Assimineidae), and both species are usually found associated with coastal freshwater springs and seepages (Fukuda & Ponder, 2003). Ponder et al. (1999) describe the distribution range of *W. westralis* as occurring from "between Cape Naturaliste and the Weld River" (the Weld River is a major tributary of the Deep River), and thus this study now extends the known range of this species to as far east as the Walpole River.

The most common snails in waterways of the Eastern South Coast bioregion were members of the genus *Coxiella* (found in 73.3% of rivers), a group of snails living mainly in coastal, often saline waters (usually lakes) along the southern and western coasts of Australia and in northern and eastern Tasmania (Fig. 15) (Smith, 1996). These snails were far less common in waterways of the Western South Coast bioregion (11.1% or rivers). Specimens of the planorbid, *Pygmanisus* sp. were also relatively common

(occurring in 26.7% or rivers sampled) in waterways of the Eastern South Coast bioregion.

The most common snails in waterways of the western South Coast bioregion were the introduced physid, *Physa acuta* (found in 22.2% of rivers) and the planorbid, *Glyptophysa* sp. (27.8% of rivers). *Physa acuta* did not occur in the more saline waters of the Eastern South Coast bioregion, and only one waterway in this bioregion (Phillips West) harboured specimens of *Glyptophysa* sp.

Fish

Ten species of native freshwater fish are known from southwestern Australia, of which eight are endemic to the region (Morgan et al., 1998). These ten species include one species of Plotosidae (the catfish, *Tandanus bostocki*), the only known species in the family Lepidogalaxiidae (*Lepidogalaxias salamandroides*), five species in the family Galaxiidae (*Galaxias maculatus, G. truttaceus, G. occidentalis, Galaxiella nigrostriata* and *G. munda*), one species in the family Percichthyidae (*Bostockia porosa*) and two species in the family Nannopercidae (*Edelia vittata* and *Nannatherina balstoni*). Four of these species (*L. salamandroides*, *G. nigrostriata*, *G. munda* and *N. balstoni*) have been described as being typically confined to the high rainfall region in the extreme lower southwestern corner of Western Australia (Morgan et al., 1998).

Nine of the ten native freshwater species known from southwestern Australia were collected from the South Coast Region (*G. nigrostriata* was not found; Table 9). In addition, five estuarine (*Leptatherina wallacei, Pseudogobius olorum, Geotria australis, Mugil cepahlus* and *Acanthopagrus butcheri*) and two exotic (*Gambusia holbrooki* and *Oncorhynchus mykiss*) species were also collected (Table 9).

Table 9: Significant fish species collected from waterways in the South Coast region.

Taxa	Western South Coast	Eastern South Coast
Galaxias truttaceus hesperius	5.6%	0%
Lepidogalaxias salamandroides	5.6%	0%
Nannatherina balstoni	33.3%	0%
Galaxiella munda	22.2%	0%
Galaxias maculatus	11.1%	50.0%
Leptatherina wallacei	5.6%	57.1%
Pseudogobius olorum	27.8%	78.6%

Two of the rarest native freshwater fish species in southwestern Australia are the Western Trout (or Spotted) Minnow, *Galaxias truttaceus hesperius* and the Salamanderfish, *Lepidogalaxias salamandroides*. Both species were found in only one location each – the Spotted Minnow occurred in Goodga River, but is known to also occur in the Angove River (not sampled in the present study), and the Salamanderfish was found in the Walpole River. The latter species, listed as 'Rare' (IUCN, and also on Conservation Status Listing for Australian Freshwater Fishes published by the Department of the Environment, Water Heritage and The Arts), has been described as being distributed on heathland peat flats between the Blackwood and Kent Rivers, with its centre of distribution being around the Northcliffe area (Berra & Pusey, 1997).

The Balston's Pygmy Perch, *Nannatherina balstoni*, was found in six river systems (Shannon, Deep, Frankland Gordon, Kent, Bow and Denmark) in the Western South Coast bioregion. This species is listed as 'vulnerable' under the *Environment Protection Band Biodiversity Act 1999* (EPBC Act), and is also listed as rare or likely to become extinct under the *Wildlife Conservation (Specially Protected Fauna) Notice 2006(2)* of Western Australia because of its severely fragmented distribution and the threatening processes operating throughout its range. The addition of 'new' populations in the Frankland Gordon and Bow Rivers brings the known subpopulations of this species to 17.

The Mud Minnow, *G. munda* was found in four river systems (Gardner, Shannon, Deep and Hay Rivers) in the Western South Coast bioregion. This species is listed as 'restricted' by the Australian Society for Fish Biology, due to it being restricted to a small

area that extends from Albany in the east to Margaret River in the west, with an isolated population 350 km north at Gingin (Gill & Morgan, 1997). The possibility that this discontinuity in the distribution of the species is due to habitat loss caused by widespread urban and rural development led to its nomination for listing as a threatened species (Gill & Morgan, 1997). However, in their advice to the Minister for the Environment and Heritage regarding the status of the Mud Minnow, *Galaxiella munda*, the Threatened Species Scientific Committee (TSSC) concluded that since the species is known from 19 river systems, has an estimated area of occupancy of 10,000 km^2, has an unknown population size and historical occurrence, and the impact of threatening processes on the species' survival is not verified, it is not eligible for inclusion for 'listing' under the EPBC Act.

The only native freshwater fish species found in rivers in the Eastern South Coast bioregion (found in eight rivers) was the Common Jollytail (or "Spotted minnow") *Galaxias maculatus*. This species is known to be widely distributed throughout southern Australia, and has been described as occurring from "Albany in the west to Esperance in the east" (Morgan et al., 1998), and more recently, as being distributed from the Thomas River in the east to Walpole River in the west and Harvey River in the north (Morgan et al., 2006). This study has revealed that the centre of the distribution of this species in southwestern Australia runs from the Goodga River in the west to the Coromup River in the east. This species was found in only two river systems (Goodga and Waychinicup Rivers) in the Western South Coast bioregion. Although this species was not collected from the Fitzgerald, Jerdacuttup, Dalyup, Thomas and Walpole Rivers and Bandy Creek in the present study, it has been collected from these systems previously (Morgan et al., 2006).

Assessment of ecological values

Five indicators were used to obtain a score for 'naturalness' (Table 2; Appendix B), thus resulting in a potential maximum score of 15 for systems in pristine condition. The indicator, 'level of catchment disturbance' was scored using the measure '% natural

vegetation cover remaining.' Three measures were used to represent the 'level of riparian zone disturbance': the width of the native riparian zone, the canopy cover of native vegetation in this zone, and the presence of understorey weeds.

Rivers with the highest ranking, and thus the 'best condition' in the Western South Coast bioregion were the Shannon River (14.80), the Deep River (14.43) and the Denmark River (14.25) (Table 10; Appendix C). All of these waterways drained relatively well vegetated catchments, riparian zones were in good condition, channel disturbance was minimal, and little or no variation from that which could be expected for rivers of this type was detected for water chemistry and biodiversity values. The lowest ranked waterway in this bioregion was the Sleeman River (score of 9.58) (Table 10). This waterway drained a poorly vegetated catchment, the riparian zone at both sites sampled was disturbed, and water quality sampling revealed nutrient enrichment, resulting in a decline in the more sensitive taxa such as mayflies, stoneflies and caddisflies (EPT taxa).

Table 10: Scores obtained for degree of 'naturalness', for waterways of the South Coast Region. Waterways have been ranked in descending order within each bioregion.

Western South Coast		**Eastern South Coast**	
River	**Score**	**River**	**Score**
Shannon	14.80	Oldfield	13.79
Deep	14.43	Jerdacuttup	13.22
Denmark	14.25	Gairdner	12.70
Gardner	13.93	Phillips_West	12.69
Walpole	13.50	Young	12.53
Kent	13.03	Dailey	12.33
Limeburners	13.00	Steer	12.00
Waychinicup	13.00	Bremer	11.79
Hay_Mitchell	12.73	Bandy	11.58
Frankland_Gordon	12.45	Thomas	11.00
Bow	12.25	Fitzgerald	10.64
Bluff	12.00	Coromup	10.58
Marbellup	11.49	Dalyup	10.33
Goodga	11.00	Pallinup	10.19
Kalgan	11.00	Coobidge	8.17
Seven Mile	10.83		
Kordabup	10.67		
Sleeman	9.58		

The top three ranked rivers in the Eastern South Coast bioregion were the Oldfield River (13.79), the Jerdacuttup River (13.22) and the Gairdner River (12.70). These rivers drained moderately to well-vegetated catchments, had riparian zones in generally good condition, had minimal channel disturbance at the sites sampled, and showed only moderate variation in the water chemistry variables and biodiversity values assessed. The lowest ranked waterway was Coobidge Creek (8.17), a relatively disturbed waterway draining a predominantly agricultural landscape west of Esperance.

The 'diversity' criterion was scored using four indicators – channel heterogeneity, in-stream habitat heterogeneity, invertebrate diversity and vertebrate diversity, thus resulting in a potential maximum score of 12 for highly diverse, 'pristine' systems (Table 2; Appendix B).

Table 11: Scores obtained for degree of 'diversity', for waterways of the South Coast Region. Waterways have been ranked in descending order within each bioregion.

Western South Coast		Eastern South Coast	
River	**Score**	**River**	**Score**
Shannon	10.40	Oldfield	10.13
Frankland_Gordon	9.55	Bremer	9.27
Gardner	9.40	Jerdacuttup	9.00
Deep	9.00	Young	9.00
Kent	9.00	Phillips_West	8.88
Hay_Mitchell	8.59	Fitzgerald	8.00
Marbellup	8.23	Coromup	8.00
Bow	7.50	Gairdner	7.60
Denmark	7.50	Pallinup	7.50
Waychinicup	7.33	Dalyup	7.50
Kalgan	7.33	Steer	7.00
Sleeman	7.00	Bandy	7.00
Walpole	6.50	Thomas	7.00
Kordabup	6.00	Dailey	6.67
Limeburners	6.00	Coobidge	4.00
Seven Mile	5.00		
Bluff	5.00		
Goodga	5.00		

The most diverse of the waterways in the Western South Coast bioregion were the Shannon (10.40), the Frankland Gordon (9.55) and the Gardner (9.40) Rivers (Table 11;

Appendix D). These systems were particularly diverse in terms of their biota, and all systems scored highly for macro-invertebrate and fish diversity. Seven Mile Creek, Bluff Creek and Goodga River were least diverse in terms of the substrata, in-stream habitat and faunal diversity found in these systems. The Oldfield (10.13), Bremer (9.27), Jerdacuttup (9.00) and Young (9.0) rivers were the most diverse of the waterways in the Eastern South Coast bioregion, while Coobidge Creek (4.0) was found to be the least diverse of systems in this bioregion.

The criterion 'rarity' was scored using three indicators – the number of 'flagship' species, the number of threatened species, and the presence of endemic or rare species, thus resulting in a potential maximum score of 9 for 'pristine' systems with either threatened, rare, endemic or flagship species (Table 2; Appendix B). Numbers of native freshwater crayfish species were used as the measure for 'flagship' species. Because of their charismatic appeal, flagship species serve to increase public awareness (Nickoll & Horwitz, 2000). These species usually have high public profile, and require conservation. After evaluating the use of marron as a flagship species, Nickoll & Horwitz (2000) concluded that this species was an appropriate flagship for the restoration of the Blackwood River, and thus it is likely that crayfish would be appropriate to use as flagship species in other riverine systems in southwestern Australia. The number of fish species listed as either threatened or rare by the IUCN was used as a measure of threatened species. Species of concern included the Spotted Minnow, *G. truttaceus hesperius* (listed as 'critically endangered'), Balston's Pygmy Perch, *N. balstoni* (vulnerable) and the Salamanderfish, *L. salamandroides* (rare). The mayflies and the caddisflies, two groups known to have high numbers of endemic species were used as measures of the indicator, 'endemic or rare species'.

River systems in the Western South Coast bioregion that ranked highest for 'rarity' were the Shannon (8) and Deep (7) Rivers, and Marbellup Brook (7) (Table 12; Appendix E). Rivers in the Eastern South Coast bioregion that scored highest for 'rarity' were the Bremer (7), Gairdner (7), Fitzgerald (6) and Phillips West (6) Rivers.

Table 12: Scores obtained for degree of 'rarity', for waterways of the South Coast Region. Waterways have been ranked in descending order within each bioregion. Bioregion A: Eastern South Coast, Bioregion B: Western South Coast.

Western South Coast		Eastern South Coast	
River	**Score**	**River**	**Score**
Shannon	8	Bremer	7
Deep	7	Gairdner	7
Marbellup	7	Fitzgerald	6
Gardner	6	Phillips_West	6
Walpole	6	Jerdacuttup	6
Bow	6	Oldfield	5
Hay_Mitchell	6	Bandy	5
Frankland_Gordon	5.5	Pallinup	4
Kent	5.5	Coromup	4
Denmark	5.5	Dailey	4
Goodga	5	Steer	3
Waychinicup	4.5	Young	3
Sleeman	4	Coobidge	3
Seven Mile	4	Dalyup	3
Bluff	4	Thomas	3
Kordabup	3.5		
Kalgan	3.5		
Limeburners	3		

When 'naturalness', 'diversity' and 'rarity' are considered together to obtain an overall assessment of ecological value, with the three criteria equally weighted (each scaled up to a possible score of 15 for each), the top three ranked rivers in the Eastern South Coast bioregion were the Bremer River (score of 35.1), the Oldfield River (34.8) and the Jerdacuttup River (34.5) (Table 13; Appendix F). Although the Oldfield River does not contain any known threatened fish species, it does provide a home for some 'charismatic' decapod species ('flagship species') and caddisflies. The system is also in good condition, and is diverse, particularly in term of invertebrate and fish species richness. Coobidge Creek (15.17) scored the lowest for this bioregion. The top three ranked rivers in the Western South Coast bioregion were the Shannon River (score of 41.2), the Deep River (37.4) and the Gardner River (35.7).

Table 13: Scores obtained for overall ecological value of waterways of the South Coast Region. The three criteria (naturalness, diversity and rarity) have been assigned equal weighting. Waterways have been ranked in descending order within each bioregion.

Western South Coast		Eastern South Coast	
River	**Score**	**River**	**Score**
Shannon	41.2	Bremer	35.1
Deep	37.4	Oldfield	34.8
Gardner	35.7	Jerdacuttup	34.5
Frankland_Gordon	33.6	Gairdner	33.9
Kent	33.5	Phillips_West	33.8
Marbellup	33.5	Fitzgerald	30.7
Hay_Mitchell	33.5	Young	28.8
Denmark	32.8	Bandy	28.7
Walpole	31.6	Dailey	27.3
Bow	31.6	Coromup	27.3
Waychinicup	29.7	Pallinup	26.2
Kalgan	26.0	Steer	25.8
Goodga	25.6	Thomas	24.8
Limeburners	25.5	Dalyup	24.7
Sleeman	25.0	Coobidge	18.2
Bluff	24.9		
Kordabup	24.0		
Seven Mile	23.8		

Discussion

Bioregionalisation

Classification of rivers based on macroinvertebrate data revealed two distinct, broad 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 coincided with environmentally distinct geographic regions, and were characterized by the presence of a number of 'indicator' taxa. The recognition of aquatic bioregions is important for a number of reasons. For example, the relatively low O/E scores (thus implying poor condition) obtained by Halse et al. (2007) for naturally saline, 'reference' 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 only 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. Use of biotic indices such as the SIGNAL (Stream Invertebrate grade Number Average Level) index (Chessman 1995) and the EPT index would also be further enhanced if natural regional differences were to be incorporated into their use.

Of interest would be a comparison of the longitudinal profiles of Western and Eastern rivers. Rivers in the Eastern South Coast bioregion commonly start with a shallow gradient in their upper sections located on the Yilgarn Plateau, then fall sharply through granite regions, before finishing off with another shallow gradient in their lower sections. This longitudinal profile is quite different from some of the rivers of the Western South Coast bioregion, which start with a steep gradient and end with a shallow gradient as they broaden near the coast.

While the Eastern South Coast aquatic bioregion 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. Although not the subject of this study, further testing of the applicability of the IBRA subregions would involve further analysis at the site level.

The successful implementation of an *a posteriori* method 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. Past sampling program, such as the Australian-wide AusRivAS (Australian River Assessment System) program have generated large macroinvertebrate datasets, and these have been used by some authors to define interim aquatic bioregions (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.

Additional sampling is also needed to clarify the delineation of bioregions in 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, Mullocullop Creek, Cordinup River, Willyun Creek and Eyre River) were not included in the analysis. 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 would also be required to test whether the two broad aquatic bioregions can be divided into aquatic sub-regions.

In-stream biodiversity

Although many taxonomic groups show reduced species richness in the south-west in comparison to other regions in Australia, a high proportion of macro-invertebrate and fish species are endemic to southwestern Australia. Many of these species were collected from the waterways of the South Coast Region, mostly in the western part of the region. In particular, the Shannon and Gardner Rivers harbour many endemic species, including some which are only known from a few river systems. Rivers in the Eastern South Coast bioregion have far fewer endemic species, and those species which occur in these systems are able to tolerate more saline conditions. The high values for total species richness, and EPT obtained for the Hay River and the Marbellup Brook can be partly attributed to the number of samples collected from these systems, suggesting that species richness is likely to be underestimated in those systems where fewer samples were collected.

There are a number of taxa which could be used as 'indicators' for river health for rivers in the Western South Coast bioregion, as they are generally widespread across the bioregion. Despite the fact that the Ephemeroptera, Plecoptera and Trichoptera are poorly represented in southwestern Australia when compared to eastern Australia (Bunn & Davies, 1990), the EPT index could still prove a useful biotic index, especially if it can be shown that it is sensitive and changes in response to environmental gradients. A total of 46 species of mayflies, stoneflies and caddisflies were collected from rivers of the South Coast region, with some of these species occurring in over half the rivers. Some macrocrustacean species are also well represented, suggesting that these could be used as indicators of river health. These include the endemic amphipod *Perthia branchialis*, the koonacs *Cherax crassimanus* and *C. preissii* and the gilgie, *C. quinquecarinatus*. Other potential indicator species include the endemic dragonfly species *Austroaeschna anacantha* and the more widespread species *Hemicordulia tau*. All of these species would need to be tested for sensitivity to various degradation gradients.

There are a number of taxa that could be used as 'indicators' of river health in rivers of the Eastern South Coast bioregion. These include the unidentified paramelitid amphipod, the caddisflies *Notolina spira* and *Symphitoneuria wheeleri*, the damselflies *Austroagrion cyane* and *Austrolestes annulosus*, the bivalve *Westralunio* sp., the snails *Coxiella* spp and the Common Jollytail, *Galaxias maculatus*.

Assessment of ecological values

By applying a consistent set of criteria and indicators that provided measures of naturalness, diversity and rarity, we were able to successfully identify systems that could be considered as 'high conservation value aquatic ecosystems' (HCVAEs) in the South Coast Region. Signatories (including Western Australia) to the National Water Initiative (NWI) have committed to "identify and acknowledge surface and groundwater systems of high conservation value, and manage these systems to protect and enhance those values". Currently there is no nationally consistent approach to the identification, categorization and management of these HCVAEs. Identification, categorization and criteria frameworks for Ramsar wetlands, the Directory of Important Wetlands in Australia (DIWA), and assessment for National Heritage List nominations provide the only consistent frameworks of HCVAE identification across all States. In the case of Western Australia, identification of HCVAEs falls into three broad categories: (i) wetlands, (ii) waterways, and (iii) threatened species. Presently, rivers are ranked as either "high", "medium" or "low" for value, condition and pressures using the State Waterways Needs Assessment (SWNA). However, a 'new' framework for WA is presently under development which allows a more detailed assessment of ecological values – this report has used these proposed criteria, indicators and measures to assess the ecological values of waterways in the South Coast region.

The top three ranked rivers in terms of overall 'ecological value' in the Eastern South Coast bioregion were the Bremer River, Oldfield River, and the Jerdacuttup River. Although none of these rivers harboured any species known to be threatened, they were home to a number of caddisfly species, koonac (Bremer River), the Common Jollytail,

Galaxias maculatus (Oldfield and Bremer) and an unidentified paramelitid amphipod, likely to be endemic to the area. The top three ranked waterways in terms of overall ecological value in the Western South Coast bioregion were the Shannon, Deep and Gardner Rivers. These waterways are home to a number of other significant taxa in addition to those used to 'score' the ecological values of these systems. For example, when Sutcliffe (2003) assessed the odonate species in her study for conservation status using the IUCN criteria for listing threatened species, she assigned *Armagomphus armiger* as 'vulnerable', *Archaeosynthemis spiniger* as 'endangered' and *Hesperocordulia berthoudi* as 'near threatened'. The former two species were collected from the Gardner River, while the latter species was found in the Shannon River in this study. Similarly, the highly restricted trichopteran species, *Acritoptila margaretae*, assigned a status of 'critically endangered' by Sutcliffe (2003) occurs in the Gardner River.

This study has given equal weighting to the three criteria used (naturalness, diversity and rarity) to assess ecological value of waterways. This might not always be desirable, as there might be cases where a higher weighting should be used for a particular criterion. For example, moderate to lower levels of naturalness, diversity and rarity result in the Goodga River (located in the Western South Coast bioregion) being ranked lower down on the list for overall ecological value. The Goodga River is certainly of ecological importance, as it is one of only two systems known to be home to the critically endangered Western Trout Minnow. Managers could choose to categorise such a system as a 'top priority' waterway regardless of their ranking, or they might choose to give the rarity criterion a much higher weighting than the other criteria when assessing overall ecological value using a number of criteria.

A number of other key waterways were not sampled as part of this project. These systems include the Lort and Hamersley Rivers in the Eastern South Coast bioregion, and the King Creek, Angove River, and the King River in the Western South Coast bioregion. A number of smaller systems also remain unsampled. Inclusion of these systems in

future sampling aimed at determining the ecological values of South Coast Region would greatly enhance our knowledge of the area, and would provide a more complete picture of the ecological values of waterways in the Region.

Acknowledgements

This report was completed for the Department of Water (DOW), South Coast Region on behalf of the South Coast Natural Resource Management Inc (previously SCRIPT), and we thank both organizations for the opportunity to increase our understanding of ecological values of waterways in the South Cast region. In particular, our thanks are extended to Naomi Arrowsmith, Chris Gunby and Mieke Bourne of DOW for their active management, and in-kind field assistance for this important project.

Kaye Stott and Geoff Prince are thanked for producing the 'Our Living Rivers' website. This website includes information collected during this project for the broader community (www.livingrivers.southcoastwa.org.au).

Field work and sample processing in the laboratory was assisted by Steve Janicke, Susan Blandford, Caroline Versteeg, Joselyn Berkelaar and Cassie Bell. Thanks to Dr Paul Close for confirming fish identifications.

We are grateful to the numerous landholders that kindly allowed access to waterways on their properties. Many of whom assisted with anecdotal information, and in some cases assisted with 'live picks' and guided tours to sample sites. These include Mr George Toovey, Goundrey Wines, Mr Len Handasyde, ITC Plantation 'Peaceful Valley', Mr Charlie Gill, Rocky Horror Vineyard, Trevor & Phyllis Barker, Mr Roger Sweetman, Mr Richard Kratochvill, Mr Peter Walmsley, Greening Australia Gondwana Link, Paula Deegan, Angela Sanders, Fred Powell, Mr Ernest and Terri Jaekel, Sandalwood Farm, Mr Stuart and Leanne Bee, Mr Darryl Spinks, Mr Andy Chapman, C & N Wisewould, and Mr Alan & Bec Hoggart.

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Appendix A: Waterways and sites sampled in the South Coast Region

No	Catchment	Waterway name	Site	Northing	Easting
1	Gardner River	Buldania Creek	GAR01	6153399	428402
1	Gardner River	Cantebury River	GAR02	6158122	426908
1	Gardner River	Boorara Creek	GAR03	6168633	428850
1	Gardner River	Gardner Rd	GAR04	6167152	421164
1	Gardner River	Gardner River	GAR05	6151395	425207
2	Shannon River	Shannon River	SHA01	6175262	449045
2	Shannon River	Fish Creek	SHA02	6163183	442924
2	Shannon River	Shannon River	SHA04	6158616	441708
2	Shannon River	Shannon River (lower)	SHA05	6144730	442848
2	Shannon River	Cheasapeake Brook	SHA06	6145568	439284
3	Deep River	Deep River	DEE01	6159884	465128
3	Deep River	Deep River	DEE02	6166307	465254
3	Deep River	Weld River	DEE03	6160708	455919
3	Deep River	Weld River	DEE04	6153596	455365
3	Deep River	Deep River	DEE05	6136917	465499
4	Walpole River	Walpole River	WAL01	6130034	473554
4	Walpole River	Walpole River	WAL02	6134217	470287
5	Frankland Gordon	Frankland River	FRA01	6133298	481722
5	Frankland Gordon	Frankland River	FRA02	6162106	486699
5	Frankland Gordon	Frankland River	FRA03	6172358	481423
5	Frankland Gordon	Elsie Brook	FRA05	6142006	475241
5	Frankland Gordon	Frankland River	FRA07	6184978	491313
5	Frankland Gordon	Gordon	GOR01	6243817	558987
5	Frankland Gordon	Wadjekanup Creek	GOR02	6236952	551616
5	Frankland Gordon	Slab Hut Gully	GOR03	6225127	533386
5	Frankland Gordon	Old Terlinga Pool	GOR04	6211962	544365
5	Frankland Gordon	Gordon River	GOR05	6212318	523348
5	Frankland Gordon	Towerlup Brook	GOR06	6217681	499560
6	Bow River	Bow River lower Trib	BOW06	6136406	494984
6	Bow River	Bow River	BOW07	6137087	489471
7	Kent River	Nile Creek	KEN01	6144923	503447
7	Kent River	Kent River	KEN02	6145407	505620
7	Kent River	Styx River	KEN03	6140095	512415
7	Kent River	Kent River	KEN08a	6170501	502165
7	Kent River	Kent River	KEN10	6161943	509657
8	Kordabup River	Kordabup River	KOR04	6130700	513355
9	Denmark River	Denmark River Upper	DEN01a	6160243	519850
9	Denmark River	Makoyup Creek	DEN08	6159754	525483
9	Denmark River	Denmark/Quickup confluence	DEN-Pw	6135156	533140
9	Denmark River	Denmark River	DEN-AC	6132668	532794
9	Denmark River	Denmark River	DEN-LG	6145917	523021
9	Denmark River	Quickup River	QUI01	6136210	534337
9	Denmark River	Quickup River	QUI02	6140269	535353
10	Hay River	Hay River	HAY01	6155420	551414

10	Hay River	Hay River	HAY02	6161811	555389
10	Hay River	Hay River	HAY03	6165676	550978
10	Hay River	Hay River	HAY04	6166011	550317
10	Hay River	Hay River	HAY05	6167116	545750
10	Hay River	Hay River	HAY06	6168926	540232
10	Hay River	Hay R. Trib.	HAY07	6169619	539795
10	Hay River	Hay River	HAY08	6139273	546447
10	Hay River	Sheepwash Creek	HAY09	6152707	539916
10	Hay River	Sheepwash Creek	HAY10	6153374	540787
10	Hay River	Sheepwash Creek	HAY11	6152727	545524
10	Hay River	Sheepwash Creek	HAY12	6155914	546672
10	Hay River	Sleeman Creek	HAY13	6144268	557940
10	Hay River	Sleeman Creek	HAY14	6147919	560430
10	Hay River	Snake Gully	HAY15	6173133	542926
10	Hay River	Yamballup Creek	HAY16	6166156	553417
10	Hay River	Yamballup Creek	HAY17	6168903	555685
10	Hay River	Bluegum Creek	HAY18	6144220	551137
10	Hay River	Crystal Brook	HAY19	6154514	552873
10	Hay River	Mitchell River	MIT01	6143344	539997
10	Hay River	Mitchell River	MIT02	6146014	535916
10	Hay River	Mitchell River	MIT03	6147773	531795
11	Sleeman River	Sleeman River	SLE01	6131473	544410
11	Sleeman River	Sleeman River	SLE02	6133001	556857
12	Marbellup River	Central Marbellup	MAR01	6130918	564657
12	Marbellup River	Central Marbellup	MAR02	6130757	564509
12	Marbellup River	Central Marbellup	MAR03	6129689	565450
12	Marbellup River	Central Marbellup	MAR04	6131699	562777
12	Marbellup River	Central Marbellup	MAR05	6128360	561775
12	Marbellup River	Central Marbellup	MAR06	6133380	565160
12	Marbellup River	Marbellup Down Road	MAR07	6134372	568073
12	Marbellup River	Marbellup Down Road	MAR08	6134181	567960
12	Marbellup River	Marbellup Down Road	MAR09	6133655	567423
12	Marbellup River	Marbellup Down Road	MAR10	6132779	566619
12	Marbellup River	Marbellup Down Road	MAR11	6130746	567035
12	Marbellup River	Marbellup Down Road	MAR12	6128531	566233
12	Marbellup River	Marbellup Down Road	MAR13	6128416	565851
12	Marbellup River	Marbellup Down Road	MAR14	6133156	568706
12	Marbellup River	Marbellup Down Road	MAR15	6132672	567838
12	Marbellup River	West Marbellup	MAR16	6130780	560024
12	Marbellup River	West Marbellup	MAR17	6130315	560182
12	Marbellup River	West Marbellup	MAR18	6129187	560245
12	Marbellup River	North Marbellup	MAR19	6135246	567239
12	Marbellup River	North Marbellup	MAR20	6134995	566986
12	Marbellup River	North Marbellup	MAR21	6134411	566276
12	Marbellup River	North Marbellup	MAR22	6134311	566186
12	Marbellup River	North Marbellup	MAR23	6133451	564593
12	Marbellup River	North Marbellup	MAR24	6133908	566076
12	Marbellup River	North Marbellup	MAR25	6134170	564814
12	Marbellup River	North Marbellup	MAR26	6133703	563815
12	Marbellup River	North Marbellup	MAR27	6134275	563128

12	Marbellup River	North Marbellup	MAR28	6133376	565221
13	7Mile Creek	7Mile Creek	7MIL01	6127242	571061
14	Bluff Creek	Bluff Creek	BLF07	6145753	626403
15	Goodga River	Goodga River	GOO01	6133038	598813
15	Goodga River	Goodga River	GOO02	6131715	598748
16	Limeburners Ck	Limeburners Creek	LIM01	6116488	583075
17	Waychinicup River	Waychinicup River	WAY01	6139640	621483
17	Waychinicup River	Waychinicup River	WAY02	6141304	620666
17	Waychinicup River	Waychinicup River	WAY03	6146808	616023
18	Kalgan River	Kalgan River	KAL01	6167844	595632
18	Kalgan River	Kalgan River	KAL02	6174095	591132
18	Kalgan River	Kalgan River	KAL03	6180885	573565
18	Kalgan River	Napier Creek	KAL-K1	6146188	578267.7
18	Kalgan River	Napier Creek	KAL-K2	6144528	583901.7
18	Kalgan River	Napier Creek	KAL-K3	6145054	587811.3
18	Kalgan River	Chelgiup Creek	KAL-K4	6138179	591677.3
18	Kalgan River	Chelgiup Creek	KAL-K5	6140528	595779.4
18	Kalgan River	Takenup Creek	KAL-K7	614938	593299.4
18	Kalgan River	Little Creek	KAL-K8	6140648	589474.4
18	Kalgan River	"Churchlane Creek"	KAL-K9	6138471	590991.5
19	Pallinup River	Peniup Creek	PAL01	6223724	670808
19	Pallinup River	Hegarty Creek	PAL02	6225935	672439
19	Pallinup River	Corackerup Creek	PAL03	6216822	660129
19	Pallinup River	Waperup Creek	PAL04	6242199	636066
19	Pallinup River	Penebup Creek	PAL05	6225691	641520
19	Pallinup River	Penebup Creek	PAL06	6226571	631750
19	Pallinup River	Pallinup River	PAL07	6231580	596333
19	Pallinup River	Pallinup River	PAL08	6204500	634036
20	Bremer River	Bremer River	BRE01	6200063	706906
20	Bremer River	Bremer River	BRE02	6212057	696838
20	Bremer River	Devils Creek	BRE03	6211085	688046
20	Bremer River	Bremer River	BRE04	6222842	685717
20	Bremer River	Bremer River	BRE05	6234138	683802
20	Bremer River	Bremer River trib.	BRE06	6198598	712799
20	Bremer River	Devils Creek	BRE07	6204890	701541
21	Gairdner River	Gairdner River	GAI01	6211156	710196
21	Gairdner River	Gairdner River	GAI02	6234261	690703
21	Gairdner River	Calyerup Creek	GAI03	6242632	691951
21	Gairdner River	Gairdner River	GAI04	6256893	667664
21	Gairdner River	Nyerilup Creek	GAI05	6251197	664317
22	Fitzgerald River	Fitzgerald Tributary	FIT01	6248602	710508
22	Fitzgerald River	Robbies Creek	FIT02	6259927	712138
22	Fitzgerald River	Jacup Creek	FIT03	6263479	700526
22	Fitzgerald River	Fitzgerald River	FIT04	6263243	707171
22	Fitzgerald River	Jacup Creek	FIT05	6263449	704679
22	Fitzgerald River	Sussetta River	SUS01	6261059	724604
22	Fitzgerald River	Sussetta River	SUS02	6256459	725557
22	Fitzgerald River	Sussetta River	SUS03	6236579	725932
22	Fitzgerald River	Twertup Creek	TWE01	6234809	723124
23	Phillips/West	Phillips River	PHI01	6250263	784137

23	Phillips/West	Carracarra Creek	PHI02	6262522	776085
23	Phillips/West	Phillips River	PHI03	6285524	768942
23	Phillips/West	Unnamed pool	PHI04	6297803	762577
23	Phillips/West	Phillips River	PHI05	6277823	767469
23	Phillips/West	West River	WES01	6256993	773312
23	Phillips/West	West River	WES02	6271306	748602
23	Phillips/West	West River	WES03	6278723	743799
24	Steere	Steer River	STE01	6254735	793661
25	Jerdacuttup River	Jerdacuttup River	JER01	6244913	797939
25	Jerdacuttup River	Jerdacuttup River	JER02	6262668	804768
25	Jerdacuttup River	Cordingup Creek	JER03	6279833	792544
25	Jerdacuttup River	Jerdacuttup River	JER04	6300242	789703
26	Oldfield River	Oldfield River	OLD01	6264601	289548
26	Oldfield River	Munglinup River	OLD02	6276715	298919
26	Oldfield River	Oldfield River	OLD03	6271757	283978
26	Oldfield River	Cheadanup Creek	OLD04	6285762	280980
26	Oldfield River	Oldfield River	OLD05	6285945	271194
26	Oldfield River	Oldfield River	OLD06	6293963	819745
26	Oldfield River	Oldfield River	OLD07	6317934	260520
27	Young River	Young River	YOU01	6268233	329404
27	Young River	Yerritup Creek	YOU02	6286857	310034
27	Young River	Young River	YOU03	6290162	310433
27	Young River	Young River	YOU04	6297554	299434
27	Young River	Cascade Creek	YOU05	6294921	316232
28	Coobidge Creek	Coobidge Creek	COO01	6279002	360006
28	Coobidge Creek	Coobidge Creek	COO02	6286021	357058
29	Dalyup River	Dalyup River	DAL01	6262880	366395
29	Dalyup River	Dalyup River	DAL02	6279181	373572
29	Dalyup River	Dalyup River West	DAL03	6279097	367341
29	Dalyup River	Dalyup River West	DAL04	6290368	362457
30	Bandy River	Bandy River	BAN01	6265921	406224
30	Bandy River	Bandy River	BAN02	6279575	413011
31	Coromup Creek	Coromup Creek	COR01	6263406	400207
31	Coromup Creek	Coromup Creek	COR02	6275424	400950
32	Dailey River	Dailey River	DAI01	6249834	462603
32	Dailey River	Duke Creek	DAI02	6251335	462820
32	Dailey River	Dailey River	DAI03	6251779	460891
33	Thomas River	Thomas River	THO01	6258807	503492

Appendix B: Proposed criteria and indicators for assessing ecological value of waterways. Criteria and indicators used in this study have been italicized.

Criterion	Indicators
Naturalness (condition)	*Level of catchment disturbance* *Level of riparian zone disturbance* *Level of river channel disturbance* Level of flow modification *Variation from natural state of water chemistry* Variation from natural temperature regimes *Variation from natural state of in-stream biota*
Representativeness	Hydrological regime Water quality characteristics Biotic characteristics
Diversity or richness	Hydrological diversity *Channel heterogeneity* *In-stream habitat heterogeneity* *Invertebrate diversity* *Vertebrate diversity* Floral diversity
Rarity	Unusual hydrological regimes Unusual water quality types Rare geomorphological and habitat features *Presence of threatened and priority species and communities* *Presence of 'flagship' species* *Presence of rare or endemic species*
Special features	Drought refuge Maintenance of hydrological features Biotic special features Significant areas Refuge habitat Habitat for species of special interest Significant scientific sites

Appendix C: Scores for measures and indicators used to assess degree of naturalness of each river system based on sites sampled. Yellow = Western South Coast bioregion, Green = Eastern South Coast bioregion.

	Catchment disturbance	Riparian disturbance				Channel disturbance			Water chemistry variation			Biota variation			Naturalness
River system	%remnant	width	cover	weeds	Mean	erosion	sediment	Mean	Salinity	TP	Mean	Spp_richness	EPT	Mean	TOTAL
Gardner	3.00	3.00	3.00	2.80	2.93	2.40	2.60	2.50	3.00	2.00	2.50	3.00	3.00	3.00	**13.93**
Shannon	3.00	3.00	3.00	3.00	3.00	2.80	2.80	2.80	3.00	3.00	3.00	3.00	3.00	3.00	**14.80**
Deep	3.00	3.00	2.75	3.00	2.93	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.50	**14.43**
Walpole	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	2.00	1.50	**13.50**
Frankland_Gordon	2.00	3.00	2.09	2.27	2.45	3.00	2.82	2.91	1.18	3.00	2.09	3.00	3.00	3.00	**12.45**
Bow	2.00	3.00	3.00	3.00	3.00	3.00	2.50	2.75	3.00	2.00	2.50	2.00	2.00	2.00	**12.25**
Kent	2.00	3.00	2.80	3.00	2.93	3.00	3.00	3.00	2.20	3.00	2.60	3.00	2.00	2.50	**13.03**
Kordabup	2.00	3.00	3.00	2.00	2.67	3.00	3.00	3.00	3.00	1.00	2.00	1.00	1.00	1.00	**10.67**
Denmark	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.50	3.00	2.75	3.00	2.00	2.50	**14.25**
Hay_Mitchell	2.00	2.64	2.50	2.36	2.50	2.77	2.91	2.84	1.70	2.95	2.39	3.00	3.00	3.00	**12.73**
Sleeman	1.00	2.00	1.50	2.00	1.83	3.00	3.00	3.00	3.00	1.50	2.25	2.00	1.00	1.50	**9.58**
Marbellup	1.00	2.00	2.33	1.96	2.04	2.80	2.84	2.82	3.00	2.24	2.62	3.00	3.00	3.00	**11.49**
Seven Mile	2.00	2.00	3.00	2.00	2.33	3.00	3.00	3.00	3.00	1.00	2.00	2.00	1.00	1.50	**10.83**
Bluff	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	**12.00**
Goodga	2.00	3.00	3.00	3.00	3.00	3.00	2.50	2.75	3.00	1.50	2.25	1.00	1.00	1.00	**11.00**
Limeburners	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	**13.00**
Waychinicup	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	**13.00**
Kalgan	1.00	3.00		1.00	2.00	3.00	3.00	3.00	1.00	3.00	2.00	3.00	3.00	3.00	**11.00**
Pallinup	1.00	2.88	1.50	2.38	2.25	2.88	2.88	2.88	2.00	2.13	2.06	2.00	2.00	2.00	**10.19**
Bremer	1.00	2.82	2.73	2.45	2.67	2.73	2.82	2.77	2.70	2.00	2.35	3.00	3.00	3.00	**11.79**
Gairdner	2.00	3.00	3.00	2.40	2.80	3.00	2.60	2.80	2.20	2.00	2.10	3.00	3.00	3.00	**12.70**
Fitzgerald	2.00	3.00	2.22	2.44	2.56	2.78	2.89	2.83	1.33	3.00	1.75	1.00	2.00	1.50	**10.64**

Phillips_West	2.00	3.00	2.75	2.88	2.88	3.00	3.00	3.00	1.63	2.14	1.81	3.00	3.00	3.00	**12.69**
Steer	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	**12.00**
Jerdacuttup	2.00	2.90	2.68	2.79	2.79	3.00	3.00	3.00	2.26	2.61	2.43	3.00	3.00	3.00	**13.22**
Oldfield	3.00	3.00	2.75	3.00	2.92	3.00	3.00	3.00	2.38	2.43	2.38	3.00	2.00	2.50	**13.79**
Young	2.00	3.00	2.80	3.00	2.93	3.00	3.00	3.00	2.60	2.60	2.60	3.00	1.00	2.00	**12.53**
Coobidge	1.00	2.50	1.00	3.00	2.17	2.00	2.00	2.00	1.00	3.00	2.00	1.00	1.00	1.00	**8.17**
Dalyup	1.00	3.00	2.75	2.00	2.58	2.75	3.00	2.88	1.75	3.00	2.38	2.00	1.00	1.50	**10.33**
Bandy	1.00	3.00	3.00	2.50	2.83	3.00	3.00	3.00	2.50	3.00	2.75	2.00	2.00	2.00	**11.58**
Coromup	1.00	2.50	1.50	1.50	1.83	3.00	2.50	2.75	3.00	2.00	2.50	3.00	2.00	2.50	**10.58**
Dailey	1.00	3.00	3.00	3.00	3.00	3.00	2.67	2.83	3.00	3.00	3.00	3.00	2.00	2.50	**12.33**
Thomas	1.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	**11.00**

Appendix D: Scores for measures and indicators used to assess degree of diversity of each river system based on sites sampled. Yellow = Western South Coast bioregion, Green = Eastern South Coast bioregion.

	Channel	Habitat	invertebrate	vertebrate	Diversity
River system	Substrata	Instream	Invert_richness	fish_richness	TOTAL
Gardner	1.80	2.60	3.00	2.00	**9.40**
Shannon	2.00	2.40	3.00	3.00	**10.40**
Deep	1.80	2.20	2.00	3.00	**9.00**
Walpole	1.50	2.00	1.00	2.00	**6.50**
Frankland_Gordon	2.00	1.55	3.00	3.00	**9.55**
Bow	2.00	1.50	2.00	2.00	**7.50**
Kent	2.00	2.00	3.00	2.00	**9.00**
Kordabup	2.00	2.00	1.00	1.00	**6.00**
Denmark	1.75	1.75	2.00	2.00	**7.50**
Hay_Mitchell	1.77	1.82	3.00	2.00	**8.59**
Sleeman	1.50	1.50	2.00	2.00	**7.00**
Marbellup	1.64	1.59	3.00	2.00	**8.23**
Seven Mile	1.00	1.00	2.00	1.00	**5.00**
Bluff	1.00	2.00	1.00	1.00	**5.00**
Goodga	1.50	1.50	1.00	1.00	**5.00**
Limeburners	2.00	2.00	1.00	1.00	**6.00**
Waychinicup	1.67	1.67	2.00	2.00	**7.33**
Kalgan	1.67	1.67	2.00	2.00	**7.33**
Pallinup	2.25	1.25	2.00	2.00	**7.50**
Bremer	2.27	2.00	3.00	2.00	**9.27**
Gairdner	2.00	1.60	2.00	2.00	**7.60**
Fitzgerald	2.44	1.56	2.00	2.00	**8.00**
Phillips_West	2.25	1.63	3.00	2.00	**8.88**
Steer	2.00	2.00	1.00	2.00	**7.00**
Jerdacuttup	2.00	2.00	3.00	2.00	**9.00**
Oldfield	2.25	1.88	3.00	3.00	**10.13**
Young	2.40	1.60	3.00	2.00	**9.00**
Coobidge	1.00	1.00	1.00	1.00	**4.00**
Dalyup	1.75	1.75	2.00	2.00	**7.50**
Bandy	2.00	2.00	2.00	1.00	**7.00**
Coromup	2.50	1.50	2.00	2.00	**8.00**
Dailey	1.67	2.00	2.00	1.00	**6.67**
Thomas	3.00	2.00	1.00	1.00	**7.00**

Appendix E: Scores for measures and indicators used to assess degree of rarity of each river system based on sites sampled. Yellow = Western South Coast bioregion, Green = Eastern South Coast bioregion.

	Flagship	Threatened	Endemic			Rarity
River system	Decapods	fish	mayflies	caddisflies	Mean	TOTAL
Gardner	2.00	1.00	3.00	3.00	3.00	**6.00**
Shannon	3.00	2.00	3.00	3.00	3.00	**8.00**
Deep	2.00	2.00	3.00	3.00	3.00	**7.00**
Walpole	2.00	2.00	2.00	2.00	2.00	**6.00**
Frankland_Gordon	2.00	2.00	1.00	2.00	1.50	**5.50**
Bow	2.00	2.00	2.00	2.00	2.00	**6.00**
Kent	2.00	2.00	1.00	2.00	1.50	**5.50**
Kordabup	1.00	1.00	2.00	1.00	1.50	**3.50**
Denmark	2.00	2.00	1.00	2.00	1.50	**5.50**
Hay_Mitchell	2.00	1.00	3.00	3.00	3.00	**6.00**
Sleeman	2.00	1.00	1.00	1.00	1.00	**4.00**
Marbellup	3.00	1.00	3.00	3.00	3.00	**7.00**
Seven Mile	1.00	1.00	2.00	2.00	2.00	**4.00**
Bluff	1.00	1.00	2.00	2.00	2.00	**4.00**
Goodga	1.00	3.00	1.00	1.00	1.00	**5.00**
Limeburners	1.00	1.00	1.00	1.00	1.00	**3.00**
Waychinicup	2.00	1.00	1.00	2.00	1.50	**4.50**
Kalgan	1.00	1.00	1.00	2.00	1.50	**3.50**
Pallinup	1.00	1.00		2.00		**4.00**
Bremer	3.00	1.00		3.00		**7.00**
Gairdner	3.00	1.00		3.00		**7.00**
Fitzgerald	2.00	1.00		3.00		**6.00**
Phillips_West	2.00	1.00		3.00		**6.00**
Steer	1.00	1.00		1.00		**3.00**
Jerdacuttup	2.00	1.00		3.00		**6.00**
Oldfield	2.00	1.00		2.00		**5.00**
Young	1.00	1.00		1.00		**3.00**
Coobidge	1.00	1.00		1.00		**3.00**
Dalyup	1.00	1.00		1.00		**3.00**
Bandy	2.00	1.00		2.00		**5.00**
Coromup	1.00	1.00		2.00		**4.00**
Dailey	1.00	1.00		2.00		**4.00**
Thomas	1.00	1.00		1.00		**3.00**

Appendix F: Scores for overall ecological value based on equal weighting of criteria. Yellow = Western South Coast bioregion, Green = Eastern South Coast bioregion.

	Naturalness	Diversity	Rarity	Total
Shannon	14.80	13.00	13.36	41.16
Deep	14.43	11.25	11.69	37.37
Gardner	13.93	11.75	10.02	35.70
Frankland_Gordon	12.45	11.93	9.19	33.57
Hay_Mitchell	12.73	10.74	10.02	33.48
Kent	13.03	11.25	9.19	33.47
Marbellup	11.49	10.29	11.69	33.46
Denmark	14.25	9.38	9.19	32.81
Walpole	13.50	8.13	10.02	31.65
Bow	12.25	9.38	10.02	31.65
Waychinicup	13.00	9.17	7.52	29.68
Kalgan	11.00	9.17	5.85	26.01
Goodga	11.00	6.25	8.35	25.60
Limeburners	13.00	7.50	5.01	25.51
Sleeman	9.58	8.75	6.68	25.01
Bluff	12.00	6.25	6.68	24.93
Kordabup	10.67	7.50	5.85	24.01
Seven Mile	10.83	6.25	6.68	23.76
Bremer	11.79	11.59	11.69	35.07
Oldfield	13.79	12.66	8.35	34.80
Jerdacuttup	13.22	11.25	10.02	34.49
Gairdner	12.70	9.50	11.69	33.89
Phillips_West	12.69	11.09	10.02	33.80
Fitzgerald	10.64	10.00	10.02	30.66
Young	12.53	11.25	5.01	28.79
Bandy	11.58	8.75	8.35	28.68
Dailey	12.33	8.33	6.68	27.35
Coromup	10.58	10.00	6.68	27.26
Pallinup	10.19	9.38	6.68	26.24
Steer	12.00	8.75	5.01	25.76
Thomas	11.00	8.75	5.01	24.76
Dalyup	10.33	9.38	5.01	24.72
Coobidge	8.17	5.00	5.01	18.18