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Development of AUSRIVAS models for New South Wales

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AUSRIVAS in NSW

Philosophy

The main philosophy in developing predictive models for AUSRIVAS is derived from the approaches adopted for the River Invertebrate Prediction And Classification System (RIVPACS) in the UK, which was the first large-scale application of predictive modelling of macroinvertebrates worldwide (Wright 1995). The RIVPACS approach was adopted for the National River Health Program (NRHP) in Australia with some modifications (Davies 1994, Schofield and Davies 1996). The main modifications from RIVPACS that were adopted for the NRHP were habitat specific sampling and definition of season. Changes to the sampling protocol were also made.

One feature of the NRHP strategy was that the first step in the program would be to identify key regions of management concern (Davies 1994). The selection of reference and test sites used to develop and test the AUSRIVAS models should then be based on this knowledge (Davies 1994). The development of AUSRIVAS models for NSW, however, followed a slightly different course. The aim was to develop a tool that would be applicable to all the major river systems in the state (Turak et al 1999). The first step was to partition the state into smaller, more ecologically homogeneous regions (Turak et al 1999). A major assumption was that types of landscapes (defined as Natural Regions) could broadly represent natural variability in river systems. Reference sites were then chosen to represent each of these natural regions. Although an attempt was made to represent all running-water site types in NSW this was conducted at a broad scale and therefore the models may not cover some stream types that are rarely encountered but may be of great importance in particular locations.

The criteria for selecting reference sites required some thought on what condition the reference sites should represent. It is anticipated that the reference condition may serve as a goal for some users of AUSRIVAS as a tool for river restoration and management. For the NSW program, reference sites were the best available sites for a given region and stream type. The notion of best available is based on a judgement that the pre-European condition of rivers represents the natural or good condition. Hence best available sites are those thought to be closest to the pre- European condition. The reference condition used in the models represents an averaging of the reference sites for each stream type. For some types of streams relatively undisturbed sites are not available or very difficult to find e.g. lowland rivers of the Murray-Darling system. When an adequate number of reference sites are chosen for such streams inevitably some of these sites will be more affected by human activities than others. The reference condition for such streams, therefore is actually more degraded than the best available condition.

Site selection; process and rationale

Selection of reference sites follows the philosophy outlined above. The data set used for this procedure included the Natural Region Classification system (Biodiversity Advisory Committee 1992) and Catchment Boundaries of New South Wales (DLWC). Natural regions as defined in the NPWS Natural Region Classification system were used to partition catchments into subdivisions. These subdivisions served as the land units within which the reference condition criterion described above was applied. This resulted in the reference condition representing different degrees of deviation from naturalness in different parts of the state. The process of selecting reference sites was carried out in three stages as shown in Fig. 1.

The first stage in site selection for the NRHP was the selection of 250 reference sites, mostly from topographic maps, during the first year. These sites were sampled for two years over 4 consecutive sampling seasons from spring 1994 to autumn 1996. Preliminary models were developed using the data collected from these reference sites. In addition 22 test sites, representing different types of disturbance, were sampled during this period and used for testing model performance. Each further stage of site selection was tied to a discrete stage in model development.

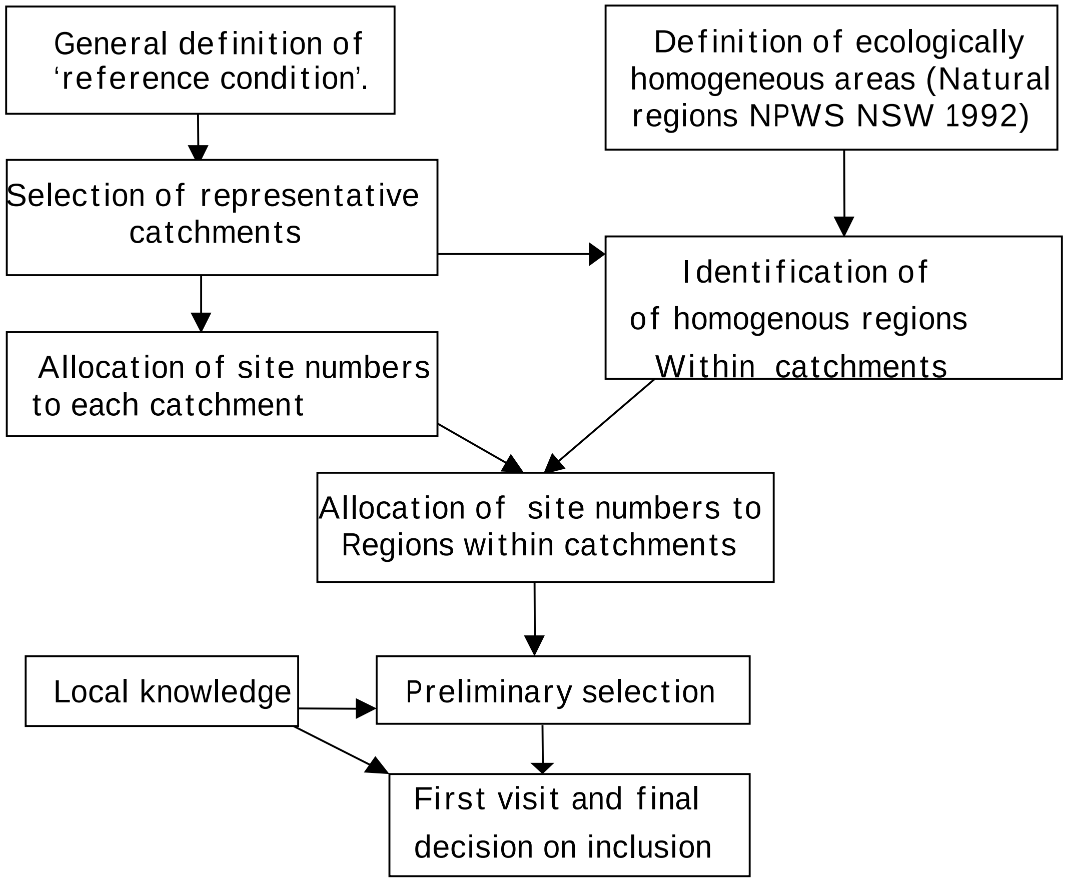

Fig.1. Steps in preliminary site selection for the MRHI (March-September 1994)

During 1997 no new reference sites were selected, as the main objective of the sampling program in that year was to test the preliminary models. As part of the site selection procedure for that year a large number of government agencies were invited to nominate sampling sites affected by disturbances of management concern in their region. In total 350 test sites were selected covering a range of different disturbance types in all areas of the state. Degrees of disturbances also varied among sites and a few undisturbed sites were also selected as they were of particular interest to individual stakeholders. In addition a subset of MRHI reference sites were selected to represent a variety of stream types. Sampling continued at these reference sites for the rest of the program.

Prior to sampling in 1998 all previously sampled reference sites were reviewed and the performance of the models for different types of rivers and different geographic regions across the state were assessed. Stream types and geographic regions that required greater representation in the models were then identified. Appropriate sites were then selected to fill in these gaps. Stream types for which more reference sites were needed included lowland rivers in the Murray-Darling Basin, small creeks in sandstone geology, small acidic upland streams and low gradient coastal streams. As a result about 100 new reference sites were sampled during 1998. Over 100 new test sites were also selected for sampling in 1998. The strategy used for selecting test sites in 1998 can be summarised as follows.

- Inclusion of sites subjected to the types of disturbance that represent the interests of a wide range of stakeholders.
- Inclusion of disturbed sites for all the stream types represented in the models.
- Provision of a good coverage of sampling sites across the state including representation of all Natural Regions, all major land uses and all major stream types.

Dialogue was established and maintained throughout the program with other government agencies, local government and community groups. This provided them with opportunities to nominate sampling sites and identify important management issues.

Prior to the final year of sampling for AWARH in 1999 the coverage of sites for the entire state was revised and gaps in the geographic coverage were identified. The process of identifying gaps in the coverage was carried out in a number of steps using Geographical Information Systems (GIS), staff knowledge and local information. Firstly, all existing sites were mapped using GIS and the boundaries of river catchments and Natural Regions defined using the data sources mentioned above. The coverage of sampling sites within all major river catchments was then examined and natural regions that were poorly represented identified. Natural regions within catchments were used throughout this program as land units which were considered to be relatively homogeneous ecologically. The next step was to overlay a land use data layer and examine the coverage of sites within each land unit according to the range of land uses present. The NSW Department of Conservation and Land Management (CaLM) Land Use of New South Wales data set was used for this purpose. Land uses within each land unit that were poorly represented were then identified.

All relevant information was then complied including information gained by previous sampling events and consultation with local sources to determine any major river type or land use that required better representation. A large number of new test sites were then selected and sampled if proved suitable in the field following ground-truthing. During site selection for the 1999 sampling seasons some consideration was also given to achieving a balance in the number of sites at different levels of disturbance. For this reason many of the test sites sampled during this year were from relatively undisturbed rivers. In total an additional 272 new test sites were sampled in this final year.

In total over 1100 sites were sampled in NSW throughout the NRHP representing a wide range of stream types and disturbances across the state. An effort was made to represent a gradient within each of the major disturbance types. This probably makes the coverage of sites sampled throughout the NRHP in NSW suitable for reporting on spatial trends in river health throughout the state.

Sampling methodology

The sampling of macroinvertebrates and sample processing methods in NSW has been based on Davies (1994). The environmental data required for AUSRIVAS assessments in NSW includes most variables used by Davies (1994). Some changes, however, have been made to the live-pick methods and the habitat definitions. Sampling instructions have also been tightened and these are described in detail in the New South Wales (NSW) Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual (Turak and Waddell 2001). New data sheets were designed to make the process of data collection as easy as possible. The most recent version of the field data sheets is included with the manual.

Stages in model development

Over the duration of the NRHP, three versions of AUSRIVAS models have been developed. The first two versions developed in 1997 were preliminary and will be referred to as the beta models (β-1, β-2). These essentially served to determine a sound strategy for developing the final or alpha models that were developed in 2000.

The first version (β-1) models were developed in March 1997 using data collected in spring and autumn 1995. Preliminary evaluation of Version 1 models indicated that the single season models were performing poorly for many rivers (Turak et al. 1997). The number of predicted taxa were low for most sites, and many of the test sites considered disturbed were assessed as being in good condition. Conversely many reference sites known to be undisturbed were assessed as being in poor condition. These results prompted a revision of the models.

The second version (β-2) models were developed in December 1997 using data from Autumn 96 instead of Autumn 95, together with data from spring 1995. Examining these results it was concluded that a major factor contributing to the unreliability of these models was data quality, especially for data collected in Autumn 1995 at which time many of the rivers had experienced a prolonged drought followed by floods.

Some of the unsuitable reference sites were excluded from use in the β-2 models and additional site attributes such as slope of the river at each sampling site were derived. These data were used to develop combined season models that were used to assess sites sampled for the AWARH in 1997. The results obtained using β-2 models for reference sites were then evaluated to determine types of streams that needed to be better represented for the models to be more reliable.

Development of the current (α-1) AUSRIVAS models for NSW was completed in mid-2000. The earlier versions (β-1 and β-2) of NSW AUSRIVAS models provided a good basis for identifying the gaps in the spatial coverage of sampling sites and for determining the attributes needed for effective predictive modelling in NSW. The development of the current models was guided by these needs.

Development of the current models for AUSRIVAS

In undertaking development of the current models it was determined that models should be:

- free of poor quality data,
- not unduly affected by temporal variation, i.e., the new models should provide consistent results at sites (where no new disturbances occurred) for different years over the period of sampling,
- robust to spatial variation i.e. the models should work well for river systems where few or no reference sites were located,
- usable for all major river types in all parts of NSW,
- sensitive to the types of disturbance that are of management interest.

The extensive data set collected from 1994 to 1998, including data from the long-term sampling sites, made it possible to develop final models with these desired attributes. In order to proceed with the development of new models, however, data needed to be reviewed and new approaches in model development had to be adopted. It was necessary to tighten the definition of reference condition, revise the test/reference status of all sites, remove all poor quality data and add data from new reference sites. It was also necessary to refine the procedures for defining biological groups and choosing predictor variables, and to exclude particular sites from the model development process.

The steps taken in developing the current models in NSW are listed under four major headings: data preparation, definition of biological groups, choice of predictor variables and testing the performance of the models, as explained below.

Data preparation

The following steps were taken to prepare data sets for model development:

- Revision of reference/test status for all sites (777) sampled in NSW from 1994 to 1998 based on land use, field experience, local knowledge and earlier assessments.
- Classification of sites assigned “reference” status into three classes A, B and C. Classes A and B indicating near pristine and slightly modified reference sites respectively and C indicating moderately disturbed sites, which were nominated as reference sites because more appropriate sites were not available for that type of river.
- Revision of all biological records from reference and test sites against a set of criteria (see Waddell 2001), assignment of “fail” to samples that did not meet these criteria and removal of all failed samples from the process of model development and performance assessment.
- Revision of all environmental records against a set of criteria (see Waddell 2001) and replacement of erroneous data with plausible substitutes.
- For the single season models, compilation of data sets using two samples selected randomly from all sites that had more than two years data. Only records that passed the quality assurance and quality control tests were included in this process.
- For combined season models, samples from consecutive seasons were combined for individual sites and from this set of combined records two were randomly selected from each site where possible. Again only records that passed the quality assurance and quality control tests were included in this process.
- Removal of invertebrate families that occurred at less than 10 sites and records (samples) that included less than 10 invertebrate families.
- Removal of fine substratum (silt and clay) from potential predictor variables. This followed the finding that the recording of fine substratum was highly variable and this variability contributed significantly to inconsistencies in AUSRIVAS outputs for some sites.
- Examination of the distribution of values for all potential predictor variables using a number of different tests for normality and kurtosis. Transformations were used to normalise any non-normal data and reduce kurtosis.

Definition of biological groups

The definition of biological groups was based on multivariate analyses of the updated data sets. However, the experience gained during the development of the earlier models and the knowledge of the sites acquired during the 6 years of this program were critical in interpreting the results of these analyses. The following procedures were used in defining biological groups:

- Classification of all data using UPGMA to produce dendrograms from which preliminary biological groups were defined.
- Generation of 3-dimensional ordination plots (SSH MDS).
- Principal Axis Correlation (PCC) analysis of families on the ordination to determine the contribution of each family to the patterns of ordination. This provided some indication of the macroinvertebrate families that were characteristic of different stream types and hence biological groups. Monte-Carlo simulations were used to determine the significance of these relationships.
- PCC analysis of environmental data on the biological ordination to determine the relationship between the environmental variables and patterns in the ordination. Of these variables, the most likely predictor variables were those that yielded a high correlation coefficient. Monte-Carlo simulations were used to determine the values of correlation coefficients cut off at $\alpha = 0.01$ significance.
- Generation of 3-dimensional rotating plots of ordinations that included all taxa that had an R^2 value greater than 0.4 and all environmental variables that had an R^2 value greater than 0.5.
- Identification of the preliminary biological groups (determined from the dendrograms) on the rotating plot with different colours or symbols.
- Examination of patterns in the 3-dimensional ordination plot and modification of group definitions by seeking gaps in the ordination patterns, the environmental gradients and the characteristic taxa. In making these modifications, the experience gained during the construction of the previous models as well as the six years of sampling and analysis was utilised to ensure the biological groups generated made ecological sense. If this process is carried out carefully, the groups should represent an identifiable "stream type".

- After each modification, constancy and fidelity tables were generated to examine the tightness of the groups. These tables showed the percentage of sites within each group for which a taxon was present, and hence the probability of finding a taxon within sites from a particular group. These tables were used to make final adjustments to groups by moving sites from one group to another or occasionally removing a site altogether in order to achieve greater constancy and fidelity.

Choosing predictor variables

For each model, predictor variables that were highly correlated with the ordination pattern were chosen. It was important that each variable also contributed different information to the assignment of group memberships. Based on the previous experience with model development and knowledge of the sites the following guidelines were used:

- Minimisation of error rates in the cross validation procedure.
- Minimisation of the use of predictor variables that are effected by human activities e.g. substratum, alkalinity, and avoidance of those those that are particularly indicative of disturbance for a given habitat (e.g. sand in the riffle habitat).
- Preference for variables that are not subjective estimates.
- Inclusion of climatic variables.
- The ease with which model users may obtain the values for test sites.

The procedure followed was as follows.

- Entering all potential variables (including transformed and non-transformed) into a stepwise-discriminant function analysis (DFA).
- Choice of transformed or non-transformed data for a variable depending on which one is preferred in the stepwise function.
- Examination of group probabilities assigned to each site in the discriminant function (cross validation procedure).
- Check that the Generalized Squared Distances among groups based on the environmental data (a matrix generated in DFA) is congruent with the distances among those based on the biological data observed in the three dimensional ordination plots.

Testing the performance of the models

There are no published rigourous tests for assessing the performance of predictive models of the type developed for AUSRIVAS. However, the regression equation of Observed (O) values (dependent) and Expected (E) values (independent) has been used for this purpose (Richard Norris pers comm) and for assessing alternative methods to classification in developing new predictive models (Linke 2000). The assumption is that when O is regressed over E for reference sites, a good model should yield a slope of 1, an intercept of 0 and a high correlation coefficient. Although the data analysed suggested that this method is probably of little use as an absolute measure of the performance of any one model, it is of some value for comparing the performance of different models including various versions of a model derived from the same dataset.

Further to this comparison, the effect of temporal and spatial variation needs to be examined for individual sites. For a good model, sites sampled over several years should give consistent results provided that there has been no big change in the amount of disturbance over time. Also, sites affected by the same disturbances in similar types of rivers should give similar results.

The most important use of the AUSRIVAS models was to indicate situations in which poor management practices have impacted on macroinvertebrate fauna. It was not easy to assess whether the models were accurately detecting impacts because information available on the disturbances at each sites i.e. type and extent, was often limited. However, the large number of test sites sampled during the NRHP in NSW, including sets of sites along known pollution gradients, allowed some judgements to made on the sensitivity of the models to changing management practices.

In addition to testing the internal consistency of the models, it was also important to undertake a procedure of external validation. The approach adopted for this purpose was to obtain extra data from all available reference sites as suggested in the River Bioassessment Manual (Davies 1994). All quality-assured data from all seasons was then run through the relevant models allowing a comparison between model outputs from data sets used in developing the models and outputs from data sets that contained all available data for these reference sites. The ability of the models to produce consistent results in terms of group membership and temporal variation could then be assessed. Models that gave similar regression equations and correlation coefficients for these two data sets were likely to be robust to temporal and spatial variation.

It was also essential to undertake some sensitivity analysis during the process of developing the models so that the most useful of several possible alternatives could be chosen.

In assessing the performance of the models in NSW the following steps were taken:

1. The O/E values for individual reference sites, the overall distribution of O/E values and the relationship between O and E values for reference sites were examined. Comparisons were made between reference site data included in the models and those left out of the models (the number of records for each of the 7 models is given in Table 1).

2. Model outputs for all available test sites were examined (the number of records for each of the 7 models is given in Table 1). In this process, the results from sites with known types and degrees of disturbance were greatly relied on to judge whether the models were providing suitable outputs.

Table 1. Number of reference sites in each model and the number of reference and test sites used to assess model performance.

Model	Number of reference samples used in model	Total number of reference samples	Number of test samples	Total number of samples (reference and test)
Combined edge (east)	216	417	508	925
Combined riffle	148	332	182	514
Autumn edge	310	426	783	1209
Autumn riffle	246	320	368	688
Spring Edge	292	360	733	1093
Spring riffle	228	279	254	533
Combined edge (west)	35	53	268	321

Attributes of the models developed for AUSRIVAS in NSW

In total, seven AUSRIVAS models were developed for NSW. It was necessary to develop a separate model for the sites on the floodplains of the Murray-Darling Basin in Western NSW. Only a combined-season edge model was developed for these rivers as edge was the only available habitat and neither the spring nor the autumn collections from reference sites had enough taxa to allow the development of reliable single-season models in that area. Fig. 2 shows the geographic boundary used to develop the western combined model and the eastern edge models.

Predictor Variables

A list of predictor variables used in AUSRIVAS models for NSW is presented in Table 2. The variables used for each model are given in Table 3.

Table 2. Predictor variables used for each of the 7 models

Variable	Name in AUSRIVAS	Definition	Units
Elevation	ALTITUDE	Elevation at the site.	m
Distance from source	LOGDFSM	The longest distance that can be travelled along drainage lines (in metres) from the site to the top of the ridge delineating its catchment.	m
Latitude	LATITUDE	Latitude at the site (including negative eg. –33.33).	decimal degrees
Longitude	LONGITUDE	Longitude at the site.	decimal degrees
Slope	LOGSLOPE1KUS	The elevation difference (metres) between the site and a point 1km upstream along the river.	m
Stream width	LOGMODEWIDTH	Mode stream width at the site.	m
Riffle depth	LOGMODEDEPTH	Mode riffle depth at the site.	m
Mean annual rainfall	RAINFALL	Mean annual rainfall at the site.	mm
Alkalinity	ALKALINITY	A measure of the buffering capacity of the water expressed as the concentration of $CaCO_3$.	mg/L ($CaCO_3$)
% Bedrock	BEDROCK	Percentage cover of bedrock in the stream substratum at the site.	%
% Boulder	BOULDER	Percentage cover of boulder in the stream substratum at the site.	%
% Cobble	COBBLE	Percentage cover of cobble in the stream substratum at the site.	%

Table 2. Predictor variables used for each of the 7 models

	AUSRIVAS MODEL						
VARIABLE	Autumn Edge	Autumn Riffle	Spring Edge	Spring Riffle	Combined Edge (East)	Combined Riffle	Combined Edge (West)
Elevation	X	X	X	X	X	X	X
Distance from source	L	L	L	L	L	L	
Latitude	X	X	X	X	X	X	X
Longitude	X	X	X	X	X	X	X
Slope	L+1	L+1	L+1	L+1	L+1	L+1	X
Stream width			L		L	L	
Riffle depth						L	
Mean annual rainfall	X	X	X	X	X	X	
Alkalinity	X		X		X		
% Bedrock	X		X		X		
% Boulder	X		X				
% Cobble	X		X		X		

X = raw data used, L = data Log10 transformed, L+1 = Log10 x+1 transformed

Of the climatic variables included in development of the α-1 models, Mean Annual Rainfall is used as a predictor variable in 6 of the 7 models. The data source used to derive the Mean Annual Rainfall for sites used in the development of these models is part of the Annual Mean Precipitation data set created by ERIN in 1996 (see Fig. 3).

A major difference between the eastern models for the riffle and edge habitats is that the riffle models do not rely as much on subjectively estimated variables and those that are affected by human disturbances such as alkalinity and substratum composition. Although efforts were made to minimise the contribution of such variables in the edge models some were included as the reliability of the predictions were compromised if they were removed.

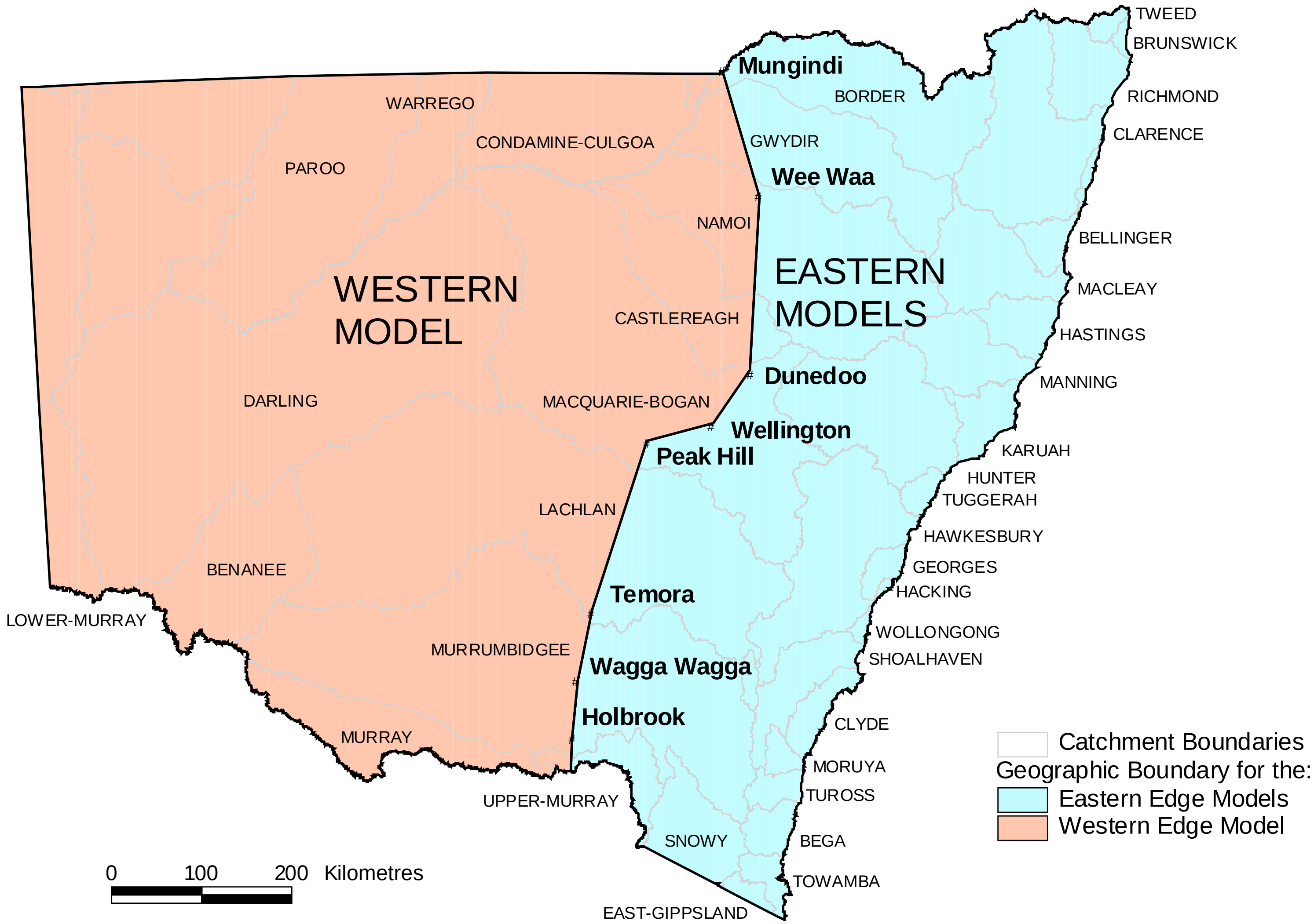

Fig. 2. Map of NSW showing the geographical boundary of the Western and Eastern Edge Models.

The new combined edge model for western NSW uses only permanent site attributes i.e. location, slope and elevation. This differs considerable from previous models that relied heavily on the subjective estimates of silt and clay for assessing sites on the floodplains of the Murray-Darling system. Upon examination of the environmental records it was found that silt and clay percentages recorded for given sites in this region, varied considerable between seasons. This was evident not only among recorders but also among different observations from the same recorder. This was true for both experienced and inexperienced recorders. This variation was later determined to be the cause of major fluctuations in O/E values for different sampling occasions. These fluctuations in O/E values occurred as sites in far western NSW were predicted in different site groups for different samples on the basis of the recorded substratum. Creation of the new combined edge model for western NSW has resulted in a major improvement in AUSRIVAS assessments at sites on the floodplains of the Murray-Darling system.

Due to the predictor variables selected, the new riffle models and the western combined edge model can be used reliably where human disturbances have lead to changes in alkalinity or substratum. This is particularly relevant to the riffle models where the deposition of sand and gravel in riffle zones often occurs as a result of poor management practice. Since the edge models use alkalinity and some substrate variables, caution should be exercised when using these models particularly in situations where the disturbance of concern is likely to have caused changes to these variables. Under such circumstances it would be necessary to use estimates of the "natural" values for alkalinity or substratum expected for the site. Values recorded at similar reference sites in the area can be used for this purpose.

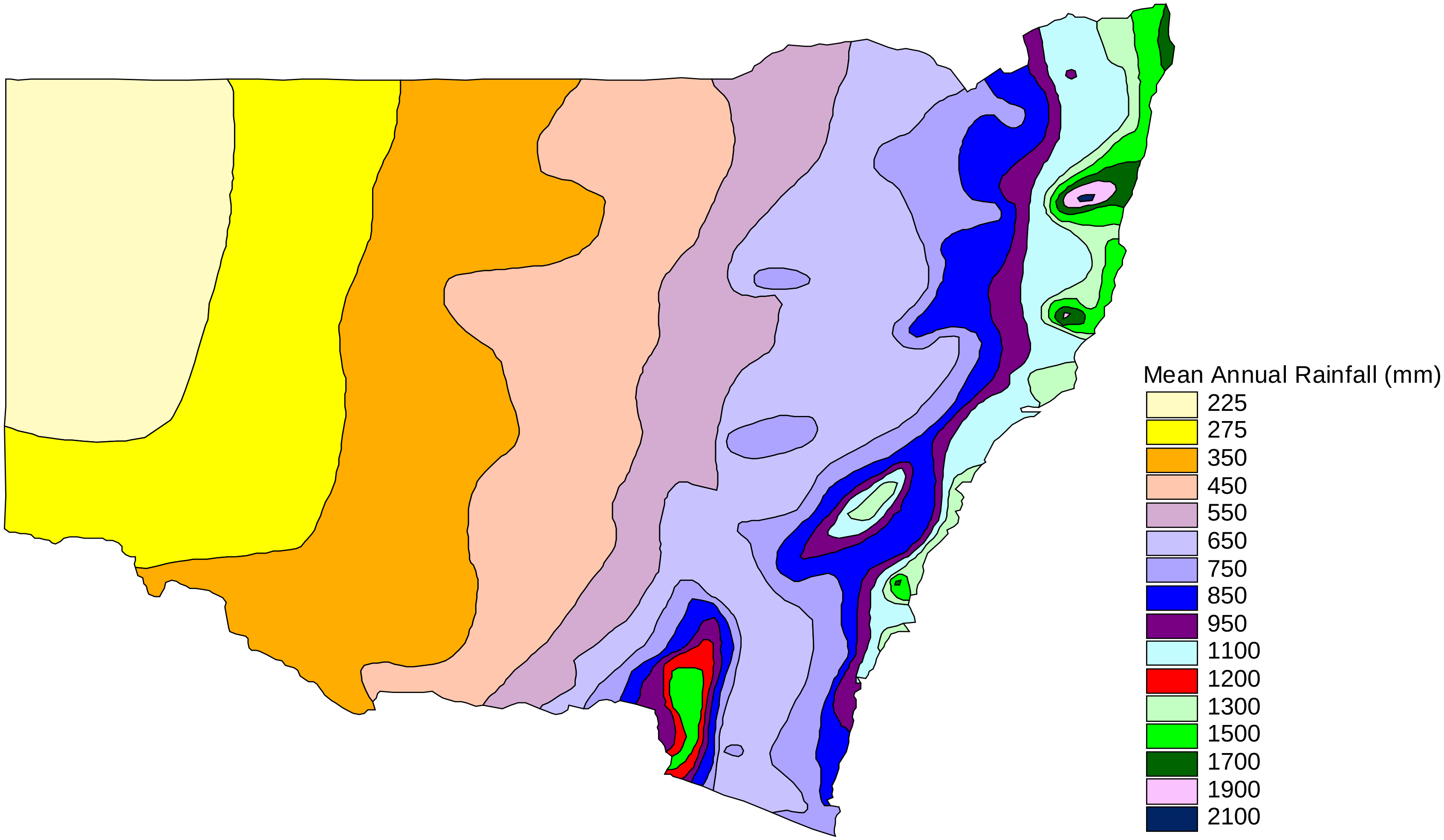

Fig. 3. Mean Annual Rainfall for New South Wales (Annual Mean Precipitation, ERIN, 1996).

Model Groups

Model groups for the 3 combined season models are presented in Figs. 4, 5 and 6. The combined models are representative of the groups produced for the single season models. These are also relatively similar to the biological groups formed in previous versions of the models i.e. β-1 and β-2 versions. One exception, however, is the distinction of separate groups for the northern and southern large rivers in the new models. Separate groups were also formed for small streams along the north and south coast in the riffle models. The new combined edge model for western NSW includes 3 biological groups from the north-west, south-west and slopes.

Other Attributes

Some other attributes of the current models are also presented in Tables 4 and 5, showing misclassification rates for the different models and thresholds for the bands of impairment. On the whole the new models are performing far better than the previous versions but more detailed examination of the sensitivity of the models to a wide range of disturbances is necessary to fully judge their utility.

Table 4. Number of biological groups and misclassification rates (%) for the AUSRIVAS models developed for NSW.

Model	Number of groups	Cross validation misclassification	Resubstitution misclassification
Combined Edge (East)	9	22.85	15.42
Combined Edge (West)	3	19.78	17.4
Combined Riffle	7	9.92	8.42
Autumn Edge	10	13.71	10.93
Autumn Riffle	8	17.15	14.03
Spring Edge	10	12.97	10.21
Spring Riffle	7	25.36	24.35

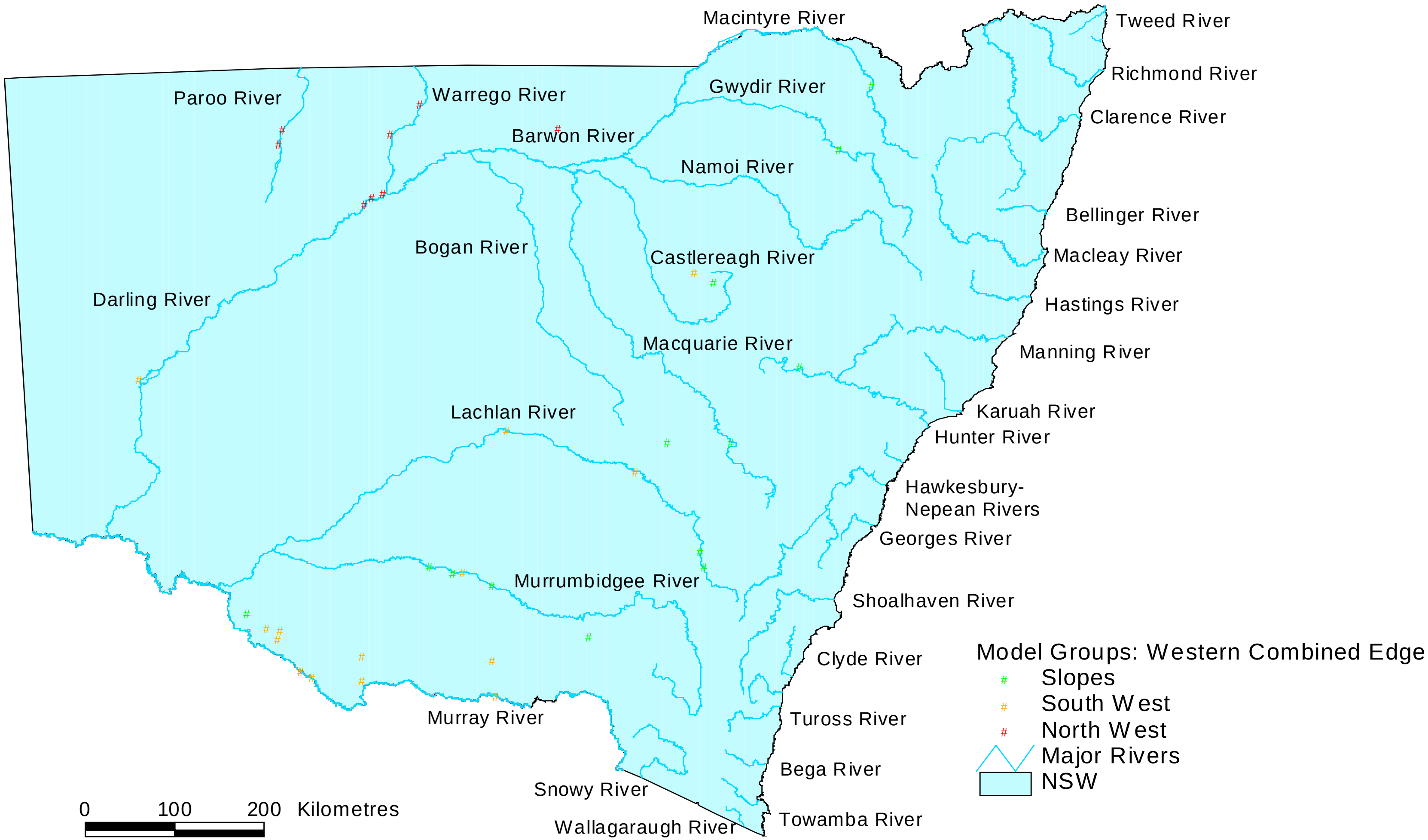

Fig. 4. Location of sites in model groups of the western combined edge AUSRIVAS model for NSW.

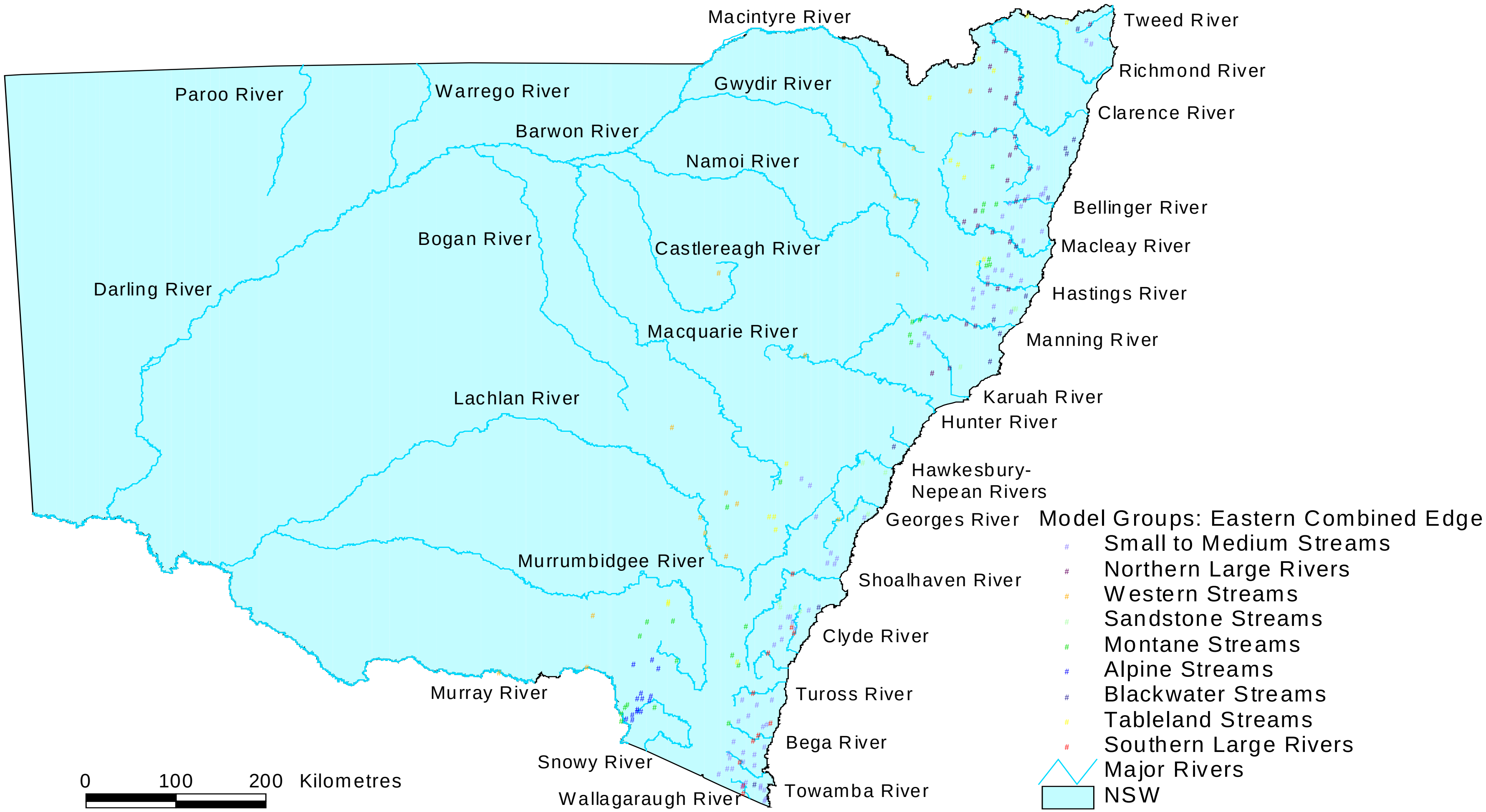

Fig. 5. Location of sites in model groups of the eastern combined edge AUSRIVAS model for NSW.

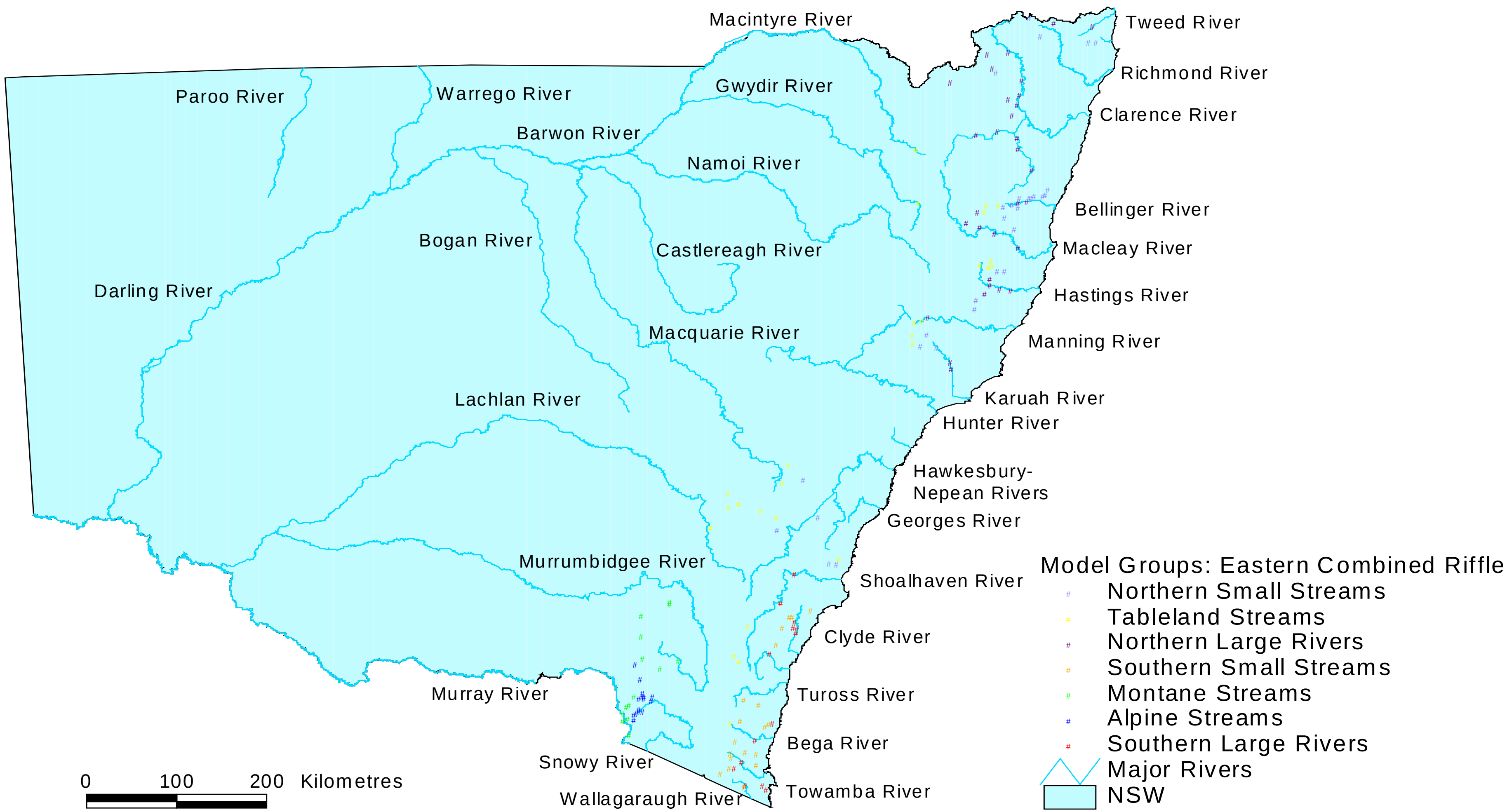

Fig. 5. Distribution of reference sites within model groups for the combined riffle AUSRIVAS model for NSW.

Table 5. Upper thresholds for bands of impairment (O/E-Taxa) for AUSRIVAS models developed for NSW.

Model	Threshold			
	A	B	C	D
Combined Edge (East)	1.17	0.82	0.48	0.14
Combined Edge (West)	1.14	0.85	0.57	0.29
Combined Riffle	1.14	0.85	0.57	0.29
Autumn Edge	1.17	0.81	0.46	0.11
Autumn Riffle	1.13	0.86	0.60	0.34
Spring Edge	1.16	0.83	0.51	0.19
Spring Riffle	1.18	0.80	0.43	0.06

Acknowledgments

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