The Tasmanian Conservation of Freshwater Ecosystem Values (CFEV) framework: developing a conservation and management system for rivers.

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1. Introduction

The Tasmanian Government initiated the development of a State Water Development Plan in 1999, which has been active since 2000/01. The Plan had two main arms: exploring and initiating opportunities for further development of water resources through expansion and intensification of infrastructure, water use and trading; and evaluation of environmental aspects of water management. A scoping review of environmental aspects pertaining to the WDP by Davies 1999 made two sets of recommendations: changes to existing water management and planning processes, and the development of a conservation system for freshwater dependent ecosystems. Davies (1999) recommended the development of a conservation system based on the 'CAR' principles (Comprehensiveness, Adequate and Representative), locally familiar through such processes as the Tasmanian Regional Forest Agreement. The emphasis of the recommendation was on developing a 'reserve system' for freshwater dependent ecosystems involving a suite of formal and informal ‘reserves’, which were to be coupled with improved water management and planning processes.

Subsequently, during 2000/01, the Tasmanian government approved the development of a CAR-based freshwater conservation system, and allocated funding. This has now become the CFEV (Conservation of Freshwater Ecosystem Values) framework project, and has expanded on the initial remit of the Davies (1999) review to include:

- All freshwater dependent ecosystems (rivers, estuaries, wetlands, other waterbodies, groundwater dependent ecosystems, and saltmarshes);
- A standardized assessment of conservation values;
- A standardised assessment of conservation management priority.

The CFEV framework project is not aimed at establishing ‘reserves’. Instead, it is focused on establishing a system in which all examples of each ecosystem type (mapped at 1: 25 000 scale) are assigned a relative conservation value (accompanied by a wide range of biophysical condition and classification data underpinning it’s development) and management priority, so that water, catchment and natural resource management and planning for at state and regional level could work from a consistent basis with regard to conservation and management of freshwater ecosystem values.

This paper provides a brief introduction to the framework project, which is a ‘work in progress’. An overview of the framework is followed by some detail on the conduct of an Audit of river condition and biophysical classes. The project is progressing rapidly and is scheduled for completion in mid 2005.

2. The CFEV Framework

The framework is being developed as shown in Figure 1, and has several key elements:

1. Audit: An audit of the biophysical types (classes) of all freshwater dependent ecosystems and of their biophysical condition. This required the collection/collation of consistent data at a statewide level on key biological (e.g. faunal and floral species and assemblages etc) and physical (e.g. geomorphological, flow regime etc) components of the mapped ecosystems (e.g. river reaches, mapped wetlands etc). Consistent data on these components were frequently lacking, and this component therefore required a process of collation of internally consistent ‘real’ sample-based data, expert evaluation, mapping rules, GIS-scripting, attribution and mapping, and validation. A separate classification was conducted for each component, and no attempt was made to develop an integrated ‘meta classification’. Each component class was treated as a separate attributed of the mapped ecosystem units in further analyses.

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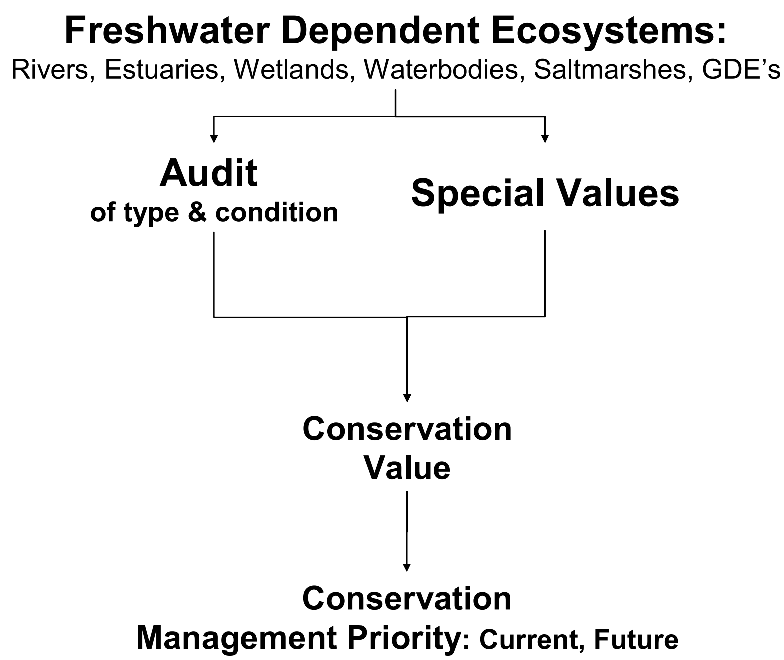

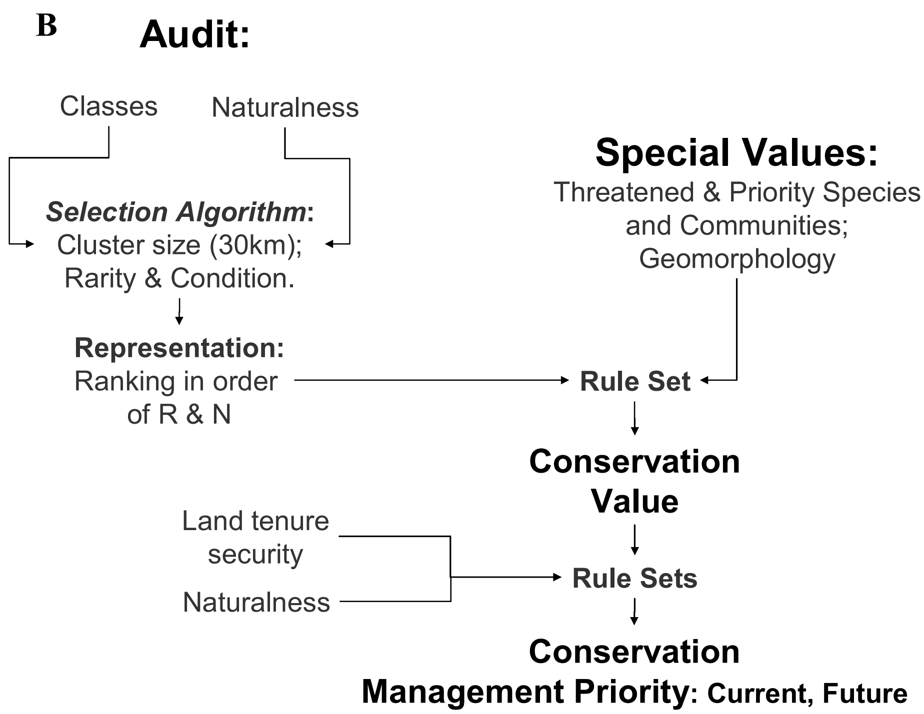

Figure 1. A. General flow chart for the CFEV framework project. B. Summary of data analyses.

The condition assessment required the development of a data-set describing the biological and physical condition of the mapped units. Condition was equated to ‘naturalness’ and was evaluated in terms of the degree of departure from pre-European reference condition. Again, consistent data on condition was required and was generally lacking, except for a few components (e.g. riparian vegetation, stream macroinvertebrates). A major emphasis was placed on evaluating observed and published relationships between condition and various mappable features of human development, as surrogates for anthropogenic change. These relationships were ‘encoded’ by the use of expert rule sets (aka fuzzy logic), developed in a workshop setting with a variety of people with relevant technical expertise. A series of indices of condition were developed and aggregated using expert rules (encoded into the Matlab® package) into a final condition or naturalness score, representing the degree of departure from natural reference condition and encoded.

For each ecosystem type, a set of features (e.g. biological assemblages etc) were selected which could be used in the classification and condition analyses, based on considerations of data availability, quality and comprehensiveness, and on the need to have features representing a variety of functional components within the ecosystem (e.g. fish, plants, invertebrates, geomorphology, flow etc).

The results were applied to the mapped units, which required development of GIS layers for stream drainage, wetlands etc linked to a digital elevation model. As various aspects of existing (cartographically) mapped GIS layers for these components were unsatisfactory, much work was done to develop new/revised drainage, wetland etc layers for this analysis, and indeed for the entire project. Details of this work are not reported here.

The principle output of the Audit was a set of mappable GIS layers and database files with all component features attributed with measures of biophysical condition.

2. Special Values: A component was required which incorporated a range of ‘special values’ which could not be included within the formal standardized Audit. Considerable effort was expended in defining the classes of special values for inclusion in the framework. These included threatened species, priority species and communities, significant freshwater geomorphological features etc.. These data were by their nature noisy and inconsistent and biased in spatial coverage. Criteria were developed to assess their inclusion/exclusion. Special value data were sourced from a variety of locations and experts, screened for their relationship to freshwater dependent ecosystems, classified by their ecosystem type (e.g. rivers, estuaries etc), and collated into a single, GIS-based data set. The special value data types were classified into high and moderate value depending on whether an attribute was listed under legislation (e.g. formally listed species), and on relative confidence in the data records.

3. Conservation Value: Relative conservation value was derived for all mapped ecosystem features (GIS polygons or lines) by a two-stage process, first using Audit data only, then incorporating special value data. Firstly, a spatial algorithm (scripted in ArcView) was applied to the Audit data set which selected examples in order of rarity and condition. Details of this algorithm and the selection process will be published elsewhere. Initially, all mapped features were attributed with their various biological and physical classes and their size (drainage length, wetland area etc). Each feature was assigned a unique numerical string consisting of its naturalness score and the set of biophysical classes attributed to it. This defined both its condition and its biophysical 'type'. To this string was appended a 'rarity' score which represented the cumulative length (for rivers) or number of features of a particular type. The selection algorithm then proceeded by selecting features in the order of the best condition example of the rarest type (e.g. the highest condition scoring example of the smallest unique biophysical type). After selecting and 'removing' a feature, it then re-assessed the overall rarity of the biophysical types and re-ran the selection process after recalculating the rarity score.

The main output of the selection process was a ranking of all the mapped features for that ecosystem type (e.g. all stream drainage sections) in order of declining naturalness and representation. These ranks were then 'banded' into very high, high, medium and low bands based on consideration of the number of selected units. This was called the interim conservation value.

The second step involved combining the interim conservation value outputs with special value data to derive a conservation value. A rule set was developed to change the interim conservation value depending on whether a special value was associated with the feature. The rule set was initially was designed to reduce the potential for the special value data (with its inherent errors and biases) to dominate the assignment of conservation value.
The output was an assignment of relative conservation value, banded as very high, high, medium and lower, to every example (feature) of each ecosystem type.

4. Conservation Management Priority: The relative priority for management was derived by considering three attributes: conservation value, condition and land tenure security. It was considered that priority for management would be defined by whether a feature had higher or lower conservation value; whether it was in good or poor condition; and whether the land tenure was secure or not. Ideally, some indicator of water management 'security' should be included here, but no such measure or context currently exists.
A rule set was developed which considered these three aspects in the light of the need for:

- improved management of ecosystem values under current conditions ('Current Conservation Management Priority'); and
- protection/maintenance of existing ecosystem values during future development/management ('Future Conservation Management Priority').

This rule set was applied to the attributed features in GIS in order to produce a mappable set of attributes for each feature which assigned a level of Conservation Management Priority under Current and Future conditions, assigned as very high, high, moderate or low.

3. The Rivers Audit

The audit analyses differed between ecosystem types, depending on their key ecosystem components and data availability. The analyses conducted for rivers are shown in Figure 2.

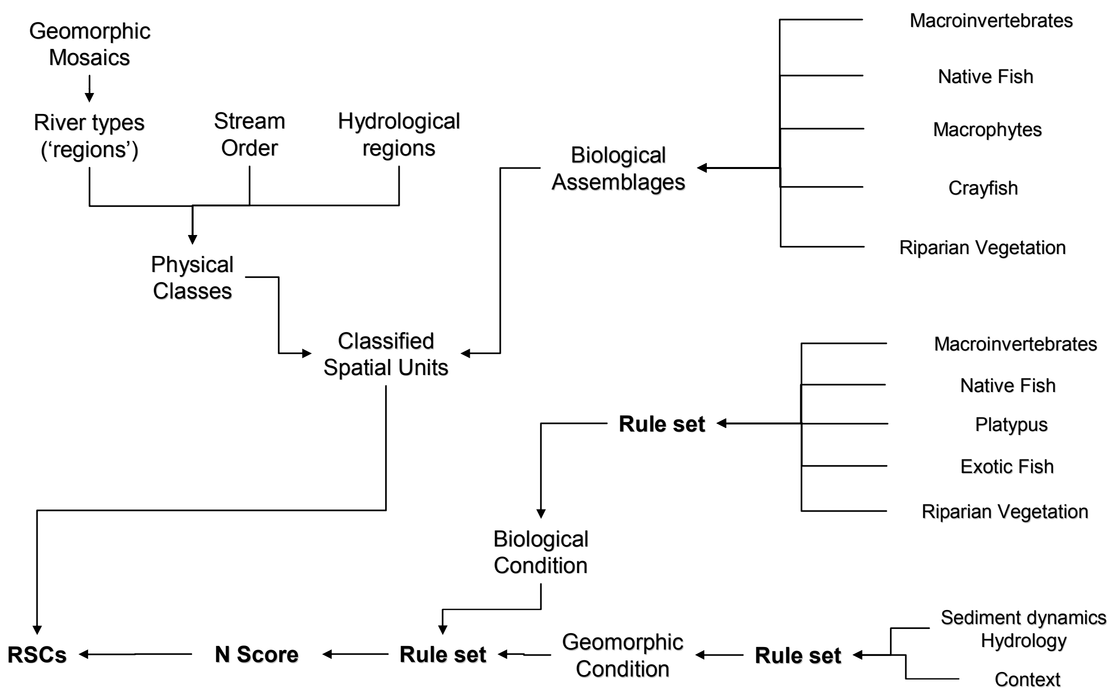

Figure 2. The CFEV Tasmanian river audit. Flow chart showing attribution of river drainage sections and river section catchments (RSC's) with biophysical classes derived from a number of biological and physical classification data sets (upper section) and with an index of naturalness ('N Score') derived from a number of biological and physical indicators of departure from reference condition.

3.1 Rivers - Biophysical Classes

Five ecosystem components were included for the biological classification – fish assemblages, benthic macroinvertebrates, aquatic macrophyte assemblages, riparian tree assemblages, and crayfish species. Three components were included in the physical classification – fluvial geomorphology, hydrological regime, stream order. A separate classification was conducted for each component. These were developed as follows:

Fish assemblages: A fish distributional database prepared during the Regional Forest Agreement in 1997 was updated with new records. A workshop was attended by five freshwater fish biologists and a set of mapping rules developed for each of 15 fish species. These rules were used to generate fish species range maps in GIS. These range maps (as attributed polygons) were overlayed to generate a state wide map of potential fish assemblages. These were reviewed and small unlikely overlaps removed ('slivers') resulting in 55 fish assemblages. Additional mapping rules were then used to convert this fish assemblage range map (Figure 3) to a stream drainage layer attributed with fish assemblages.

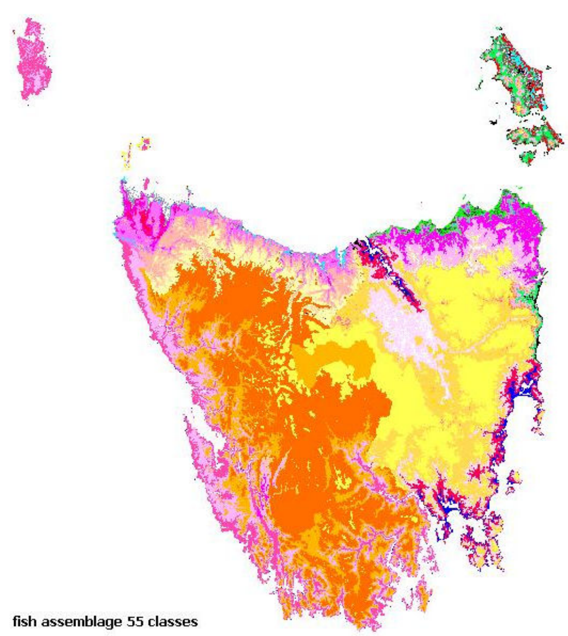

Figure 3. Native fish assemblage range map.

Benthic macroinvertebrates: Benthic macroinvertebrate samples from some 290 sites, collected by kick sampling of riffle and edge habitats in, during the 1997 – 1999 National River Health Program autumn sampling seasons were collated. These samples were re-assessed by genus/species identification and counting of ephemeroptera, plecoptera, trichoptera, coleoptera and odonata. These data from the two habitats were pooled to provide a composite taxon list for each site. Cluster analysis (by unweighted paired group mean averaging of a Bray Curtis Similarity matrix on presence/absence data) was conducted, and site groups defined. Some additional site groups were also identified following inclusion of data from an additional 60 sites for which only riffle habitat data was available, by conducting the UPGMA classification for all riffle samples including the new ones. The classification was confirmed by conducting an analysis using Kohonen Self Organising Map neural networks (X). The classes were then related to environmental variables using both discriminant function analysis and neural network (multi-layer perceptron) analyses. However, these techniques could not account for more than 45-50% of the variance in group membership. Modeling of the macroinvertebrate assemblage distributions was then abandoned.

The benthic macroinvertebrate assemblages defined from the UPGMA analysis were instead assigned to the stream drainage using regional boundaries defined by eye, and attributed by overlaying regional boundary polygons over the drainage in GIS. First order and alpine (> 800 m) streams were assigned to a separate sub-classes of each regional assemblage.

Aquatic macrophyte assemblages: Macrophyte assemblages were identified during a workshop, building on the classes defined by Hughes (1987). Mapping rules were developed, based on elevation, stream size, climatic region and geomorphology and used to assign classes to the drainage layer.

Riparian tree assemblages: A reconstruction of pre-European tree assemblages had been developed as a catena in GIS at a 1 km2 grid scale (M Brown, D Peters unpub. data). This was intersected with the drainage in ArcView and stream sections attributed with their mid-point assemblage classes.

Crayfish species: Distributional range maps for *Astacopsis gouldi* were provided by Forestry Tasmania, and combined as GIS polygons with polygons describing the known historical distribution of *A. franklinii* and *A. tricornis*.

Fluvial geomorphology: Landscape areas of similar fluvial geomorphological character were identified using a domain analysis conducted by Jerie et al. (2003) on variables describing key geomorphological controls (geology, runoff, process history etc). This analysis was subsequently completed for the entire Tasmanian drainage, and mosaics attributed to all drainage sections. Specific attributes describing the geomorphological character of the drainage were also tabulated. A typology of river geomorphological character at sub-catchment level was developed by inspection of mosaic distributions and by multivariate classification and ordination (UPGMA and multi dimensional scaling) of river-length-mosaic sequences derived fro all major sub-catchments. These river types were also attributed to the drainage.

Hydrological regime: Results of the hydrological characterisation conducted by Hughes (1987) were re-evaluated and used to develop GIS polygons for broad regions describing areas with similar natural (pre-development) flow regimes. This analysis was based on hydrological variables of high ecological relevance.

Stream order: Strahler stream order was assigned to all stream drainage sections.

3.2 Biophysical condition

The assessment of biophysical condition was conducted by combining data on geomorphological and biological condition into a single index of naturalness using expert rules (see Figure 2). The biological condition assessment was conducted by combining data on the status of benthic macroinvertebrates, native and exotic fish, riparian vegetation, willows and platypus. All of these data were attributed to the entire stream drainage by a variety of modeling and mapping rules, derived from field data. A number of derived variables were applied to the drainage by accumulation downstream through the stream drainage network in GIS using either a catchment area or runoff weighting, using dedicated GIS scripts. Individual components of the assessments were combined by the use of expert rules, developed through workshops and coded into

Matlab® scripts for analysis. The geomorphological condition assessment incorporated measures of the effects of land clearance, flow regulation, and dam sediment storage on stream sediment budgets. Ideally, the recent version of SedNet would have been used as part of this assessment, but at the time of conducting this analysis, confidence in SedNet's ability to model sediment budgets at reach scale were low.

Modeled stream flow was a significant input to the condition analyses for geomorphology (e.g. in weighting various input variables for sediment inputs), and for a number of biological and physical condition indicators (e.g. as in input into a flow regulation or abstraction indices). Stream flow was modeled as mean annual runoff (MAR) by applying long-term modeled estimates of 'effective precipitation' (rainfall minus evapotranspiration) to the catchment and drainage layers, using a catchment area-weighted downstream accumulation script. The resulting natural MAR data was validated against long term MAR figures from 32 gauging stations across a wide range of catchment areas and locations (with an $r^2 = 0.998$ for log-log linear regression over three orders of magnitude of catchment area).

Three indices of change to flow regime were derived representing:

- Net flow abstraction = the net proportion of long term MAR abstracted under current conditions (estimated from accumulated licensed abstraction and inter-basin transfers);
- Flow regulation = the sum of all upstream storage divided by MAR (storage being derived by accumulating the sum of licensed storage volumes – including ;active' hydroelectric storage – and all unlicensed mapped farm dams, estimated from an area-volume relationship);
- Change in flow variability – attributed as an index to drainage sections immediately downstream of specific water regulating infrastructure and 'diluted' downstream in proportion to relative MAR.

All of the condition analysis input data were attributed to the entire stream drainage by a variety of modeling and mapping rules, starting where possible with data derived from field or aerial-photo sources and input onto GIS.

Groups of condition indicators were combined when necessary by the use of expert rules, developed through workshops and coded into Matlab® scripts for analysis. Expert rules also allowed for adjustment of outputs within specific contexts (e.g. different geomorphological mosaics were associated with differing levels of stream response to flow change). The primary output of the condition analysis was an index (ranging from 0 to 1) of biophysical condition of the stream reach.

4. Results

4.1 The Audit

The project is very much a work in progress. Maps of the distributions of benthic macroinvertebrate and macrophyte assemblages are shown in Figure 4. A map of the river condition (naturalness) rating is shown in Figure 5. Overall, river condition was lowest in the midlands, south east, north and north west of the state, including King Island. Condition was highest in the south west and World Heritage Area of Tasmania, with some rivers (e.g. the Gordon and King Rivers being shown as in poor condition).

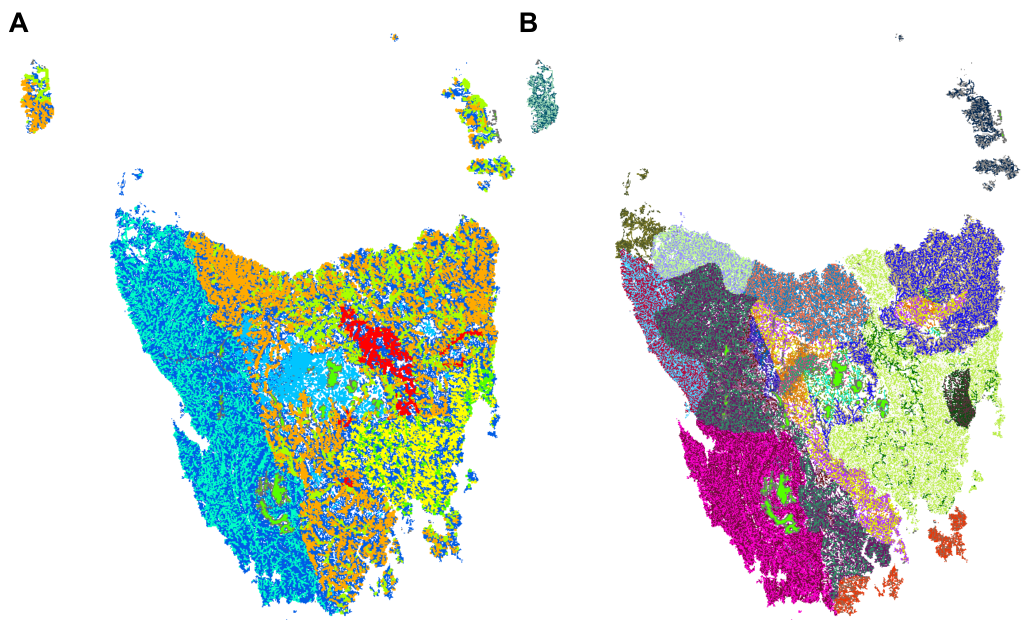

Figure 4. Derived maps of macrophyte (A) and benthic macroinvertebrate (B) assemblages associated with stream drainage in Tasmania. Each colour represents a distinctive assemblage.

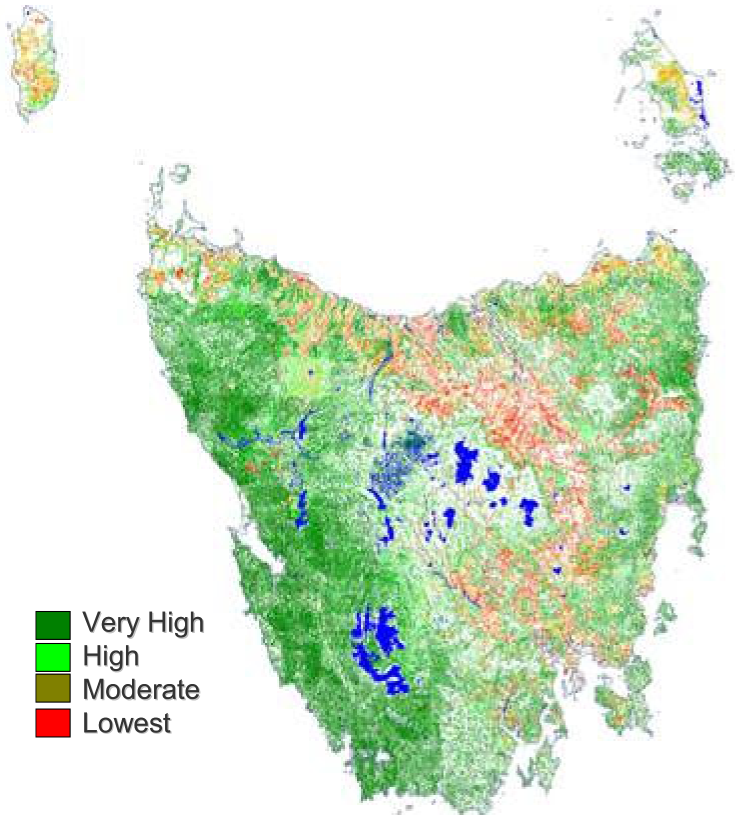

Figure 5. Biophysical condition rating (N Score) for Tasmanian rivers. The N score is a continuous variable, but has here been divided into bands for presentation.

4.2 Conservation Value and Management Priority

Rule sets for developing an assessment of Conservation Value and management priority were under development at the time of this conference, and will be completed in early 2005.

5. Summary & Conclusions

The Audit analyses for Tasmanian rivers have demonstrated that the application of expert knowledge, standardized environmental data on stream biota and physical character, multivariate analysis with a marked reliability on GIS analysis and spatial data manipulation can result in a comprehensive state-wide audit of biophysical typology and condition. Our desire to conduct these analyses at a small scale (1: 25 000), due to the need to develop conservation and management prescriptions at sub-catchment scale by aggregation of data at a higher spatial resolution, resulted in large data sets, occasionally long computational times and the need for a well organised GIS support.

The assignment of Conservation Value and Management Priority to the stream drainage is a key deliverable of the CFEV project. It should result in a consistent approach to water management, development application assessments, licensing and to the environmental aspects of water management planning

There is considerable government interest in developing the CFEV framework as the basis for a number of regulatory, policy and management and planning decisions, and to integrate it within the NRM and catchment planning context.

6. References

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