National River Health Program

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MONITORING RIVER HEALTH INITIATIVE TECHNICAL REPORT
REPORT NUMBER 7

Australia-Wide Assessment of River Health: Western Australian Bioassessment Report

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Natural Heritage Trust
Helping Communities Helping Australia
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First National Assessment of River Health: Western Australian Program

Milestone Report 5 and Final Report

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This milestone report covers the period 1 July 1994 to 30 June 2001

Front cover photos:
Main photo
Cangan Pool on the Yule River, Pilbara. *S. Halse*
Inset photos, clockwise from top right
M. Scanlon and J. Cocking live-picking in the south-west of WA. *M. Scanlon*
Sorting trays containing portions of a sample sieved into different size fractions for live-picking, sieves behind. *J. Cocking*
J. Cocking sweep sampling in the Helena River. *M. Scanlon*
Common macroinvertebrate families, top to bottom - Corixidae, Aeschnidae, Dytiscidae. *J. McRae*

Summary

The First National Assessment of River Health (FNARH) comprised the second phase of the Monitoring River Health Initiative (MRHI), an Australia-wide program to develop a biomonitoring system for rivers based on macroinvertebrates. The biomonitoring system is called AusRivAS and measures river condition using a series of simple predictive models that compare the macroinvertebrate families occurring at a river site with those expected if the site were in good condition.

During the three years of FNARH fieldwork (1997-1999), the condition of 561 sites in all major rivers in Western Australia was assessed. Some further assessment work was done in 2000 and additional sites were evaluated during the first phase of the MRHI. In general terms, river condition is good in northern Australia, especially the northern Kimberley, although the Ord River catchment is noticeably degraded. Rivers in the Murchison-Gascoyne region are also mostly degraded. In the south-west of WA, rivers are mostly in poor condition with only the Shannon River, in a mostly forested catchment, being undisturbed. Rivers in coastal areas were degraded. The inland rivers of the Wheatbelt appeared to be only moderately impaired but this reflects some shortcomings of the AusRivAS models when assessing river condition in uniformly degraded regions. The reality is that Wheatbelt rivers are probably the most degraded in WA.

Results from AusRivAS confirmed that many catchment activities commonly regarded as inimical to river health are associated with changed macroinvertebrate community structure. These include activities causing erosion, nutrient and organic loads, loss of riparian vegetation and increased salinity. River regulation, channel modification and fire also deleteriously affect river condition but recreation did not appear to do so.

AusRivAS models are publicly available on the national AusRivAS website (http://ausrivas.canberra.edu.au). The website also contains a sampling manual that explains how to go about AusRivAS assessments in WA and what information must be collected. Access to the models is currently controlled by passwords that are obtainable from the University of Canberra via authorisation from the Department of Conservation and Land Management. This report, and the sampling manual, highlight that undertaking AusRivAS assessments requires biological expertise and suitable equipment. AusRivAS models are not an appropriate tool for widespread assessment of river condition by the community unless consultants are involved in the assessment process.

There are many potential applications of AusRivAS. Broad-scale assessment of river condition for State of the Environment reporting is one of the most obvious. Other uses include evaluation of the effects of local catchment management on river health, long-term monitoring of the condition of high-value river sites, environmental impact assessment and, possibly, compliance monitoring. The users of AusRivAS outputs are likely to range from individuals and community groups to Local Government and to the Commonwealth, who in conjunction with the State Government, funded the development of AusRivAS in WA. AusRivAS will work best with a State Government agency as sponsor to ensure that models are updated as environmental protection evolves and knowledge of WA rivers becomes more sophisticated. The agency could also provide training courses and assist first-time users of the system.

Major achievements and conclusions of the MRHI in WA include:

- Development of AusRivAS models for assessment of ecological condition of WA rivers
- Assessment of river condition, using AusRivAS, at 685 sites throughout the State
- Proposed bio-regionalisation scheme for aquatic invertebrates in WA
- AusRivAS has the potential to measure the ecological effect of a wide range of catchment activities and processes; and can be used to increase understanding of river ecology as well as to monitor river health
- AusRivAS models appeared to provide a more reliable measure of condition than chemical monitoring and some of the species-based metrics commonly used for assessment
- AusRivAS outputs are easier to interpret and, in some cases at least, cheaper to obtain than broad-spectrum chemical monitoring
- Aquatic macroinvertebrate family richness and ecological health are, within the bounds set by stream type, inter-related
- Human-induced disturbances in rivers change the macroinvertebrate community structure and reduce the overall number of macroinvertebrate families present
- Catchments in the northern Kimberley were mostly assessed as undisturbed and the region contains some of the least disturbed rivers in Australia

Contents

1 Description of the Milestone Report

This report summarises previous work undertaken for the Monitoring River Health Initiative (MRHI) and First National Assessment of River Health (FNARH) and provides a detailed report of work undertaken to achieve the tasks outlined under Milestone 5 of the contract between the Department of Conservation and Land Management (CALM) and Environment Australia (EA) for the final year of the FNARH. The report concludes by evaluating the extent to which the AusRivAS program has been successful in Western Australia and making some suggestions for its future development. Specific milestone items dealt with in the report include:

- Revising AusRivAS models for river assessment using macroinvertebrates
- Handing the revised models to the CRC for Freshwater Ecology for placement on the AusRivAS website
- Completing bioassessment models runs for all reference and test sites sampled during the AusRivAS program (1994-2000 inclusive)
- Mapping of bioassessment results for 1997-2000 and assessing river condition at a catchment scale
- Examining the effect of catchment activity on *O/E* scores produced by AusRivAS models
- Comparing Habitat Assessment Scores (*HAS*) and *O/E* values
- Technology transfer and AusRivAS adoption
- Program performance against NHT Performance Indicators

2 Background

The MRHI is part of the National River Health Program, which was announced by the Prime Minister in 1992. Initial discussions about the MRHI in WA were conducted between the Commonwealth and the Water Authority, a predecessor of the Water and Rivers Commission (WRC), but it was decided among WA government agencies that CALM should be the Lead Agency for the program because, at the time, it was the agency with most biological expertise in aquatic systems. The MRHI began in WA in April 1994 with funding from the Land and Water Resources Research & Development Corporation (now Land and Water Australia) and the Department of Environment Sports and Territories (now EA).

WA covers almost one-third of Australia with a latitudinal range of 13°S to 33°S (Fig 1). There are four major drainage divisions in the State. Although WA is thought of as dry, the Timor Sea Division in the Kimberley (and Northern Territory) discharges more water than any region of Australia other than Queensland (AWRC 1987), while the South-west Division has Australia's most predictable rainfall pattern (Fig 32 in Gentilli 1971). There are a range of river types in WA, from permanent streams in the extreme north and south-west of the State to very episodic rivers in the central arid latitudes. However, flow is rapid only during flood-induced spates because of low topographic relief and most streams have sandy beds and few cobble-based riffle zones (Halse & Blyth 1992). Many of the well-known groups of river invertebrates are less conspicuous in WA than in eastern Australia, especially in the south-west (Bunn & Davies 1990). The size of WA, the arid nature of much it, and the relatively depauperate macroinvertebrate fauna of its southern rivers mean that developing a biomonitoring system, based on macroinvertebrates, to assess river condition within the State was always likely to be challenging.

The aim of the MRHI was to develop a biomonitoring system for assessing river health throughout Australia using macroinvertebrates (Schofield & Davies 1996, Davies 2000). It was decided to use biological indicators of river condition in this national program, rather than chemical measurements, because biological results are usually more meaningful, unless sites are heavily enough contaminated that the implications of chemical results are obvious (Norris & Georges 1986). Macroinvertebrates were chosen as the group of indicator organisms but, rather than focus on particular indicator species, the MRHI took a community-based approach to monitoring (see Resh *et al*. 1995). River condition was assessed by comparing the whole macroinvertebrate community at a site against the communities of minimally disturbed reference sites. Disruption to community structure and disappearance of some macroinvertebrate families were equated with a decline in river health. Comparisons with undisturbed reference sites were made through a series of predictive models called AusRivAS (**Aus**tralian **R**iver **A**ssessment **S**cheme), which is the central plank of the MRHI (Davies 2000). AusRivAS models are based on the successful RivPACS models used in the UK since 1985 (Wright 1995).

The MRHI has had two phases. The first phase, from 1994 until mid-1997, was aimed at collecting data from reference sites to build the initial AusRivAS models. These models were based on sampling done in spring 1994 and autumn 1995 and were validated using datasets collected primarily in 1995 and 1996. The main output of AusRivAS models is an *O/E* score, which is loosely the ratio of the number of macroinvertebrate families observed at a test site (*O*) to the number of families expected to be present at the same site if it were in pristine condition (*E*). Thus, *O/E* values for undisturbed sites approximate 1.0 (Smith *et al*. 1999). The second phase of the MRHI was the FNARH, which had two objectives. These were (1) to assess river condition at about 600 sites in WA and (2) to refine the AusRivAS models, based on experience gained doing the site assessments. Approximately 6000 sites were sampled across Australia during the FNARH, with just over 10 % being located in WA.

In WA, the first phase of the MRHI involved three universities as well as CALM. This was partly a consequence of the Water Authority involving the universities prior to CALM assuming the role of Lead Agency but it was also done to facilitate fieldwork. One of the reasons universities were not involved in the FNARH was that it became obvious during model-building that analysis and interpretation of the AusRivAS outputs would be difficult if different groups worked relatively independently in different regions and no-one had an overview of all the WA river systems. But perhaps more crucially, the delays in contract negotiations and payment associated with the FNARH precluded sub-contracting work to third parties that were not prepared to carry financial risk. None of the universities was able to do this.

Most of the procedures associated with the MRHI and AusRivAS models were prescribed prior to the commencement of the project, as a result of reviews commissioned by LWRRDC and preparatory work by Dr Peter Davies (1994). Some minor variations of protocols between different States and Territories were adopted after a national workshop in mid-1994. One variation was the choice of 'channel' as the most common sampling habitat in WA, rather than the 'edge' habitat used most States and Territories (eg Turak *et* *al*. 1999). The Northern Territory and Queensland sampled a habitat similar to channel, although with a different name and slight differences in definition.

The largest discrepancies between States and Territories revolved around whether samples were live-picked, or preserved and sorted in the laboratory. WA initially live-picked in the southern part of the State, where the universities sampled, and laboratory-sorted in the north. It was intended that universities would laboratory-sort in the second year of sampling so that results of the two methods could be compared but limited funding prevented this plan being pursued and also forced CALM to abandon the more expensive laboratory-sorting once the FNARH began (see Smith *et al*. 1999). The live-picking protocol was modified during the MRHI, at the instigation of Dr Davies, because an R&D project on sorting efficiency had shown that live-picking had significant shortcomings (Humphrey *et al*. 2000). The modifications, which principally involved an increase in picking time from 30 to 60 mins per sample, were aimed at reducing errors.

This report, which combines the Milestone 5 and Final Reports, summarises results in WA over the entire period of the MRHI but focuses principally on the results produced in final year of the FNARH and the requirements of the contract between CALM and EA associated with that period. Thus, the report describes how the final AusRivAS models were constructed, gives assessment scores for sites during the FNARH and earlier rounds of the MRHI, and discusses overall patterns of river condition in WA. Catchment activities and environmental factors that may contribute to lower assessment scores are highlighted. Some other issues associated with river assessment in WA have been covered in more detail in published papers (listed under *Publications*) or are described in the WA sampling manual on the AusRivAS website (http://ausrivas.canberra.edu.au).

3 Summary of earlier work

Habitat selection

The revised models for WA are based on channel habitat, although riffles, macrophytes and pools rocks were sampled where possible during the first two years of the MRHI and an interim model was developed for macrophytes. Channel habitat in WA is defined as consisting of the central part and margins of the main channel of a stream, without riffles, submerged macrophytes or pool rocks (see WA sampling manual on AusRivAS website). Areas of emergent sedges and shrubs along the banks do not constitute channel habitat but bare stream edges do. Detritus and leaf packs in the central channel and along edges also form part of channel habitat.

Reasons for stratifying sampling by habitat were outlined by Davies (1994) and revolve around the frequently made observation that different habitats have different characteristic faunas. For example, Kay *et al*. (1999) found in north-west WA that family richness and family composition differed between habitats, with channel having a family composition intermediate between that of other habitats. Collecting samples from a single well-defined habitat type reduces the chances of different assessment scores between sites being the result of sampling different habitats (eg riffle and macrophyte bed) rather than reflecting genuine differences in water quality.

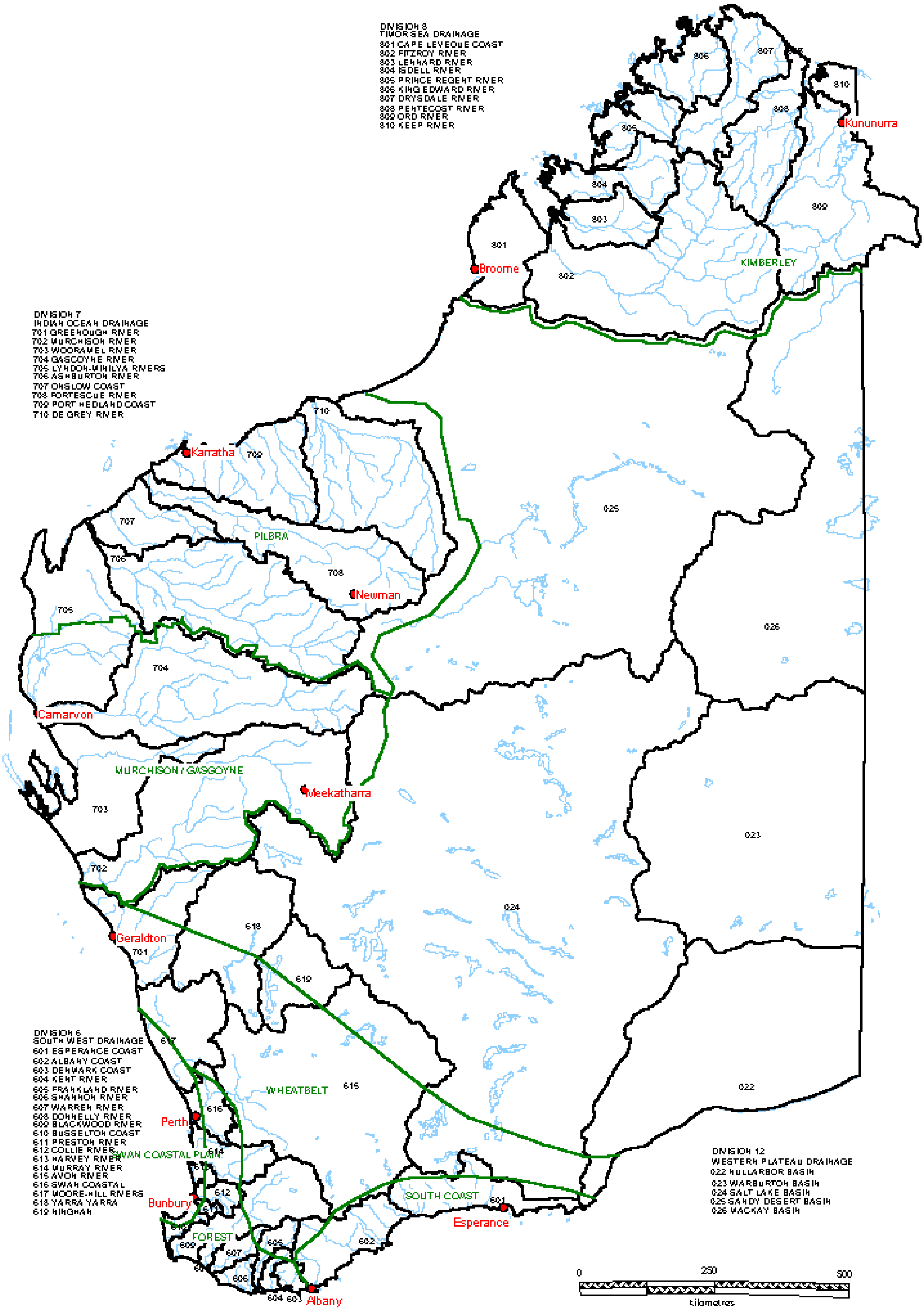


Figure 1. Map of WA showing major watercourses and large lakes (in blue), river basins (in black), AWRC drainage divisions, geographic regions referred to in text (in green) and major towns

It is very rare to find a stream reach without channel habitat in WA and, therefore, virtually all streams can be assessed using models based on channel. Macrophytes, riffles and pool rocks occurred infrequently at reference sites and are even scarcer at test sites, so that models based on these habitats have very limited applicability. A further problem caused by scarcity of macrophyte, riffle and pool rock habitat was that, in the first two years of the MRHI, many unrepresentative examples of these three habitats were sampled in an effort to aquire sufficient information to build models (eg macrophytes that were sparse, riffles that were flowing seeps over bedrock). This caused invertebrate data from these habitats to be noisy, which is the opposite result from that intended by habitat stratification (Parsons & Norris 1996).

Sampling window

Sampling windows in WA were originally chosen by examining data from Prof Stuart Bunn's PhD thesis on jarrah forest streams and by examining hydrographs for rivers farther north and then aligning sampling dates with the objectives set out in Davies (1994). The windows were modified somewhat after the first national river health workshop to accommodate views of staff in Northern Territory agencies (we were trying to maintain comparable sampling regimes) and as a result of experience during the first year of sampling in the southern WA, when annual variations in rainfall were shown to affect the summer availability of surface water more than expected. Thus, the WA sampling manual recommends sampling times as follows:
North-west: September - October for spring (base) flows and March - May for autumn (recessional) flows
South-west: August - September for spring (recessional) flows and December - January for autumn (base) flows.
With the body of information now available, we would modify the south-west regime and suggest August - October is a suitable spring sampling window, with high rainfall sites being able to be sampled as late as mid-November, while January - March is a more suitable window for autumn, with sampling of well-watered sites being acceptable up to mid-April.

Rounds 1-4

River or stream reaches at 188 reference and 20 test sites throughout Western Australia were chosen for sampling between 1994 and 1996. Of these 208 sites, 201 contained water and were sampled in spring 1994, 160 in autumn 1995, 208 in spring 1995 and 183 in autumn 1996. The reaches were chosen to maximise the possibility of sampling four habitats (channel, macrophytes, riffles, pool rocks) at each site. Samples in the south-west were live-picked in the field with 30 mins of sorting. The University of Western Australia sorted only a portion of the sample thoroughly and scanned the remainder for any additional large, obvious taxa. Edith Cowan and Murdoch Universities sorted the whole sample with minimal pre-processing to reduce the amount of organic matter in the sample. Samples in the north-west were preserved in the field and sorted in the laboratory, after removing large debris by hand and sieving the sample into different sized fractions. Smith *et al*. (1999) suggested laboratory-sorting under a microscope recovered almost 20 % more families than live-picking, while Kay *et al*. (1999) showed that a 10 m sweep recovered only about 75 % of the macroinvertebrate fauna in a reach. Thus, both sampling and field-processing were subject to considerable stochastic error and a strong bias towards underestimating richness. Work in WA, Victoria and Queensland showed little benefit in taking larger sweeps to try to reduce sampling errors (Metzeling & Miller 2001) but an R&D project on picking methods suggested that longer live-picking times (and collecting more animals) would reduce errors in field sorting (Humphrey *et al*. 2000).

Round 5

In spring 1997, the FNARH began with the aim of assessing condition of all major rivers in the State over three years. A different part of WA was sampled each year. In 1997, the focus was on the Wheatbelt but, at the request of WRC, a few sites nearer the coast in the south-west were also assessed. Altogether 181 sites were sampled, 102 of which were regarded as test sites and the remainder reference. The reference sites comprised a mix of re-sampled reference sites and newly selected sites that could be used for refining models. There were two important differences between FNARH sampling and that undertaken previously. Firstly, sampling was restricted to channel or macrophyte habitats with an emphasis on channel as the preferred habitat. Secondly, in response to the work of Humphrey *et al*. (2000), the sorting protocol was revised so that elaborate pre-processing occurred, the sample was sieved into a series of size fractions for sorting, and two people picked each sample for a combined time of 60 mins (ie 2 x 30 mins) (see WA sampling manual on AusRivAS website for fuller description).

As well as being used to assess river condition in the Wheatbelt, the 1997 data were used to examine patterns of distribution of Wheatbelt macroinvertebrates and their environmental tolerances (Kay *et al*. 2001). Families in this region usually tolerate a wide range of environmental conditions, especially salinity, making it difficult to assess river condition using macroinvertebrates. The issue of assessments in the Wheatbelt is discussed further in the section on *Wheatbelt* in ***Assessment of catchment condition in WA***.

Rounds 6-7

In 1998, a total of 185 river or stream reaches were sampled in northern WA, with 179 (103 test) sites being sampled in autumn and 169 (101 test) sites in spring. Seventeen sites in the Collie Basin in south-west WA were also sampled at the request of WRC. As with the Wheatbelt sampling, a large number of reference sites from 1994-1996 were included in the northern dataset to examine changes over time and to facilitate refinement of models. At the completion of the 1998 sampling, models were revised so that interim site assessments could be produced for the north-west and Wheatbelt.

Rounds 8-9

In 1999, the coastal plain and forest areas of the south-west were sampled. The program was disrupted because of difficulty agreeing on terms of a contract with EA and because of an inadequate budget. As a result, only 84 (39 test) sites were sampled in autumn 1999 and these were mostly located in southern forest areas or around Collie. In spring 1999, 201 (104 test) sites were sampled. Combined with previous Wheatbelt sampling restricted to spring, the 1999 sampling gave good coverage of the south-west in spring but patchy coverage in autumn.

Models developed in 1998 were capable of detecting gross disturbance, especially when assessments from the models were supplemented with other metrics (Kay *et al*. 2000), but produced unsatisfactory results when all sites sampled in 1999 were assessed. Disturbance was detected at few sites (Table 1) and the results highlighted the need for further model development.

Round 10

In response to the perceived lack of model sensitivity, 25 sites in the south-west were sampled in spring 2000 using both the standard 60 mins live-pick protocol and a modified protocol based on sub-sampling with a box sampler (Marchant 1989). It was hoped that use of a box sampler would enable macroinvertebrate community structure to be reflected more closely in the invertebrates picked from the sample than was the case with the standard 60 mins live-pick protocol. Benefits of sub-sampling are discussed more fully in ***Box sampler and live-picking protocol***. In addition to this R&D work, six sites on Marbelup Brook in south-west WA were assessed using the box sampler to provide a demonstration of the usefulness of AusRivAS assessments (two of the sites were also used in the comparison of 60 mins live-pick and box sampler).

Early models

Four iterations of models for channel habitat and one set of macrophyte models have been produced in WA. The first channel and the macrophyte models were developed in close association with A/Prof Richard Norris and Justen Simpson during, and subsequent to, their two visits to WA. They and Paul Blackman, also of the CRC for Freshwater Ecology, provided a great deal of guidance and assistance with the second-iteration channel models as well and provided us with an Excel model shell that made development of the final models much simpler.

The first channel and the macrophyte models were put on the AusRivAS website in 1997. The channel models were removed in mid-2001 but the macrophyte models remain. The second iteration channel models provided the assessment scores on which results in Smith *et al*. (1999) are based. The third-iteration in 1998 provided a range of channel models, including the models for the north-west region to which Dr Davies objected in his comments on Milestone 2 because reference site groupings were formed on the basis of geographic boundaries (a discriminant function was, however, used to determine the group membership of test sites). These north-west models were never widely used. Alternative state-wide models were used more often, providing assessments of the Collie River (Kay *et al*. 2000) and Marbelup Brook. However, as mentioned above, analysis of the *O/E* scores of reference and test sites sampled in 1999 suggested even the best of the third-iteration models was insensitive and needed further refinement (Table 1). The principal problems were (1) *O/E* scores were too high (reference sites averaged 1.13 instead of 1.00) and (2) even after standardising *O/E* scores, so that the reference average was 1.00, fewer test sites had low *O/E*s than other evidence of site condition suggested should be the case.

Biodiversity information in MRHI/FNARH data

In addition to providing information about river or stream health, samples collected during the MRHI/FNARH have the potential to provide useful biodiversity information. AusRivAS results have been used to propose a preliminary aquatic bioregion classification for WA (Appendix 3; see Kay *et al*. 2000) and

Table 1. Assessment scores from autumn 1999, using third-iteration models, showing percentage of site assessments in south-west forests that agreed with expectation and average *O/E* values for test and reference sites (taken from the WA Milestone 3 Report). Test sites were expected to be disturbed; reference sites were expected to be undisturbed

Autumn 1999	**No. of sites**	**No. *O/E* indicating disturbance**	**% concordance between *O/E* and expected condition**	**Average *O/E***
Test sites	39	6	15	1.03
Reference sites	45	2	96	1.13
Adjusted scores				
Test sites		*11*	*28*	*0.90*
Reference sites		*6*	*87*	*1.00*

examination by specialist taxonomists of some of the oligochaetes, hemipterans, trichopterans, odonates, coleopterans and ephemeropterans collected has revealed new species or range extensions (eg Dean 2000, Pinder 2001, Alarie *et al*. 2001). New crustacean species have been collected as well, with the new genus of isopod *Pilbarophreatoicus* found in springs of the Robe River being of particular interest (Knott & Halse 1999).

At present, a PhD student at Murdoch University (Karen Sutcliffe) is using the MRHI/FNARH samples from the south-west to examine the distribution and conservation status of several insects groups and then using the accompanying environmental data to define their habitat preferences (Sutcliffe *et al*. 2002). This work has shown that museum collections and previously published information provide an erroneously restricted picture of the distribution of many species.

It is planned to provide north-west samples to another PhD student, if possible, to undertake similar work on the aquatic insect fauna of the Kimberley. At present, MRHI/FNARH results are being used to identify springs in the Pilbara that are likely to contain stygofauna as part of a preliminary study of the distribution of these animals in WA (Halse *et al*. 2002). Conservation and management of stygofauna has recently become an important biodiversity issue (Humphreys 1999).

QA/QC and sampling errors

There have been a series of checks conducted to assess the quality of data being produced by the WA AusRivAS program. WA has participated in all national projects examining data quality (eg Hawking & O'Connor 1997, Humphrey *et al*. 2000, Metzeling & Miller 2001), as well as conducting internal quality assurance and quality control programs. Results have been presented in previous Milestone Reports, or in the reports of other investigators, and are summarised below so that implications can be discussed.

External checking of identifications of animals in a subset of animals collected during the first year (1994-1995) of the Monitoring River Health Initiative revealed high error rates in some samples by one university

Table 2. Results of re-identification of 13 invertebrate samples in 2000. The family list did not change at any site as a result of re-identification; misidentifications were the results of mis-counts or mistakes with very juvenile animals

No. of samples	No. with miscounts	No. with >5% error in counts	No. with misidents	No. with new taxa	No. with >5% error in identificationss
13	12	0	2	0	0

staff member. CALM staff re-identified all north-west samples that had been processed by that staff member. There may still be significant numbers of errors in some first-year south-western samples but these have not been used for model construction or in the assessments of river condition presented in this report.

Samples identified by all other staff in the first year passed the quality control process. In all subsequent checks of accuracy of identification and data entry, no sample failed quality control. There has been some turnover of staff within CALM since external checking has been conducted and greater internal pressure to process samples quickly in recent years. However, the most recent results of internal quality control (see Table 2) and information provided by experts using the AusRivAS collection for taxonomic work both suggest CALM staff have made no significant errors in identification. We believe this is the result of relatively good continuity of staff (despite some turnover), good laboratory facilities, access to a wide range of taxonomic keys, attendance at the national taxonomic workshops, experience undertaking species as well as family-level identifications and a strong emphasis within the program, supported by quality assurance procedures, on correct identifications.

The number of errors in the physico-chemical dataset is small. All data were printed out after entry and logical checks were routinely performed to detect unusual values, which were then re-examined. External vetting by Australian Water Technologies found the methodology for collecting habitat and physico-chemical data to be sound and detected no significant error in data entry. The procedure for scoring habitat condition (eg condition of riparian vegetation) was not assessed but we regard these data as subject to an, as yet, unquantified level of error, operator variability and bias. Similarly, data for substrate variables such as percentage silt or clay in the stream bed are unreliable and will probably always be so unless quantitative laboratory analyses are undertaken or staff are familiar with the results obtained by laboratory analysis. These problems are not unique to the WA AusRivAS program and have been discussed at national workshops. WA provided habitat data to the CRC for Freshwater Ecology as part of an R&D project on habitat assessment that, hopefully, will provide better tools for assessment of physical habitat condition.

Other than some of the substrate and habitat measurements mentioned above, which are not used directly in Western Australian AusRivAS models, the largest source of errors in assessments were associated with macroinvertebrate sampling and sorting procedures, rather than identification and environmental data. There are five main issues:

(1) microhabitat sampling. Most reaches contain a series of microhabitats within the main sampling habitat. This is analogous to the occurrence of several habitats within a stream and many of the

arguments for and against the habitat stratification used in AusRivAS apply to microhabitats. It is possible for an experienced AusRivAS operator to manipulate the families collected in samples from some streams by selecting or avoiding micro-habitats. Thus, it is important that sampling habitats are clearly defined and a consistent approach is adopted in relation to sampling micro-habitats if different operators are to produce similar results. (At present the importance of micro-habitats is not recognized in the national protocol, Davies 1994). There are strong cases for sampling randomly within the chosen habitat (ie channel) when assessing habitat quality in a river and for stratified sampling to ensure even effort in all microhabitats (irrespective of their areal occurrences) if water quality is the main interest.

(2) representativeness of the sample. The questions of how representative one AusRivAS sample is of conditions in the reach, and how far upstream and downstream the *O/E* value is likely to apply, were not addressed in any AusRivAS R&D project, although they were identified by Dr Davies as warranting investigation. Many reaches show considerable gradients in micro-habitat from one end to the other and it is unlikely that a 10-m sweep from one section will be representative of the whole reach, let alone 1 km upstream. In WA, the 10-m sweep was collected as a series of sweeps, each approximately 1-m, in different areas of channel (or macrophyte) habitat through most of the reach, if there was obvious variation in micro-habitat, in an attempt to increase representativeness.

(3) replicate sampling. Sets of three replicates showed that, on average, a 10-m sweep collected < 75 % of the families present in the immediate vicinity of sampling (Kay *et al*. 1999; see also Marchant & Hehir 1999) and this translated to 22 % variation in *O/E* scores between three replicate samples from the same reach (Smith *et al*. 1999). In one case out of four, assessment band changed. The tighter band widths of the revised models may increase the likelihood of changed band assignments, especially from Band A to B or X, and *O/E* scores at individual sites must be recognized as partly the result of chance. Assessment of two habitats, or on multiple occasions, will reduce stochastic error (Davies 1994) but the former is rarely an option in WA.

(4) live-picking. The shortcomings of live-picking techniques are alluded to throughout this report and are best described by Humphrey *et al*. (2000). In summary, results from live-picking are strongly influenced by experience of the operator, type of stream substrate, amount of sample processing done prior to picking, and amount of time spent searching for animals. From 1997 onwards, after the problems of live-picking had been revealed, large debris was washed and removed from samples while still in the net. Samples were then agitated in a set of large sieves, of different mesh sizes, to sort the sample into different size fractions prior to picking and each sieve was emptied into one or more sorting trays (Kay *et al*. 2001). Staff swapped all sorting trays mid-way through picking to minimise operator variability. All samples were picked for 60 mins with the aim of collecting about 200 animals. Despite this comparatively rigorous protocol, there is no doubt that many families were missed if samples came from streams with a lot of fine detritus (see Table 9). An alternative sorting method, involving a box sampler, was developed to overcome this problem (see ***Box sampler and live-picking protocols***).

(5) difficult sites. Many sites that are probably in good ecological condition are assessed as degraded by AusRivAS because of failure to obtain satisfactory macroinvertebrate samples. Assessments

made during spates and droughts return low *O/E* scores but these are caused by sampling at an inappropriate time, when the macroinvertebrate community is disturbed, rather than failure to obtain adequate samples. One of the most obvious causes of inadequate samples is the stream being deep and steep-sided, which makes manipulation of a pond-net difficult. There was a perception among staff that sites with very high proportions of bedrock substrate also yielded fewer families than those with a greater mix of substrates, although this was not supported by analysis (Fig 2), perhaps because of intensive sampling of the small amounts of sand or pebbles and leaf packs present at such sites. A variety of other types of site do not readily yield samples that contain all families present and this needs to be borne in mind when interpreting AusRivAS outputs.

4 Work conducted to achieve Milestone 5

AusRivAS models

Model building

In what might be viewed as a fourth iteration of the WA models, three revised models for channel habitat were supplied to the CRC for Freshwater Ecology in mid-2001 for placement on the AusRivAS website, where they are now available. They cover the spring and autumn sampling periods, as well as a combined-season model. Channel was the only habitat for which revised models were developed. Rivers in WA have low gradients and are usually sandy (see Halse & Blyth 1992), so that riffles are uncommon. In many areas, canopy cover is dense, water is darkly stained or flow is short-lived so that extensive macrophyte beds are also uncommon. Channel is the only habitat reliably encountered.

As a result of the large latitudinal range in WA, the pattern of rainfall varies from summer monsoonal in the north to winter Mediterranean in the south (Gentilli 1972), with the transition between these patterns being most pronounced in the Murchison-Gascoyne (Fig 1). Initial AusRivAS models in WA were based on 'wet season/dry season', so that a sample collected from the Kimberley in April and one from the south-west in September were both assessed using a wet season model. However, it was difficult to assign samples from central WA to an appropriate model because of variable rainfall patterns. Halse *et al.* (2000) showed there is some rainfall-independent seasonality in arid WA, so revised models were based on the conventional spring and autumn assignment of samples.

Early (1997 and 1998) versions of the AusRivAS models lacked ability to distinguish between sites with small amounts of ecological impairment (Table 1). This was attributed partly to them being based on 30 mins live-pick data and, therefore, the revised spring and autumn models were based on 60-mins live-pick data as far as possible. Live picking for 60 mins, instead of 30 mins, increased the number of families collected (Table 3). The other likely cause of poor discriminatory power was inclusion of sites with depauperate faunas in the reference dataset. Such sites were identified prior to revising models and were omitted from reference datasets. Details of the screening processes are provided below for each model.

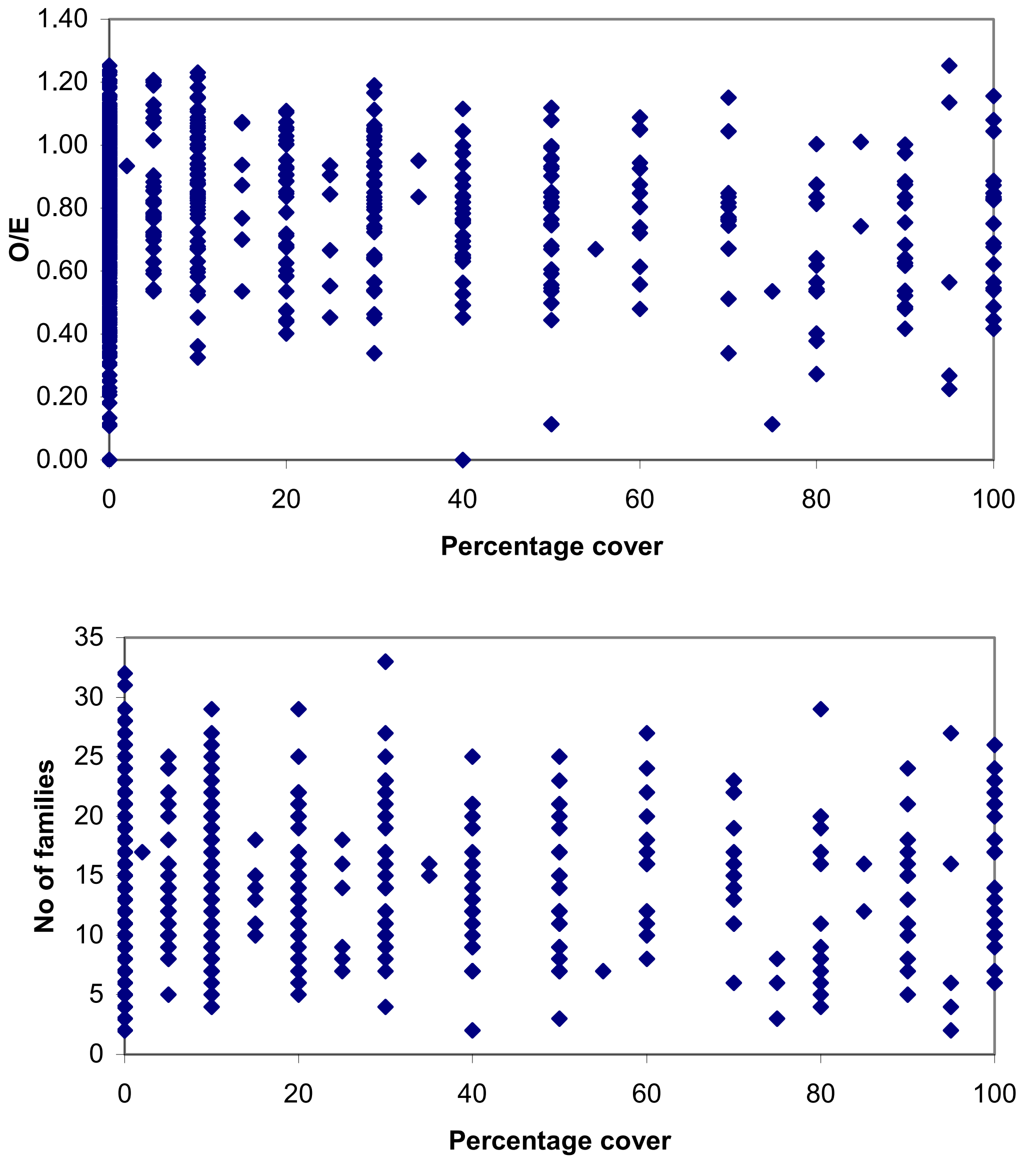


Figure 2. Comparison of *O/E* scores and number of families present at sites with different percentage cover of bedrock

Table 3. Comparison of *O/E* scores from third-iteration models for reference sites in the south-west sampled in spring 1994 and 1995 (with 30 mins live-pick), and in spring 1997 or 1999 (with 60 mins live-pick). The difference between 1994 and 1995 probably reflects a combination of seasonal conditions (1994 was dry) and increased efficiency with experience. *N* = number of sites

	N	1994	1995	1997/9
Wheatbelt	*14*	0.69	0.77	0.97
Forest	*40*	0.86	0.96	1.08
Overall	*54*	0.82	0.91	1.05

Spring model

A total of 199 reference sites were sampled and processed with 60 mins live-pick between spring 1997 and spring 1999, with good geographical coverage of all river systems in WA. After screening, these sites were the basis for building a revised spring model. In the initial screening process, 74 sites that had been sampled in 1994, 1995 and at least once subsequently with 60 mins live-pick were put through a nine-group, third-iteration spring (wet season) model. Nine sites had low *O/E* scores in all three rounds. Scores at these and other sites were examined to determine two thresholds. The first was a general cut-off value for 60-mins live-pick *O/E*s, below which sites should automatically be omitted from model development, and the second was a score below which they should be discarded if evidence of sampling difficulties or habitat degradation existed. The threshold *O/E*s were 0.80 and 0.85, respectively, for north-west sites, 0.72 and 0.77 for Wheatbelt sites, and 0.83 and 0.88 for south-west forest and coastal plain sites. The purpose of this screening was to eliminate sites that had truly depauperate faunas (whatever the cause of few families) or where sampling error resulted in apparently depauperate faunas. It reduced the number of reference sites to 165.

Remaining reference sites were classified into eight groups on the basis of their invertebrate families using unweighted pair-group mean averaging (UPGMA) in the PATN analysis package, after families occurring at less than five sites were masked out of analyses. The site classification employed the Czechanowski dissimilarity measure and $\beta = -0.175$ to control space distortion. The families themselves were then classified into eight groups, using UPGMA with the Two-Step dissimilarity measure and $\beta = -0.10$, and a two-way table of sites by families was plotted. Reference sites containing families belonging to family groups that did not occur at other sites of the same reference site group were discarded if geological setting or other environmental parameters suggested the site was atypical. In a parallel analysis, reference sites were ordinated using semi-strong hybrid multi-dimensional scaling and sites that were outliers in ordination space from their classification group were subjected to the same examination as unusual sites in the two-way table. This resulted in 11 sites being removed from the classification to yield a final classification of 154 sites into eight groups based on 61 families (Fig 3).

Data on 45 environmental variables were collected at each reference site (see Davies 1994, Smith *et al*. 1999) and an additional three derived measures of substrate heterogeneity were calculated (*shet, surf, size*; Marchant *et al*.1997). Eleven of the variables were free from anthropogenic influence, had normally distributed residuals (often after transformation), showed significant variation among reference site groups and, thus, had the potential to be useful predictor variables in a discriminant function assigning sites to a reference classification group on the basis of environmental characteristics (Table 4). Step-wise discriminant analysis in the SAS analysis package was used to choose five predictor variables for the discriminant function. Only five variables were selected, even though more contributed significantly to the function, because each additional variable contains less information and discriminant function predictions are more stable if the ratio of sites to predictor variables remains >20 (Stevens 1992).

Table 4. Variables available for selection in the stepwise discriminant analysis for spring, autumn and combined-season models, showing transformation used and significance levels of variables in a one-way ANOVA in the SAS analysis package

	Spring		**Autumn**		**Combined**	
Variable	***P***	**Trans.**	***P***	**Trans.**	***P***	**Trans.**
Size *substrate particle size index*	0.05	-	0.01	-	0.01	-
mineral substrate % mineral substrate cover	0.001	arcsine	0.001	arcsine	0.01	arcsine
Slope *fall in riverbed, m km^{-1}*	0.0001	$\log_{10}$	0.0001	$\log_{10}$	0.0001	$\log_{10}$
Distance from source *km*	0.0001	$\log_{10}$	0.0001	$\log_{10}$	0.0001	$\log_{10}$
Discharge category *logarithmic scale 1-6*[1]	0.0001	-	0.0001	-	0.0001	-
Average annual rainfall *mm*	0.0001	-	0.0001	-	0.0001	$\log_{10}$
Mean river width *wetted channel width, m*	0.0001	$\log_{10}$	0.0001	$\log_{10}$	0.0001	$\log_{10}$
Maximum flow *maximum flow velocity in channel, cm sec^{-1}*	0.0001	$\log_{10}$	N/A		0.0001	$\log_{10}$
Latitude *decimal degrees*	0.0001	-	0.0001	-	0.0001	-
Longitude *decimal degrees*	0.0001	-	0.0001	-	0.0001	$\log_{10}$
Altitude *m*	0.0001	-	0.0001	-	0.0001	$\log_{10}$

[1] calculated using formulae supplied by WRC based on rainfall and percentage of the upstream catchment cleared, calibrated with river gauging data

Table 5. Details of final models (now on website) for channel habitat in WA, showing type of reference site data used, the number of reference sites in the final model, the number of site groups, the cross-validation error and the predictor variables used (see Table 4 for transformations used)

Season	**Data**	***N***	**Groups**	**Error (%)**	**Predictors**	**Band width**
Spring	60 mins live-pick from 1997-1999	143	8	24	Latitude, rainfall, longitude, $\log_{10}$max flow, discharge	0.30
Autumn	30 and 60 mins live-pick from 1995, 1998 and 1999	114	6	23	Latitude, rainfall, $\log_{10}$width, longitude, size	0.30
Combined -season	30 and 60 mins live-pick from 1995 and 1998	128	7	29	Latitude, $\log_{10}$rainfall, $\log_{10}$longitude, $\log_{10}$max flow, $\log_{10}$altitude	0.30

After calculating the discriminant function and ensuring that all five canonical vectors were significant, the proportion of error in assigning reference sites to the correct classification group was calculated. A cross-validation error of 29 % was obtained. Four sites classified to obviously erroneous groups and were removed from the dataset, the step-wise discriminant analysis was repeated and the discriminant function re-calculated without improvement in cross-validation error (30 %).

Based on this dataset and the output of discriminant function analysis, the revised spring model was constructed using an Excel model shell provided by the CRC for Freshwater Ecology. Inputs to the model were:

(1) group frequencies - the probability of each family occurring at a site in each reference site group
(2) Raw canonical co-efficients - from PROC DISCRIM in SAS
(3) grand means raw - mean score for each predictor variable (after transformation) across all sites
(4) group means - class means on canonical variables from PROC DISCRIM

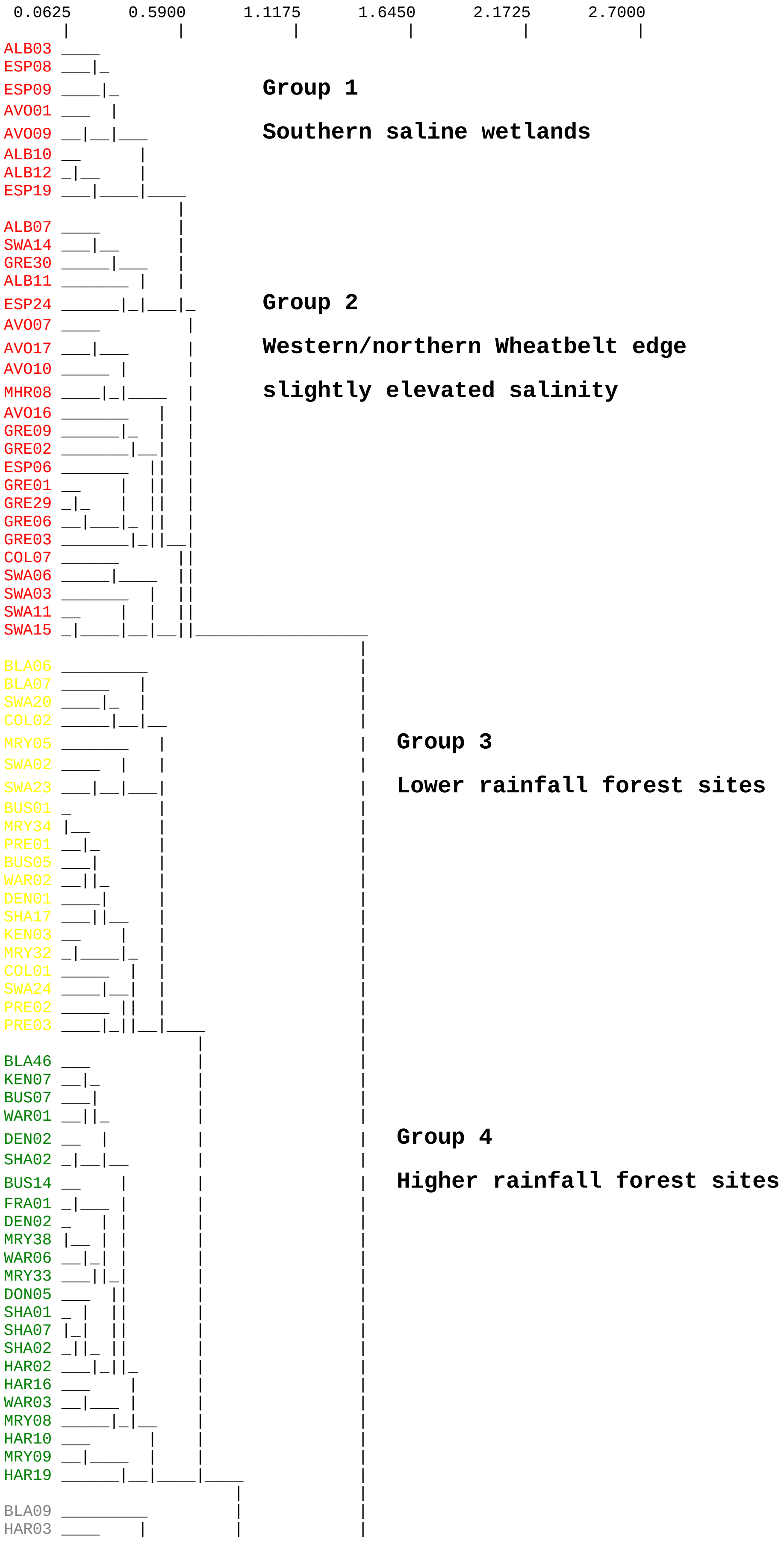
After the model was constructed, the reference sites on which it was based were run through it to generate *O/E* scores. Seven sites had scores <0.75 and were discarded because they were outliers. The process of step-wise discriminant analysis and calculating a discriminant function was repeated with the reduced dataset to create a final model. Details of this model, which had lower cross-validation error, are summarised in Table 5.

Autumn model

The autumn revised model was constructed in a similar manner to the spring model except that some south-west reference site data from autumn 1996 (30 mins live-pick) were included. This was done because the lack of sampling in autumn 1997, and the small number of sites sampled in autumn 1999, meant that geographic coverage with 60 mins live-pick was incomplete.

Including 61 samples from the south-west in autumn 1996, 174 reference sites were sampled and processed with 30 or 60 mins live-pick in autumn 1996, 1997 or 1999. The threshold *O/E* scores used to screen out poor quality reference sites, using the third-iteration autumn model, were 0.83 for north-west sites, 0.75 for 30 mins live-pick sites in the south-west and 0.93 for 60 mins live-pick south-west forest sites. One of the objectives of including 30 mins live-pick data was to retain some Wheatbelt and northern coastal plain sites (see Fig 1) in the model, although it was recognised that setting a lower *O/E* threshold for these sites because they were processed with 30 mins live-pick might result in classification groups based on processing methods rather than biogeography. Screening reduced the number of 30 min live-pick sites by 41 % and the number of 60 mins live-pick sites by 11 % to leave 136 sites in the autumn model.

The 136 sites were then classified into six groups based on their invertebrate families, using $\beta = -0.175$, after families occurring at less than five sites were masked out of all analyses. Examination of the classification, ordination and two-way table resulted in nine sites being removed from the classification because they were outliers to yield a final classification of 125 sites into six groups based on 57 families (Fig 4).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1.1175
1.6450
2.1725
2.7000
ALB03
ESP08
ESP09
AVO01
AVO09
ALB10
ALB12
ESP19
Group 1
Southern saline wetlands
ALB07
SWA14
GRE30
ALB11
ESP24
AVO07
AVO17
AVO10
MHR08
AVO16
GRE09
GRE02
ESP06
GRE01
GRE29
GRE06
GRE03
COL07
SWA06
SWA03
SWA11
SWA15
Group 2
Western/northern Wheatbelt edge
slightly elevated salinity
BLA06
BLA07
SWA20
COL02
MRY05
SWA02
SWA23
BUS01
MRY34
PRE01
BUS05
WAR02
DEN01
SHA17
KEN03
MRY32
COL01
SWA24
PRE02
PRE03
Group 3
Lower rainfall forest sites
BLA46
KEN07
BUS07
WAR01
DEN02
SHA02
BUS14
FRA01
DEN02
MRY38
WAR06
MRY33
DON05
SHA01
SHA07
SHA02
HAR02
HAR16
WAR03
MRY08
HAR10
MRY09
HAR19
Group 4
Higher rainfall forest sites
BLA09
HAR03

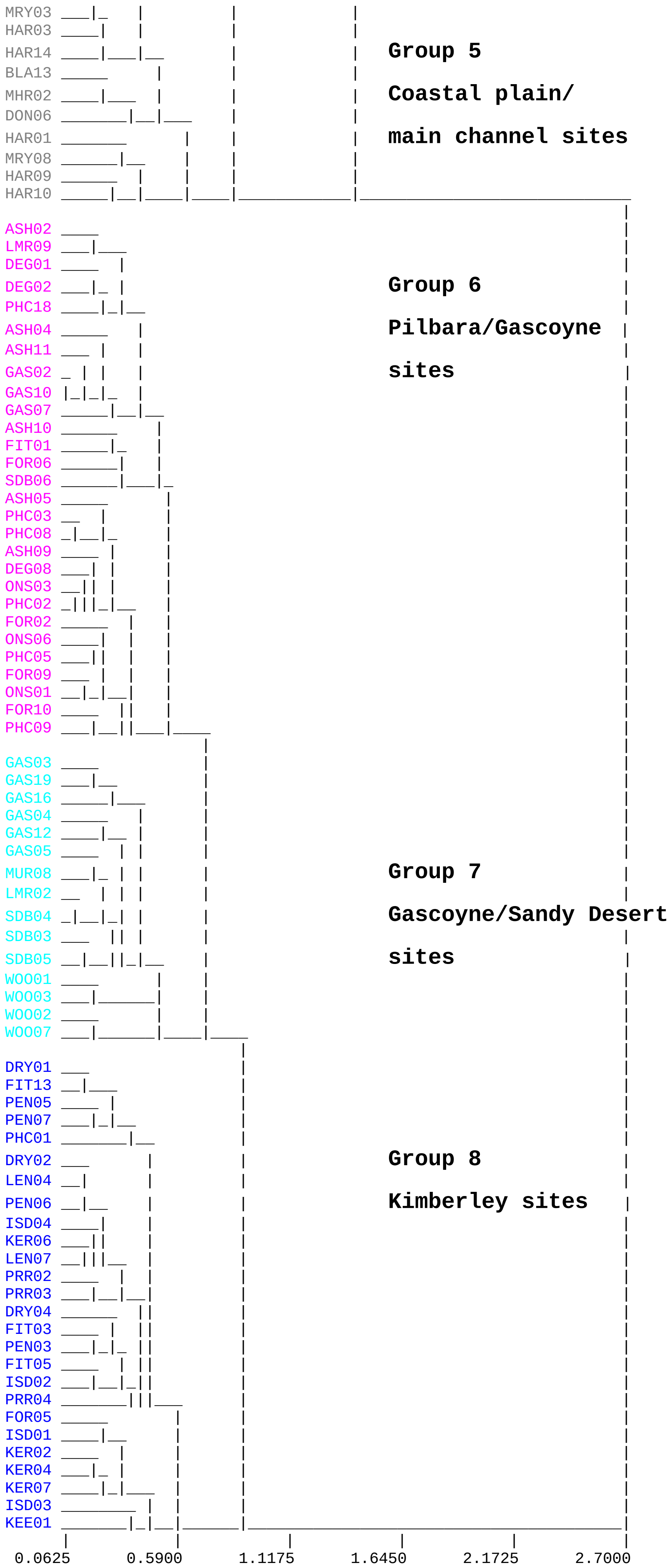
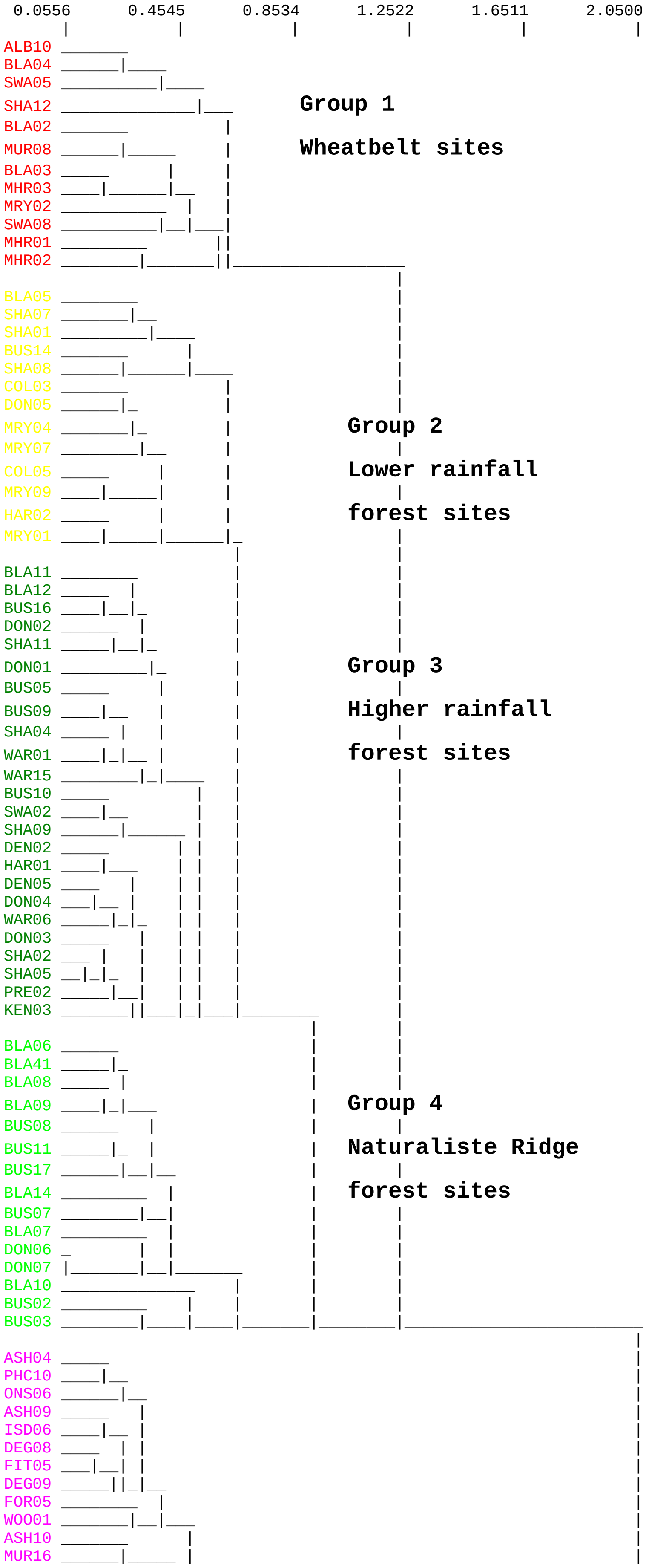


Figure 3. Classification of reference sites on which spring model was based. Eight groups of sites were recognised based on macroinvertebrate families present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ALB10
BLA04
SWA05
SHA12
BLA02
MUR08
BLA03
MHR03
MRY02
SWA08
MHR01
MHR02
Group 1
Wheatbelt sites
BLA05
SHA07
SHA01
BUS14
SHA08
COL03
DON05
MRY04
MRY07
COL05
MRY09
HAR02
MRY01
Group 2
Lower rainfall
forest sites
BLA11
BLA12
BUS16
DON02
SHA11
DON01
BUS05
BUS09
SHA04
WAR01
WAR15
BUS10
SWA02
SHA09
DEN02
HAR01
DEN05
DON04
WAR06
DON03
SHA02
SHA05
PRE02
KEN03
Group 3
Higher rainfall
forest sites
BLA06
BLA41
BLA08
BLA09
BUS08
BUS11
BUS17
BLA14
BUS07
BLA07
DON06
DON07
BLA10
BUS02
BUS03
Group 4
Naturaliste Ridge
forest sites
ASH04
PHC10
ONS06
ASH09
ISD06
DEG08
FIT05
DEG09
FOR05
WOO01
ASH10
MUR16

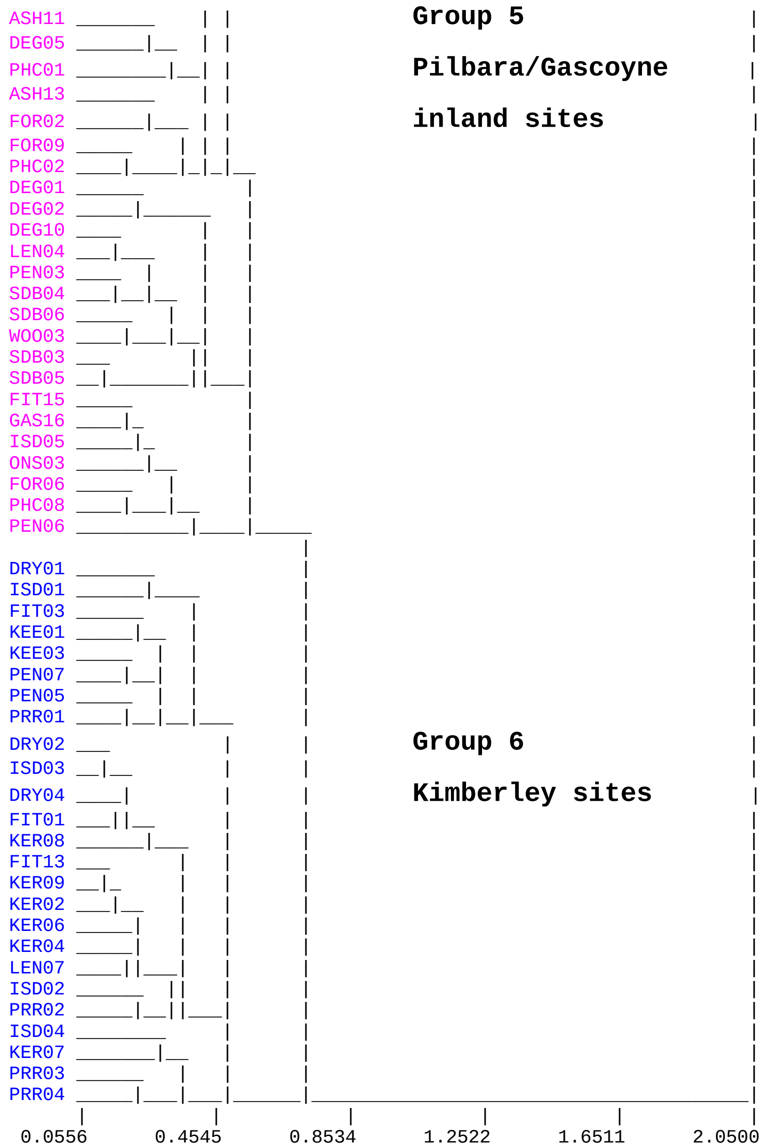


Figure 4. Classification of reference sites on which autumn model is based. Six groups of sites recognised based on macroinvertebrate families present

Ten environmental variables had normally distributed residuals and showed significant differences among reference-site groups (Table 4) and were fed into a step-wise discriminant analysis that identified five predictor variables. Only four canonical vectors in the discriminant function were significant (so the fifth was discarded) and cross-validation error rate was 29 %. Three sites in Site Group 1 that classified to other groups were then removed from the classification, leaving Site Group 1 with only nine members. The step-wise discriminant analysis was repeated and the discriminant function re-calculated to give a cross-validation error of 26 %. Based on this dataset and the output of discriminant function analysis, the revised autumn model was constructed and reference sites were run through the model to generate *O/E* scores. Eight sites had scores <0.75 and were discarded. The process of step-wise discriminant analysis and calculating a discriminant function was repeated on this reduced dataset to create a final model with less cross-validation error, details of which are summarised in Table 5.

Combined-season model

The lack of south-west reference sites sampled in both spring and autumn made it to difficult to revise the combined-season model in a meaningful way. As a result no screening was done prior to classification and the model was constructed from 60 mins live-pick data in the north-west and 30 mins live-pick data in the south-west. This is not regarded as an ideal process and it is one of the reasons we do not recommend use of this model (see section on *Combined-season model* in ***Evaluation of model performance***). The only solution, however, is widespread sampling of autumn sampling of reference sites in the south-west using the 60 mins live-pick protocol. Because of financial constraints, this was not done in the Wheatbelt, on the Swan Coastal Plain and in much of the South-west Forest during the FNARH.

A total of 150 sites (59 north-west from autumn and spring 1998, and 91 south-west from spring 1995 and autumn 1996) were classified into seven groups on the basis of their invertebrate families, using $\beta = -0.175$, after families occurring at less than five sites were masked out of all analyses. Examination of the classification, ordinations and a two-way table resulted in five sites being removed because they were outliers. A further two sites were removed because they had fewer than five families to yield a final classification of 143 sites into seven groups based on 66 families (Fig 5).

Eleven environmental variables (Table 4) were fed into a step-wise discriminant analysis that identified five predictor variables. A discriminant function based on these had a cross-validation error rate of 29 %. One site was obviously mis-classified and was discarded before repeating step-wise and discriminant function analysis, which produced little improvement in cross-validation error (29 %). A revised combined-season model was constructed and the reference sites were run through the model to generate *O/E* scores. Fourteen sites had scores <0.75 and these were discarded. The process of step-wise discriminant analysis and calculating a discriminant function was repeated to create a final model, details of which are summarised in Table 5.

Band scores and basin condition categories

O/E scores from AusRivAS models were divided into a series of band scores to facilitate mapping and interpretation. Through coincidence, band thresholds were the same for all WA models:

X	*O/*E score	> 1.15	Enriched (slightly disturbed or biological hotspot)
A	*O/E* score	0.85 - 1.15	Undisturbed
B	*O/E* score	0.55 - 0.84	Significantly impaired
C	*O/E* score	0.25 - 0.54	Severely impaired
D	*O/E* score	0.00 - 0.24	Extremely impaired

There is still some debate occurring nationally about the thresholds for *O/E* bands and the descriptions of site conditions that should be attached to them. The current system uses the 10th and 90th percentiles of *O/E* scores of sites used to build the model as the lower and upper limits of A band and uses an equal range of *O/E* scores (0.30) to define A, B and C bands. In practice, this means that B band covers considerable variation in ecological condition and there is perhaps justification in splitting this band.

When assessing river basin or catchment condition, it is sometimes useful (especially when mapping) to calculate a basin condition category rather than just averaging *O/E* values. This was done by converting *O/E* values to bands and assigning a score to each site based on its band (X,A = 1; B = 2; C = 3; D = 4). Band scores at all sites in the basin were averaged across spring and autumn and a basin condition category was calculated using the following system (average band score ≤ 1.25 = A_C, 1.26-1.50 = B_C, 1.51-1.75 = C_C, ≥1.76 = D_C). We have used the subscript $_C$ to distinguish basin condition categories from *O/E* bands (ie A refers to a site with *O/E* score of 0.85 - 1.15 whereas A_C refers to a river basin with average band score ≤ 1.25).

We have used spring and/or autumn model outputs to calculate basin condition categories rather than combined-season model outputs for two reasons. Firstly, many sites were sampled in only one season because of financial constraints or seasonal drying. Secondly, the outputs of the combined-season model appeared less reliable than those of the spring and autumn models (see below).

Evaluation of model performance

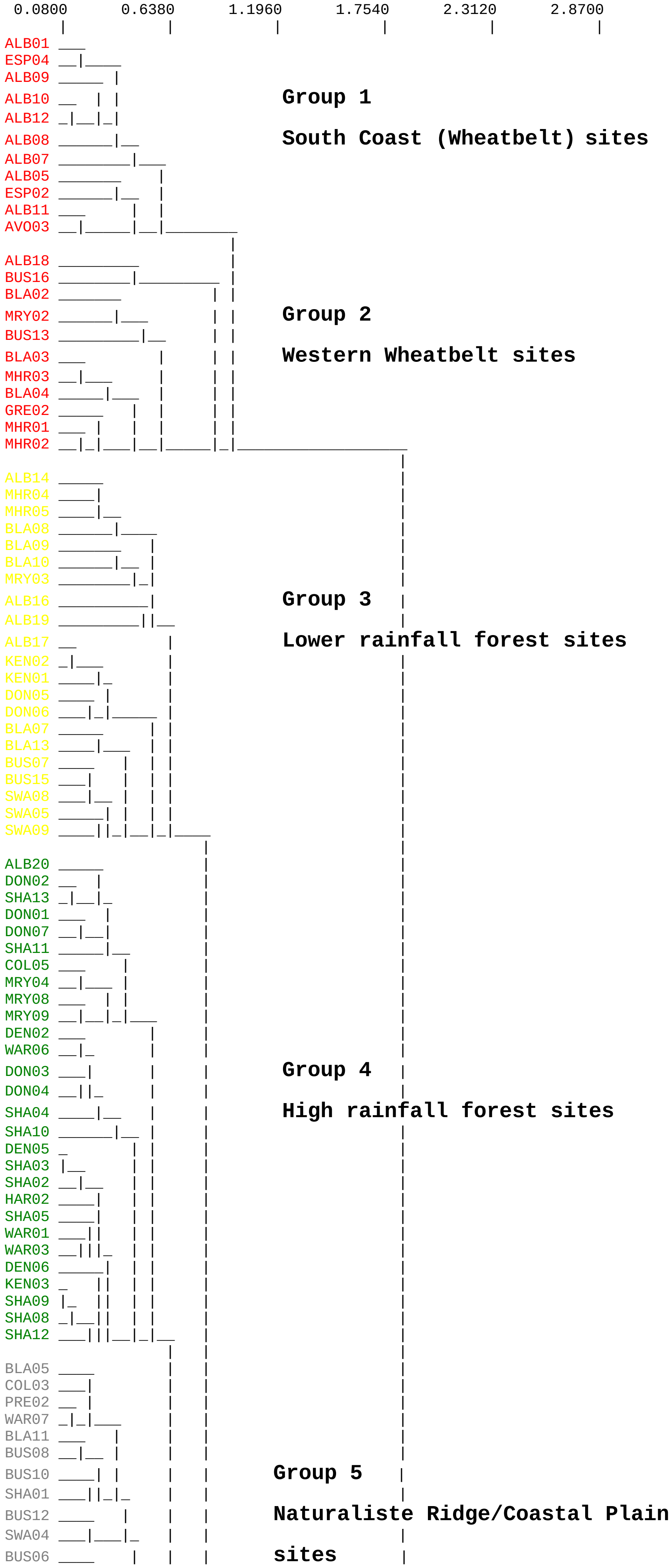
Evaluating model performance is difficult without independent datasets that provide a reliable measure of at least some aspects of river condition, such as the long run of physico-chemical measurements for selected rivers available to Marchant *et al.* (1997) in Victoria. In WA, we assessed model performance in a qualitative way using four criteria:

(1) difference between average *O/E* scores of sites classified as reference (least disturbed) and test (often disturbed)
(2) consistent occurrence of low *O/E* scores at test sites with obvious disturbance
(3) ease of explanation of extreme *O/E* scores (both low and high)
(4) agreement of average scores in a catchment with pre-existing information about basin condition or levels of disturbance.

The above tests address how well the models perform at sites in extreme condition and how accurately they reflect average condition of a large number of sites, many of which may be only marginally impacted. The tests do not address the critical issue of reliability of individual assessments at marginally impacted sites because there was a lack of alternative, accurate data on river health for any marginally impacted sites to compare against AusRivAS assessments. The existence of potential errors listed under the section on ***QA/QC and sampling errors*** make it likely that single assessments of individual sites in marginal condition will sometimes be wrong but the frequency with which this occurs is unknown.

Spring model

The average *O/E* of all 60 mins live-pick reference sites in spring was 0.91 compared with 1.00 for those used to build the model. The discrepancy is the result of screening many reference sites out of the model because they were (a) genuinely depauperate in terms of macroinvertebrate families (the case in much of the Wheatbelt and South Coast where salinity levels were elevated), (b) difficult to sample, (c) not truly in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0.6380
1.1960
1.7540
2.3120
2.8700
ALB01
ESP04
ALB09
ALB10
ALB12
ALB08
ALB07
ALB05
ESP02
ALB11
AVO03
Group 1
South Coast (Wheatbelt) sites
ALB18
BUS16
BLA02
MRY02
BUS13
BLA03
MHR03
BLA04
GRE02
MHR01
MHR02
Group 2
Western Wheatbelt sites
ALB14
MHR04
MHR05
BLA08
BLA09
BLA10
MRY03
ALB16
ALB19
ALB17
KEN02
KEN01
DON05
DON06
BLA07
BLA13
BUS07
BUS15
SWA08
SWA05
SWA09
Group 3
Lower rainfall forest sites
ALB20
DON02
SHA13
DON01
DON07
SHA11
COL05
MRY04
MRY08
MRY09
DEN02
WAR06
DON03
DON04
SHA04
SHA10
DEN05
SHA03
SHA02
HAR02
SHA05
WAR01
WAR03
DEN06
KEN03
SHA09
SHA08
SHA12
Group 4
High rainfall forest sites
BLA05
COL03
PRE02
WAR07
BLA11
BUS08
BUS10
SHA01
BUS12
SWA04
BUS06
Group 5
Naturaliste Ridge/Coastal Plain
sites

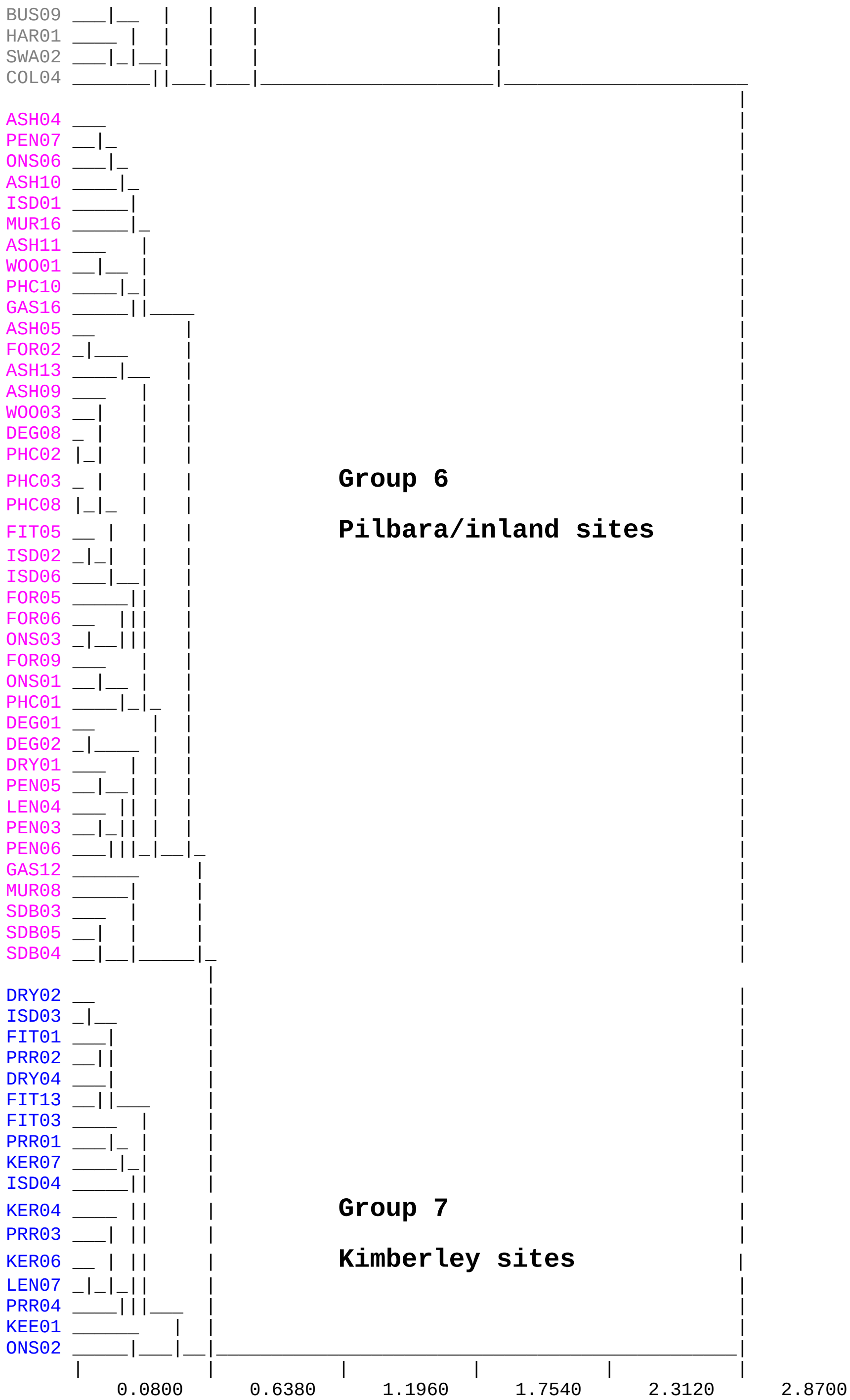

Figure 5. Classification of reference sites on which combined-season model is based. Seven groups of sites were recognised based on macroinvertebrate families present

reference condition, having disturbance that was initially overlooked, or (d) atypical of regional conditions. Sites screened out of model construction usually had fewer families than those remaining.

The average scores of all 60 mins live-pick test sites differed by 0.16 from sites used to build the model (0.84±0.01SE vs 1.00±0.01), representing a highly significant difference of more than half a band width.Test sites represented a range of site conditions, including a few without obvious anthropogenic disturbance and others where disturbance was likely to result in an increased number of families, but average test site scores were expected to be lower than those of model-building sites as a result of many test sites being substantially degraded and biologically depauperate. The large difference in average scores suggests the fundamental assumptions of AusRivAS apply in WA and the spring model was detecting disturbance efficiently at a range of sites.

The efficiency of the model in detecting disturbance was further investigated by examining the *O/E* values of 18 sites thought, at the time of sampling, likely to be impacted based on visual assessment and surrounding land use (this did not comprise an exhaustive list) (Table 6). One of these sites returned a score in Band X (slightly disturbed or biological hotspot), 13 in Band B (significantly impaired), three in Band C (severely impaired) and one in Band D (extremely impaired). The fact that all but one sites recorded scores strongly indicative of disturbance is further evidence the spring model detects degradation effectively. The Band X score also reflected disturbance, although at a lower level than expected on visual inspection.

Additional model validation included examining data from 11 sites throughout WA with Band X *O/E* scores (1.25-1.20). All four north-west sites were undisturbed and appeared to be biodiversity hot-spots, as did one south-west site (Appendix 1). Two other south-west sites on the Arrowsmith River were reference sites but their riparian margins were slightly disturbed and they were probably exhibiting disturbance-induced enrichment, although they may have been natural biodiversity hot-spots as well. Of the remaining four sites, two were best-available reference sites, one was a moderately salinized test site and one was a test site in excellent condition but near a rural town. The high *O/E* scores at these four sites were most likely owing to small amounts of disturbance increasing biodiversity, as predicted by the intermediate disturbance hypothesis (Townsend & Scarsbrook 1997). Thus, it appears that high *O/E*s scores in the spring model are associated with ecologically healthy, biodiverse sites and with slightly disturbed sites containing elevated nutrients or other factors that enrich the faunal community.

Five of the 11 sites with lowest *O/E* scores (0.13-0.41) exhibited high levels of physical disturbance, a further two were recognised as in spate and, therefore, difficult to sample at the time of fieldwork, and one site on a short coastal stream could not be associated with an appropriate reference group (Appendix 1). The remaining three sites would have been expected to have higher *O/E* scores: two were in open jarrah forest (one had been unlogged and unburnt for more than 60 years) and the other was on the northern coastal plain. The low scores were the result of few animals in the samples (9, 25 and 31 instead of the 200 aimed for) leading to few families (see Humphrey *et al*. 2000). Low abundances were probably the result of low nutrient levels, exacerbated by abundant detritus that made sorting difficult. Thus, low *O/E* values in the spring model are associated with degradation at a site, spates and sampling/sorting difficulties leading to few animals being collected, and sites for which there is no appropriate reference group.

Autumn model

The average *O/E* of all 60 mins live-pick reference sites in autumn was 0.95 compared with 1.00 for the mixture of 60 and 30 mins live-pick sites used to build the model. The reasons for a smaller discrepancy than in the spring model are probably (a) despite a high proportion of potential 30 mins live-pick reference samples being screened out of the model, the inclusion of 30 mins live-pick data resulted in baseline family

Table 6. *O/E* scores of 18 sites sampled in spring and regarded at time of sampling as impacted based on visual evidence and catchment activity. ESP10 and MRY21 sampled in 1997, SBD02 sampled in 1998, others sampled in 1999

Site	Signs of disturbance	*O/E*
BLA45	No riparian vegetation, rubbish tip in upper catchment	1.19
DON11	Adjacent to clear-felling, regeneration burn escaped into stream buffer	0.58
DON12	Below large vineyard dam, deep siltation	0.59
ESP10	Channelised stream, no riparian vegetation	0.74
FRA12	Sedimentation, dead trees, salinization	0.80
FRA14	Organic ooze, de-oxygenation, dead trees, salinization	0.80
FOR14	Grazing, eutrophication	0.67
MAR01	No riparian vegetation	0.74
MRY21	Salinized stream, little riparian vegetation, dead trees	0.67
MRY23	Downstream from refinery	0.63
MRY35	Downstream from tailings dump	0.66
SDB02	Organic ooze, de-oxygenation, naturally high salinity	0.43
SWA19	Channelised urban drain	0.29
SWA22	Modified channel, cleared riparian vegetation, impounded	0.81
SWA28	Urban stream, urban run-off, weeds and degraded	0.17
SWA29	In mixed urban/industrial area	0.83
SWA30	In industrial area, receiving discharge from drain	0.34
WAR16	Clear-felling upstream	0.77

richness being slightly lower than if only 60 mins live-pick data had been used, and (b) a predominance in the dataset of sites from the north-west, where reference site quality and sampling difficulties were less significant issues than in the south-west.

The average *O/E* scores of test sites and those used to build the autumn model differed by 0.24 (0.76±0.02SE vs 1.00±0.01), representing a highly significant difference of four-fifths of a band width. The large difference between scores of test and model-building sites showed the models were distinguishing degradation well, although the difference was accentuated by drought conditions in the Murchison-Gascoyne, and some other north-west areas, in autumn 1997. Classification of sites as reference or test was partly based on their drought status (discussed further in ***Assessment of river condition in WA*** - *Murchison/Gascoyne*).

The efficiency of the model in detecting disturbance was further investigated by examining the *O/E* values of 14 sites thought likely to be disturbed, based on habitat condition and surrounding land use (Table 7). Four of these sites were Band B (significantly impaired), seven were Band C (severely impaired) and three were Band D (extremely impaired). The results suggest the autumn model detects degradation effectively.

Table 7. *O/E* scores of 14 sites sampled in autumn and regarded at time of sampling as impacted based on visual evidence and catchment activity. North-west sites sampled in 1998, south-west sampled in 1999

Site	**Signs of disturbance**	***O/E***
COL10	Low pH, iron deposition, grazing in cleared paddock	0.67
COL11	Secondary salinization from irrigation	0.33
COL15	Low pH, iron deposition	0.52
COL16	Low pH, iron deposition	0.48
COL26	Low pH, iron deposition	0.45
DEN20	Low DO, elevated salinity, organic load	0.61
FOR14	Grazing, eutrophication	0.77
GAS10	Grazing, siltation, low DO	0.54
GAS11	Drought, elevated salinity	0.23
GAS17	Grazing impact (yards beside pool), no riparian vegetation	0.62
LMR10	Organic load, low DO, over-grazing, drought and elevated salinity	0.31
MUR05	Drought, extremely elevated salinity	0.23
MUR07	Drought, elevated salinity	0.31
SDB02	Organic load, elevated salinity	0.15

Additional model validation included examining data from 10 sites in Band X (*O/E* scores >1.15). Five of the sites appeared to be biodiversity hotspots (Appendix 1). One of these sites (Callytharra Spring on the Wooramel River) was somewhat disturbed in autumn 1998 but previous sampling, during wetter seasons when grazing pressure of cattle was less, also showed it to be a natural hotspot (Halse *et al*. 2000). The other five sites appeared to be enriched because of mild disturbance; only two of them were in any form of reference condition. Thus, as in the spring model, high *O/E* values were the result of both naturally high biodiversity and enrichment through mild disturbance.

Nine of the 10 sites with lowest *O/E* scores (0.00-0.46) exhibited degradation in terms of salinity, organic load and low dissolved oxygen, low pH and iron deposition, or eutrophication. In many cases the ultimate factor causing degradation was drought. There was one exceptional site, however, that had flooded the day before sampling and had not been colonised by animals. As with the spring model, low *O/E* values usually appeared to be associated with degradation at a site or recent flooding.

Combined-season model

Combined-season models are usually more sensitive to poor river condition than single season models (eg Marchant *et al*. 1997, Turak *et al*. 1999) because of the greater number of families expected and observed and the concomitant reduction in stochastic errors (ie *O/E* ratios are more stable). We do not recommend use of the WA combined-season model, however, because of the unsatisfactory nature of the baseline data used to construct it (particularly the spring 1995 / autumn 1996 30 mins live-pick data) and because of its failure to produce more convincing results than the spring and autumn models alone. It should produce reasonably reliable assessments in north-western Australia but separate spring and autumn assessments are likely to be more informative.

The average *O/E* of all 60 mins reference sites was 0.90 compared with 1.00 for sites used to build the model. The difference reflects screening of sites during model construction but this failed to produce a sensitive model. The average *O/E* scores of all 60 mins live-pick reference and test sites were not significantly different, varying by only 0.03 (0.90±0.02 vs 0.87±0.02). A similar result was obtained with 30 mins live-pick data (0.73±0.02 vs 0.72±0.03). It is notable that the average *O/E* of 60 mins live-pick was ca 0.15 greater than for 30 mins sites, irrespective of whether the sites were test or reference. This highlights the influence of picking method on AusRivAS results and the susceptibility of assessments to experience of the operator.

The efficiency of the model in detecting disturbance was investigated by examining the *O/E* values of nine sites thought likely to be significantly disturbed, based on autumn and/or spring assessments (see Tables 6 & 7). Two of these sites were assessed as Band A (undisturbed), five as Band B (significantly impaired) and one as Band C (severely impaired) (Table 8). This suggests the combined-season model detects degradation less effectively than the autumn and spring models.

Additional model validation included examining data from 10 sites in Band X (*O/E* scores >1.15). One of the sites (WOO03, Callytharra Spring on the Wooramel River) is a biodiverity hotspot, as are the three Pentecost River sites in the Kimberley (Appendix 1). Four mildly disturbed, brackish or naturally saline sites probably showed some enrichment due to disturbance. A Band X score is difficult to reconcile with the visual estimate of condition at the remaining site (BUS18) but it, too, may have been enriched. Thus, high *O/E* values in the combined-season model were probably the result of naturally high biodiversity and enrichment through mild disturbance.

While we have accepted that the three naturally saline sites in Appendix 1 (ALB01, ALB08, ESP04) showed disturbance-induced enrichment, their high *O/E* scores may have been artefacts of the modelling process. The combined-season model was the only model in which a group of naturally saline (and hence depauperate) sites on the South Coast was recognized. A corollary of recognizing a group of sites with few families is that very few extra families are required to put sites predicted to that group into Band X. The screening process associated with the other models prevented enough South Coast sites remaining in the classifications to form a group. The increase in family lists associated with two sampling events, combined with less rigorous screening of saline sites, helped retain the South Coast group in the combined-season model.

Five of the 10 sites with lowest *O/E* scores (0.00-0.40) were degraded in terms of salinity, riparian habitat or erosion. Two scores were the result of the model containing no appropriate reference groups for assessing the sites (short coastal stream and naturally saline inland site), two were caused by sites being steep-sided and

Table 8. *O/E* scores of combined-season model of nine sites regarded in autumn and/or spring as impacted, based on visual evidence and catchment activity

Site	**Signs of disturbance**	***O/E***
DEN20	Low DO, elevated salinity, organic load in autumn	1.06
FOR14	Grazing, eutrophication	0.69
GAS10	Grazing, siltation, low DO in autumn	0.91
GAS11	Drought, elevated salinity in autumn	0.69
GAS17	Grazing impact (yards beside pool), no riparian vegetation	0.75
LMR10	Organic load, low DO, grazing, drought and elevated salinity in autumn	0.80
MUR05	Drought, extremely elevated salinity in autumn	0.53
MUR07	Drought, elevated salinity in autumn	0.64
SDB02	Organic load, elevated salinity	0.32

difficult to sample. The score at one site could not be explained but it was probably difficult to sample. Thus, as with the autumn and spring models, low *O/E* values were usually associated with degradation.

Box sampler and live-picking protocols

There is an extensive literature on aquatic invertebrate sampling and sample processing for assessment of river condition, with considerable argument about the relative value of areal and fixed-count sampling (eg Barbour & Gerritsen 1996, Courtemanch 1996, Walsh 1997). The benefits of areal sampling, where the same-sized area is sampled at each site and all the sample is sorted, are that it provides information about total abundance of animals and a better estimate of taxon richness. It is often argued that areal sampling is the more appropriate protocol for biodiversity survey. Fixed-count methods based on random sub-sampling, which result in the same number of animals but possibility a different proportion of the sample from each site being sorted, provide better information about community structure and are usually regarded as the more appropriate protocol for assessing ecological condition.

Published comparisons of the two methodologies are based on laboratory processing and conclusions are not readily applicable to the live-picking protocol used in AusRivAS, which is a mixture of both methods (the whole sample is 'sorted' but only selected representatives of each family are picked out, usually in different proportions than their abundance, to give a total of around 200 animals). The relatively high proportion of families overlooked when live-picking (Humphrey *et al*. 2000) further complicates evaluation of the AusRivAS protocol. Growns *et al*. (1997) evaluated some live-picking options but performance was judged relative to other field-picking methods known to be subject to operator variation (no sample was comprehensively checked under a microscope and their Methods section suggests the 'random' sample was not truly random).

Throughout the south-west, but particularly in the South-west Forest region, the standard AusRivAS live-picking protocol appears to impair the ability of AusRivAS to detect impact. The principal reason is that animal abundance is often low in pristine sites, which frequently also contain a lot of detritus that makes the few animals present difficult to find. It is a mathematical consequence of the way most communities are structured that the proportion of the families present at a site contained in any sample is related to the number of animals in the sample. Therefore, live-picking frequently underestimates family richness at pristine sites. Disturbance changes community structure by reducing the overall number of families present at a site and altering the relative abundances of different families (see Rosenberg & Resh 1993). In the South-West Forest region, disturbance causes at least an order of magnitude increase in overall animal abundance (see Edward *et al*. 2000), leading to a higher proportion of families being recovered by the live-picking protocol. Consequently, assessments at disturbed sites are upwardly biased relative to pristine forested sites.

Figure 6. Box sub-sampler being used in the field to recover a random sample of animals. *S. Halse*

Random sampling a fixed number of animals, so family richness values are determined by community structure rather than invertebrate abundance, should provide more reliable assessments of stream condition. The method we employed to randomly recover a fixed number of animals in the field was a box sub-sampler (Fig 6), slightly modified from the design of Marchant (1989). Our sampler was made of Perspex and had only 64 cells, rather than the 100 used by Marchant, so that cell size was slightly larger. This made it easier to remove cell contents and also enabled larger pieces of debris to fit into the cells. The invertebrate sample, collected in the normal way, was placed in the sub-sampler after removal of large pieces of detritus and the sub-sampler was agitated to distribute the sample amongst the cells. We then sequentially sorted the contents of as many of the 64 cells as was necessary to obtain 200 animals. At some reference sites, 64 cells did not provide 200 animals (ie there were fewer than 200 animals in the 10 m sweep) and another sample had to be collected. Each cell was emptied into a sorting tray and picked by two operators until they were confident all animals had been recovered (ie there was no time limit on picking).

Table 9. Comparison of 60 mins live-pick and 200-animal random sub-sample at 26 sites (nine reference and 17 test) in south-west WA. Test sites were expected to be impacted, based on physical habitat

	No of animals		**No of families**		**Families missed**		**O/E scores**	
	Ref	Test	Ref	Test	Ref	Test	Ref	Test
Live-Pick	133±16	200±17	18±1	17±1	4±1	2±2	0.94±0.04	0.86±0.04
Sub-Sampler	193±6	194±3	19±1	13±1	-	-	0.96±0.05	0.71±0.04

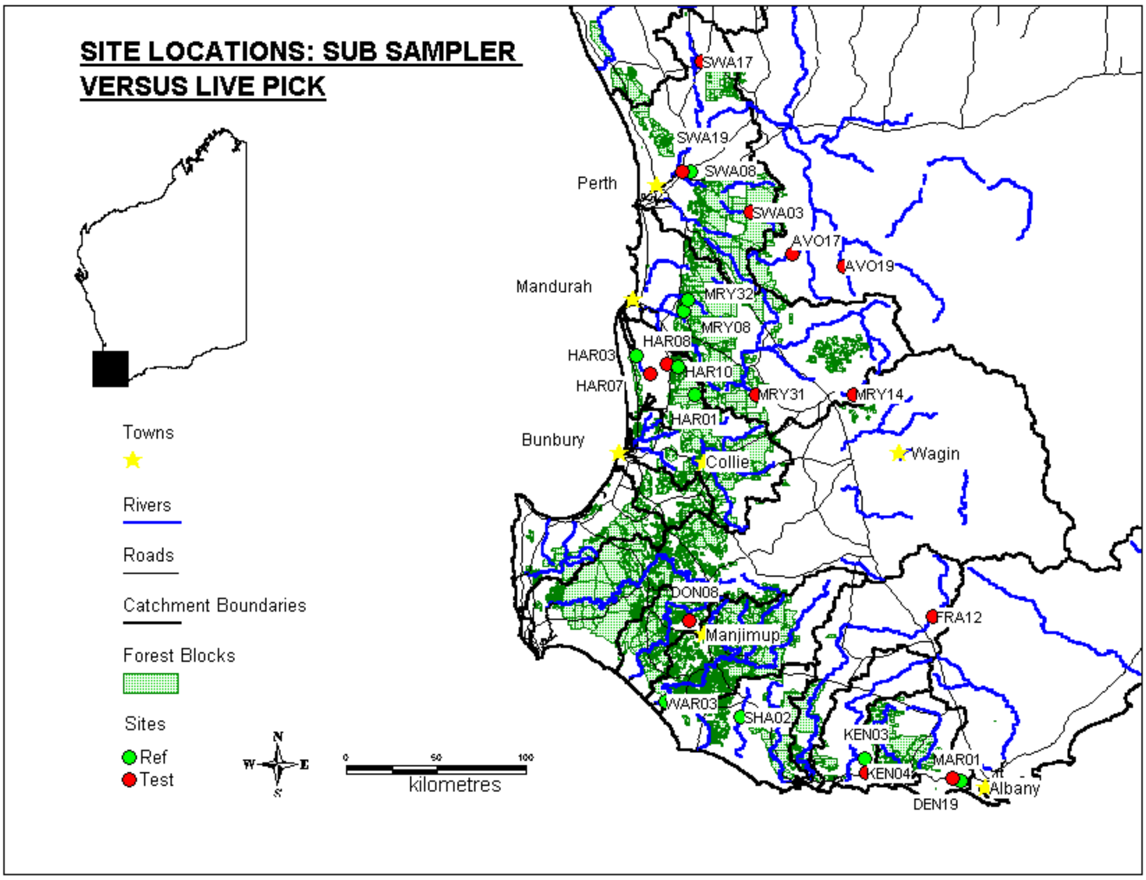

Figure 7. Map of sites where box sub-sampler and live-picking protocols were compared

Assessments using the box sub-sampler and the standard AusRivAS live-picking protocol were compared at 26 sites in the south-west (Fig 7, Table 9). It can be seen that sub-sampling increased the number of animals collected from reference sites as well as causing a slight (ca 5 %) increase in the number of families. The most obvious change, however, was the 23 % decrease in number of families collected at test sites, which translated to 17 % decrease in *O/E* score. It is also worth noting that, on average, box-sampling collected 4.5 families from reference sites that were not recovered in the live-picking. While this may be partly the result of each 10-m sweep collecting only part of the fauna at a site (Kay *et al*. 1999), it probably also reflects incomplete retrieval of families by live-picking even by experienced operators (Smith *et al*. 1999, Humphrey *et al*. 2000). The problem was usually less severe at test sites.

Use of a box sub-sampler in the field has the potential to increase the rigour of live-picking substantially. In the trials conducted to date, average *O/E*s of reference sites have been the same with both methods but sub-sampling has resulted in four-fold increase in the average difference of test and reference *O/E* scores. The sub-sampler is easier to use in the field than the laboratory and, provided sites are not too far removed from vehicle access, transport of the equipment is not a major issue. Reducing the volume of material in the sorting tray to the contents of a single cell from the sub-sampler increases sorting efficiency markedly. We found no macroinvertebrates (other than nematodes, which are not visible to the naked eye) in the residues of box sub-sampler sorting at three sites, suggesting that sub-sampling enables experienced operators to achieve 100 % retrieval of macroinvertebrates and overcomes one of the major criticisms of live-picking in the field (Humphrey *et al*. 2000).

Use of a box sub-sampler has little effect on overall time spent in the field if a variety of sites are being assessed. While sub-sampling is slower at pristine sites with low animal abundance, it is much faster at disturbed sites. Two hundreds animals are often collected from such sites within 10 mins, whereas the AusRivAS protocol requires two operators to pick for 30 mins each.

Assessment of river condition in WA

An assessment of river condition in WA, based on 60 mins live-pick samples and the revised spring and autumn models, is provided in Figs 8 and Table 10. We have used AWRC basins as the basis for this assessment because they represent convenient-sized units with which most water managers are familiar. We emphasize that conditions may be highly variable within a basin, however, and recommend consulting assessment results for individual sites, which are mapped in Appendix 2. Overall, river condition is better in the northern half of the State than the southern half, although catchments in good condition are found throughout WA and degradation occurs in the north as well as the south.

We believe Fig 8 and Table 10 provide useful information about the condition of rivers in WA but there are some discrepancies in assessments between regions (see *State-wide overview of river condition*). Inconsistent assessments and some obvious errors are not unexpected in the first broadscale assessment of river condition across WA and assessments are likely to become more accurate as the amount of available data increases and experience enables potential pitfalls in assessment to be avoided. This has been the UK experience with RIVPACS (Wright 2000). When looking at Fig 8 and Table 10, the reader should be aware of five sources of error:

Firstly, assessments were sometimes affected by an un-representative distribution of test sites or extreme scores, especially when few sites were sampled in a catchment. This was obvious in the Sandy Desert, where one naturally saline site had a disproportionate effect on basin assessment (see Appendix 2), but affected assessments in several other catchments, including the Prince Regent.

Secondly, like all categorisations, the basin condition categories can portray two catchments in very similar condition as different categories because their average scores fall either side of an arbitrary boundary. This occurred in the Pilbara, where catchments were all in similar condition (see Appendix 2) but fell into two condition categories. To a lesser extent, the phenomenon occurred elsewhere too.

A third important factor affecting assessments was quality of reference sites. This is most obvious in the Avon catchment in the Wheatbelt, which was classed as basin condition category B_C despite widespread salinization and other agricultural disturbances. All reference sites in the groups to which discriminant functions assigned Avon test sites suffered some degree of salinization and associated eutrophication, even when the sites were in reserves. Thus, baseline condition was itself disturbed and the category B_C rating in the Avon reflected a much greater level of disturbance than a category B_C rating in a Kimberley or Pilbara catchment.

Fourthly, many catchments in the south-west were assessed only in spring because of limited funding and results may have been different if based on two seasons of sampling. For example, one of the few catchments with both spring and autumn sampling, the Donnelly, had average band scores each season of 1.75 and 1.00, respectively, to return a basin condition category B_C, although it was category C_C based on spring data alone and category A_C in autumn (Table 10).

A fifth factor influencing assessment was seasonal conditions. The differences between spring and autumn band scores of the Gascoyne, Wooramel and Murchison ranged between 0.8 and1.2. These large changes illustrate the magnitude of the effects of drought and flushing on river condition. The Murchison catchment would have been classed as basin condition category D_C if assessed in autumn 1997 alone, after prolonged drought, and as category A_C if assessed in spring 1997 alone, after extensive winter rain and flushing of the river had occurred (Table 10).

Our assessment of river condition was based only on 60 mins live-pick data because different processing methods affected assessment scores substantially (Tables 3 & 9). Only sites selected for State of the Environment reporting were used, although results would have been similar had all 60 mins line-pick sites been incorporated (see Appendix 2).

Site selection

Three types of sites were sampled in WA (see Kay *et al*. 2001). 'Reference' sites with minimal disturbance were selected through (a) using maps to identify areas with large amounts of uncleared vegetation, (b) the recommendation of people with local knowledge, and (c) reconnaissance. Reference sites were intended to be included in the model-building process. 'Degraded' sites were selected on the basis of their position in relation to a known source of pollution, on advice of people with local knowledge, and through reconnaissance. 'SOE' sites were mostly selected from maps, with the criterion for selection being to obtain a good geographic spread of a range of stream types in whatever land-use categories were visible from topographic maps, although access was a major constraint. Some SOE sites were of reference quality because they were intended to provide a reasonably unbiased assessment of river condition. Often they were chosen from a map and only recognized as suitable for model-building during fieldwork.

The national terminology for the MRHI/FNARH defined sites as 'reference' or 'test'. Test sites were usually defined as any kind of site not intended for use in model-building but the meaning was ambiguous: it sometimes implied a site was degraded. In WA, test sites included both SOE sites and sites chosen because pre-existing information suggested they were degraded (this was especially true during the first phase of the MRHI). The latter sites were sometimes excluded from SOE analysis because the aim in selecting SOE sites (which was not realised in all catchments) was to obtain an unbiased set of sites, representative of catchment conditions. Including sites that were sampled only because they were known *a priori* to be contaminated biases SOE analysis and makes it difficult to detect future deterioration in the catchment.

The main sources of information for site selection were topographic maps, State Government agencies, land-care coordinators and group members, and individual landholders. The importance of different sources varied regionally, with landholders being most important in pastoral areas, land-care groups and farmers more important in the Wheatbelt and State Government agencies most important in South-west Forest. With experience, however, it was possible for MRHI staff to locate a large proportion of suitable sites from maps alone.

Kimberley

Most of the river systems in the Kimberley show little sign of disturbance. Systems in the north Kimberley are in excellent condition (Fig 8, Table 10), probably because the sandstone substrates are not susceptible to erosion, there has been a relatively short history of grazing, and water is plentiful so that stock are widely dispersed. The Prince Regent River, with its catchment almost entirely located within the eponymous nature reserve, would be expected to be one of the most undisturbed rivers in Australia and the B_C assessment of the Prince Regent Catchment, which also contains Glenelg River, appears surprising. However, cattle have been present in large numbers on the Glenelg and Prince Regent for longer than in more northern catchments and there is evidence of erosion (sandy slugs in the stream bed and bank erosion with uprooted trees) in parts of the upper Prince Regent. Two of the three sites on the Prince Regent River itself were located in sandy, eroded parts of the headwaters. This represented disproportionately high sampling effort in such areas but, because of the threat from saltwater crocodiles in the main channel, all Prince Regent sites were located in headwater streams.

The rivers showing greatest disturbance in the Kimberley are the Ord and Fitzroy (too few sites in the Keep were sampled to be representative of its whole catchment, most of which is in the Northern Territory, but it too appeared to be degraded). Cattle grazing caused severe erosion on parts of the Ord catchment before the middle of last century, leading to commencement of partial de-stocking and a rehabilitation program in the 1960s (Fitzgerald 1968). Grazing has also had detrimental effects on the floodplain of the Fitzroy River (Payne *et al* 1979).

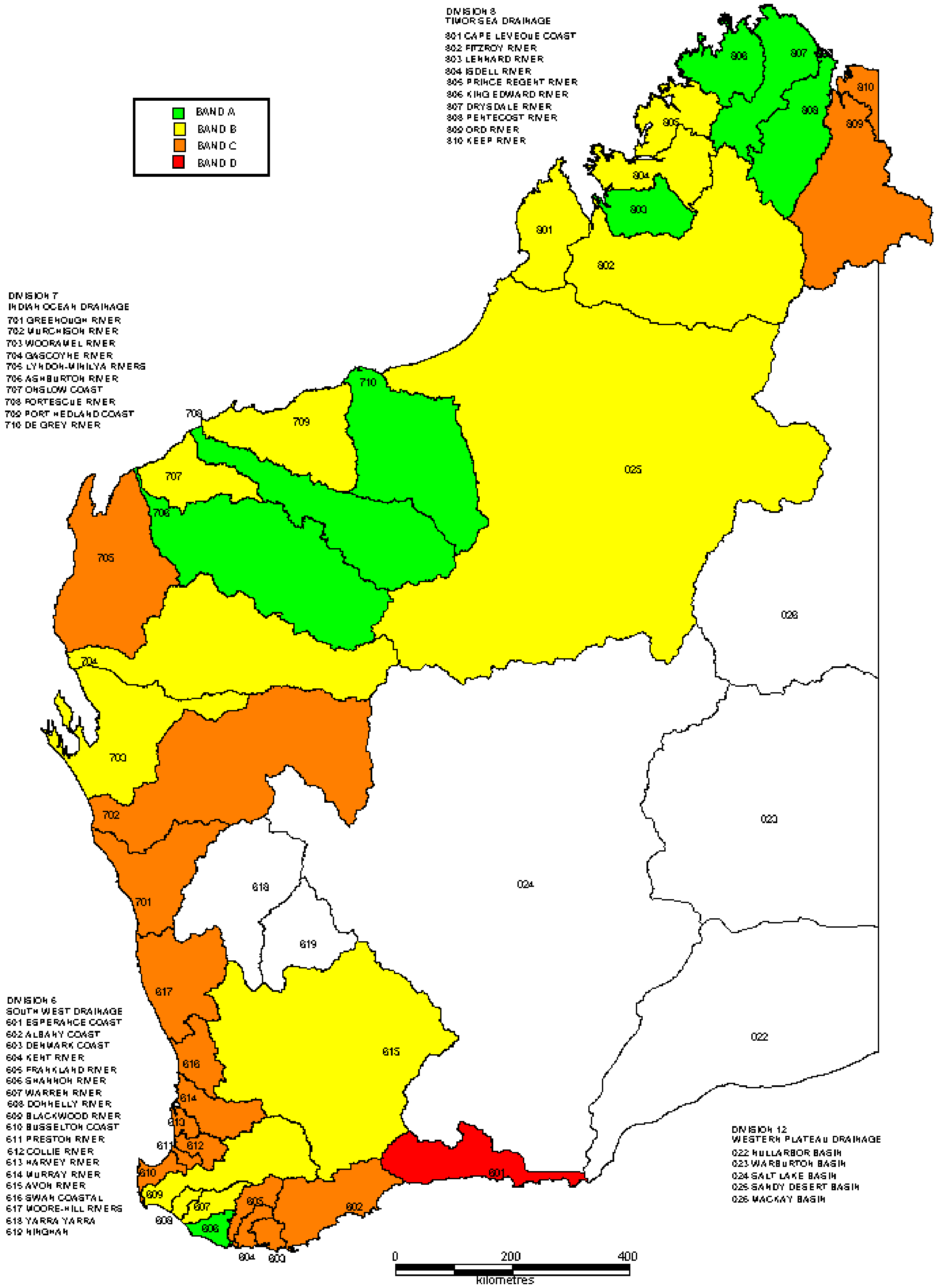

Figure 8. Basin condition categories in WA as assessed using macroinvertebrates and AusRivAS models (see Table 10)

Table 10. Assessment of basin condition based on average spring and autumn *O/E* and band scores of SOE sites within basin (see *Band scores and basin condition categories* for method of deriving basin condition). See Appendix 2 for band scores of individual sites

Basin number	Basin name	Spring average		Autumn average		Basin condition
		O/E	**Band**	***O/E***	**Band**	
601	Esperance Coast	0.75	2.00	n/a	n/a	D
602	Albany Coast	0.79	1.73	n/a	n/a	C
603	Denmark Coast	0.82	1.74	0.86	1.50	C
604	Kent	0.84	1.71	n/a	n/a	C
605	Frankland	0.81	1.69	n/a	n/a	C
606	Shannon	0.89	1.38	0.93	1.00	A
607	Warren	0.83	1.63	0.96	1.17	B
608	Donnelly	0.78	1.75	1.03	1.00	B
609	Blackwood	0.88	1.50	0.91	1.29	B*
610	Busselton Coast	0.87	1.57	0.87	1.50	C
611	Preston	0.87	1.33	n/a	n/a	B
612	Collie	0.90	1.31	0.69	2.00	C*
613	Harvey	0.86	1.60	n/a	n/a	C
614	Murray	0.82	1.65	n/a	n/a	C
615	Avon	0.87	1.42	n/a	n/a	B*
616	Swan Coastal	0.74	1.81	n/a	n/a	C
617	Moore-Hill	0.82	1.70	n/a	n/a	C
701	Greenough	0.90	1.56	n/a	n/a	C
702	Murchison	0.93	1.15	0.56	2.36	C
703	Wooramel	0.92	1.00	0.75	1.83	B
704	Gascoyne	0.95	1.23	0.60	2.42	B
705	Lyndon-Minilya	0.94	1.86	0.52	2.50	C
706	Ashburton	0.88	1.29	0.99	1.00	A
707	Onslow Coast	0.93	1.40	0.89	1.20	B
708	Fortescue	0.96	1.29	0.89	1.17	A
709	Port Hedland Coast	1.02	1.36	0.89	1.30	B
710	De Grey	0.99	1.00	0.89	1.30	A
801	Cape Leveque	0.73	1.75	n/a	n/a	B
802	Fitzroy	0.82	1.75	0.96	1.09	B
803	Lennard	1.02	1.33	1.01	1.00	A
804	Isdell	0.93	1.40	0.96	1.20	B
805	Prince Regent	0.85	1.75	0.97	1.00	B*
806	King Edward	1.08	1.00	0.99	1.00	A
807	Drysdale	1.03	1.00	1.01	1.17	A
808	Pentecost	0.97	1.00	0.95	1.33	A
809	Ord	0.83	1.71	0.89	1.44	C
810	Keep	0.70	2.00	0.93	1.25	C
1225	Sandy Desert	0.94	1.33	0.83	1.60	B*

* condition uneven across catchment and score affected by location of sites

Previous assessment of river condition in north-west WA suggested the Prince Regent was the only large river system in the Kimberley in pristine condition, although three other nodes containing smaller rivers in undisturbed condition were recognized (WRC 1997). This work was based on a GIS study, with some ground-truthing, and placed a lot of emphasis on land tenure and condition of riparian vegetation. Interestingly, although not classifying them as all undisturbed, WRC (1997, p. 66) suggested that all rivers between the Isdell and Pentecost had natural heritage value. This is in general agreement with AusRivAS results (Fig. 8) and there is little doubt that the northern Kimberley contains some of the least disturbed rivers in Australia. By contrast, rivers of the southern and eastern Kimberley show signs of degradation.

Sandy Desert

The assessment of the Sandy Desert as slightly impacted reflects average (but not modal) condition at the small number of sites sampled. The entire catchment of Rudall River is contained within the eponymous National Park and sites on that river were consistently classified as undisturbed (Appendix 2). Staff who sampled Rudall River sites regarded them as amongst the least disturbed in WA, although SDB05 (Queen Desert Baths) is under increasing tourist pressure. The disturbance detected at one site on Savory Creek was at least partly the result of natural salinity, exacerbated by low rainfall, rather than anthropogenic disturbance although cattle have access to much of the creek. We did not sample Sturt Creek, the other WA river system in the Western Plateau Drainage Division, although a considerable amount of information about its terminal basin is available (Halse *et al*. 1998a,b). It is located in the MacKay Basin, east of the Sandy Desert.

Pilbara

In our analysis of catchment condition, the three major rivers in the Pilbara (Ashburton, Fortescue and De Grey) appeared to be relatively undisturbed, whereas the shorter rivers of the Onslow Coast and Port Hedland Coast catchments showed greater impact (Fig 8). Examination of the results for individual sites (Appendix 2) suggests the differences between the various rivers are small and this is reflected in Table 10.

Assessments of two Port Hedland Coast sites as Band C, the lowest *O/E* scores in the Pilbara, agreed with impressions at the time of sampling and provide some justification for the basin condition score of B_C. Nevertheless, we suggest that all river systems in the Pilbara probably fall between condition categories A_C and B_C, being in better condition than the Ord and parts of the Fitzroy, but not as undisturbed as the northern Kimberley. There are noticeably more sites in Band X condition in the Pilbara than the Kimberley in both spring and autumn. In calculating basin condition categories, Band X was scored in the same way as Band A because of the uncertainty whether X represented disturbance or a biodiversity hotspot. If Band X had been treated in the same way as Band B, the resulting basin condition categories would have been quite different from those shown in Fig 8 and the difference between Kimberley and Pilbara would have been more pronounced.

Unlike the Kimberley, there is a pronounced difference between WRC (1997) and AusRivAS assessments of whole river system condition in the Pilbara, even allowing for the modifications to Fig 8 suggested above. We suggest the overall level of degradation is less than suggested by WRC (1997), which identified only three small areas (headwaters of the Yule, Sherlock and Robe Rivers) as relatively natural. AusRivAS also rated individual sites in the upper Sherlock and Robe as undisturbed (Appendix 2).

The most significant differences were between the AusRivAS assessment of the Ashburton, Fortescue and De Grey Rivers and that of WRC (1997) and other vegetation/soil-erosion based assessment work (Payne & Mitchell 1992, Payne *et al* 1982). To a large extent, however, differences between the assessments disappear at the scale of individual sites, ie when comparisons are made between AusRivAS results and WRC assessment of land tenure and local riparian zone condition. Thus, it is likely that different methods of calculating basin condition, rather than differences in site-by-site assessment, caused most of the discrepancies. For example, Payne & Mitchell (1992) assessed the sole AusRivAS headwater site on the Fortescue as over-grazed, with a reduced frequency of flooding caused by Ophthalmia Dam. AusRivAS assessed the site was assessed as Band B (Appendix 2). Sites on parts of the Fortescue where WRC (1997) recorded intact riparian vegetation, such as in the Hamersley Range, were classified as Band A by AusRivAS.

The relationship between river condition, rainfall and surrounding land use is perhaps somewhat different in the arid Pilbara and Gascoyne-Murchison from that in higher rainfall landscapes. In the Pilbara, average rainfall is low but highly variable. Seasonal, as well as long-term drought, causes low water levels and heavy use of pools by stock and indigenous animals so that only resilient invertebrate families survive. Then storm events can deposit up to 200 mm of rain over a few days, resulting in short periods of flooding in rivers with high stream power before the rivers rapidly contract back to a series of very isolated groundwater-fed pools. Flood events remove accumulated nutrient and organic matter and can substantially alter channel morphology (Mitchell & Leighton 1997). Despite causing some erosion, floods generally re-set rivers back to a condition of good water quality with an associated macroinvertebrate fauna typical of undisturbed conditions, although Davies (1996) found delayed re-colonisation by some animals after cyclonic flooding on the Robe River.

As a result of the strong relationship between rainfall and water quality, river condition in the Pilbara and Murchison-Gascoyne is perhaps more strongly related to antecedent weather than surrounding land-use, except in extreme cases of degradation.

Murchison-Gascoyne

The Gascoyne, Wooramel and, particularly, Murchison and Lyndon-Minilya systems were assessed as degraded by AusRivAS (Fig 8, Table 10), in agreement with WRC (1997). However, the AusRivAS assessments principally reflected river condition during a drought. The true extent of degradation is difficult to ascertain because of pronounced difference between the autumn 1997 (drought) and spring 1997 (post-flood) assessments (Table 10). Only the Lyndon-Minilya system still showed widespread evidence of degradation after flooding. This catchment and the Murchison are generally regarded as the most degraded pastoral catchments in WA (eg Williams *et al*. 1980, Curry *et al*. 1994). Comparisons between catchments are probably somewhat subjective, however.

Assessment of the Murchison system is complicated by the occurrence of saline water through most of the system. In drought conditions, salinity levels increase through evapo-concentration but major flood events are also associated with moderate increases in salinity. It appears that large playa salt lakes in the headwaters of the river overflow and discharge saline water into the river during when they flood, with detrimental effects on macroinvertebrates. The better basin condition of the Wooramel than surrounding rivers is probably largely attributable to lower salinity levels, although parts of the upper catchment also appear to be comparatively well vegetated.

As mentioned in the section on *Pilbara* above, antecedent rainfall appears to be a major determinant of river health in the Murchison-Gascoyne. Despite land degradation, many rivers, springs and associated wetlands in the region contain significant invertebrate biodiversity (Halse *et al*. 2000). Much of the fauna appears adapted to high turbidity and harsh environmental conditions. But the overall weight of evidence from AusRivAS, and other vegetation and erosion-based assessments, is that rivers in the Murchison-Gascoyne region are more degraded than in pastoral areas farther north, notwithstanding the existence of small pockets of land in reasonable condition.

Wheatbelt

The Wheatbelt of WA is a loosely defined area, occurring between the 600 and 300 mm isohyets in the south-west where most cereal crops are grown. In this report, we have excluded the area along the South Coast so that our definition of Wheatbelt approximates the catchments of the Avon, Greenough, Moore-Hill, upper Blackwood and upper Frankland (Fig 1). River systems were degraded, with basin condition varying between B_C and C_C, but the striking result was that AusRivAS models assessed the central Wheatbelt, which contains the most severe secondary salinization in Australia (Schofield *et al*. 1988, Williams 1999), as being in better condition than coastal, less salinized parts of the south-west (Fig 8, Table 10). This seems likely to be erroneous and is in contrast to other assessments of catchment condition for the region (George *et al*. 1995, Anon. 1996), although the more saline, eastern parts of the Wheatbelt usually lack defined streams and were not assessed by us.

One cause of AusRivAS underestimating disturbance in Wheatbelt rivers was lack of unsalinized reference sites to provide a benchmark for assessments. As a result, the families predicted to be present at reference-condition Wheatbelt sites were resilient ones that usually remained at a site unless impacts were very severe. This reduced sensitivity of the models. We suggest a more realistic measure of impact at a basin level would be obtained by lowering all AusRivAS scores at Wheatbelt sites by one band (ie A should be interpreted as B etc) to take account of the lack of suitable reference sites, although this would not improve the reliability of comparisons between individual sites.

River assessment in the Wheatbelt is complex, however, and there is an alternative explanation for performance of AusRivAS models in the region. Salt has been present in the Wheatbelt landscape throughout recent geological time (Salama *et al*. 1992; see also Schofield *et al*. 1988) and much of the biota has adapted to, and speciated in, saline environments (Halse 1981; Halse & McRae 2001). As a result, Wheatbelt macroinvertebrates are much more tolerant of salt than suggested by Hart *et al*.'s (1990) review of the Australian freshwater biota as a whole Kay *et al*. (2001). There are no surveys pre-dating the onset of secondary salinization and the degree to which present-day macroinvertebrate species and family richness of Wheatbelt sites has been reduced by salinization is equivocal (Williams *et al*. 1991).

Bunn & Davies (1990) showed that the fauna of all south-west WA rivers is depauperate compared with eastern Australia. They attributed this mostly to low productivity but noted that past periods of climatic aridity, and the difficulties animals experienced re-colonising from wetter regions, may mean that historical factors have also affected the biota. In fact, low productivity has not prevented elements of the biota that possess drought-resistant life-stages being richer in the south-west than elsewhere in Australia (eg anostracans, Geddes 1981; copepods, Maley *et al*. 1997; ostracods, Halse 2002). This suggests that productivity has been less influential than past aridity, and episodes of climate-induced salinity, in shaping the fauna of rivers in the south-west. The occurrence of relatively few, but resilient, macroinvertebrate families at Wheatbelt reference sites may, therefore, reflect geological and past climatic factors rather than the effects of widespread secondary salinization. If the fauna is resilient, then changes in riverine physico-chemical attributes may have little effect on the ecology of a river (see Kay *et al*. 2001).

Despite the possible explanation of ecological robustness given above, we believe it is most likely that the AusRivAS assessments of basin condition for the Avon and Blackwood are upwardly biased (see Pen 1997). Catchments of both river systems have been mostly cleared since 1930, with some areas cleared before 1900 (Jarvis 1979, p 56). As a result, riparian vegetation generally consists of only a thinned band of overstorey species and channel morphology shows the effects of sedimentation and erosion. Water is uniformly brackish or saline and the macroinvertebrate fauna is depauperate and predictable. By comparison, most clearing in the Hill River catchment occurred in the 1960 or 1970s and substantial downstream areas remain uncleared and stoneflies and some other families typical of freshwater sites still occur in this area (Kay *et al*. 2001). Yet the Moore-Hill was assessed as being in poorer condition (C_C, Fig 8). The Hutt River, within the Greenough Basin, is another example of a northern Wheatbelt river that contains areas of good habitat, although salinity is elevated. The Greenough was also assessed as C_C. Category C_C assessments for the Moore-Hill and Greenough are in general agreement with other evaluations based on mostly physical and riparian condition (Skitmore & Olsen 1991) and probably accurately reflect basin condition. However, they highlight the anomalous assessment of the Avon and Blackwood.

We believe that, although they give inconsistent results, the current AusRivAS models provide a useful starting point for assessment of river health in the Wheatbelt. It will probably require many years of biomonitoring to devise satisfactory methods of measuring the ecological condition of Wheatbelt rivers, particularly if accurate comparisons with other regions are needed. All assessment methods, whether physico-chemical or biological, suffer in this region from the lack of data for calibration. Although pre-impact data will never be available, the very large amount of species-level survey data collected from

Wheatbelt wetlands over the past four years as part of the State Salinity Strategy will be one step towards calibration (Pinder *et al*. 2000, 2002, unpublished data).

South Coast

AusRivAS assessment ranked rivers of the South Coast as the most degraded in WA, with Esperance Coast being the only basin in D_C condition and Albany Coast being in C_C. Esperance Coast is an area of rapidly increasing secondary salinity (Short 1997), and its hinterland has long been considered at high risk of secondary salinization (Paterson 1917), but all major rivers are in large corridors of native vegetation and their riverine habitat is usually in better condition than in the central Wheatbelt. We regard the Albany Coast assessment as accurate and the Esperance Coast assessment of higher order streams as biased downwards, relative to assessments in the Wheatbelt. However, some uncertainty is associated with expectations about river assessments on the South Coast (see below) because there is little baseline information available: sedimentation and eutrophication were seen as the major threats by Olsen & Skitmore (1991), who appeared to underestimate the importance of salinity. Hodgkin (1998) warned against too much focus on nutrients in South Coast estuaries and suggested sedimentation, salinity and hydrological regime were more important parameters. These comments may well apply to rivers.

The cause of downwards bias in assessment of larger rivers of Esperance Coast, and to a lesser extent the eastern part of Albany Coast, is high salinities. The degree to which these are natural remains unclear. Conductivities at two reference sites with intact riparian vegetation and large buffers were 37,800 and 65,300 µS/cm. While the shrub species in riparian vegetation indicated these rivers were naturally saline, some secondary salinization was also present. Historical records of salinities in Esperance Coast rivers are anecdotal and often contradictory, so are of little assistance in elucidating original river condition. If it is accepted that present-day salinities are within the historical range, then satisfactory assessments of river condition could probably be produced by a regionally based AusRivAS model that used salinity as a predictor variable to assign sites to reference groups. *O/E* values produced by such a model would be somewhat unstable because of the small number of expected taxa (see comments in *Combined-season model* in ***Evaluation of model performance***).

We emphasize, however, that we are sceptical that present-day salinities and water volumes are within the historical range. Significant areas of salinization are becoming visible in the headwaters of most South Coast rivers, including the Fitzgerald in the south-eastern corner of the 94,000 ha Lake Magenta Nature Reserve. While salinity remains the greatest anthropogenic disturbance, it is not a suitable predictor variable. We also emphasize that some smaller tributaries on the South Coast, without riparian buffers, are obviously highly degraded.

South-west Forest

The catchments of rivers in the South-west Forest region frequently extend inland into the Wheatbelt and seawards onto the coastal plain, where intensive agriculture and urbanisation occur. The forest zone itself contains an increasing amount of intensive agriculture (orchards, vineyards, horticulture), in addition to more

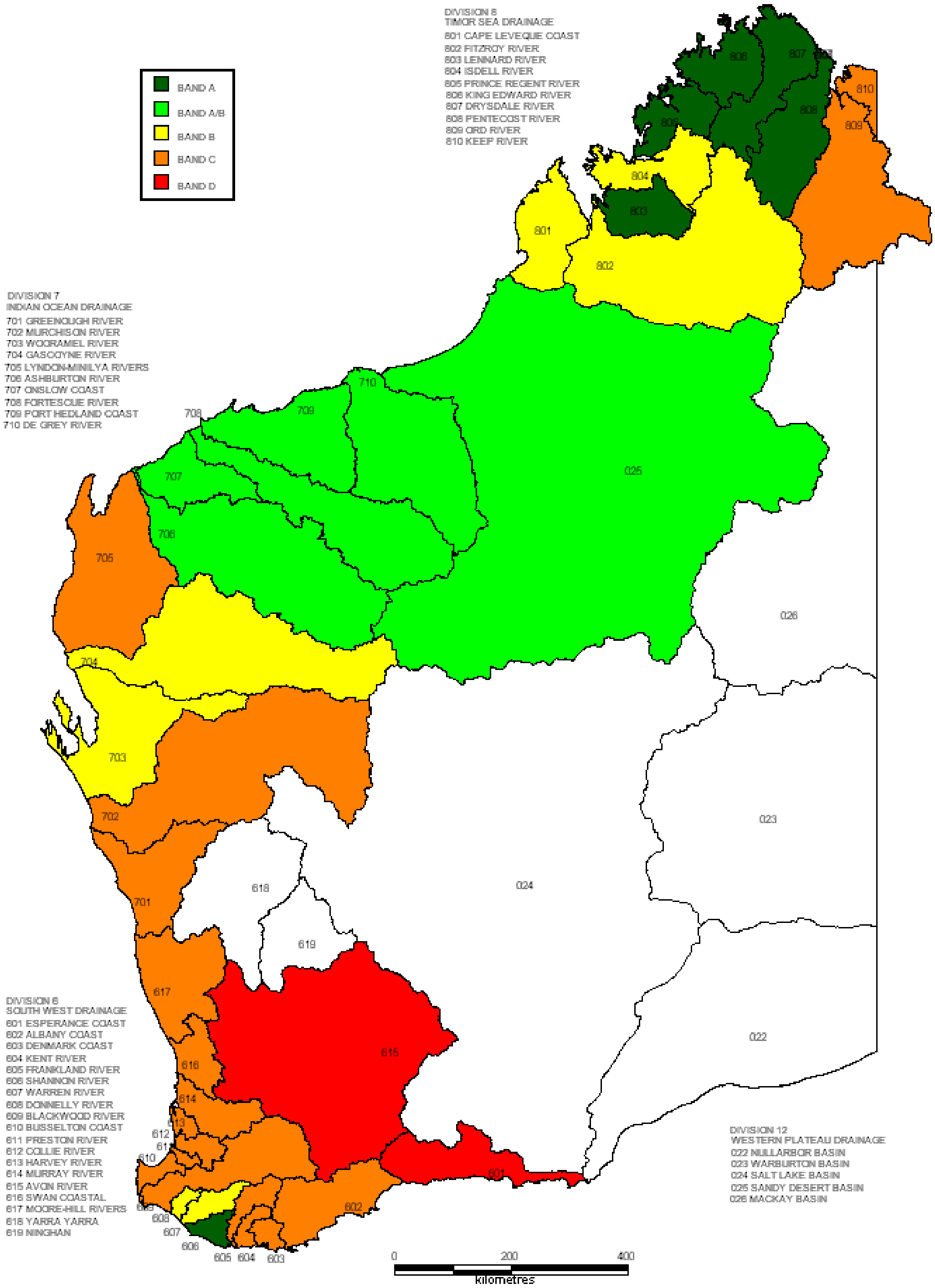

Figure 9. Corrected basin condition categories of WA rivers based on AusRivAS assessments

traditional farms and large tracts of forest. Thus, condition of rivers crossing the South-west Forest is determined by a variety of land-uses, both within and outside the zone. This point was first made by Morrissy (1974) when studying the reverse longitudinal salinity gradient of the Blackwood River. Secondary salinization in the Wheatbelt causes rivers to become saline but water quality improves after they enter State Forest (see also Pen 1997).

The condition of most river basins in the South-west Forest is C_C, although rivers in the extreme south-west corner, including the Blackwood, appear to be in better condition (B_C) (Fig 8, Table 10). The Shannon, with almost all its catchment in National Park, despite some small pockets of farmland, is undisturbed (A_C) (see Pen 1997). The poor condition of the Frankland, Kent and Denmark Coast Rivers is less surprising than it first appears. Rainfall declines rapidly with distance from the west coast and, in some soil types, secondary salinization begins to occur in cleared areas once rainfall drops below ca 900 mm (Schofield *et al*. 1988). The Kent catchment, for example, has been the focus of much salinity research and the headwaters of the Frankland contain one of WA's first Biodiversity Recovery Catchments funded under the State Salinity Strategy (Lake Muir - Anon 1996). Results of the AusRivAS assessments are in general agreement with descriptions of the rivers given by Olsen & Skitmore (1991) and Pen (1997). The one anomalous assessment was the Blackwood. While its downstream portion is probably corrected assessed as B_C, its Wheatbelt component should be rated substantially lower for the reasons discussed in the *Wheatbelt* section above.

Condition of rivers in the South-west Forest appears to be primarily a product of the amount of cleared agricultural land and the number of people in the catchment. Whether forests are being used for timber production or are in National Parks and Nature Reserves is of secondary importance in terms of river health at the catchment scale, although impacts of logging activities were occasionally detected. For example, a Donnelly first order stream located in the burnt buffer beside a recently clear-felled coupe, from which the regeneration fire escaped (DON11), was clearly impacted with an *O/E* of 0.58 (Band B). A site in a larger Warren stream below clear-felling, beside a logging road and with large amounts of sediment in the streambed had an *O/E* of 0.69 (Band B).

Although there have been few classically replicated species-level studies of the impacts of logging in WA and we have not fully analysed AusRivAS data with respect to logging, both appear to have similar capacity to detect impacts of logging operations. Changes are found in macroinvertebrate community structure when prescriptions are not followed (significant damage to buffers etc) (Growns & Davis 1991) but there appears to be little damage if buffers remain intact. Despite significantly elevated levels of suspended sediment during spates in the system they studied, Growns & Davis (1994) provided little statistically significant evidence of biological change where a buffer was in place along most of the logged area, which is the standard logging prescription. In a similar study, Trayler & Davis (1998) also found little evidence of impact on macroinvertebrates within the stream itself but found highly significant changes among the fauna deeper in the stream-bed. The physico-chemical causes of these changes remain unclear.

We dwell on the impact of logging and appropriate methods of detecting logging impact because of its political importance; as already mentioned, the evidence suggests it constitutes a relatively minor disturbance in the South-west Forest region. There have been suggestions that AusRivAS is an unsuitable tool for evaluating logging impacts and that species-level assessments are more appropriate (eg Edward *et al*. 2000). Some support for this view is provided by Hawkins *et al*. (2000), who found AusRivAS-type models detected logging disturbance in Californian streams only if species-level data were used. However, subsequently Bailey *et al*. (2001) suggested that family-level AusRivAS-type biomonitoring often detects impact more efficiently than species-level studies, especially when the fauna is depauperate, as is the case in WA streams, and results to date appear to suggest the power of AusRivAS to detect impact is similar to that of existing WA species-level studies.

Swan Coastal Plain

All river basins on the Swan Coastal Plain are C_C condition (Fig 8, Table 10). These basins extend beyond the coastal plain itself and, as in rivers of the South-west Forest, their condition is influenced by activities outside the zone. Nonetheless, extensive clearing and urbanisation on the coastal plain resulted in this region having the highest concentration of sites assessed as disturbed of anywhere in WA (Appendix 2).

The poor ecological condition of rivers and wetlands on the coastal plain is widely recognised (Balla 1994, Pen 1997, WRC 1999) and, overall, AusRivAS results are in agreement with previous work. The major problems are land clearing and loss of riparian zones, leaching of fertiliser and effluent from sandy non-binding soils into rivers, and direct discharge of contaminants via drains. De-snagging and river training, dams in the Darling Scarp east of the coastal plain, invasion of weed species, and the host of issues associated with urbanisation and high concentrations of people have caused further disturbance.

State-wide overview of river condition

Detailed results and interpretation of the FNARH in WA have been provided in Table 10, Fig 8, Appendix 2 and the above regional accounts. As already stated, we are aware that some inconsistencies exist between assessments in different regions because of seasonal conditions at the time of sampling, unrepresentative distribution of SOE sites on which the assessment was based, and inadequacies of current models. We have attempted to correct some of these inconsistencies in Fig 9, which provides what we believe to be a more accurate picture of basin condition in WA than that provided by Fig 8. Justification for the differences between Figs 8 & 9 is provided in the accounts for individual regions.

Factors causing disturbance

Factors impacting on river health in WA are difficult to disentangle because a variety of potentially impacting land-uses and processes are present at most sites. For example, if stock are present, they may cause erosion and increase nutrient levels, as well as creating pugging and removing understorey species from the riparian zone. In the assessment of physical habitat condition at WA sites, the two (if any) catchment activities or processes most likely to be responsible for any degradation were recorded. In some cases, additional catchment activities causing degradation were obvious but un-recorded.

Table 11. Effect of different catchment activities on river health, as judged by *O/E* scores (mean±SE, *N* given below)

	Erosion[1]	**Nutrients**[2]	**Stock**[3]	**Dams**[4]	**Channel**[5]	**Riparian**[6]	**Salinity**[7]	**Fire**[8]	**People**[9]	**No impact**
Autumn	0.83±0.03	0.66±0.07	0.75±0.03	0.78±0.07	0.84±0.05	0.86±0.11	0.82±0.19	0.86±0.05	0.94±0.03	0.95±0.02
	44	17	100	14	7	6	4	4	33	79
Spring	0.87±0.02	0.83±0.04	0.90±0.01	0.91±0.05	0.83±0.04	0.83±0.04	0.83±0.02	0.88±0.05	0.92±0.03	0.93±0.01
	140	31	99	21	28	57	76	11	42	169

[1]Erosion, sedimentation and roading; [2]Nutrients and organic load; [3]Stock; [4]River regulation, de-watering, abstraction, impoundment; [5]Channel modification
[6]Riparian vegetation cleared; [7]Secondary salinization; [8]Fire; [9]Recreation pressure

Table 12. Key physico-chemical parameters associated with erosion, sedimentation and roading, with nutrients and organic load, and with secondary salinization compared with values at no-impact sites (mean±SE, *N* given below)

	Turbidity NTU		**Total N mg/L**		**Total P mg/L**		**Electrical conductivity µS/cm**	
	Erosion[1]	No impact	Nutrients[2]	No impact	Nutrients[2]	No impact	Salinity[3]	No impact
Autumn	125±71	12±7	2.22±0.59	0.45±0.05	0.14±0.05	0.03±0.01	22938±13040	712±187
	44	79	17	79	17	79	4	79
Spring	34±22	6±1	2.40±0.91	0.67±0.05	0.57±0.33	0.03±0.01	15576±1122	2015±263
	140	156	31	155	31	155	75	156

[1]Erosion, sedimentation and roading; [2]Nutrients and organic load; [3]Secondary salinization

In a first analysis to quantify the level of impact caused by various catchment activities, *O/E*s of sites associated with various activities and processes were compared. To simplify the analysis and increase sample sizes, similar activities were combined (Table 11) and compared with sites where no impacts were recorded. Recreation (usually organised parking, cleared areas with picnic tables etc) was the only activity not associated with significantly lowered *O/E* scores. In most cases, impacts were more strongly expressed in autumn than spring. Autumn is the period of little flow and low water levels in the south-west and, in the particular dataset analysed here, it was also a period of drought in the Murchison-Gascoyne and parts of the Pilbara. Thus, impacts were greater during the 'dry' season than the 'wet'. This is unsurprising because strong flows usually flush accumulated nutrients and sediment and reduce salinity levels. Furthermore, wet weather is associated with less use of watercourses by stock and a greater likelihood of herb and grass cover along riverbanks.

The lower *O/E*s at sites with putative impacts were accompanied by significant changes in physico-chemical parameters when there was an obvious parameter to examine (Table 12). Sites where erosion, sedimentation and road crossings were recorded as an activity had higher turbidity than non-impact sites, and sites where nutrients and organic load were recorded showed elevated nutrient levels. Sites where secondary salinity was recorded were significantly more saline than non-impact sites (naturally saline sites excluded). There were no obvious physico-chemical measurements to relate to the other catchment activities and so, rather than trawl for significant relationships, no further analysis was attempted.

The above analyses are exploratory in nature but they probably provide a conservative assessment of the potential impact of various catchment activities because typical levels of the activities were examined rather than extreme examples. While it is sometimes difficult to disentangle the effect of co-occurring activities (eg stock, erosion and nutrient enrichment), it may not be important to do so unless management responses are able to differentiate between them. The analyses are a useful guide to the relative importance of some causes of degradation in WA rivers. In combination with the more detailed work done in Victoria, associating AusRivAS scores with particular water quality parameters (Marchant *et al*. 1997), the work reported in Table 11 shows that AusRivAS has the potential to measure the ecological effect of a wide range of catchment activities and processes and can be used to increase understanding of river ecology, as well as to monitor river health.

Foreshore assessment

Other than the MRHI/FNARH, there has been no broadscale, ground-based assessment of river condition in WA. WRC (1997) attempted to assess river condition remotely in northern WA and the results, while not vastly different from the AusRivAS assessments, were not well received in some quarters. It is possible that the lack of on-ground contact with landholders during the assessment contributed to the poor reception.

More recently in the south-west, Pen & Scott (1999) devised a simple, ground-based method of assessing foreshore condition. Published results of its use have been limited, so far, to the Perth environs on the Swan

Table 13. Comparison of AusRivAS band scores and the foreshore assessments, based on the protocol of Pen & Scott (1999), at eight sites in the Wheatbelt, including comments on habitat recorded in AusRivAS assessment

River	Site	AusRivAS	Comments	Foreshore
Toodjay Brk[1]	AVO07	A	Sparse trees, no understorey	Poor
Chapman R[2]	GRE05	A	Sandy channel in cleared land	Good
	GRE17	A	Riparian trees, no understorey	Poor
Greenough R[3]	GRE04	B	Wide channel with backwaters	Good
	GRE20	C	Surrounded by samphire and bare land	Moderate
	GRE21	B	Riparian trees, *Baumea* on banks	Good
	GRE22	A	Recreation site, sedges on shoreline	Moderate
	GRE23	B	Dense riparian trees, no understorey	Moderate

[1] WRC (2001a), [2] WRC (2001b), [3] WRC (2001c)

Coastal Plain and to three Wheatbelt rivers. Eight Wheatbelt sites have been assessed by both AusRivAS models and the protocol of Pen & Scott (1999) (Table 13). There was poor agreement between the two methods. One explanation is differences in scale: the foreshore work assessed condition over larger units than AusRivAS and averaged the results. A more likely explanation, however, is that AusRivAS *O/E*s and foreshore assessment were measuring different attributes of a river. Foreshore assessment is focussed on riparian condition and channel morphology, making it similar to the Habitat Assessment Score in AusRivAS, which was also poorly related to *O/E* scores (see ***Comparison between macroinvertebrate and habitat assessments*** below). We believe *O/E* scores are a better indicator of in-stream condition and foreshore assessments provide a better measure of riparian condition.

Temporal variability

The change in live-picking protocols between the MRHI and FNARH make it difficult to assess the extent of annual variability in *O/E* scores. Humphrey *et al*. (2000) pointed out that episodically flowing rivers with variable discharge patterns are likely to exhibit changes in community structure between years. They suggested that rivers of the Pilbara and Sandy Desert, in particular, are likely to show variability in *O/E* scores between years as a result of natural fluctuation in community structure. We do not have sufficient data to assess whether this presents problems for AusRivAS-based site assessment. The dataset from the Robe River (Davies 1996), on which the analysis of Humphrey *et al*. (2000) was based, showed substantial differences in community structure after cyclonic floods. More recent sampling of Nyeetberry Pool on the Robe did not show the same level of turnover. For example, 17 families were recorded in channel habitat in spring 1995 and 13 of them were recorded again during channel sampling (for a different purpose) in 2001, despite massive cyclonic flooding in 1997 and in early 2001 that changed the nature of the stream and resulted in strong flow in 2001, whereas flow was restricted to local spring discharge in 1995.

There is no doubt, however, that drought affects *O/E* scores and that models based on sampling during drought years are likely to be insensitive (see Humphrey *et al*. 2000). If river condition is assessed during a drought period (eg Murchison-Gascoyne during 1998 in WA), the existence of drought is easily recognized from rainfall records and AusRivAS outputs can be interpreted accordingly or assessment delayed. Coping with stochastic annual variation that has no obvious cause provides a greater challenge for assessment protocols.

Humphrey *et al*. (2000) showed the river communities in south-west WA to be relatively stable and suggested annual variability was unlikely to prevent AusRivAS models working. We regard this as correct if the user has extensive experience of AusRivAS and understands the ecology of rivers of the south-west but once-off assessment of sites will result in some errors. Of 34 sites in the south-west that were assessed twice in spring between 1999 and 2001, band scores changed at 12 of them, although in one case this reflected a change in *O/E* of only 0.04. At two sites, the assessment changed by two bands (A to C). The average change in *O/E* was 0.15, reflecting 21 % fewer families present in one sample. Interestingly, the reduction in species richness of 24 % at Nyeetberry Pool on the Robe River was similar to the changes observed in the south-west.

At least some of the inter-annual 'changes' observed in the above pair-wise comparisons are sampling error rather than true changes in community structure at the site (see Smith *et al*. 1999). But whatever the cause of differences in AusRivAS outputs between years, it reinforces that individual site assessments are subject to error, especially when fine-scale differences in *O/E* values are being examined.

Comparisons between macroinvertebrate and habitat assessments

From 1998 onwards, the suitability of river habitat for macroinvertebrates was assessed in conjunction with invertebrate sampling. Details are provided in the Western Australian sampling manual. In summary, the extent of catchment disturbance, riparian cover, bank stability, substrate type and in-stream habitat were scored and these values combined into a single Habitat Assessment Score (*HAS*). It is possible to envisage situations in which a site would have a high *HAS* while supporting few macroinvertebrates (pesticides, natural salinity, steep-sided banks making sampling difficult) but, to a large extent, *HAS* represented the factors an expert would use, prior to sampling, to predict the kinds of macroinvertebrates likely to be present. Therefore, significant overall correlations between *HAS* and *O/E*s were anticipated.

There was a significant correlation between *O/E* and *HAS* values in autumn (Fig 10, $P < 0.001$) but little of the variation in individual *O/E* scores was explained by *HAS*. The correlation was even weaker in spring, partly because many sites sampled in spring 1999 were in spate, so that *O/E* scores were low even though the streams would usually provide suitable macroinvertebrate habitat. The stronger correlation in autumn was driven by a fairly strong relationship in autumn 1998 between *HAS* and *O/E* as a result of drought, and associated watering of stock, in the Murchison-Gascoyne and southern Pilbara bringing *HAS* and *O/E*s closer together.

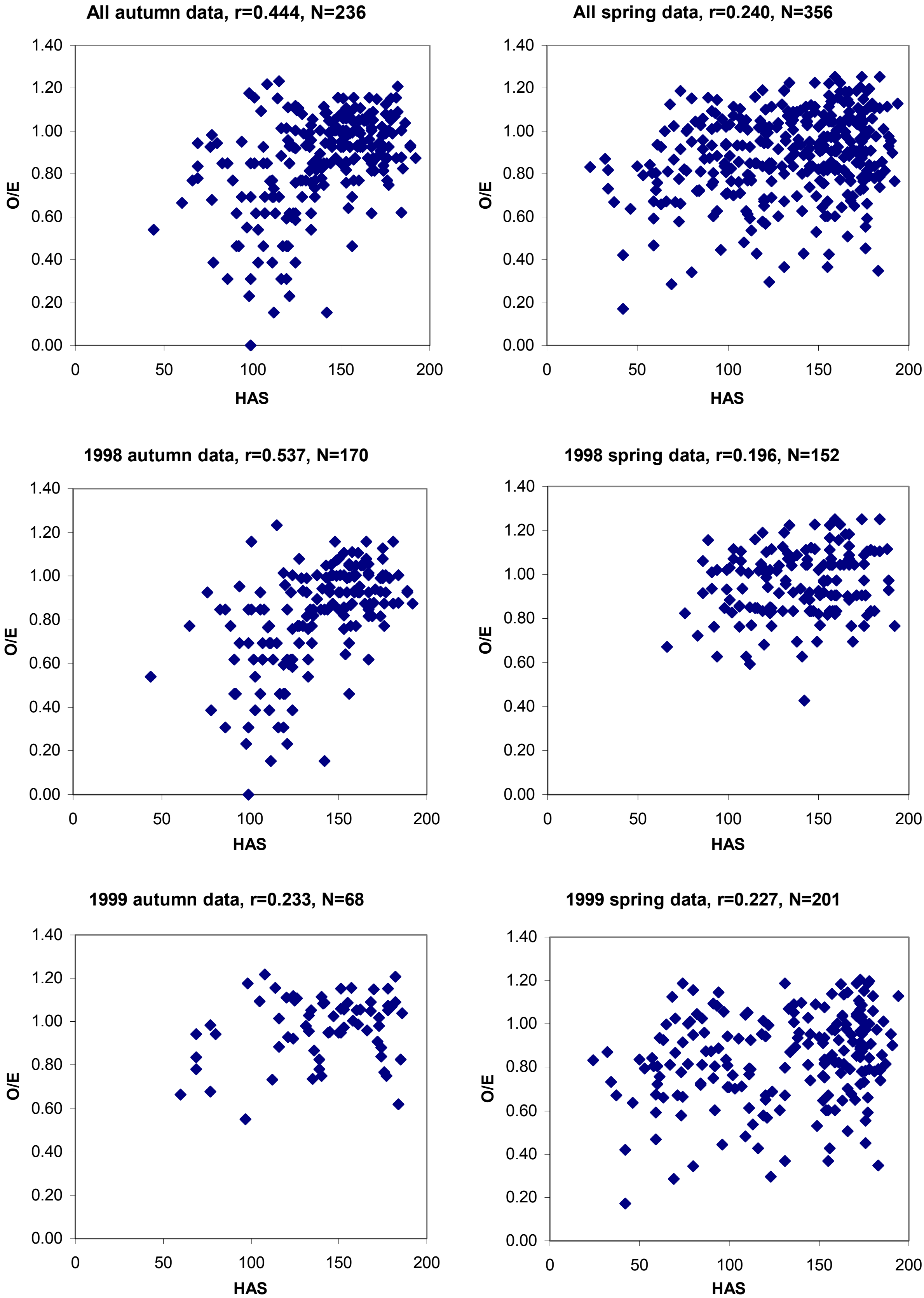

Figure 10. Relationship between Habitat Assessment Scores (*HAS*) and *O/E*s

5 Technology transfer, communication and AusRivAS adoption

Considerable effort has been made in WA to produce satisfactory models and devise sampling protocols that will provide reliable assessments of river condition within the State. Staff have given priority to this task and to conducting a state-wide assessment of river condition. Other activities suffered in consequence, although it was certainly recognised that technology transfer, to increase the number of people who understand the outputs of AusRivAS and build up the capacity to undertake assessments, was vital to the long-term future of the program. There is currently too little appreciation among managers of what AusRivAS can provide and there are also few people in WA with the technical capacity to undertake reliable assessments. The latter problem should be overcome fairly easily, however, once management support is achieved. It is also worth emphasizing that only now satisfactory models have been produced, and the results of the FNARH are available in the analysed form, does an appropriate product exist for technology transfer. The Marbelup Brook study (see *Examples of adoption* below) has been particularly useful because it demonstrated the advantages of AusRivAS in terms of cost and ease of interpretation.

One of the many obstacles to adoption of AusRivAS is the considerable number of scientists, especially in universities, who are antagonistic to the program (this phenomenon is not restricted to WA). One reason is that they feel that the AusRivAS program has taken macroinvertebrate research money out of the university system and into agencies. A second is the intuitive (and misplaced) belief that species-level assessments must be better than family-level. The paper by Edward *et al*. (2000) presents some rational support for this view but the analysis was based on an early version of the AusRivAS models and conclusions are unlikely to apply to current models. A third objection is that AusRivAS assessments miss too much biodiversity. This objection overlooks the point that AusRivAS is primarily concerned with the assessment of ecological condition rather than biodiversity. The strong relationship between family and species richness (eg Nielsen *et al*. 1998) means, however, that AusRivAS can provide useful first-cut information on the biodiversity value of a site. Nevertheless, the current perceptions and mis-conceptions about AusRivAS and affecting adoption and technology transfer at a national, as well as State, level will need to deal with them. Efforts to achieve technology transfer and AusRivAS adoption in WA are reported in the following three sections:

Workshops, field days and talks

In addition to attending the five national workshops on the MRHI/FNARH, WA staff organised a series of workshops, field days and talks during the MRHI/FNARH to provide information about the program and begin technology transfer. These include:

- June 1994 - workshop to introduce the MRHI to State Government agencies. Attended by Dr Nick Schofield, Dr Davies and about 10 agency staff
- March 1995 - workshop to inform agencies and community groups about the MRHI. Attended by Dr Roger Sweeting (National River Authority, UK), Dr Davies and about 50 others
- August 1996 - workshop on presenting outputs of AusRivAS. Attended by Prof Barry Hart, Dr Leon Barmuta, Dr Bruce Chessman and about 50 others
- November 1996 - demonstration of AusRivAS sampling in the Leschenault catchment for the Catchment Co-ordinating Group. Attended by 15 community members

- August 1998 - 2 day training course in AusRivAS methodology and macroinvertebrate identification for the Bunbury staff of WRC. Attended by 10 staff
- October 1998 - demonstration of AusRivAS techniques at Ribbons of Blue/Waterwatch field day
- May 1999 - seminar on AusRivAS at CALM-organised half-day seminar on aquatic invertebrate conservation in WA. Attended by 45 people
- June 1999 - talks on AusRivAS in WA at meetings of the Inland Aquatic Group and WA Insect Study Group
- November 1999 and 2000 - demonstration of AusRivAS techniques and assistance with assessments of Dirk Brook for WRC and Serpentine Catchment Group
- February 2001 - 2 day training course on AusRivAS and river assessment as part of a river management unit at the University of WA. Attended by about 30 people
- March 2001 - workshop to help WRC formulate its position on AusRivAS. Attended by Bruce Gray, Dr Davies and about 10 agency staff
- April 2001 - seminar on AusRivAS at Edith Cowan university. Attended by 40 people

Publications

Staff involved in the WA project have been prolific publishers of both popular and scientific material about AusRivAS, with nine articles already published on the project, or on material collected as part of the project, and further papers are planned. A chronological list of papers is provided below:

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WA staff have also contributed to more general articles about the MRHI/FNARH written by Dr Davies, Dr Schofield and others and additional papers have been published by taxonomists based on material collected during the project (see section on **Biodiversity information in the MRHI/FNARH data** for examples).

Agency action

For the first four years of the MRHI/FNARH, the program reported to a steering group (State Surface Water Control Committee) and staff sent out periodic letters to a list of government departments and community groups. As a result of this communication and workshops, seminars and field days, the profile of AusRivAS is high in WA. However, adoption appears to be proceeding slowly. Uptake of biomonitoring programs elsewhere appears to have been most successful when the agency funding development of bioassessment methods has then been responsible for, or funded, their use. A legislative requirement for biomonitoring or assessment of river condition is also crucial and attitudes within agencies are important (see Resh *et al.* 1995). In WA, there is no State legislation explicitly requiring biomonitoring and, by consensus among agencies, AusRivAS development was undertaken by the agency with biological expertise rather than with responsibility for river management. Funding was provided by the Commonwealth and CALM rather than by the river management agency. However, the future of the program lies with WRC, which undertook a review of AusRivAS in the first half of 2001 with the aim of evaluating the program and determining the level of agency support for it. The workshop attended by Dr Davies and Mr Gray was part of this process but there has been no public outcome of the review as yet. As AusRivAS moves from an R&D phase into more routine application of the protocols, involvement of CALM's Science Division will be increasingly difficult to justify, particularly in terms of financial support.

Reduced budgets across government agencies in WA are making it difficult to fund new initiatives such as widespread use of AusRivAS. However, agencies are already making use of the existing AusRivAS data for management purposes and recognise that AusRivAS provides a suitable tool for many activities required of them, such as State of the Environment reporting and compliance monitoring. At present, the only agency with sufficient expertise to carry out AusRivAS assessments is CALM. Agencies and community groups could contract out assessments to universities or private consulting firms but that raises the issue of accreditation. At present, no accreditation process is in place for AusRivAS, although it was discussed at a national workshop in November 2000.

Examples of adoption

Collie River

An inter-agency committee, chaired by WRC, commissioned the Collie study in spring 1998 and autumn 1999. The aim was to assess ecological condition of pools on the Collie River that were being supplemented in summer with groundwater from an adjacent area with a history of coal mining below the water table. As a result, the groundwater was acidic. AusRivAS showed that the fauna of the river were deleteriously affected for a short distance downstream of supplementation (Kay *et al*. 2000).

Dirk Brook

WRC staff undertook AusRivAS sampling in drains associated with Dirk Brook in spring 1999 and 2000 as part of a program to develop an index of condition of drains, so that compliance with water quality and biodiversity objectives can be assessed (van Looij & Donohue in prep). CALM trained staff in AusRivAS protocols, assisted with fieldwork and carried out the macroinvertebrate identifications.

Marbelup Brook

The Water Corporation commissioned a study of water quality, based on AusRivAS sampling plus some additional chemical analyses of sediments and animal tissue, in Marbelup Brook (Halse *et al*. 2001). The Brook is being evaluated as future water supply for Albany. Six sites on the Brook were sampled using a box sub-sampler, instead of the standard AusRivAS protocol, and macroinvertebrates were identified to species-level. *O/E* scores reflected a range of site conditions and agreed well with visual assessments and information on surrounding land use (Fig 11). *O/E*s appeared to provide a more reliable measure of condition than chemical monitoring and some of the species-based metrics commonly used for assessment (Table 14).

Macro-mapper

Dr Kerry Trayler and Ross Carew of WRC have used AusRivAS data from 1994-98 in a GIS format to produce a CD that provides information on the distribution of macroinvertebrate families in WA and the physico-chemical characteristics of rivers. This CD is aimed principally at Waterwatch and Rivercare officers and community groups, although it probably has wider application. It can be queried to provide lists of macroinvertebrate orders and families (including common names) recorded within the local catchment and can be searched against a range of parameters, including location, taxa, habitat type, and physical and chemical conditions. The CD has not yet been released.

Environmental flows

WRC is currently using the WA AusRivAS dataset to help derive interim environmental flow criteria for use in rivers throughout Western Australia and a copy has been made available to their environmental flow consultants. The AusRivAS dataset is the only comprehensive dataset containing biological information on rivers (although a lot of information is available for fish) and, in fact, is the most spatially comprehensive dataset for water chemistry. The first use of the dataset to help determine environmental water requirements was in the recent scientific panel report for the Ord River (WRC 2000). AusRivAS data show that releases from Lake Argyle have reduced seasonality in the macroinvertebrate community of the lower Ord, as a result of the more constant flow regime.

Table 14. Assessment of site condition in Marbelup Brook using a sub-sampler. *O/E* scores, family and species richness, and richness of Ephemeroptera, Plecoptera and Trichoptera are compared

	Richness		**EPT**		***O/E***		**Location**
	Species	**Family**	**Species**	**Family**	**Score**	**Band**	
MAR01	14	10	1	1	0.66	B	Cleared paddock
MAR05	23	15	7	4	1.03	A	Farm, mostly uncleared
MAR02	32	22	4	4	1.10	A	Nature reserve
MAR03	23	16	7	5	0.62	B	Beside house on farm
DEN19	23	15	1	1	0.64	B	Near weir and town site
MAR04	21	13	3	4	0.68	B	Farm, narrow buffer

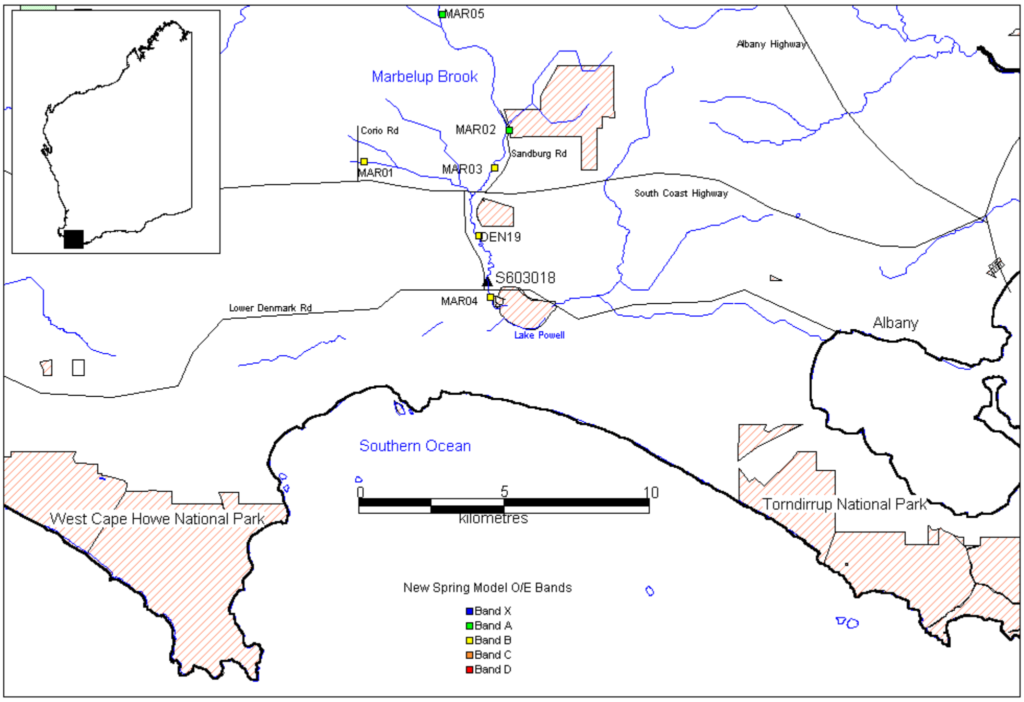

Figure 11. Sites sampled at Marbelup Brook and their band scores

Ord River

As part of the National River Health Program's Environmental Flows sub-program, WRC has sub-contracted Drs Andrew Storey and Peter Davies to undertake ecological work on the Ord River. Part of the project deals with macroinvertebrates and, as far as possible AusRivAS sampling protocols are being used so that family-level data can be put through AusRivAS models whenever appropriate, even though all identifications are taken to species-level. Staff from CALM are verifying all macroinvertebrate identifications for the project.

Murchison LCDC

Several catchment groups have done limited AusRivAS sampling but the validity of assessments remains uncertain. CALM provided AusRivAS scores for sites on the Murchison River to the local Land Care District Committee to support their application for Natural Heritage Trust funding to fence the river and reduce grazing pressure. This use of agency data to support and inform local initiatives seems to be one of the most promising avenues for improved river management.

Cost comparison of AusRivAS and chemical monitoring

The Marbelup Brook study provided an interesting insight into relative costs of AusRivAS and chemical evaluation. The per-site processing costs of AusRivAS and sediment samples (analysed with high resolution for a wide spectrum of heavy metals and pesticides by a government laboratory) are: AusRivAS macroinvertebrates $740, AusRivAS chemistry $85, heavy metals and pesticides in sediments $1295, heavy metals and pesticides in tissues (some elements not worth analysing because of metabolic breakdown) $730. While chemistry costs can be reduced substantially by using less sensitive techniques and omitting difficult-to-analyse pesticides, they are unlikely to be reduced below $1000 per site.

The above analysis includes the cost of both field sorting and laboratory identification of AusRivAS samples but excludes cost of preparation, travel time and mileage associated with collecting either chemical or AusRivAS samples because they are similar for both kinds of assessment and are highly variable between different studies, depending on location and the number of samples being taken. The Marbelup figures are more favourable to invertebrate sampling than those presented by Norris & Georges (1986), who found invertebrate sampling about five times more costly than one-off chemical sampling. Relatively cheap invertebrate costs at Marbelup reflect the low level of replication required by AusRivAS and the high cost of analysis of some new pesticides that were included in the Marbelup budget. The reduced replication required by AusRivAS has the capacity to dramatically change the nature of aquatic monitoring in Australia (see Schofield & Davies 1996).

Another benefit of AusRivAS is ease of interpretation. Because an ecological parameter (invertebrate community structure) is being measured, the connection between an *O/E* score and ecological health is direct. With chemistry, the link is indirect because it must be mediated through macroinvertebrates and other organisms and the implication of particular chemical conditions is often unclear (Maher *et al*. 1999). In the Marbelup study, both drinking water guidelines (NHMRC & ARMCANZ 1996) and the draft Australian environmental water quality guidelines (ANZECC & ARMCANZ 1999) were consulted but provided little useful information about the implications of the chemical contamination observed, particularly without repeated measurements.

6 Liaison with other MRHI/FNARH projects

Within the last 18 months of the FNARH, data have been supplied to Drs Melissa Parsons and Simon Linke for their respective R&D projects on habitat assessment and new mathematical methods of modelling. The

WA project has supplied samples to AWT for checking of sample residues and liaised, and supplied information, to enable them to assess the quality of WA environmental data.

Previously, WA supplied invertebrate samples for the external checking of identifications (Hawking & O'Connor 1997), sample residues for an evaluation of live-picking and laboratory processing (Humphrey *et al*. 2000), and participated in a program to evaluate the effects of collecting different -sized macroinvertebrate samples (Metzeling & Miller 2001).

WA staff have attended all four national workshops on the MRHI/FNARH, as well as a fifth workshop on training and accreditation. WA also supplied data to the recent Land and Water Audit to enable an assessment of the condition of catchments throughout Australia.

7 Potential uses of AusRivAS outputs at State and Local Government and community level

The principal users of AusRivAS outputs at State level are likely to be WRC/DEP and EPA. WRC will identify possible uses of AusRivAS by State Government in their review of the program (see section of ***Agency action***) but outputs have obvious application in (a) State of the Rivers and State of the Environment reporting, (b) evaluation of the effects of land and water management programs, such as the State Salinity Strategy, Forest Management Plan and activities of the major catchment authorities / Natural Resource Management groups, (c) evaluation of specific sections of river in response to concerns about river condition or as part of environmental impact assessment, and (d) monitoring condition of high-value sites. The use of AusRivAS for compliance monitoring is also possible and has been explored in South Australia, New South Wales and Victoria.

Potential Local Government uses are similar to those of State Government, albeit it at different scale. Local Government will probably rely on consultants to undertake the work, however, or will use data provided by State Government. Application of AusRivAS by Local Government probably fits between that of Sate Government and the community and, depending on institutional arrangements, the group initiating work may vary between regions. The main potential uses by the community relate to evaluation and monitoring, undertaken at a variety of scales depending on the size on the community organisation involved. The community is probably the user with greatest interest in site-specific monitoring and is also interested in finer-scale evaluation than State Government can afford. At present, very few if any community organisations have the capacity to undertake AusRivAS evaluations themselves and consultants would be required. To some extent, this may frustrate the aims of the community organisations and perhaps there is a need to examine more closely the respective roles of State Government, Local Government and the community in river management and determine realistic areas of responsibility for each.

AusRivAS outputs are yet to be incorporated into policy instruments and legislative frameworks by the State Government in WA. WRC, EPA and DEP are the agencies with the relevant responsibilities.

8 Evaluation of AusRivAS in Western Australia

Performance of models

Overall, the revised AusRivAS spring and autumn models appear to provide sensitive and reliable assessments of river condition. Figs 8 & 9 provide the first State-wide assessment of river basin condition in WA and provide a basis for assigning regional priorities in river management. However, AusRivAS models would benefit from further development to improve assessments in some river types. RIVPACS models in the UK have evolved over a 20 year period, with feedback from periodic broadscale assessments being used to direct model improvement (Wright 2000). Assessments of naturally saline sites and short coastal streams would be improved by additional reference site sampling in these stream types. Results from the Wheatbelt appear to under-estimate the level of degradation in the region because there are no undisturbed sites to provide a true baseline for modelling. This is a shortcoming of any reference-type approach in situations where impacts, such as secondary salinity, occur throughout the region of interest. Difficulties are further compounded in WA because the fauna is relatively salt-tolerant and it is difficult to assess the magnitude of the errors in assessment in the Wheatbelt *a priori* and adjust for them. However, there is a need for further development of AusRivAS models in the Wheatbelt.

The combined-season model gave less satisfactory results than the other two models and we recommend that separate spring and autumn assessments should be made instead of using the combined-season model, if both autumn and spring data are available. Over time, it may be possible to sample more reference sites in autumn with 60 mins live-pick and that will enable improved combined-season models to be developed.

Technology transfer

Attempts to sell AusRivAS during the program met with limited success, although it was probably unrealistic to expect managers to embrace the potential benefits of AusRivAS before reliable models had been produced. Some of the early attempts at technology transfer, in the absence of convincing results, may even have been counter-productive. The program is now in a position to demonstrate its value but there is some doubt about whether this will occur. With the cessation of Commonwealth funding, CALM will cease to support and promote AusRivAS without WRC having committed to it.

Suitable models and sampling protocols for WA now exist and all necessary material for training is available on the AusRivAS website or in papers and reports by project staff. The current lack of technical capacity outside CALM to undertake AusRivAS assessments can be easily rectified if the program is funded. There will be a need, however, for training courses if AusRivAS is to be widely adopted by agencies and, especially, if the wider community is to be involved.

Adoption

Historically, WRC has undertaken no animal-based biomonitoring itself and has funded relatively little external work in streams and rivers. The extensive research in the jarrah forest in the 1980s was exceptional (eg Storey *et al*. 1990, 1991). This has changed somewhat in recent years, with WRC having undertaken AusRivAS sampling at Dirk Brook and having commissioned CALM and others to do AusRivAS work on the Collie and Ord Rivers. It has paid CALM to train staff from its Bunbury office, where a considerable amount of aquatic monitoring is done, in AusRivAS protocols. Other agencies and regional landcare groups are also growing increasingly interested in undertaking AusRivAS work or using the results.

Nevertheless, significant utilisation of AusRivAS in WA is currently restricted to the FNARH and Commonwealth use of those results. There appears to slower adoption of AusRivAS in WA than in South Australia, Victoria and New South Wales, where the program is run by environmental protection agencies that have State of the Environment responsibilities and the need to assess discharge sites in rivers for compliance with environmental conditions. The Department of Environmental Protection (DEP) in WA has had little involvement with the program but its recent merger with WRC means that the two kinds of agencies that have run the MRHI/FNARH in different States and Territories of Australia are now a single agency in WA. (The merger of WRC and most of DEP was announced on 1 July 2001 but is still taking placing in operational terms and the legislation to support a single agency is yet to be passed by Parliament). The new agency has responsibility for both river management and monitoring the environmental condition of rivers, although it does not have responsibility for aquatic biota.

It is difficult to envisage AusRivAS continuing successfully through *ad hoc* use by consultants and a few students without a sponsoring agency.

Website maintenance

Debate is yet to be resolved about where AusRivAS models should reside and how costs associated with maintaining them should be met in the future. By default, they are on the website of the CRC for Freshwater Ecology, University of Canberra (http://ausrivas.canberra.edu.au). The WA sampling manual, and other information on the AusRivAS program and protocols, also resides there. Sources of funding for the long-term maintenance of the website need to be identified (this issue has already been raised by A/Prof Richard Norris of the CRC).

While WA agencies are happy for the models to be on the CRC website, access to the models is currently a logistically complicated process and needs to be simplified. The issues are:

(1) the CRC wants to charge users a fee and so needs to control access via passwords
(2) States have generally wanted to control access to ensure that users are familiar with basic AusRivAS sampling requirements before using models so that results are sound
(3) potential users are directed to a nominated State representative to obtain passwords but passwords are handed out by the CRC.

While it is logical that potential users obtain State permission for access to AusRivAS models and then approach the CRC for a password, implementation is cumbersome. The system has been set up for the State representative to forward the request directly to the CRC but this prevents the user and CRC discussing fees. In the current state of uncertainty about website funding, it is difficult for the State representatives to provide appropriate information about fees and the way a user-pays password will work. The solution to facilitating access to models, while attempting to control the quality of input data and charge users a fee, is not straightforward and needs further consideration by all Sates and Territories and the Commonwealth.

Additional R&D

Improved AusRivAS assessments can be achieved with increasing operator experience because errors associated with sampling during spates and in steep-sided reaches etc are minimised. However, the development of river assessment methods is an iterative process and continuing R&D is essential (eg Wright 2000). There are four areas or topics where further R&D in WA would be rewarding:

(1) additional reference sites. There are currently too few reference sites in naturally saline streams of the South Coast and in short coastal streams of the south-west for AusRivAS models to recognize these streams as distinct types. Assessments would be more reliable if they were recognized stream-types

(2) autumn model. The lack of autumn sampling in much of the south-west during the FNARH means that the current autumn model is sub-optimal, being partly based on 30 mins live-pick data. Additional autumn sampling of reference sites with 60 mins live-pick would enable the model to be revised and improved

(3) box sampler. Construction of models based on field sub-sampling with a box sampler are likely to result in further improvement to the sensitivity and reliability of AusRivAS

(4) assessment errors. It is clear from work already done that one-off assessments of a site with AusRivAS will sometimes result in incorrect assessment of river condition. We have pointed out some of the deterministic factors likely to result in predictable error but stochastic errors are also likely to be significant. Further R&D to quantify the frequency and likely magnitude of such errors is desirable.

9 Major achievements

AusRivAS has been a large and successful program in WA that has achieved both R&D and environmental audit aims, as well as producing many spin-offs in terms of biological inventory and improved understanding of the ecology of WA rivers. It has also provided a considerable amount of educational material on rivers, their biota and the need to conserve them. The major achievements have been:

(1) constructing and validating models for assessment of the ecological health of WA rivers. Six models are available on the AusRivAS website for assessing river condition in WA, although we recommend use of only the spring and autumn channel models. Validation suggests both the spring and autumn models provide reliable assessments of river health in most regions, unless conditions are unusual at the time of sampling. A revised protocol, using a box sub-sampler to produce more sensitive assessment of river condition among impacted sites, is available on the website

(2) conducting the first WA-wide assessment of river health. River condition was assessed at 685 sites throughout the State. All major rivers were sampled and average river condition of all AWRC basins was determined, providing a framework for decisions about regional and local priorities for catchment management and river restoration

(3) demonstrating the response of macroinvertebrates to various catchment activities and associated changes in physico-chemical conditions in rivers. AusRivAS scores were significantly lower at sites where impacting processes were observed in the catchment at the time of sampling than elsewhere. Estimates of the magnitude of impact associated with various anthropogenic activities provide a better basis for river and catchment planning

(4) undertaking the first inventory of aquatic invertebrate biodiversity in WA rivers. A by-product of the spatially comprehensive sampling of rivers that occurred in the AusRivAS program was that large numbers of macroinvertebrate samples, all collected with similar methodology, were accumulated. This has already lead to biogeographic, ecological and taxonomic studies that have provided new insights into the distribution and ecology of aquatic invertebrates in WA, described new species, and resulted in river sites being placed on the WA list of Priority ecological communities

(5) improving capacity to undertake assessment of river condition in WA. While there is still some way to go with adoption of AusRivAS in WA, the program has provided the tools for river assessment and has boosted the amount of information available about rivers, with information transfer to community organisations in the form of Macro-mapper (in development by Dr Kerry Trayler and Ross Carew) and field days. It has also provided a framework for future assessments and has significantly increased the profile of biomonitoring in government agencies and the community.

10 Performance against agreed NHT indicators

The relevant agreed performance indicators in the Partnership Agreement between the Commonwealth and WA are listed below in paraphrased form, accompanied by an assessment of compliance. A summary of contributions (both cash and in-kind) by the Commonwealth and WA Governments are provided in Table 15.

5.1 (a) - determination of priority rivers for action, in consultation with the community. The assessment of river condition throughout WA provided by the FNARH forms the ideal framework for discussion with the community and agencies about priority rivers in WA

5.1 (b) - Number of AusRivAS/FNARH sites and degree of integration of AusRivAS results into management strategies. Altogether 685 sites were sampled under the MRHI/FNARH program and WA met all contracted requirements in terms of sites sampled. There has been insufficient time for widespread integration of AusRivAS results into catchment management strategies, although this has occurred on a small scale (eg management of drains at Dirk Brook, applications by Murchison LCDC to NHT for funding to improve management of the Murchison River)

5.2 (a) - Improvements in key health parameters in priority rivers. This indicator reflects actions beyond the scope of the MRHI/FNARH, although AusRivAS has identified threatening processes and catchment activities.

5.2 (b) - Improvements in the health of rivers measured using the outputs of AusRivAS. Condition of WA rivers is declining. Restoration will require a timescale greater than that of present NHT funding but AusRivAS monitoring, through the FNARH, has put in place the benchmark by which future improvements in river health throughout WA can be measured. Furthermore, AusRivAS techniques provide the most appropriate tool for more detailed assessment of specific restoration projects.

11.2 - Overall level of State resourcing will be provided in agreed form - Audited statements documenting the overall level of State resourcing to the MRHI/FNARH have been provided annually (see Table 15).

11.3 - Progress reports and the final report will be assessed against project objectives and the goals of the contributing programs. All progress reports have been submitted and assessed as satisfactory, except for the Milestone 5 report, which is submitted herein with the Final report. Owing to a discrepancy in numbering of the reports, Milestone report 5 is in fact the fourth report in the FNARH series and has there was no Milestone report 4.

Table 15. Summary of financial support (cash and in-kind) by the Commonwealth and State Governments for the MRHI/FNARH in WA between 1994 and 2001. Significant support by WA after July 2001 has not been included

	Commonwealth	**State**	
	Cash ($)	**Cash ($)**	**†In-kind ($)**
FY93-94	98,482		54,053
FY94-95	225,266	15,000	128,856
FY95-96	289,789	15,000	151,860
FY96-97	162,409		142,042
FY97-98	186,553		255,306
FY98-99	221,299	88,119	207,929
FY99-00	153,950	89,739	207,929
FY00-01	*76,050	61,077	230,165
TOTAL	1,413,798	238,935	1,378,140

† In-kind contributions during 1993-98 included staff salaries and allowances marked as cash contributions in later years
* $22,100 of this amount still outstanding

11 Data report

An electronic version of Data report 5 is attached. It contains data from all sites sampled during the MRHI/FNARH on the templates circulated by EA. Files are in the directory **Data report 5** (reference site raw environmental data5.xls, test site raw environmental data5.xls, reference site output biological data.xls, test site output biological data.xls). A map of all sites sampled is provided in Appendix 4 and the underlying data are provided electronically in the directory **Appendix 4** (allsites.txt).

12 Names and contact details of current staff

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Many people have been involved in the WA program. Much of CALM's share of the MRHI fieldwork was done by Mick Smith and Winston Kay, both of whom also contributed significantly to the organisation of the FNARH. Mick developed the interim AusRivAS models and undertook much of the liaison with community groups and other agencies. Dr Don Edward, Dr Peter Davies and David Cale from the University of Western Australia, A/Prof Pierre Horwitz and Kim Richardson from Edith Cowan University, and A/Prof Jenny Davis and Phil Papas from Murdoch University selected MRHI sites and undertook associated fieldwork and macroinvertebrate identification.

At a national level, Dr Peter Davies provided the framework for the MRHI/FNARH and facilitated much of the development of AusRivAS. Dr Nick Schofield from LWA provided excellent program support during the MRHI and Bruce Gray and Peter Komidar from EA provided strong support during the FNARH. A/Prof Richard Norris, Justen Simpson and Paul Blackman assisted with the development of AusRivAS models.

In WA, many WRC staff have assisted the AusRivAS program. In particular, Jeff Kite provided substantial support during the MRHI and early FNARH. John Ruprecht, Verity Klemm, Dr Jane Latchford and Rob Donohue have provided subsequent support and liaised with CALM about the work to be undertaken and future directions for AusRivAS.

We also thank Bruce Gray from EA and Beth Hughes, Dr Kerry Trayler, Rob Donohue, Naomi Arrowsmith, Susan Worley, Roy Stone and Emma van Looij from WRC for very useful comments on a draft of the report.

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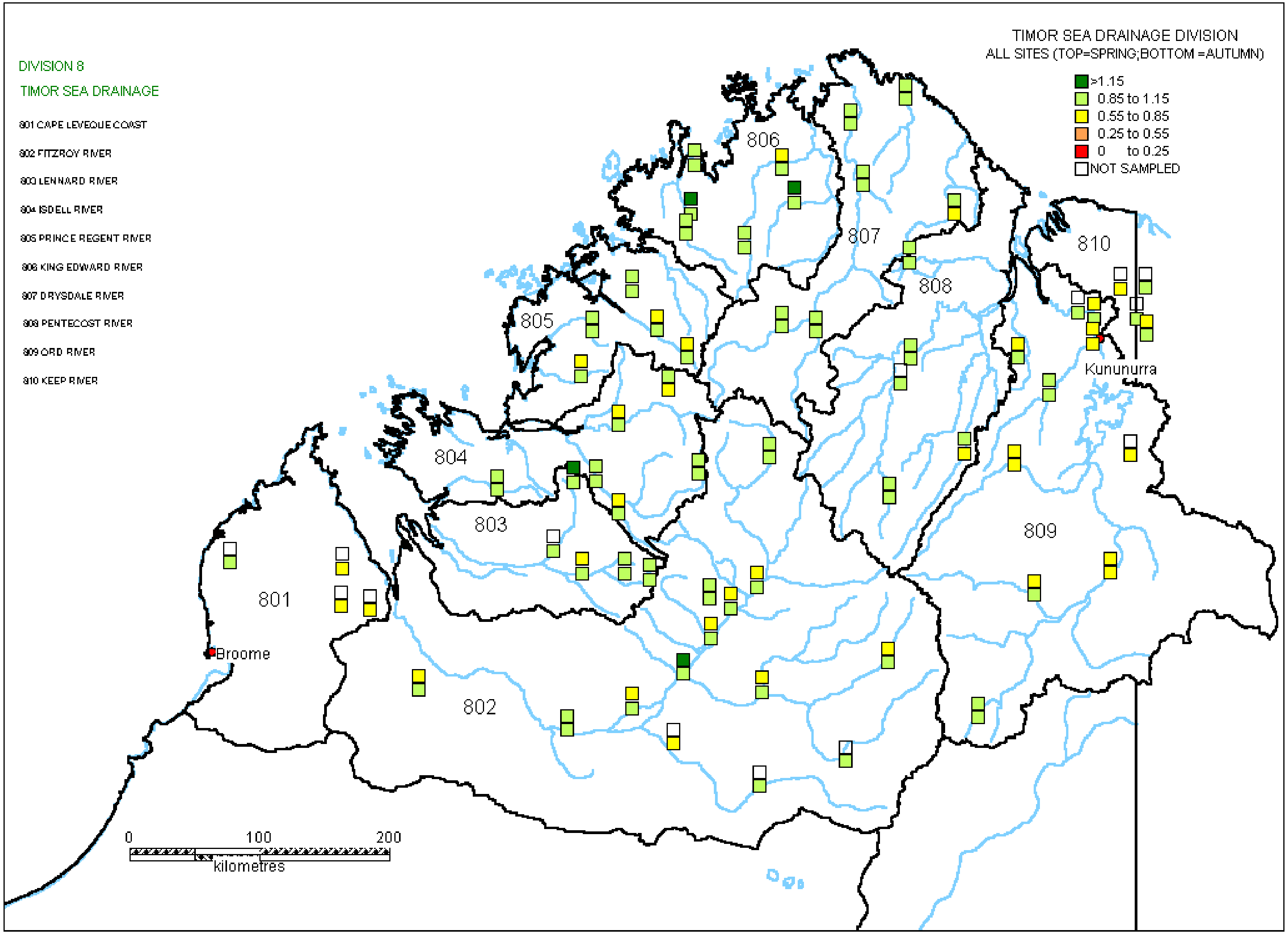
Appendix 1. Comments on condition and disturbance factors at sites with extreme O/E scores

Site	**Signs of disturbance/diagnosis**	***O/E***
	Spring	
FIT03	Ref 3, mild disturbance, biological hotspot	1.25
KER06	Ref 1, pristine biological hotspot	1.25
PHC02	Ref 2, biological hotspot	1.24
GRE06	Ref 2, biological hotspot	1.23
GRE29	Ref 2, slight disturbance, biological hotspot	1.23
HAR14	Ref 3, mild disturbance	1.22
ONS01	Ref 3, mild disturbance	1.22
AVO17	Ref 1, pristine biological hotspot	1.21
ESP08	Ref 3, mild disturbance	1.21
BLA20	Test, moderate disturbance (secondary salinity and nutrients)	1.20
DEN15	Test, urbanisation nearby but no discernable impacts	1.20
GRE20	Test, heavily disturbed (secondary salinity, cleared and modified channel)	0.41
SWA05	Ref 3, difficult to sample	0.41
BLA12	Ref 1, undisturbed site	0.39
SHA13	Ref 1, in spate after very recent rain, impossible to sample	0.37
MRY26	Test, small seasonal stream, long undisturbed	0.35
SWA30	Test, heavily disturbed (industrial area, no riparian vegetation)	0.34
MHR06	Ref 3, sandy substrate, slightly salinized	0.34
SHA14	Test, heavily disturbed (no riparian vegetation, eroded), in spate	0.30
SWA19	Test, urbanised 'drain'	0.29
SWA28	Test, heavily disturbed by urban/industrial impacts	0.17
ESP08	Ref 1, short coastal stream (no appropriate model group)	0.13
	Autumn	
WOO03	Ref 3, high quality site disturbed at time of sampling but is biological hotspot	1.23
BUS09	Ref 3, slight disturbance, riparian clearing	1.22
BLA06	Ref 3, conservation reserve, mild disturbance	1.21
WAR12	Test, brackish, mild disturbance	1.18
WAR01,	Ref 2, good quality habitat, biological hotspot	1.16
ASH04	Ref 2, good quality habitat, some recent adjacent burning, biological hotspot	1.16
ASH07	Test, mild disturbance	1.16
ASH09	Ref 2, good quality habitat, biological hotspot	1.16
SDB04	Ref 1, pristine site, biological hotspot	1.16
DEN19	Test, mild disturbance	1.16
MUR01	Test, salinity, organics, nutrients, at least partly caused by drought	0.46
GAS19	Test, organic load, nutrients	0.46
ONS01	Ref 3, grazing, stagnant water, algal scum, low DO caused by drought	0.46
COL26	Test, acid water, iron deposition	0.45

LMR04	Test, sedimentation, very shallow, drought	0.39
MUR05	Test, salinity caused by drought	0.23
GAS11	Test, salinity caused by drought	0.23
WOO02	Test, re-flooded day before sampling	0.15
SDB02	Test, salinity (natural but unusual in this region hence not well assessed)	0.15
MUR06	Test, very high salinity caused by drought	0.00
	Combined-season	
AVO05	Rnds 3&4, Test, mild-moderate disturbance (weeds, 10-21 ppt salinity)	1.20
BUS18	Rnds 8&9, Test, moderate-heavy disturbance (grass instead of riparian vegetation)	1.19
BLA03	Rnds 1&2, Ref 3, mild disturbance (brackish)	1.18
ESP04	Rnds 3&4, Ref 2, good condition, naturally saline hotspot (17-20 ppt)	1.18
ALB08	Rnds 1&2, Ref 3, mild disturbance, naturally saline (29-48 ppt)	1.18
ALB01	Rnds 3&4, Ref 3, mild disturbance, naturally saline (35-74 ppt)	1.18
WOO03	Rnds 6&7, Ref 3, mild disturbance, biodiversity hotspot	1.18
PEN07	Rnds 6&7, Ref 1, pristine site, biodiversity hotspot	1.18
PEN03	Rnds 3&4, Ref 1, pristine site, biodiversity hotspot	1.18
PEN01	Rnds 3&4, Ref 1, pristine site, biodiversity hotspot	1.18
WAR10	Rnds 1&2, Test, degraded farmland site	0.40
KEN01	Rnds 1&2, Ref 2, steep-sided, difficult to sample	0.40
KEN01	Rnds 3&4, Ref 2, steep-sided, difficult to sample	0.40
ALB18	Rnds 1&2, Ref 1, small coastal stream	0.40
MUR02	Rnds 3&4, Test, camping site, heavy use by sheep, erosion	0.37
SBD02	Rnds 6&7, Test, salinity (natural but unusual in this region hence not well assessed)	0.32
AVO04	Rnds 1&2, Test, secondary salinity (21-26 ppt)	0.28
BLA11	Rnds 3&4, Ref 2, recreation	0.27
WAR10	Rnds 3&4, Test, degraded farmland site	0.27
SWA01	Rnds 3&4, Test, cleared and degraded	0.00

Appendix 2. AusRivAS assessment results for individual sites in WA processed with 60 mins live-picking during the FNARH. Two maps are shown for each region, one showing all FNARH sites, the other showing only State-of-the-Environment sites



DIVISION 8
TIMOR SEA DRAINAGE
801 CAPE LEVEQUE COAST
802 FITZROY RIVER
803 LENNARD RIVER
804 ISDELL RIVER
805 PRINCE REGENT RIVER
806 KING EDWARD RIVER
807 DRYSDALE RIVER
808 PENTECOST RIVER
809 ORD RIVER
810 KEEP RIVER
TIMOR SEA DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM =AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
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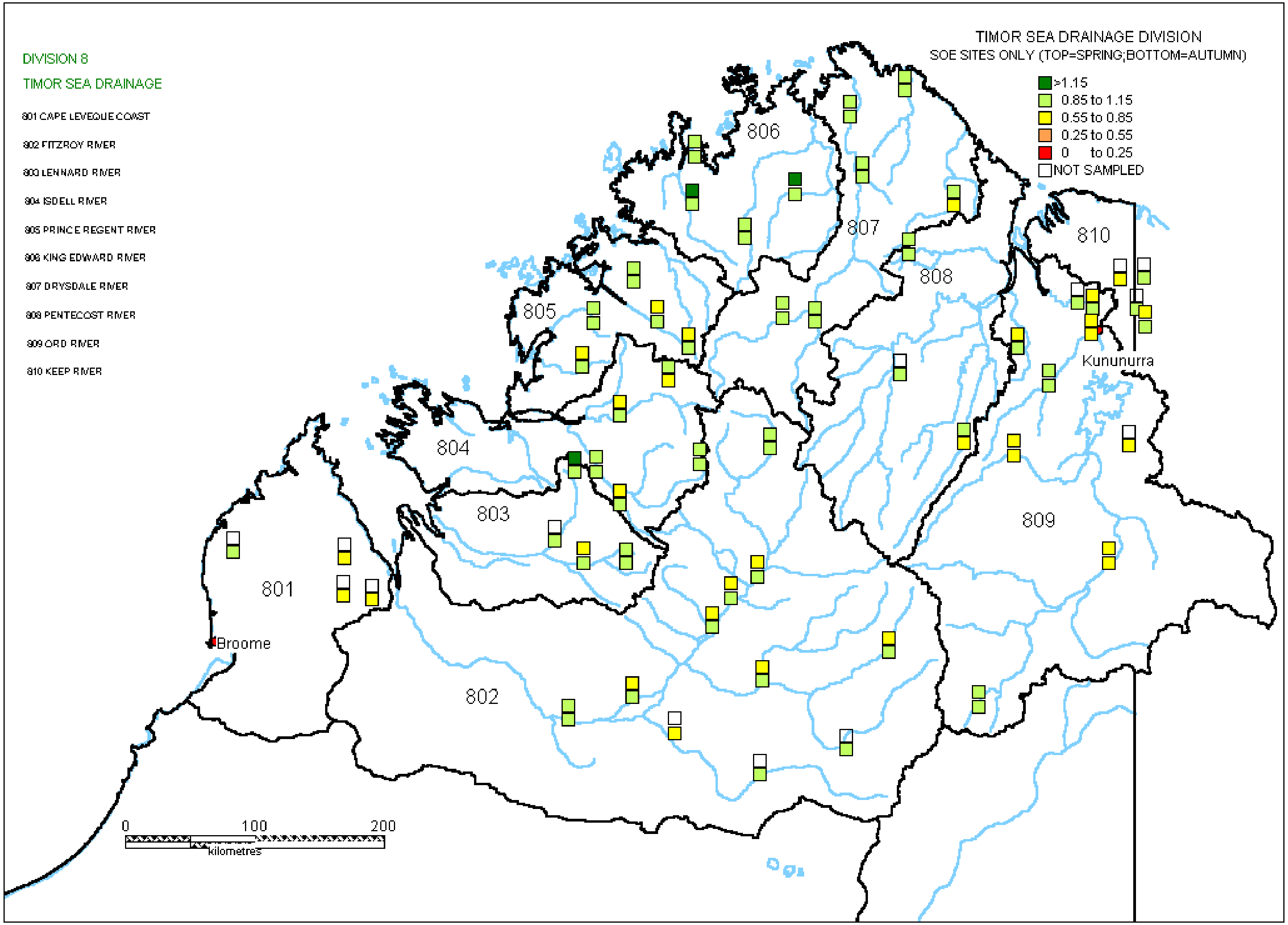

TIMOR SEA DRAINAGE DIVISION
SOE SITES ONLY (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
DIVISION 8
TIMOR SEA DRAINAGE
801 CAPE LEVEQUE COAST
802 FITZROY RIVER
803 LENNARD RIVER
804 ISDELL RIVER
805 PRINCE REGENT RIVER
806 KING EDWARD RIVER
807 DRYSDALE RIVER
808 PENTECOST RIVER
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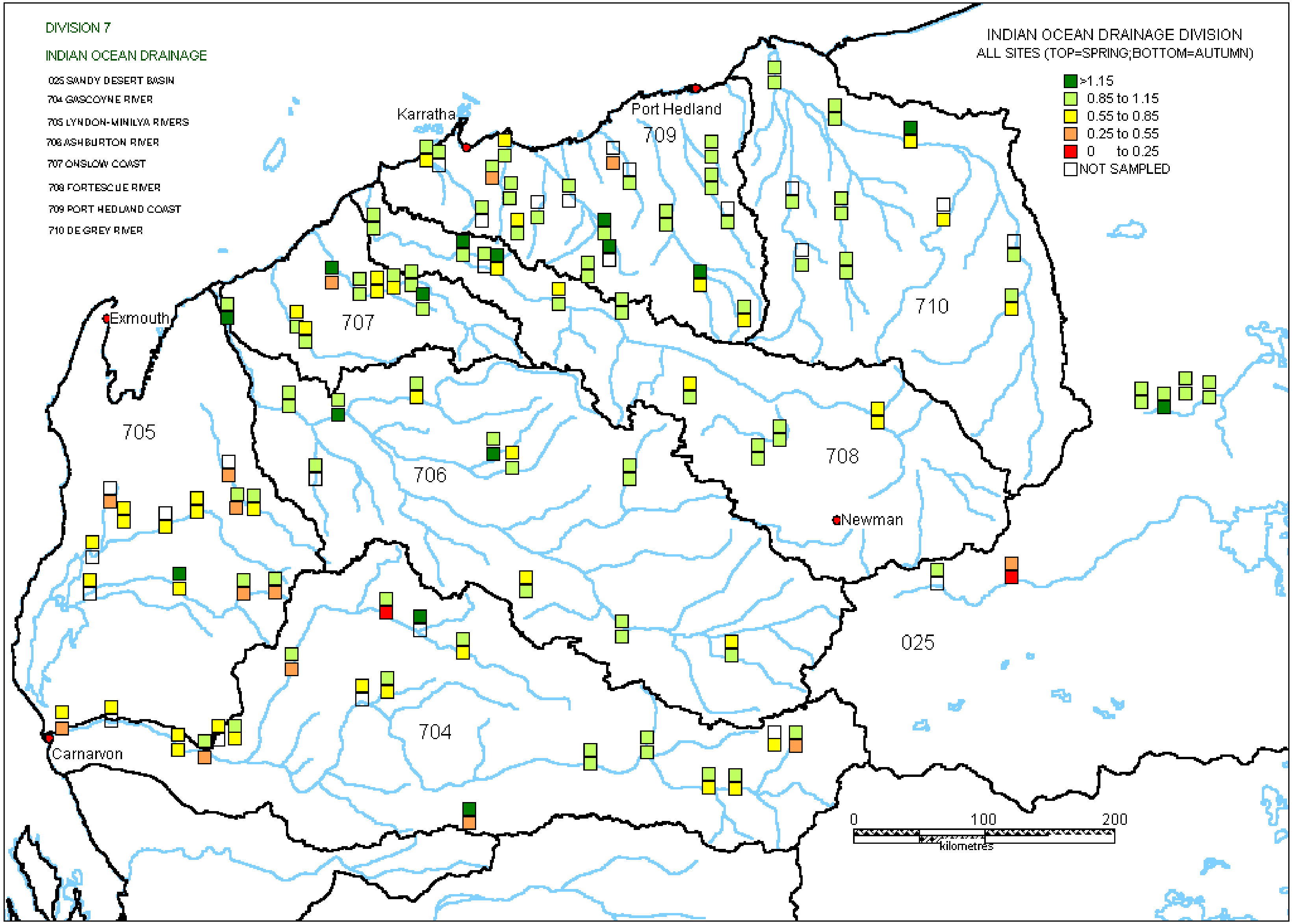
DIVISION 7
INDIAN OCEAN DRAINAGE
025 SANDY DESERT BASIN
704 GASCOYNE RIVER
705 LYNDON-MINILYA RIVERS
706 ASHBURTON RIVER
707 ONSLOW COAST
708 FORTESCUE RIVER
709 PORT HEDLAND COAST
710 DE GREY RIVER
INDIAN OCEAN DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
Karratha
Port Hedland
Exmouth
Newman
Carnarvon
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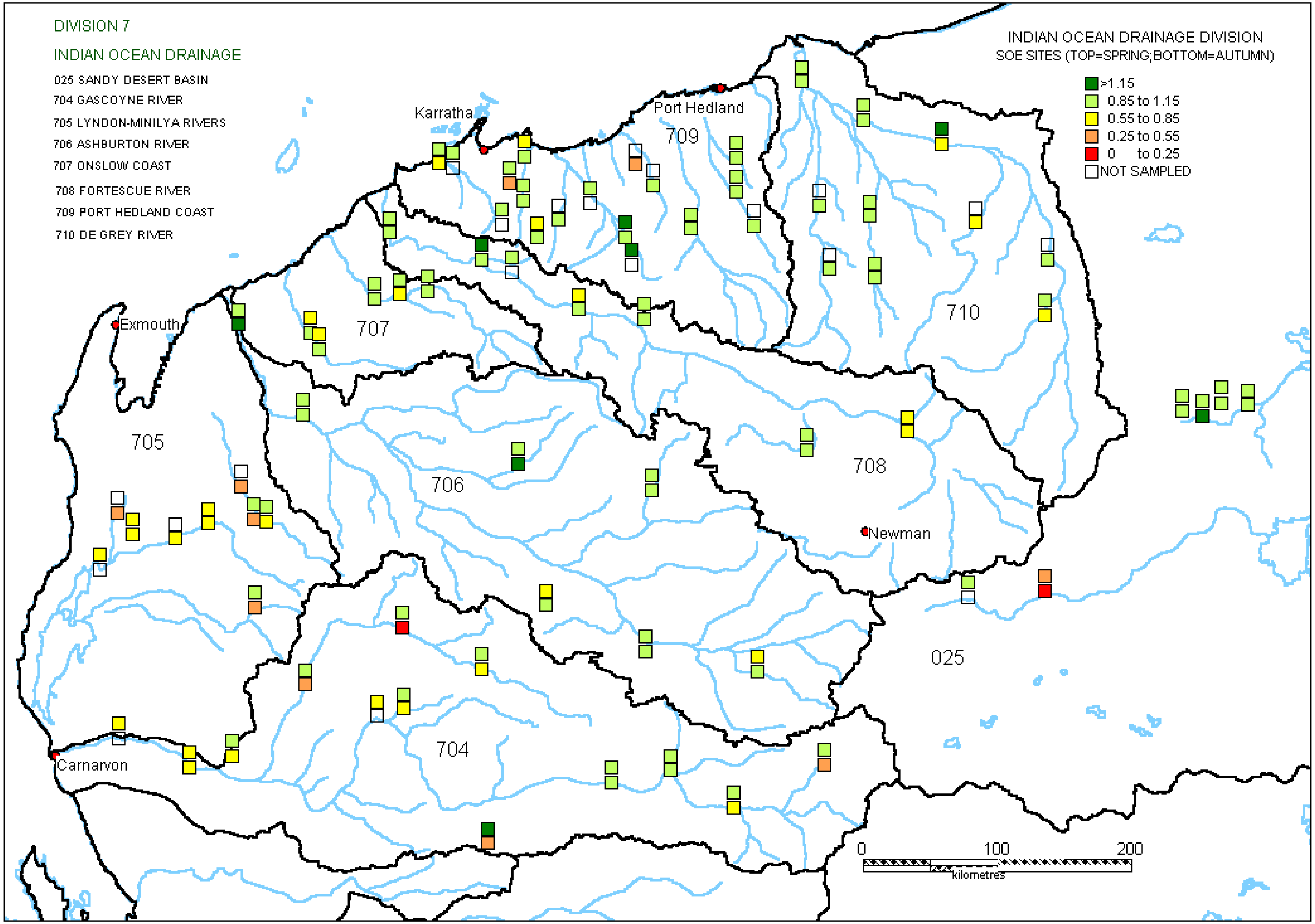
DIVISION 7
INDIAN OCEAN DRAINAGE
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704 GASCOYNE RIVER
705 LYNDON-MINILYA RIVERS
706 ASHBURTON RIVER
707 ONSLOW COAST
708 FORTESCUE RIVER
709 PORT HEDLAND COAST
710 DE GREY RIVER
INDIAN OCEAN DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
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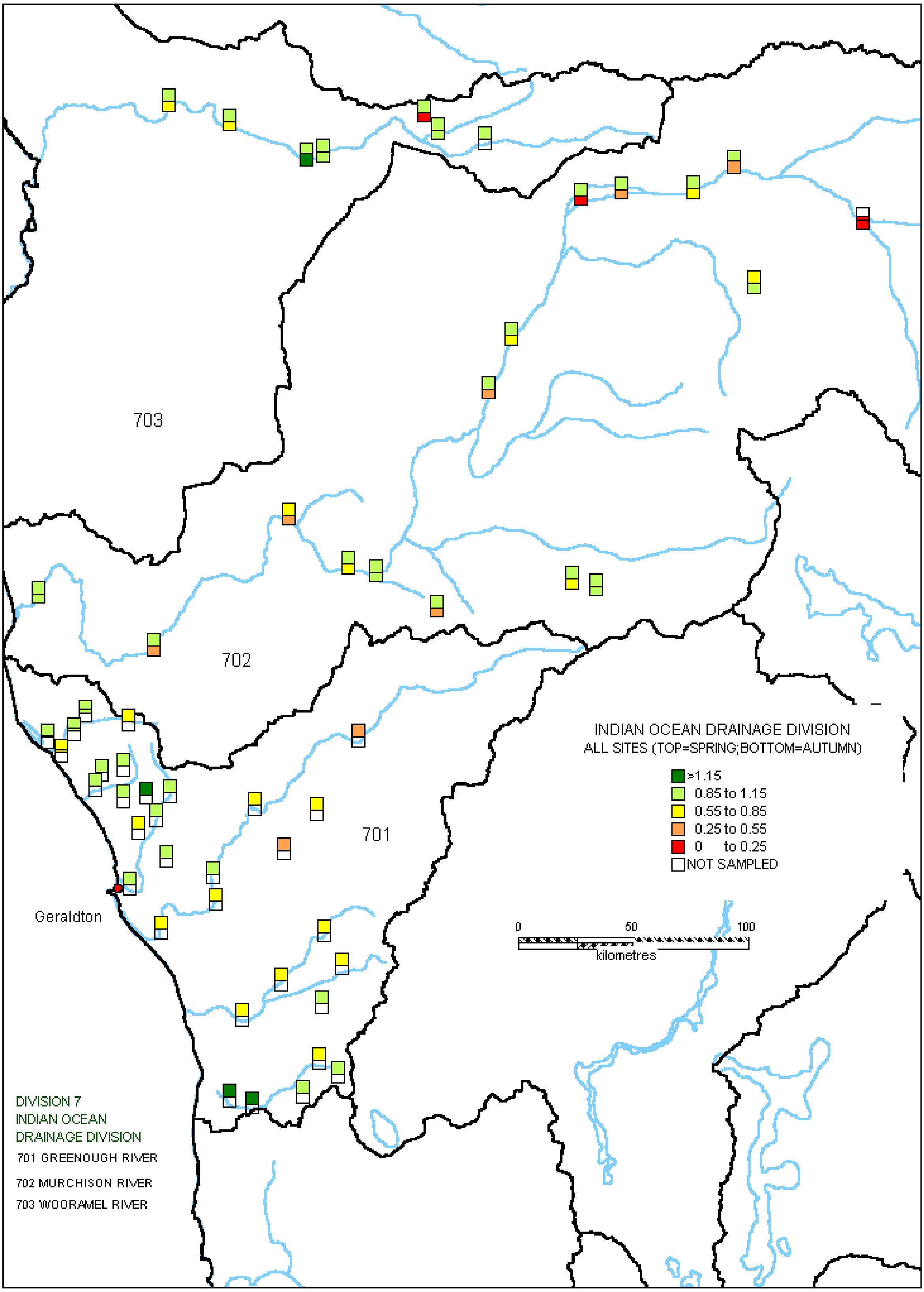
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INDIAN OCEAN DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM=AUTUMN)
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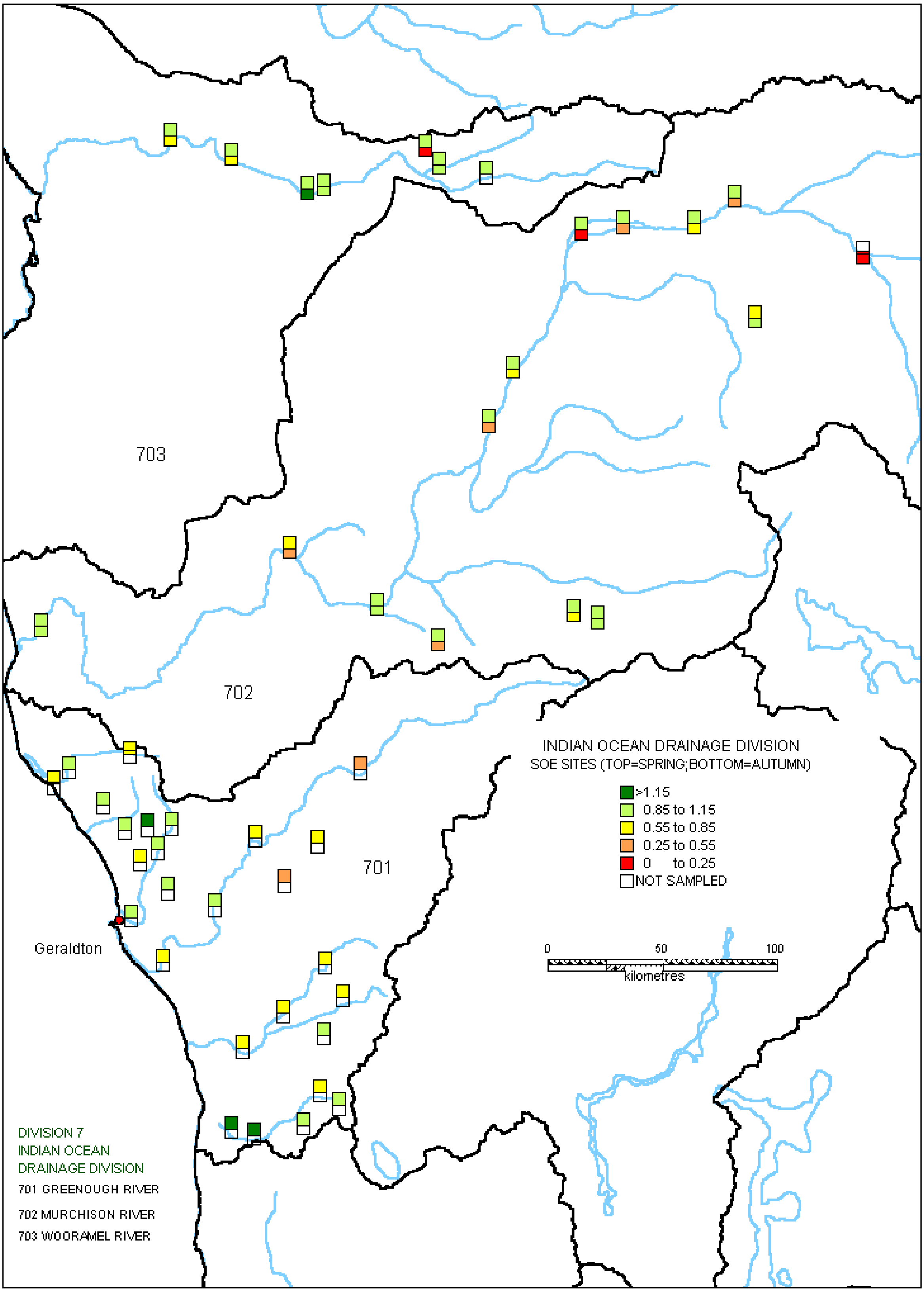
DIVISION 7
INDIAN OCEAN
DRAINAGE DIVISION
701 GREENOUGH RIVER
702 MURCHISON RIVER
703 WOORAMEL RIVER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Geraldton
INDIAN OCEAN DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
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0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
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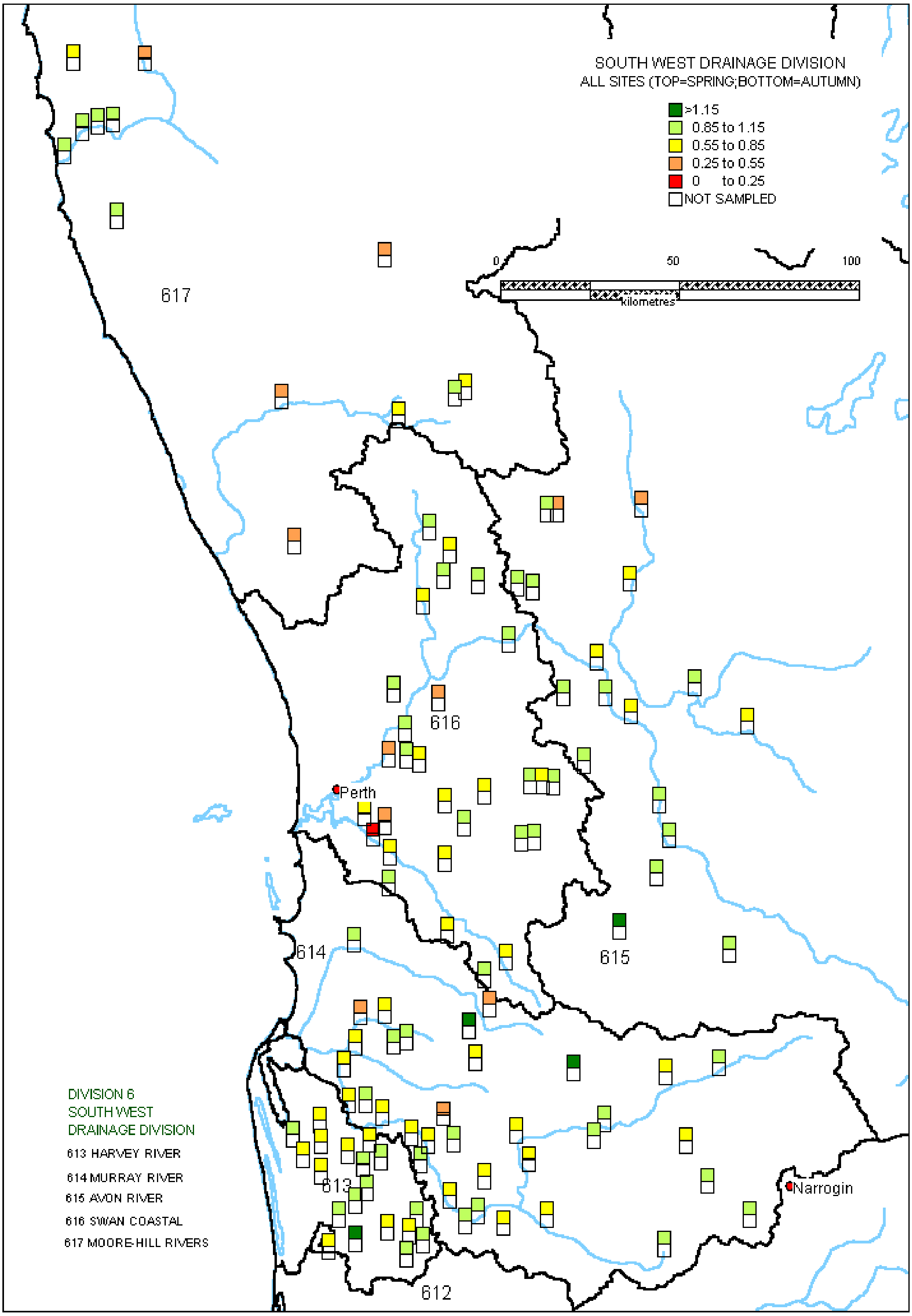
INDIAN OCEAN
DRAINAGE DIVISION
701 GREENOUGH RIVER
702 MURCHISON RIVER
703 WOORAMEL RIVER


SOUTH WEST DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
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0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
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kilometres
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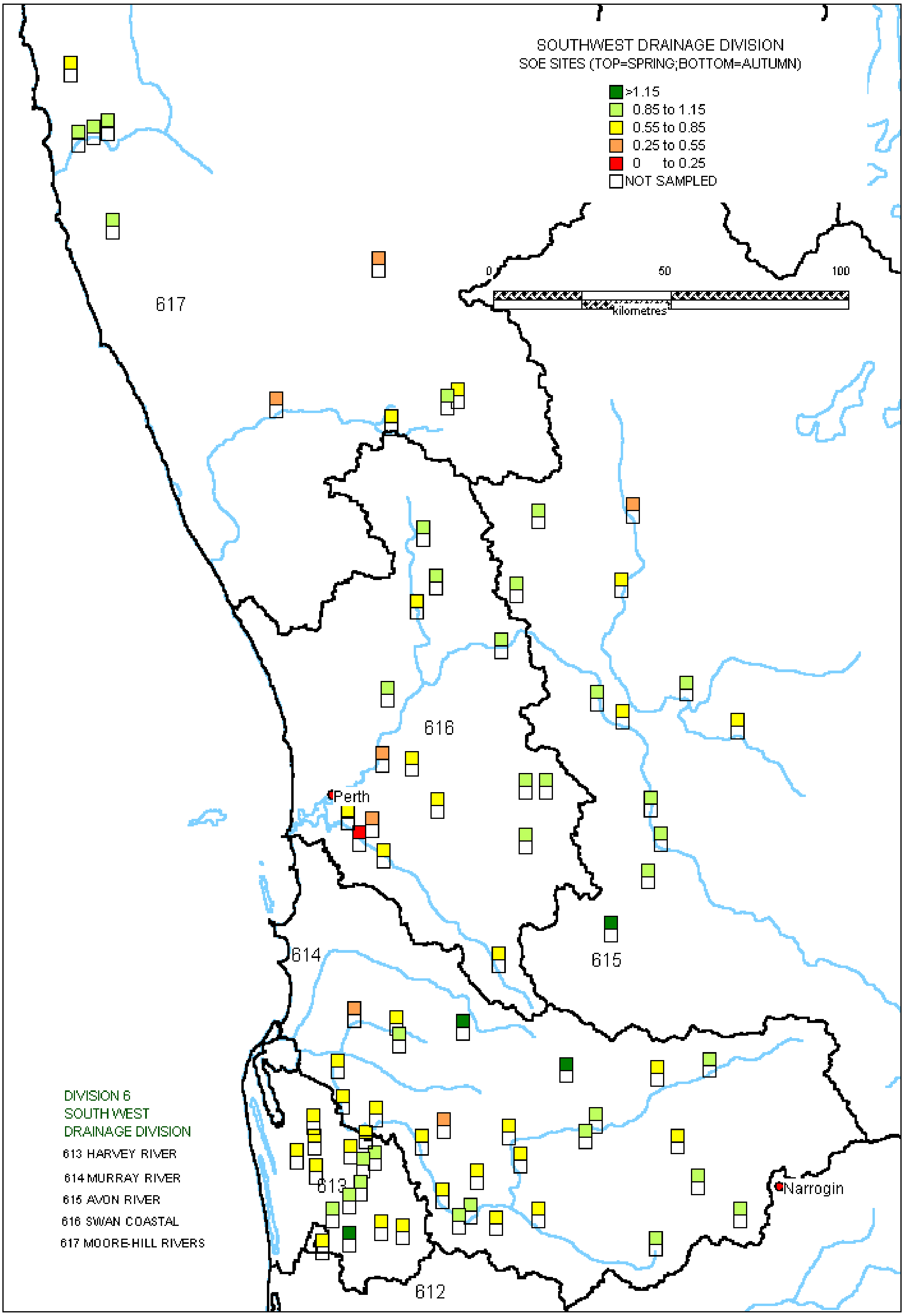
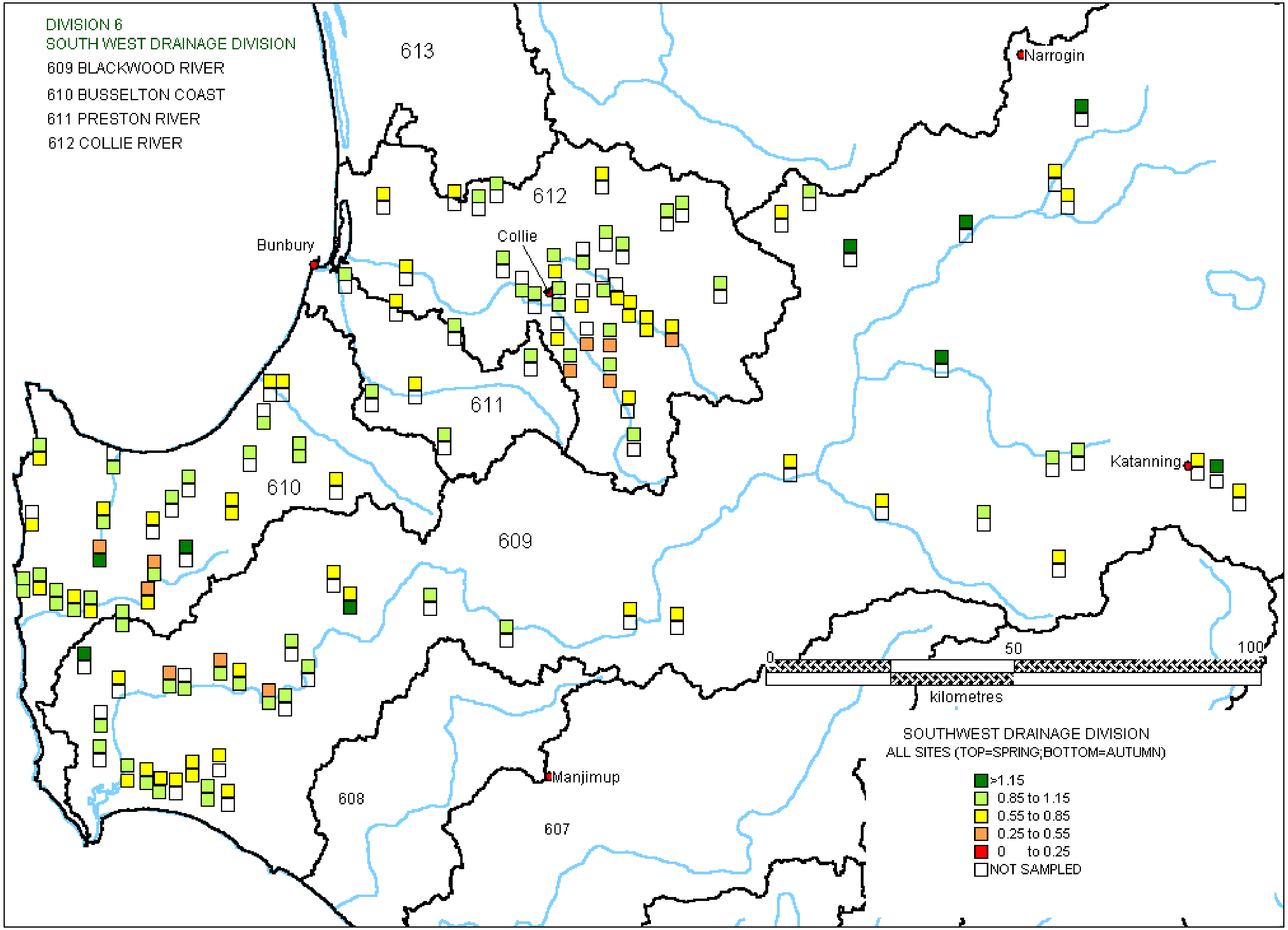
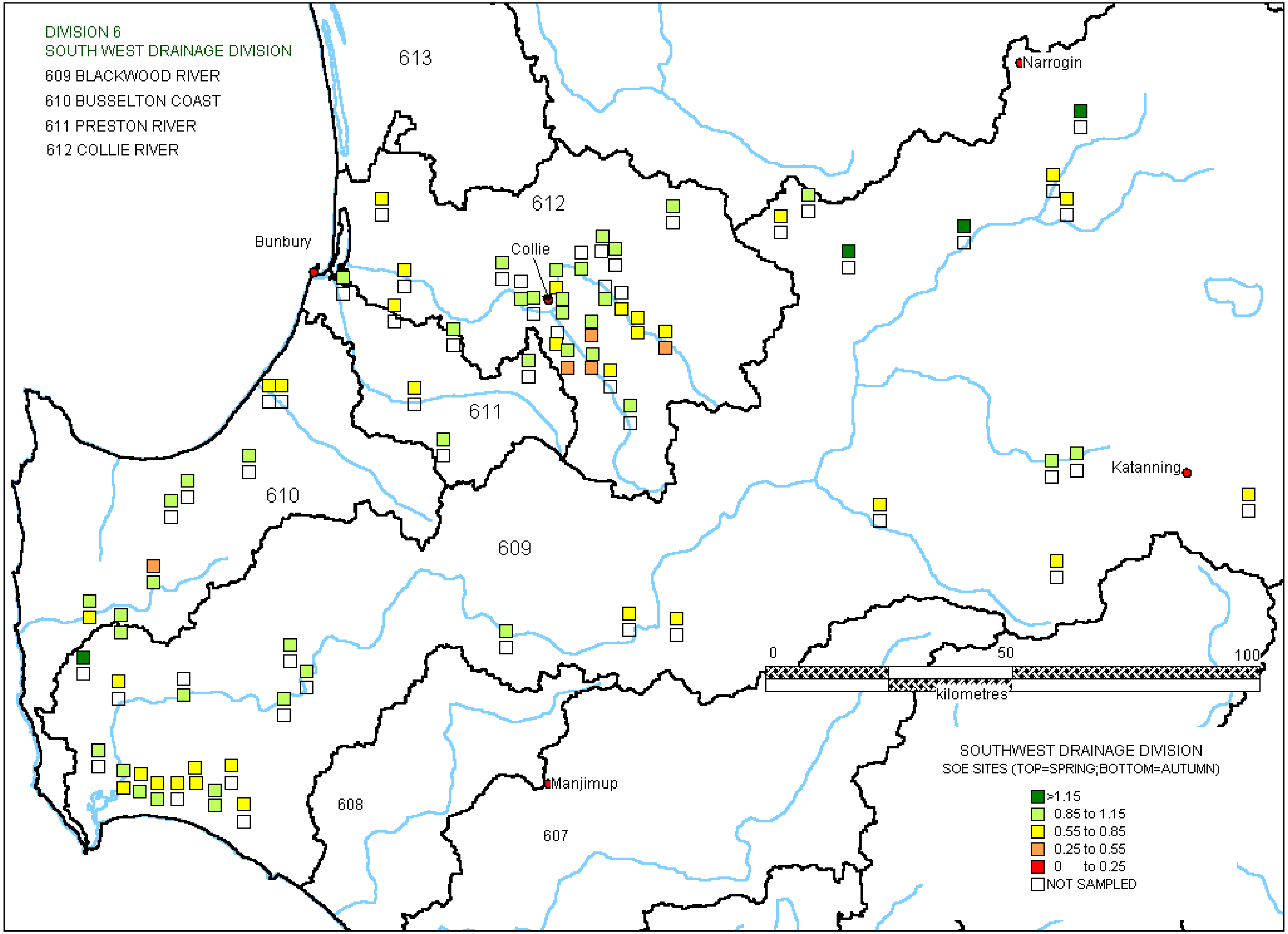
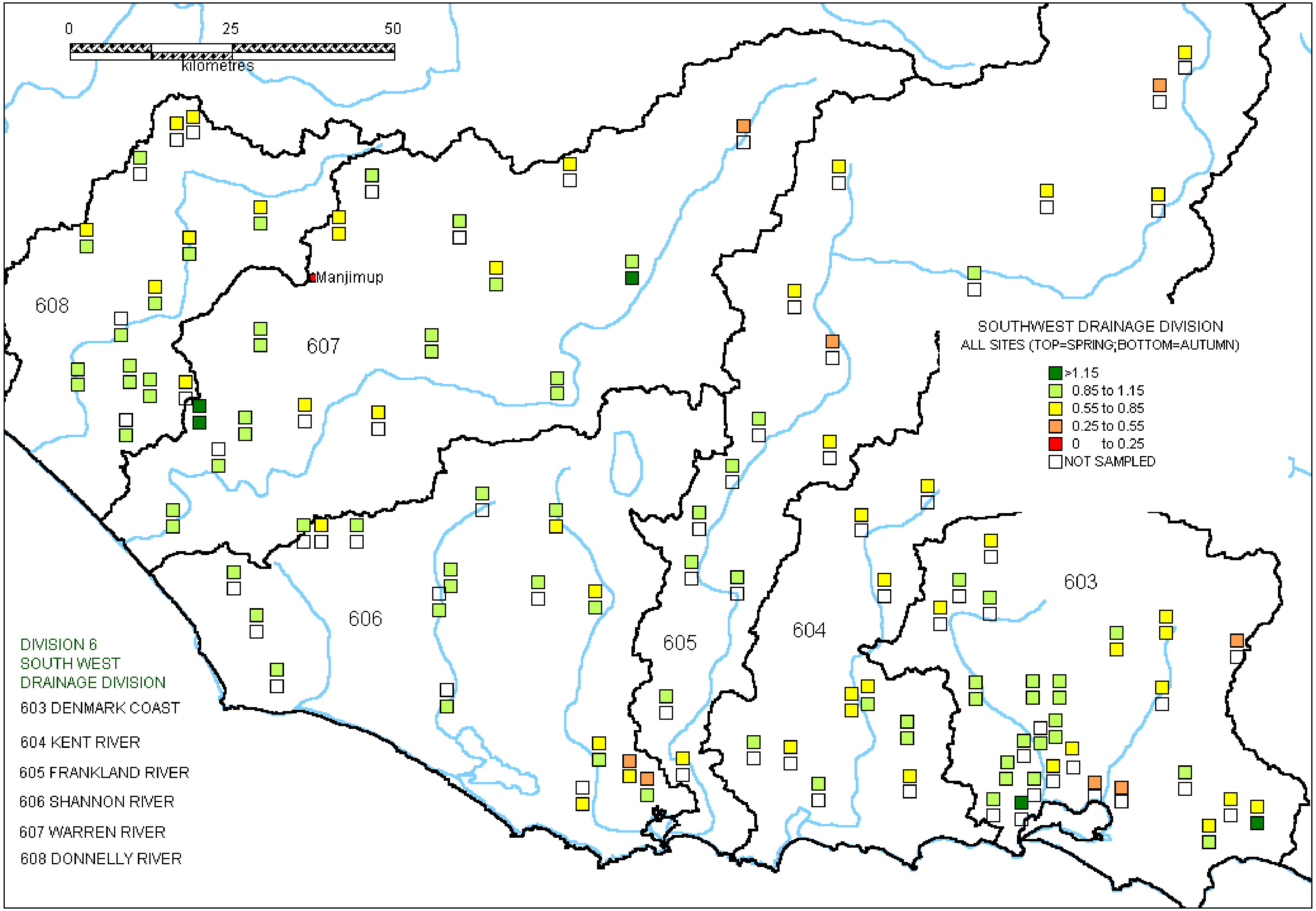
DIVISION 6
SOUTH WEST
DRAINAGE DIVISION
613 HARVEY RIVER
614 MURRAY RIVER
615 AVON RIVER
616 SWAN COASTAL
617 MOORE-HILL RIVERS


SOUTHWEST DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
0
50
100
kilometres
617
616
Perth
614
615
613
612
Narrogin
DIVISION 6
SOUTH WEST
DRAINAGE DIVISION
613 HARVEY RIVER
614 MURRAY RIVER
615 AVON RIVER
616 SWAN COASTAL
617 MOORE-HILL RIVERS

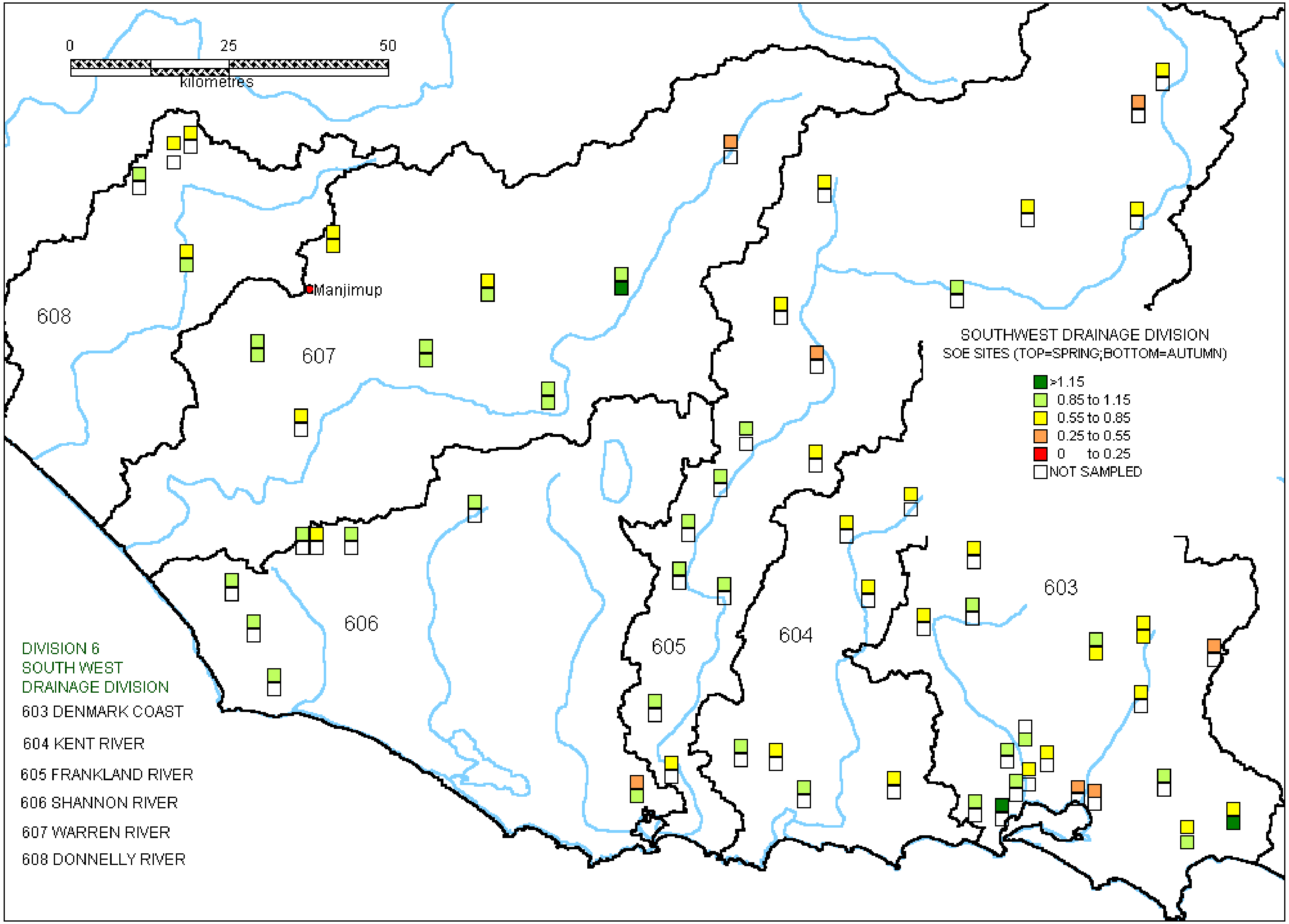

DIVISION 6
SOUTH WEST DRAINAGE DIVISION
609 BLACKWOOD RIVER
610 BUSSELTON COAST
611 PRESTON RIVER
612 COLLIE RIVER
613
612
611
610
609
608
607
Bunbury
Collie
Narrogin
Katanning
Manjimup
0
50
100
kilometres
SOUTHWEST DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED



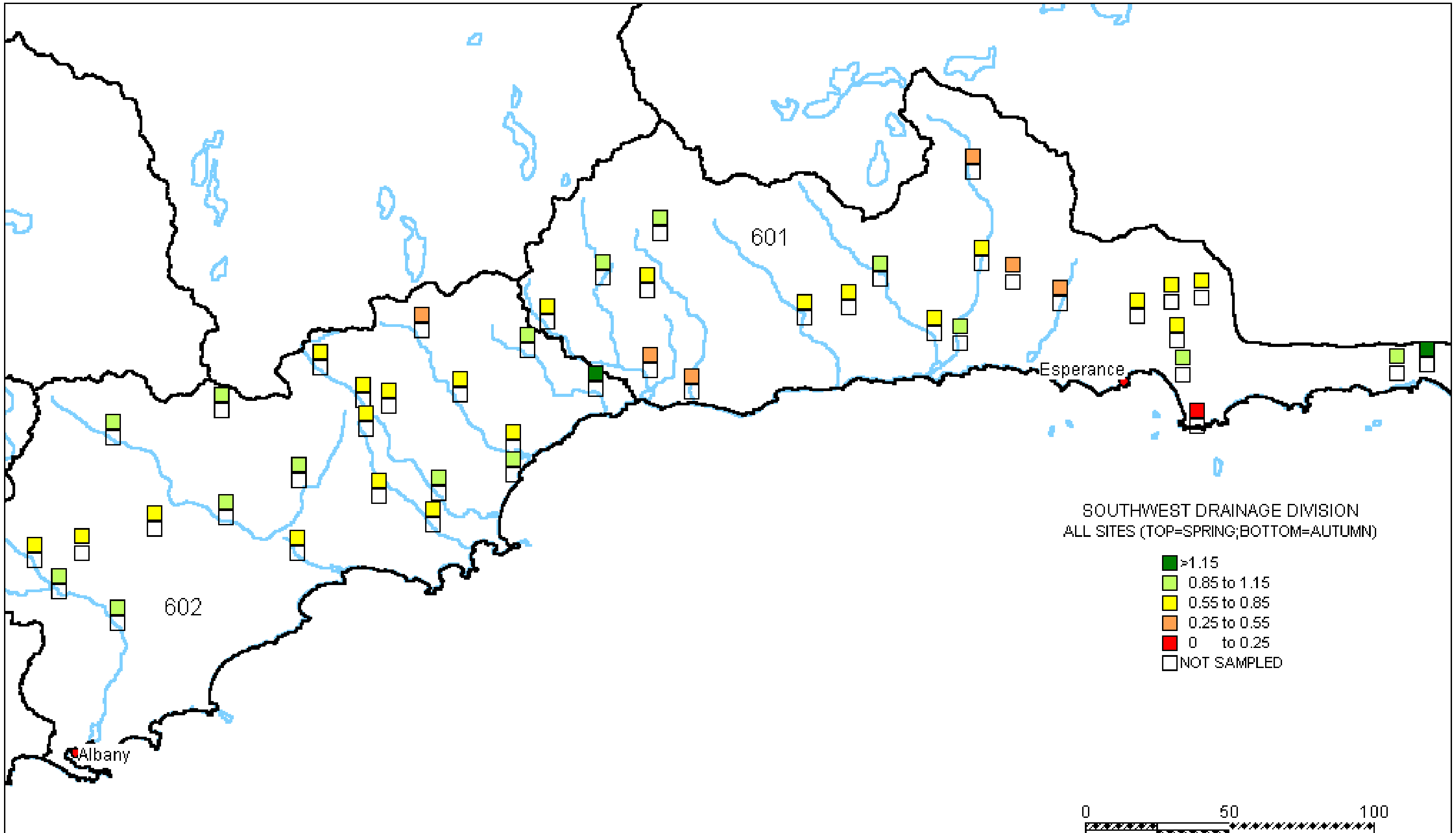
DIVISION 6
SOUTH WEST DRAINAGE DIVISION
609 BLACKWOOD RIVER
610 BUSSELTON COAST
611 PRESTON RIVER
612 COLLIE RIVER
613
612
611
610
609
608
607
Bunbury
Collie
Narrogin
Katanning
Manjimup
0
50
100
kilometres
SOUTHWEST DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED



0
25
50
kilometres
Manjimup
608
607
606
605
604
603
SOUTHWEST DRAINAGE DIVISION
ALL SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
DIVISION 6
SOUTH WEST
DRAINAGE DIVISION
603 DENMARK COAST
604 KENT RIVER
605 FRANKLAND RIVER
606 SHANNON RIVER
607 WARREN RIVER
608 DONNELLY RIVER



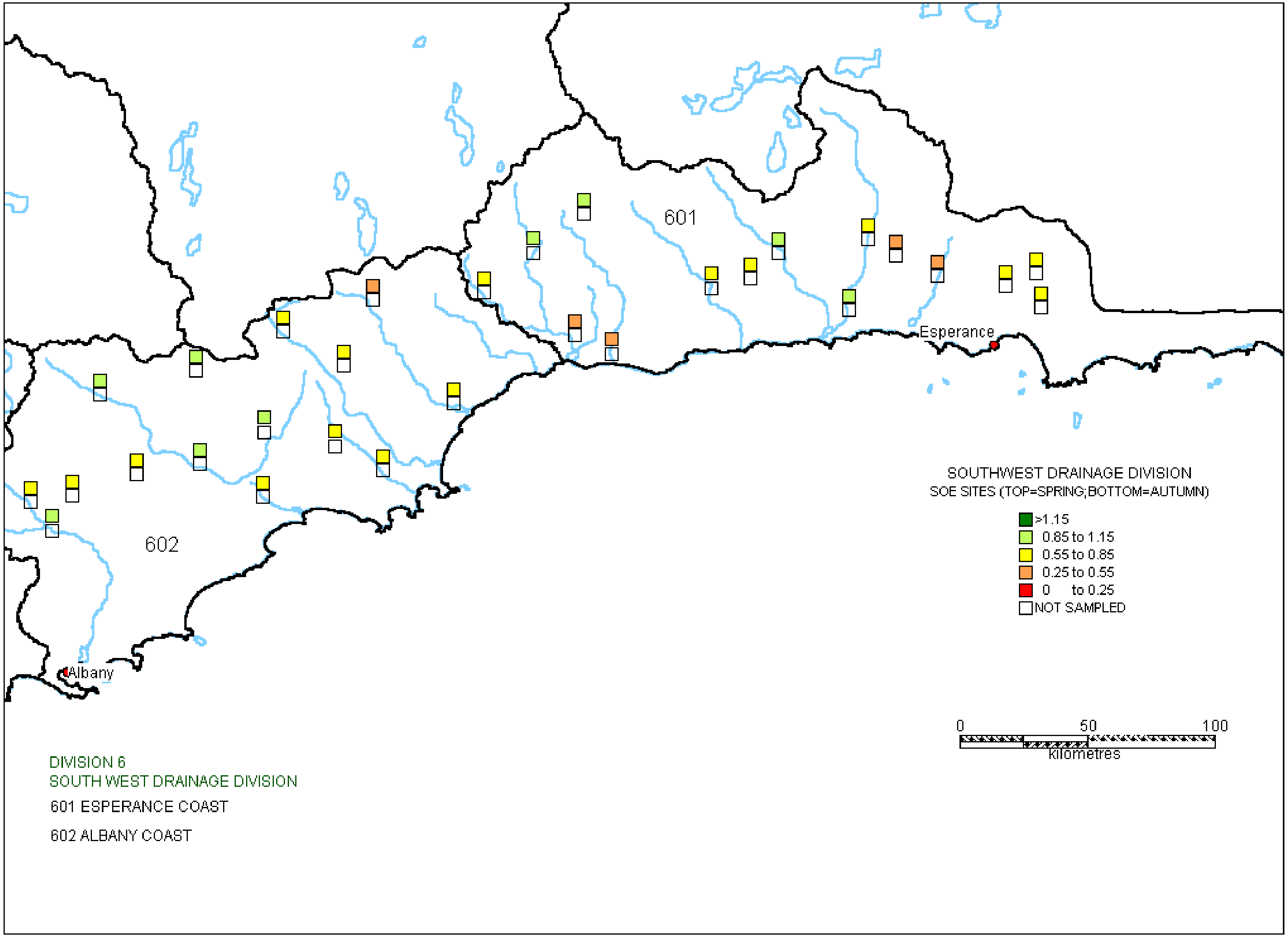
0
25
50
kilometres
Manjimup
608
607
606
605
604
603
SOUTHWEST DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
DIVISION 6
SOUTH WEST
DRAINAGE DIVISION
603 DENMARK COAST
604 KENT RIVER
605 FRANKLAND RIVER
606 SHANNON RIVER
607 WARREN RIVER
608 DONNELLY RIVER



DIVISION 6
SOUTH WEST DRAINAGE DIVISION

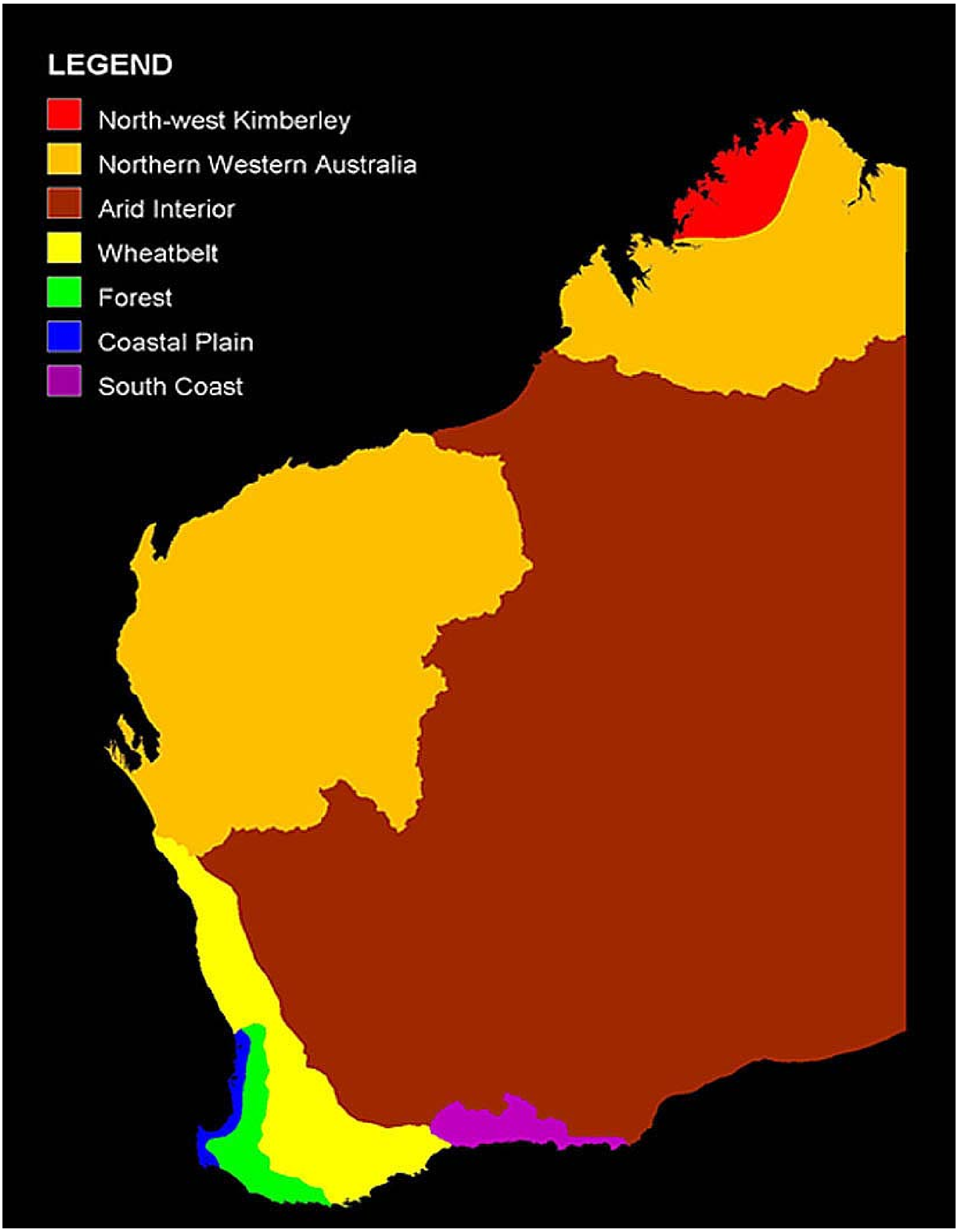
601 ESPERANCE COAST

602 ALBANY COAST

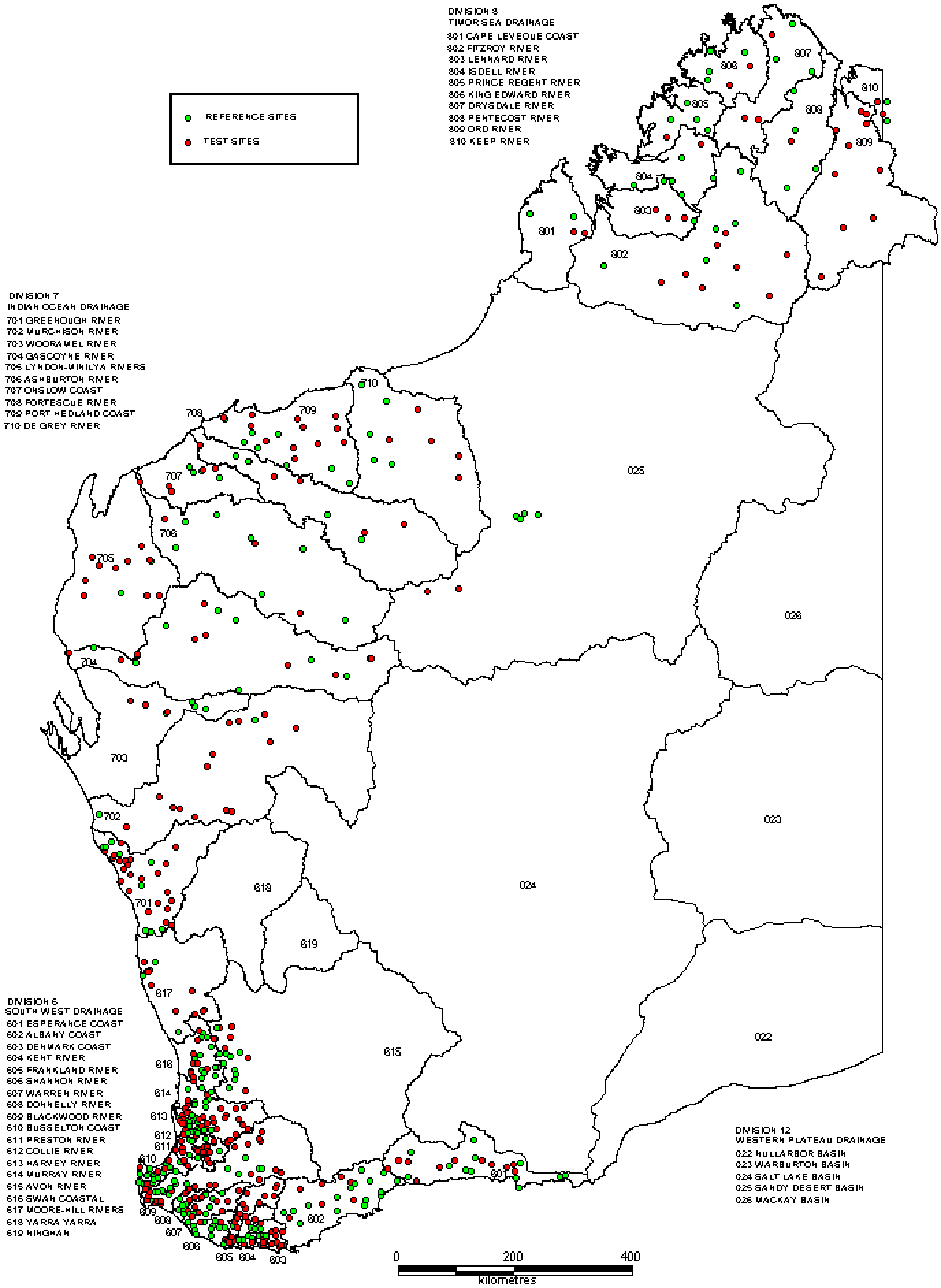


601
602
Esperance
Albany
SOUTHWEST DRAINAGE DIVISION
SOE SITES (TOP=SPRING;BOTTOM=AUTUMN)
>1.15
0.85 to 1.15
0.55 to 0.85
0.25 to 0.55
0 to 0.25
NOT SAMPLED
0
50
100
kilometres
DIVISION 6
SOUTH WEST DRAINAGE DIVISION
601 ESPERANCE COAST
602 ALBANY COAST

Appendix 3 Suggested aquatic invertebrate bioregions in WA based on AusRivAS sampling (after Kay *et al*. 2000)


LEGEND
North-west Kimberley
Northern Western Australia
Arid Interior
Wheatbelt
Forest
Coastal Plain
South Coast

Appendix 4 Map of all sites sampled in WA by AusRivAS program



DIVISION 8
TIMOR SEA DRAINAGE
801 CAPE LEVEQUE COAST
802 FITZROY RIVER
803 LENNARD RIVER
804 ISDELL RIVER
805 PRINCE REGENT RIVER
806 KING EDWARD RIVER
807 DRYSDALE RIVER
808 PENTECOST RIVER
809 ORD RIVER
810 KEEP RIVER
REFERENCE SITES
TEST SITES
DIVISION 7
INDIAN OCEAN DRAINAGE
701 GREENOUGH RIVER
702 MURCHISON RIVER
703 WOORAMEL RIVER
704 GASCOYNE RIVER
705 LYNDON-MINILYA RIVERS
706 ASHBURTON RIVER
707 ONSLOW COAST
708 FORTESCUE RIVER
709 PORT HEDLAND COAST
710 DE GREY RIVER
025
026
023
024
022
DIVISION 6
SOUTH WEST DRAINAGE
601 ESPERANCE COAST
602 ALBANY COAST
603 DENMARK COAST
604 KENT RIVER
605 FRANKLAND RIVER
606 SHANNON RIVER
607 WARREN RIVER
608 DONNELLY RIVER
609 BLACKWOOD RIVER
610 BUSSELTON COAST
611 PRESTON RIVER
612 COLLIE RIVER
613 HARVEY RIVER
614 MURRAY RIVER
615 AVON RIVER
616 SWAN COASTAL
617 MOORE-HILL RIVERS
618 YARRA YARRA
619 NINGHAN
DIVISION 12
WESTERN PLATEAU DRAINAGE
022 NULLARBOR BASIN
023 WARBURTON BASIN
024 SALT LAKE BASIN
025 SANDY DESERT BASIN
026 MACKAY BASIN
0
200
400
kilometres