Appendix 18: Planning for the persistence of river biodiversity in the Northern Rivers Region

1 Summary

1. An assessment was made of the condition of river biodiversity across the Northern Rivers Region using the integrity of riverine macroinvertebrate assemblages as a surrogate measure.
2. Using this assessment, together with data on various human-induced disturbances and a multi-attribute ecological river typology, river sections within the Northern Rivers Region were prioritised for actions aimed at ensuring the persistence of river biodiversity.
3. Several areas of high priority for catchment protection were identified outside of existing protected areas.
4. The river restoration priority map indicated that restoration actions taken in urban streams and near the main channels of large rivers are likely to be highly effective in maintaining and improving river biodiversity in the Region.
5. Some coastal river systems such as Bungawalbin Creek and Maria River were identified as having high regional conservation values for river biodiversity. These may be suitable locations to consider for actions aimed specifically at protecting freshwater biodiversity. The catchment protection and restoration priority maps may help identify the types of actions needed to achieve this.
6. The results obtained for this study are preliminary and need to be validated and refined on the basis of input from local experts and a wide range of stakeholders.

2 Introduction

A whole-of-landscape approach to natural resource management is needed to ensure the long-term persistence or regional biodiversity. It is only by evaluating a region in its entirety that it is possible to identify the areas in which land and water degradation will have significant impacts on regional biodiversity. This is particularly so for river biodiversity because of the highly connected nature of ecosystem units (i.e. river segments) within a drainage network and hence the potential for impacts on the river biodiversity in one location as a result of activities occurring at large distances upstream and downstream.

Developing a whole-of-landscape approach to the protection of river biodiversity in the Northern Rivers Region requires knowledge of river biodiversity and physical attributes of river ecosystems, and the pressures on river biodiversity across the Region. Such information has become available through the following initiatives:

- Assessments of the integrity of riverine macroinvertebrate assemblages made at more than 300 river sites sampled for the national River Health Program (Turak et al. 2002) and for the NSW river monitoring evaluation and reporting program (Muschal et al. 2009).
- Ecological river typology developed for NSW based on aquatic macroinvertebrates, fish and abiotic attributes (Turak & Koop 2008). The river typology has features that make it particularly suited for use as biodiversity surrogates in conservation planning such as the representation of broad-scale, high level similarities among biological assemblages and quantitative measures of compositional distances among the assemblages for the different river types (Turak & Koop 2008; Turak 2007).
- Methods developed by Stein et al. (1998, 2002) to quantify the disturbance of rivers in Australia at a continental scale, provide assessments that are suitable for planning exercises that have a large spatial extent. This method uses small subcatchments as the spatial unit of assessment and incorporates all upstream influences on the subcatchment while also allowing the tracking of the trajectory downstream connections.

Using these data and methods, this appendix presents an assessment of regional river biodiversity in the Northern Rivers Region and presents priority maps to guide major management actions aimed at maintaining and improving river biodiversity across the Region. The results presented here should be seen as preliminary and should not be used to guide management actions without validation and further analysis. Further development and validation of these methods are currently being undertaken to ensure greater reliability of the outputs.

3 Methods

A spatial model was developed that generates predictions of river biodiversity for alternative land management scenarios using spatial information (**Figure 1**). The ultimate outputs are predictions in the gains or losses in regional biodiversity for alternative land management scenarios.

The first step towards the development of this model was the quantification of local biodiversity at a stream section as a function of local disturbance. This allows for future local biodiversity to be predicted from anticipated future disturbance (**Figure 1**). The regional significance of this prediction for river biodiversity was then determined using river types.

The fundamental spatial unit used in the model is a river section, defined as the section of river or stream between nodes (confluences). The location of the nodes will depend on the drainage network used. The drainage network we used here was derived by Stein (2005, 2007) from a nine second resolution (~270 m) digital elevation model (Hutchinson et al. 2001) and associated definition of surface flow pathways.

The Region was then divided into small subcatchments that delineated the area draining directly to each stream section. These subcatchments form the basis of determining upstream–downstream connectivity. The attributes of the contributing area to each stream section were determined by adding the attributes of all subcatchments, weighted by their relative contribution to catchment run-off, above that section. To facilitate this we used a modified version (Stein 2005, 2007) of the Pfafstetter coding system of Verdin and Verdin (1999) which assigns to each subcatchment a specific code based on its location within the overall drainage system. The codes allow the immediate identification of all the subcatchments that are upstream from a stream section.

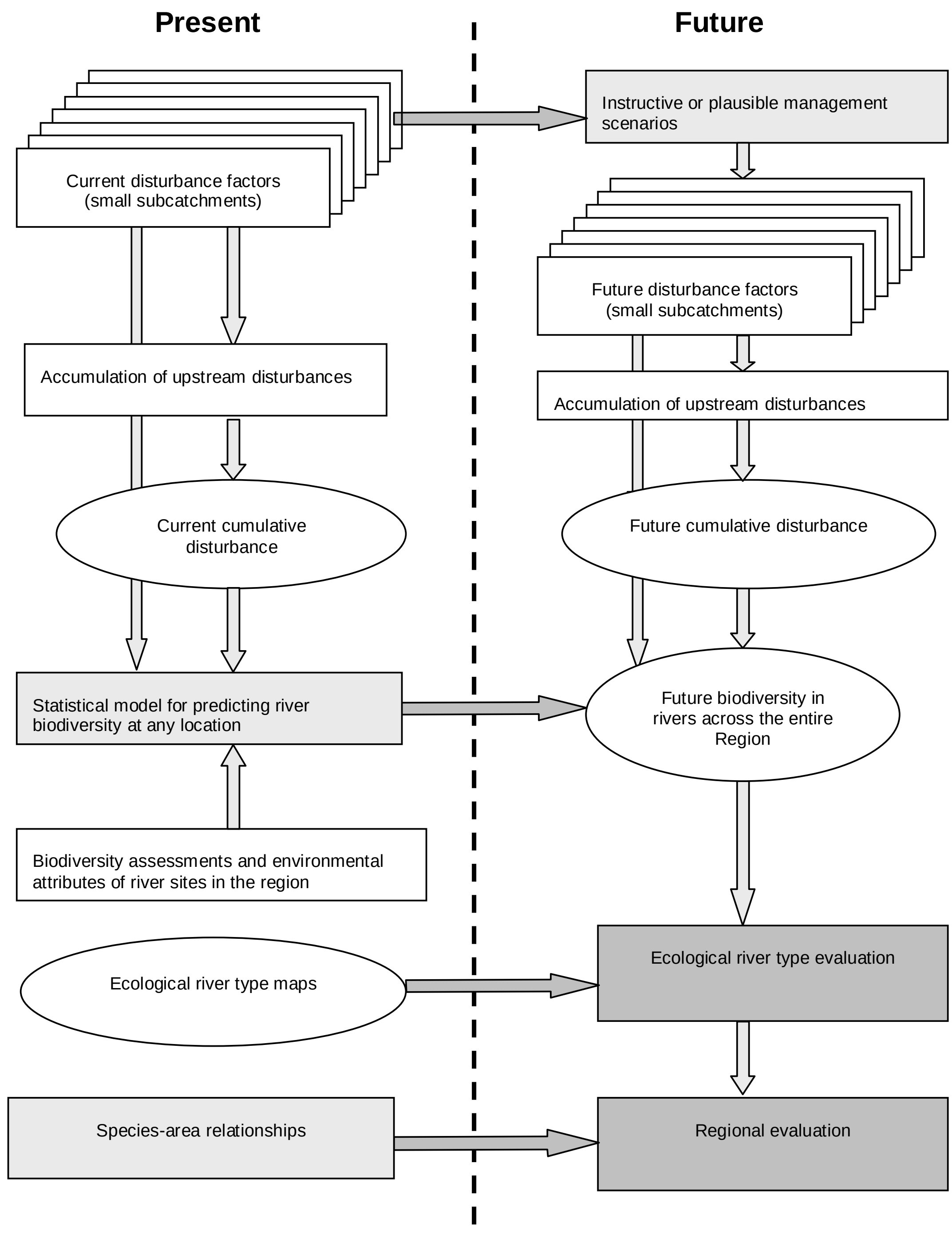

Figure 1 A spatial model for predicting the persistence of river biodiversity into the future

Current spatial data on river condition and biodiversity, and current ecological knowledge are used to make predictions for future biodiversity under different management scenarios. These scenarios may include implausible scenarios that have instructive value or they may be realistic scenarios comprising a number of different types of management actions at multiple locations.

Quantifying disturbance

To quantify local pressure on river reaches we used an index of anthropogenic disturbance developed to help identify wild rivers across Australia (Stein et al. 1998, 2002). This index uses seven different indicators to determine how much each river reach may have been modified from a pre-European (pre-1788) condition. The value of each of these indicators (factor scores) was calculated for every subcatchment or stream section, then weighted and combined to produce two summary indicators of local disturbance: the subcatchment disturbance index and the section flow regime disturbance index.

The subcatchment disturbance index (SCDI) incorporates the four factors calculated from separate indicators that reflect the spatial extent and potential magnitude of impact of activities occurring within the subcatchment:

- the extractive industries / point sources factor
- the infrastructure factor
- the settlement factor
- the landuse factor.

The section flow regime disturbance index (SFRDI) incorporates the three factors indicative of direct alterations to flow:

- the impoundments factor
- the levee bank factor
- the flow diversion factor.

SCDI and SFRDI values, weighted by their relative contribution to catchment run-off, were accumulated for all subcatchments upstream from each river reach to account for all upstream disturbances. This gives the catchment disturbance index and the flow regime disturbance index for each river reach. These values were then averaged to give the river disturbance index which we used as the single measure of local pressure of river ecosystems.

With the exception of the landuse factor, we used the values generated by Stein (2007) to represent each factor. These values were derived from primary data layers obtained from different databases (Stein et al. 1998, 2002; Stein 2007). We based the landuse factor values on the latest available landuse data from the Northern Rivers Region (DECC 2007). This meant that landuse factor values were at a high resolution and directly related to current management considerations in the Region.

To recalculate the landuse factor, we examined current landuse data layers available for the Northern Rivers Region (DECC 2007) and grouped the different landuse classes into 20 new classes, each of which were given a river disturbance weighting (see **Table 1**). The grouping and the weighting aimed to meaningfully link management actions with likely improvements in river biodiversity. It was based on local professional knowledge of river ecosystems and management targets relevant to the resource condition targets for both biodiversity and aquatic health (**Table 2**). The actions taken to meet management targets must shift landuse from one class to another with a lower weight. This would reduce the value of the river disturbance index which would be translated into an increase in the current biodiversity condition in the rivers affected.

Similarly, adverse changes to landuse would shift the landuse to a class that has greater weight and this would increase the river disturbance index and reduce biodiversity condition.

Table 1 The landuse categories used for computing the landuse factor and the weights given to each category

These categories were generated by grouping the landuse categories identified in detailed landuse maps for the Northern Rivers Region (DECC 2007).

Landuse code	Name	Weight	Explanation/Description
1	Recreation/park	0.30	Relatively high use areas with large proportions of planted grass where fertiliser use is common
2	Grazing – low tree cover	0.50	Light or no tree cover (<30%); nutrient and sediment impacts on streams are likely
3	High vegetation cover	0.00	High tree cover (>70%); optimum catchment condition for aquatic ecosystems
4	Low vegetation cover	0.40	Light tree cover (<30%) but little or no grazing; nutrient and sediment impacts are likely
5	Medium vegetation cover	0.15	Medium tree cover (30-70%); short-term target condition for replanting activities
6	Cropping	0.75	Heavy tillage operations; significant potential for nutrient, sediment and chemical impacts
7	Grazing – irrigated	0.55	Intensive grazing usually associated with dairying (usually nil tree cover)
8	Grazing – medium tree cover	0.40	Medium tree cover in grazing areas; some impacts from stock (30-70% cover)
9	Grazing – heavy tree cover	0.25	Heavy tree cover in grazing areas (>70% cover)
10	Horticulture	0.60	Intensive agriculture with likely input of nutrients and chemicals into streams
11	Organic pollution source	1.00	Intensive animal production, abattoirs or sewage ponds with discharges into waterways
12	Mining	0.90	Significant sediment input and acid, saline discharges into streams are likely
13	Industrial	0.90	Intensive landuse with multiple disturbances (e.g. hydrological, sediments, contaminants)
14	Waterways	0.00	All watercourses; they are not differentiated for condition
15	Urban – low density	0.50	Rural residential areas; similar to grazing with possible nutrient impacts (septic)
16	Urban – high density	0.85	High hydrological impacts and nutrient and sediment inputs into streams
17	Wetlands	0.00	Freshwater and estuarine wetlands and coastal lakes; they are not differentiated for condition
18	Grazing – sustainable *	0.25	Best management practice for grazing; limited nutrient and sediment impacts on the streams
19	Regrowth	0.15	Regrowth after clearing or native plantations
20	Exotic plantations	0.25	Softwood and poplar plantations

* This landuse class does not exist among current landuse but is equivalent to landuse code 9 in terms of its impact on streams

Table 2 Management targets, which are likely to influence river biodiversity through changes in landuse

Actions taken to meet these targets in any of the small subcatchments are expected to reduce the contribution of that subcatchment to river disturbance. This is quantified as the reduction in the value of the landuse factor resulting from changing landuse codes (see Table 1).

Management target	Corresponding change in landuse:
Protect native vegetation	Remains at 3 (prevent change)
Regenerate native vegetation	Changes from 4 to 5, or 5 to 3
Revegetation highly erodible soils	Changes to 8 regardless of the original code
Stabilise actively eroding soils	Changes to 5 regardless of the original code
Salinity revegetation	Changes to 5 regardless of the original code
Manage nutrient run-off	Changes from 11 to 7
Stabilise salt-affected areas	Changes from 2 to 5
Sustainable grazing management	Changes from 2 or 8 to 19 (or 9 in existing classes)
Protect native riparian vegetation	Remains at 3 (prevent change)
Regenerate native riparian vegetation	Changes to 3 regardless of the original code

Measuring biodiversity condition and predicting it from disturbance

As a measure of biodiversity condition we used observed/expected values generated from predictive models incorporated in AUSRIVAS—Australian River Assessment System (Davies 2000; Simpson & Norris 2000). The AUSRIVAS values indicate the proportion of macroinvertebrate taxa expected at a river location that were actually observed there (Simpson & Norris 2000). The regression model used for the Northern Rivers Region was based on the results of assessments made at 332 river sites across the Region between 1994 and 2008 (Turak et al. 2002; Muschal et al. 2009). We used the medians of the AUSRIVAS observed/expected values to represent the biodiversity condition separately for edge habitats and riffle habitats. Edge habitats are defined as areas on the edges of rivers with little or no flow. Riffle habitats are zones with broken water over stony substratum (Turak et al. 2004). The riffle habitat was not present at some sites, in which case the median observed/expected value for the edge habitat was used to represent the biodiversity condition at the site. Where both habitats were sampled, we averaged the results for the two habitats to obtain an overall assessment for invertebrate assemblages for these sites.

To predict biodiversity condition from disturbance, we fitted a generalised linear regression model in R statistical program (R Development Core Team 2004), where the observed/expected value observed at the sampling sites was the dependent variable, and the disturbance indices measured at subcatchments or river sections containing those sites were independent variables. Both cumulative disturbances upstream and local disturbances (including changes to the riparian zone and landuse in the immediate area) will affect instream biota at any location. To allow for this we included measures of local disturbance (subcatchment disturbance index, section flow regime disturbance index and the seven factor scores) as well as the accumulated disturbance measures (catchment disturbance index, flow regime disturbance index and river disturbance index) as independent variables in the model. Given that the disturbance indices give only coarse measures of pressure on river reaches, we assumed that the relationships between upstream catchment disturbances and the biodiversity measures may vary across the Region depending on the location. To account for such differences we considered maximum distance from source, elevation, slope, mean annual rainfall, and ecological river types (Turak & Koop 2008) as potential independent variables in the model. The regression equation for this model (**Table 3**) was used to estimate the biodiversity condition in all river sections in the Region and to predict how biodiversity condition might change in the future in response to changes in disturbances in the catchment.

Table 3 The coefficients for the regression model for observed/expected values from the river edges for calculating future (predicted) biodiversity

Model parameter	Estimate
Intercept	0.79
Natural logarithm of elevation (LOGELEV)	0.01
River disturbance index	–0.50
Subcatchment disturbance index	–0.30

This regression equation was applied to predict the current or future condition for all river reaches in the Region based on the values of the disturbance factors. By dividing these by values computed assuming no disturbance, we produced the future condition of the rivers in the Region relative to a pre-European condition.

Mapping ecological river types

The ecological river types (Turak & Koop 2008; Turak 2007) were mapped from identification keys based on slope, elevation, maximum distance from source, mean annual rainfall and latitude (Turak 2007). To do this, first a comprehensive drainage network in the Region was determined using ESRI's ArcHydro extension in ArcGIS (ESRI 2005). This hydrological analysis used existing high resolution drainage data and created a network of river reaches with catchment areas greater than or equal to 1.6 km^2. Maximum distance from source was calculated for the catchment using Arcview 3.3's Hydrotools extension (ESRI 1999). Values along the network for distance from source, elevation and rainfall were extracted from created data, a 25 m digital elevation model and NSW-wide annual rainfall data, respectively. River reach slope was calculated using the elevation network grid and a method involving neighbourhood analysis and spatial analyst, outlined by the Forest Service (USA) and undertaken in ArcGIS (ESRI 2005).

To map the river typologies, spatial analysis was used to combine and extract various areas of river for each river type, using the classification keys given by Turak (2007) and the mapped attributes outlined above.

For this study we have used three of the four river typologies defined by Turak and Koop (2008): the macroinvertebrate edge, abiotic and fish typologies. We will refer to the macroinvertebrate edge river types as 'macroinvertebrate river types'.

The biodiversity persistence index

The currency by which any scenario is evaluated is the biodiversity persistence index. Index values may be calculated for each class within a given river typology. Index values were first calculated for each river type within each typology and then for all rivers in the Region. Calculations of biodiversity persistence index values are based on the concept of the 'original habitat area' and 'effective habitat area' for each subcatchment. Original habitat area represents a condition in which all rivers types are in an undisturbed condition of 1.00, and effective habitat area represents an area for each river type that is reduced by the proportion of deviation from 1.00. We used species–area relationship rules, applied in a wide range of ecosystem types, to convert the ratio of effective to original habitat areas into the biodiversity persistence index. This involved assigning a species–area exponent value z to the ratio for each area unit. We chose a z value of 0.25 (Ferrier et al. 2004).

Prioritisation of subcatchments

Priority index values were calculated to prioritise subcatchments for different types of management actions. Three types of priority indices were estimated.

1. *Catchment protection priority*: This is to identify subcatchments to target for protection. It is an estimate of the relative contribution that protecting each subcatchment makes to the maintenance of current river biodiversity in the Region. It was calculated as follows.
    - The 'current' biodiversity persistence index was calculated using current landuse factor, settlement factor and infrastructure factor values.
    - The 'degraded' condition was simulated by changing the landuse, settlement and infrastructure factors of each subcatchment to 1 (irrespective of current value).
    - The biodiversity persistence index value under this degraded condition was calculated for the whole Region.
    - The priority value is the difference between current and degraded biodiversity persistence index values for that subcatchment.

2. *Catchment restoration priority*: This was done to identify subcatchments to target for remedial action. It provides an estimate of the relative contribution of such actions based on their likely effect on river biodiversity downstream. Calculations were made as follows.
    - Current biodiversity persistence index was calculated using current landuse factor, settlement factor and infrastructure factor values.
    - Improvement in condition was simulated in accordance with the following rules for each of the landuse, settlement and infrastructure factors:
        - if factor value ≤ 0.2, then it was adjusted to 0
        - if factor value > 0.2, then 0.1 was subtracted from factor value.
    - Biodiversity persistence index was then recalculated for the whole scenario.
    - Priority value is the difference between current and restored biodiversity persistence index.

3. *River section conservation priority*: This is to identify river sections that have high conservation value because of the significance of their biodiversity for the Region. Because it is particularly important to protect the biodiversity in these river sections, they may be suitable for inclusion into freshwater protected areas and be the focus of intensive and costly protection and restoration activities both within that river section and across its entire catchment. To estimate the importance of an individual river section, regional biodiversity persistence with and without that river section was calculated. The difference between these two scenarios, divided by the subcatchment area, can be taken as the relative importance of that river section within the Region. Priority = $(BDI_{\text{with river section}} - BDI_{\text{without river section}})$/ area of subcatchment.

For these three types of priorities, we used the average of priority index values calculated separately for the macroinvertebrate, fish and abiotic typologies. This average was then used to represent the rank position of each of the subcatchments and then converted into rank percentiles and these then mapped across the Region under seven priority categories (1 being the highest and 7 the lowest) as show in **Table 4**. In choosing these categories, we used an approach developed for producing similar priority maps for terrestrial biodiversity conserve or repair priorities based on the normal distribution of ranked priority values of all grid cells in the planning area (Andrew Steed pers. comm.).

Table 4 Mapped priority categories

Priority category	Value
1	0.95 – 1.00
2	0.85 – 0.95
3	0.65 – 0.85
4	0.35 – 0.65
5	0.15 – 0.35
6	0.05 – 0.15
7	0.00 – 0.05

4 Results

River condition

The modelled biological condition of rivers varied greatly across the Northern Rivers Region (**Figure 2**). Predictions of very poor condition were limited to streams within large urban centres such as Armidale, Port Macquarie, Coffs Harbour, Lismore, Grafton and Murwillumbah. Extensive areas with streams in poor condition were limited largely to the lower parts of the Richmond, Tweed and Brunswick catchments. However, smaller areas were also in poor condition, including in the Lower Clarence around Grafton, the lower Macleay around Kempsey, sections of the Northern Tablelands in the Upper Macleay catchment around Armidale, and to the north of Tenterfield. The following areas were in moderate condition: most of the tablelands section of the Upper Macleay; the southern parts of the upper Clarence; most of the Richmond, Tweed and Brunswick catchment; and the lowlands of the Clarence and Hasting valleys. Rivers in large parts of the Hastings, Macleay, Bellinger and Clarence catchments were predicted to be in good condition as well as upland streams in the southern and northern sections of the Richmond catchment and streams on the Tweed escarpment. Rivers in very good condition were largely confined to the escarpments, but large sections of the coastal fringe to the north of Corindi were also in very good condition.

Catchment protection priority

Most areas of very high protection priority (**Figure 3**) were either within or adjacent to protected areas. Some of the most notable examples of areas outside of reserves were the headwaters of the tributaries Mann, Boyd and Timbarra rivers in the Clarence catchment including streams of the Northern Tablelands in areas to the east of Glen Innes and Tenterfield. The headwaters of the Ellenborough River in the Hastings catchment, and Tia and Georges rivers in the Macleay catchment were also among the areas outside of the reserve systems defined as having very high protection priority.

There were large areas identified as having high catchment protection priority in the Hastings catchment (upper Papinbarra, Forbes and Ellenborough rivers); south-west and far north-west sections of the Richmond catchment; and areas adjacent to Washpool, Nymboida, Gibraltar Range, Cheulundi, and Nymboida national parks. In the Clarence catchment, areas to the east of New England National Park in the Bellinger catchment also had high catchment protection priority.

It is particularly important to identify areas of high priority for catchment protection that were outside of the reserve system, given that these are the areas where there is the greatest potential for clearing and other major changes to catchment condition. Management actions aimed at protecting the existing vegetation in these areas are likely to be particularly important for ensuring the persistence of river biodiversity in the Region.

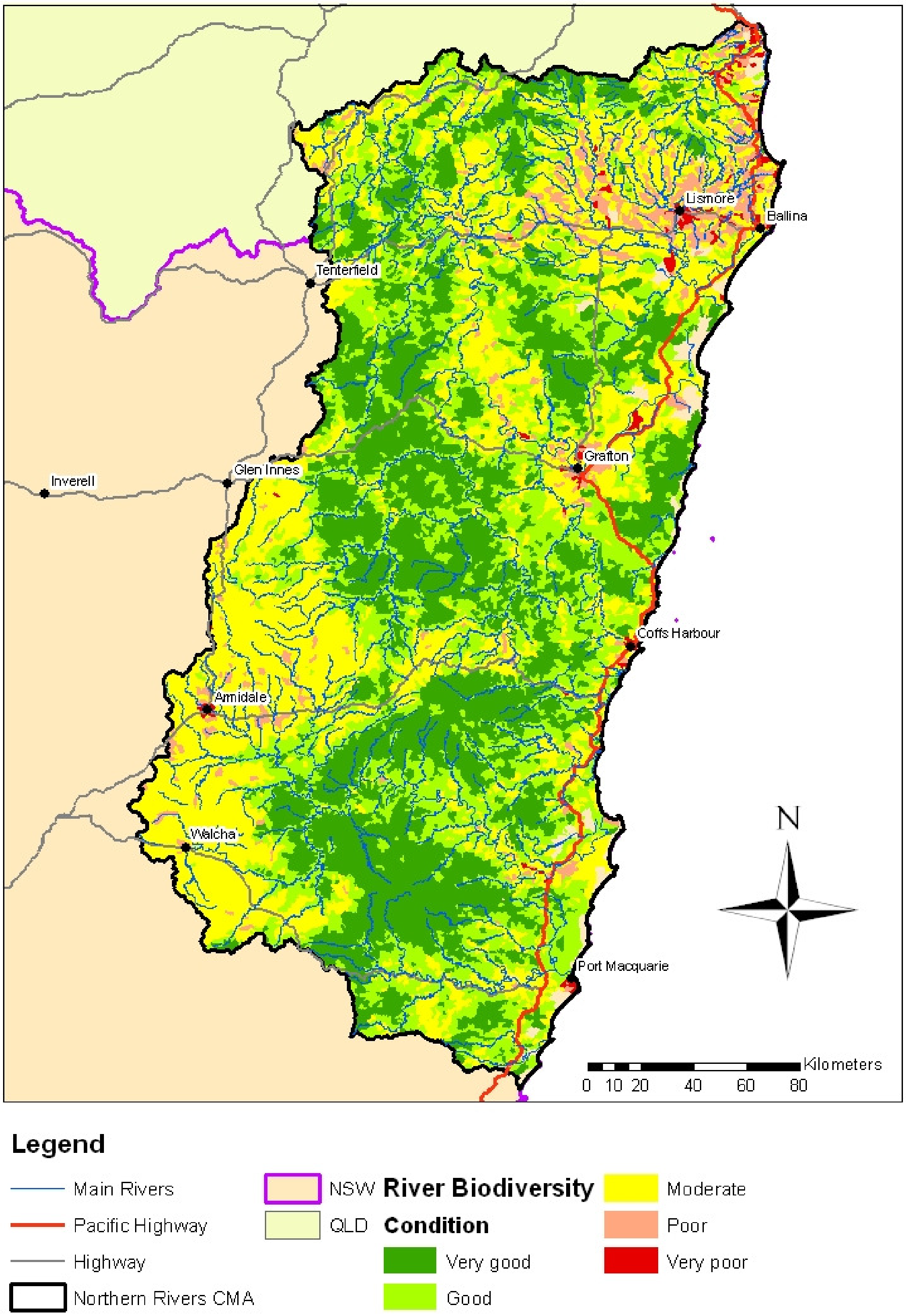

Figure 2 Predicted current condition of river biodiversity relative to an undisturbed condition.

This condition was estimated for each of more than 18 000 river reaches in the Region.

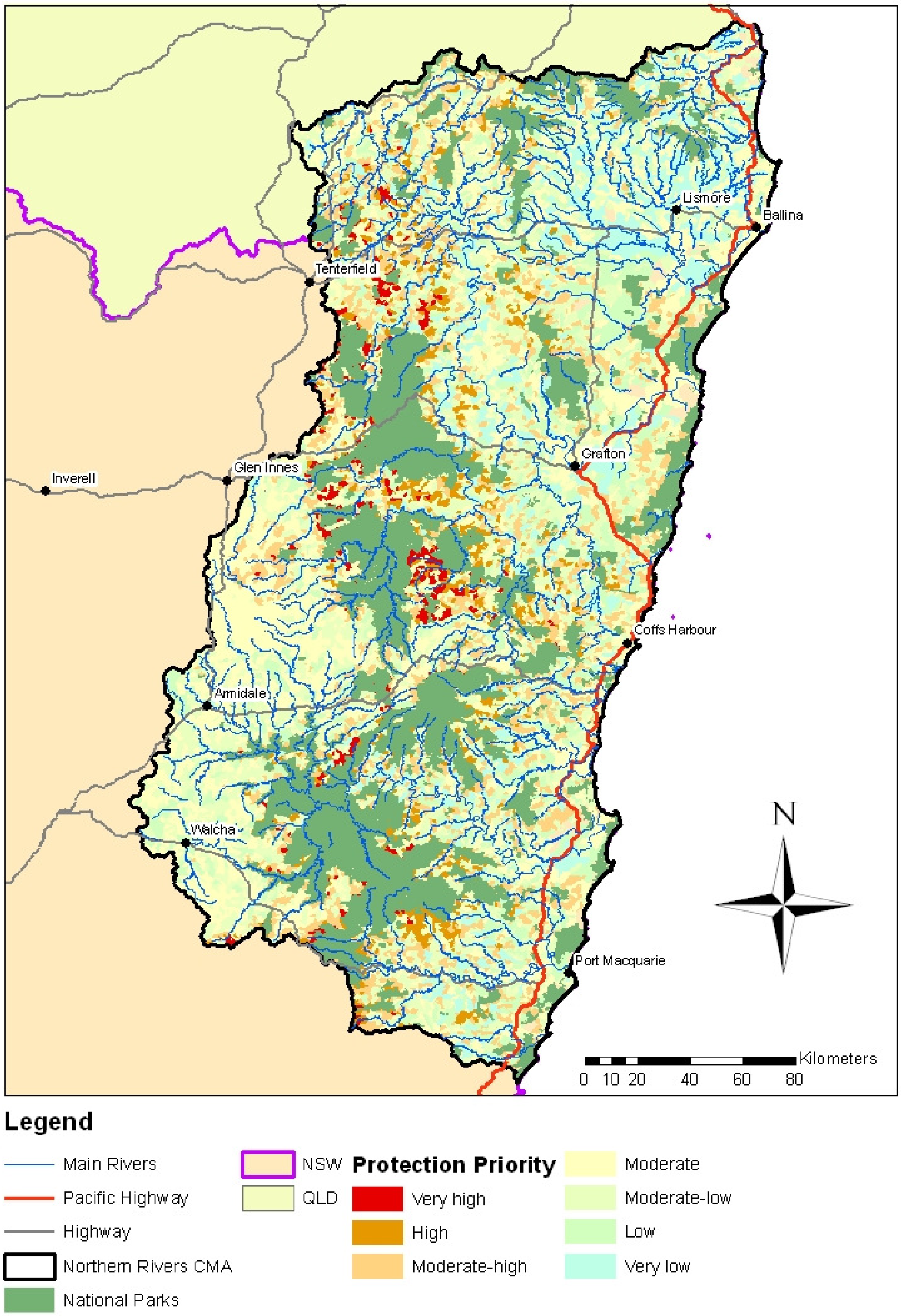

Figure 3 Catchment protection priorities for river biodiversity

This map shows the predicted levels of loss of river biodiversity under a scenario loss of existing vegetation cover and land degradation.

Restoration priority

The areas of high priority for catchment restoration (**Figure 4**) were mostly along the valley floors of the major rivers and their large tributaries. However, there were also some areas of high restoration priority in the headwaters such as the north-east section of the Richmond catchment to the west of the Tweed Escarpment, and headwaters of the Bellinger to the south-east of Dorrigo (both partly within reserves). Streams within most large urban centres were also given very high priority for restoration. The largest contiguous areas of very high restoration priority were on the floodplains of the Richmond River downstream from Casino. Only few, small areas immediately adjacent to the coast were given high restoration priority. These included areas surrounding Kempsey, Coffs Harbour, and parts of the coastal fringe in the Richmond, Brunswick and Tweed catchments.

Areas of high restoration priority include large sections of all major catchments including extensive areas along the coast in the Hasting and Bellinger catchments.

The patterns shown in the restoration priority map (**Figure 4**) suggest that restoration activities in many of the heavily populated parts of the Region have a potential to make significant contribution to the maintenance and improvement of river biodiversity in the Northern Rivers Region.

River section conservation priority

Although many of the river sections that were identified to have the highest conservation value (Figure 5) were within existing reserves, there were some large areas that contained streams outside of protected areas.

There are notable examples of these near the coast, including: large sections of the Bungawalbin Creek in the Richmond catchment; Sandon River, Coldstream River and Mangrove Creek in the Clarence; and Maria River and Cowarra Creek in the Hastings catchment.

Further inland, middle sections of the Kalang and Nambucca Rivers in the Bellinger catchment; Styx River in the Macleay catchment; Henry, Timbarra and Kangaroo rivers and Chandlers Creek in the Clarence catchment; and Stewart and Wilson rivers in the Hastings catchment were some of the notable river sections of high conservation priority outside of protected areas.

Some of the river sections with high conservation value that are within reserves are still highly vulnerable because their upstream sections are outside of reserves and many of them are in moderate to poor condition. Because of this, these areas often are given low protection priority but they often get high restoration priority. Examples of these are Timbarra River above Washpool National Park; Mann River above Nymboida National Park; Henry, Sara and Aberfoyle rivers and Pantons, Kangaroo, Doughboys and Nowlands creeks above Guy Fawkes National Park in the Clarence catchment; and Oaky, Macleay, Apsley, Tia and Yarrowitch rivers above Oxley Wild Rivers National Park in the Macleay catchment.

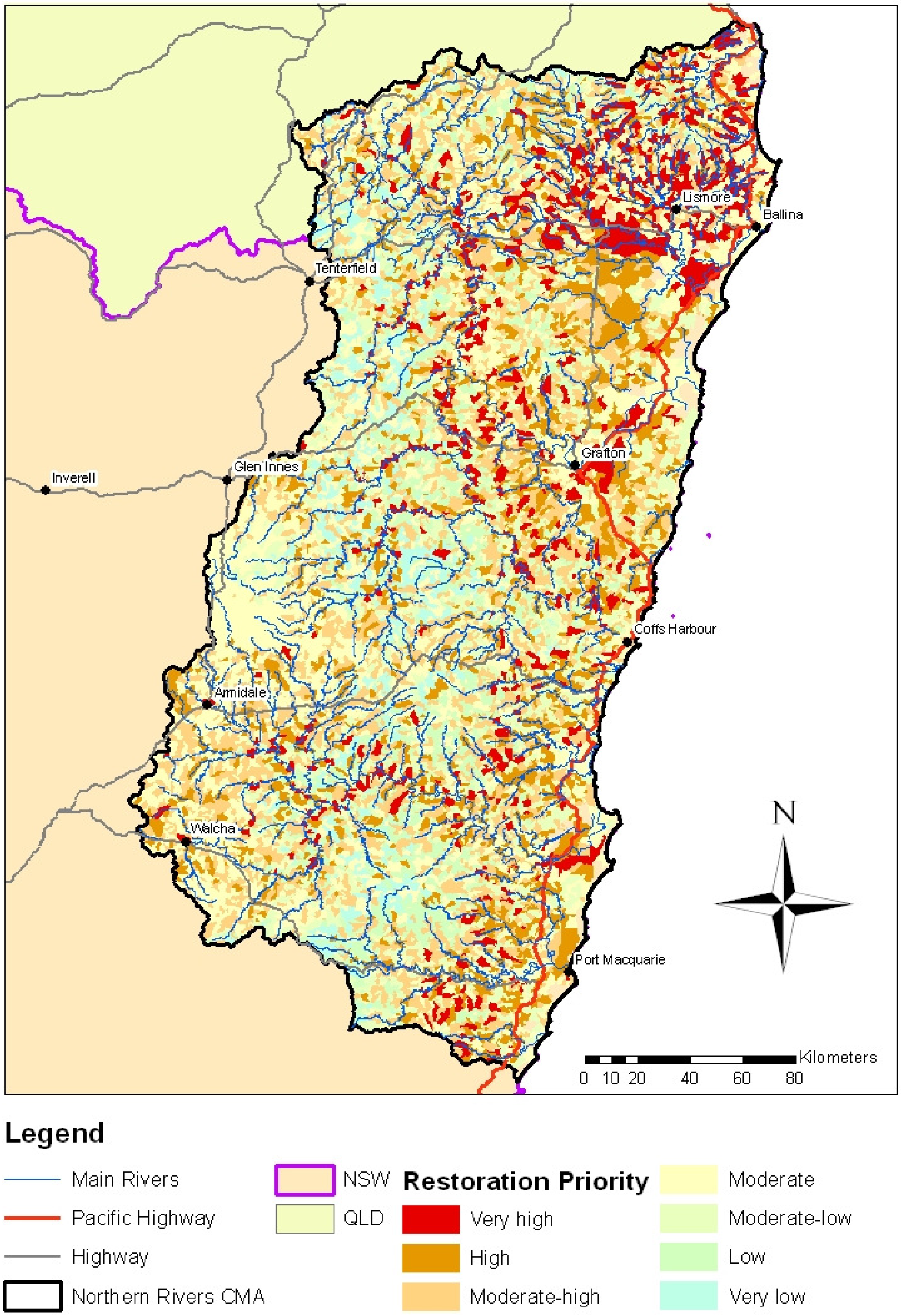

Figure 4 Catchment restoration priorities for river biodiversity

This map shows the predicted levels of improvement in river biodiversity under a scenario of effective restoration actions.

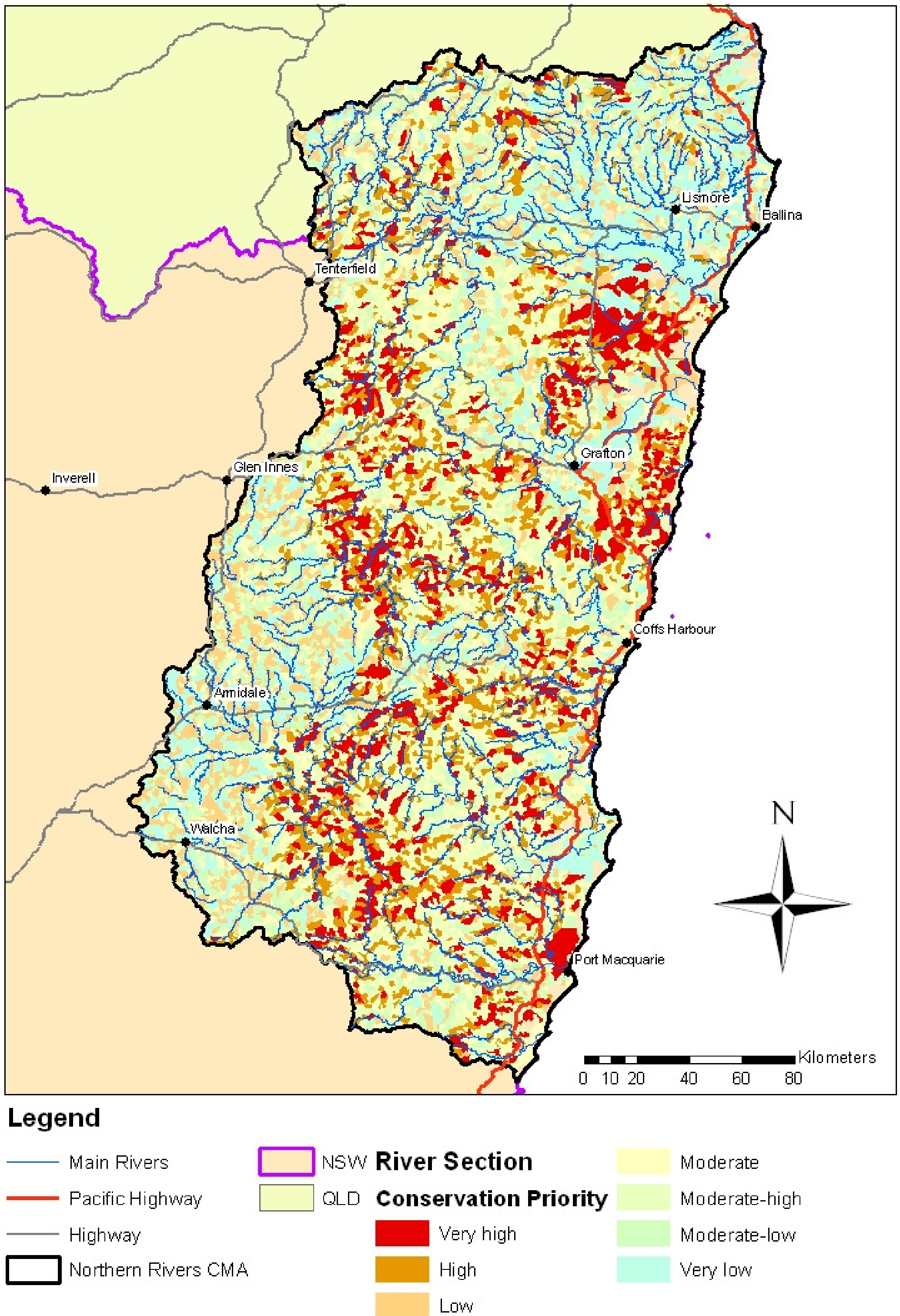

Figure 5 River section conservation priorities for river biodiversity

This map shows the predicted effect on regional biodiversity of scenarios under which all river biodiversity within each subcatchment is lost.

5 Using the outputs to guide management actions

Spatial prioritisation of management actions aimed at maintaining and improving river biodiversity can assist greatly in natural resource management in the Northern Rivers Region. The preliminary results presented here illustrate how this may be done. However, there is a need to validate these methods using local expertise and to improve the utility of this method based on feedback from a wide range of stakeholders.

The biodiversity condition map (**Figure 2**) and the three priority maps (**Figures 3 to 5**) need to be considered together in making decisions about management actions, but different types of management decisions are likely to be based more heavily on one or two of these maps.

For any major decision about changes to the management of areas with high cover of native vegetation (i.e. new developments or additions to the reserve system) the primary guide (in the context of river biodiversity) should be the catchment protection priority map (**Figure 3**). Considering this map alone, however, may lead to inadequate protection of some of the intact areas on the coastal fringes because none of the catchments of the coastal fringe streams were identified as having very high protection priority despite the very good condition assessment (**Figure 2**) and the high estimates of river section conservation priority (e.g. the catchment of Wooli Wooli River within Yuraygir National Park, **Figure 5**). It is possible that for catchments of smaller rivers, especially on the lowlands, the river section conservation priority needs to be given considerable weight together with the catchment protection priority in relation to decisions about new developments or additions to the reserve system.

For prioritising investment in restoration actions that are likely to reduce erosion and sedimentation and improve water quality, the catchment restoration priority (**Figure 4**) is likely to be the most useful first guide. The priority map suggests that restoration actions focused on streams in the large urban centres of the Northern Rivers Region and those performed close to the main stream of large rivers, such as the Clarence, Macleay and Richmond, are likely to make a very significant contribution to regional river biodiversity. Restoration actions in cleared areas, both on the tablelands and on the coastal plains, are also likely to be effective but they may need to cover a larger area than the actions mentioned above to have equivalent benefits.

Regarding decisions about new developments, new protected areas and investments in restoration actions, the outputs described here would comprise just one of the many types of inputs used. For example, considerations of river biodiversity may not influence these decisions any more than priorities for terrestrial biodiversity. However, for management solutions specifically aimed at protecting freshwater biodiversity (such as the establishment and management of freshwater protected areas), persistence of river biodiversity may become the primary consideration. The river section conservation priority (**Figure 5**) may provide the best basis for selecting suitable areas for freshwater protected areas because it helps identify rivers of high conservation value in the Region. Once this decision is made, the catchment protection priority (**Figure 3**) and the catchment restoration priority (**Figure 4**) may be used to guide the management of the area, the catchment above, and any adjacent areas that may affect the aquatic biodiversity within the freshwater protected area. For example, the river section priority map (**Figure 5**) suggests that the lower sections of Bungawalbin Creek may be an important focus for protecting freshwater biodiversity in the Region so this area may be a suitable choice for a ‘freshwater focal area’ as part of an approach to freshwater protected areas based on place-based management strategies (see Abell et al. 2007). Under this approach, freshwater focal areas are located where the biodiversity features of special interest are found. The protection of these features is ensured by actions taken not only at those locations but also in two different zones: the critical management zones and catchment protection zones (Abell et al. 2007). In the case of Bungawalbin Creek, the catchment protection and catchment restoration priorities can be used to delineate the critical management zone and the catchment management zone and to prioritise management actions within these zones.

6 References

Abell, R. Allan, D. Lehner, B. 2007, Unlocking the potential of protected areas for freshwaters. Biological Conservation 134: 48-63.

Davies, P. E. 2000, Development of the National River Bioassessment System (AUSRIVAS) in Australia. Pages 113-124 in J. F. Wright, D. W. Sutcliffe, and M. T. Furse, editors. Assessing the biological quality of freshwaters: RIVPACS and other techniques. Freshwater Biological Association, Cumbria, UK.

DECC 2007, 100m Land use Grid (ANZLIC v1.2 Metadata Standard) Department of Environment and Climate Change. Sydney

ESRI 1999, ArcView Version 3.2. Environmental Systems Research Institute, Inc.,Redlands, CA.

ESRI 2005, ARCGIS Version 9.1. Environmental Systems Research Institute, Redlands, CA.

Ferrier S., Powell G. V. N., Richardson K.S., Manion G., Overton J. M., Allnutt T. F., Cameron S. E., Mantle K., Burgess N. D., Faith D. P., Lamoreux J. F., Kier, G., Hijmans R. J., Funk V. A., Cassis G. A., Fisher B. L., Flemons P., Lees D., Lovett J. C. & van Rompaey R. S. A. R. (2004) Mapping more of terrestrial biodiversity for Global Conservation Assessment. BioScience, 54, 1101-1109.

Hutchinson, M.F., Stein, J., & Stein, J. 2001, *Upgrade of the 9 Second Australian Digital Elevation Model. A Joint Project of CRES and AUSLIG*. Retrieved 2nd. August, 2004, from http://cres.anu.edu.au/dem/index.php#4

Muschal,M., Turak, E., Miller, J., Gilligan, D., Sayers J. and Healey, M. 2009, DRAFT Technical Support Document – Riverine Ecosystems NSW State of the Catchments 2008. NSW Government, June 2009.

R Development Core Team 2004, R: A language and environment for statistical computing. ISBN 3-900051-00-3, URL http://www.R-project.org. in. R Foundation for Statistical Computing, Vienna.

Simpson, J. C., and R. H. Norris 2000, Biological assessment of river quality: development of AUSRIVAS models and outputs. Pages 143-163 in J. F. Wright, D. W. Sutcliffe, and M. T. Furse, editors. Assessing the biological quality of freshwaters: RIVPACS and other techniques. Freshwater Biological Association, Cumbria, UK.

Stein, J.L. 2005, A national landscape framework for river and stream conservation: developing a new stream and catchment reference system. Presented at *Fourth Australian Stream Management Conference: linking rivers to landscapes.* Launceston Tasmania, 19-22 October 2004. Rutherford, I.D., Wiszniewski, I., Askey-Doran, M. and Glazik, R. (Eds). Department of Primary Industries, Water and the Environment pp. 548-552.

Stein, J.L. 2007, A continental landscape framework for systematic conservation planning for Australian rivers and streams. PhD Thesis, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Stein, J.L, Stein J.A., Nix, H.A. 1998, The identification of wild rivers: methodology and database development. Environment Australia. Canberra. http://www.heritage.gov.au/anlr/code/pubs/wildrive.pdf (last accessed on 26/May/2009).

Stein, J.L, Stein J.A., Nix, H.A. 2002, Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia Landscape and Urban Planning, 60, 1-25.

Turak E., Hose G., & Waddell N 2002, Australia-wide assessment of River Health: New South Wales Bioassessment Report (NSW Final Report), Monitoring River Health Initiative Technical Report no 2a. Commonwealth of Australia and NSW Environment Protection Authority, Canberra and Sydney. http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/nsw/index.html (last accessed 26 May 2009).

Turak, E 2007, An Ecological Typology of the Rivers of New South Wales, Australia. PhD thesis. University of Technology Sydney, NSW Australia.

Turak E and Koop K 2008, A multi-attribute ecological river typology for assessing river condition and conservation planning. Hydrobiologia: 603:83-104. DOI 10.1007/s10750-007-9249-0.

Turak, E., N. Waddell, and G. Johnstone 2004, New South Wales Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual. http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/Man/Sampling/NSW/NSW_Ausrivas_protocol_Version2_2004.pdf, Commonwealth of Australia and NSW Department of Environment and Conservation, Canberra and Sydney.

Verdin, K. and Verdin, J.P. 1999, A topological system for delineation and codification of the Earth's river basins. Journal of Hydrology, 218 1-12.

Hurstville. Available at: http://www.environment.nsw.gov.au/determinations/MontanePeatlandsEndSpListing.htm.

Turak, E, Hose, G, & Waddell, N 2000, *Australia-Wide Assessment of River Health: New South Wales Bioassessment Report (NSW Final Report)*, Monitoring River Heath Initiative Technical Report No. 2a, Commonwealth of Australia and NSW Environment Protection Authority, Canberra and Sydney. Available at: http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/nsw/index.html