# Aquatic ecosystems toolkit

## CASE STUDY 2:
Northern Australia

Based on work undertaken by Dr Mark Kennard

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This case study is based on a trial of the draft Guidelines for Identifying High Ecological Value Aquatic Ecosystems. The final report from this trial is as follows:

Kennard, M.J. (ed.) (2010). *Identifying high conservation value aquatic ecosystems in northern Australia*. Report prepared for the Department of Environment, Water, Heritage and the Arts and the National Water Commission. Tropical Rivers and Coastal Knowledge (TRaCK) Commonwealth Environmental Research Facility, Australian Rivers Institute, Griffith University, Nathan.

This report is available on the Department of Sustainability, Environment, Water, Population and Communities' website <**http://www.environment.gov.au/water/publications/policy-programs/nawfa-hcvae-trial-report.html**>.

Endorsed by the Standing Council on Environment and Water, 2012.



This trial was undertaken during the time when guidance on the identification, delineation and description of aquatic ecosystems was an area of active policy development. The work informing the contents of this publication was carried out under time restraints and using readily available resources. Recommendations about possible HEVAEs in northern Australia are therefore provisional.

**Citation**

Aquatic Ecosystems Task Group (2012). Aquatic Ecosystems Toolkit. *Case Study 2: Northern Australia*. Department of Sustainability, Environment, Water, Population and Communities, Canberra.

The publication can be accessed at <**http://www.environment.gov.au/water**>

**Front cover:** Mitchell Falls, Western Australia. Photo by Cathy Zwick.

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# Abbreviations

| | |
|---|---|
| **AETG** | Aquatic Ecosystems Task Group |
| **ANAE** | (Interim) Australian National Aquatic Ecosystems (Classification Framework) |
| **ANU** | Australian National University |
| **AWRC** | Australian Water Resources Council |
| **CDI** | Catchment Disturbance Index |
| **CSIRO** | Commonwealth Scientific and Industrial Research Organisation |
| **DEM** | Digital Elevation Model |
| **EPBC** | *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) |
| **Geofabric** | Australian Hydrological Geospatial Fabric |
| **HEVAE** | High Ecological Value Aquatic Ecosystems |
| **IUCN** | International Union of Conservation of Nature |
| **NASY** | Northern Australia Sustainable Yields (project) |
| **NCB** | National Catchment Boundaries |
| **TRaCK** | Tropical Rivers and Coastal Knowledge (Research Hub) |

**Reflections at El Questro Gorge, Central Kimberley (Cathy Zwick & DSEWPaC)**

# Introduction

A trial of the draft national guidelines for identifying High Ecological Value Aquatic Ecosystems (HEVAE), which have been developed by the Aquatic Ecosystems Task Group (AETG), was undertaken by Mark Kennard, who led a team of researchers from the Tropical Rivers and Coastal Knowledge (TRaCK) consortium. The project 'Identifying high conservation value aquatic ecosystems in northern Australia' was also conducted as part of the Northern Australia Water Futures Assessment.

It should be recognised that this project was undertaken within a limited time frame and the framework was tested using readily available resources. Recommendations about possible HEVAEs in northern Australia are therefore provisional, but none-the-less form a significant starting point for identifying and characterising the HEVAEs of northern Australia.

Note that at the time the trial was undertaken:

- The terminology 'High Conservation Value Aquatic Ecosystems' (HCVAE) was still in use. However, to reflect the change in name to 'High Ecological Value Aquatic Ecosystems', the term HEVAE has been used in this case study, consistent with the other toolkit documents.
- The Guidelines for Identifying High Ecological Value Aquatic Ecosystems was known as the HEVAE Framework.
- There were six HEVAE criteria; 'evolutionary history' has since been incorporated into 'distinctiveness'.

Rock pools at the top of Gunlom Falls, Kakadu National Park (Sarah Stuart-Smith & DSEWPaC)

# Part 1: Identifying high ecological value aquatic ecosystems

## 1.1 Groundwork

Trialling the draft HEVAE identification guidelines involved a number of interrelated steps including defining appropriate scales for spatial units and reporting scales for attribution of biodiversity and environmental data. As a result of patchy data across northern Australia, preliminary work was also required to develop and validate predictive models and biodiversity surrogate datasets for the entire study region, before applying the guidelines.

### Step 1 Identify purpose

The purpose of the assessment was to test the draft HEVAE identification guidelines in tropical river basins in the Timor Sea and Gulf of Carpentaria drainage divisions.

The trial also included an application of the draft Australian National Aquatic Ecosystem (ANAE) Classification Scheme (Auricht 2010) (see Module 2).

### Step 2 Map and classify aquatic ecosystems

The draft Australian National Aquatic Ecosystem (ANAE) Classification Scheme (Auricht 2010) was used to develop a consistent and comparable classification of aquatic ecosystems in northern Australia.

A combination of the GeoScience Australia Geodata 250k Hydrography theme feature classes, the OzCoasts Geomorphic Habitat Mapping (Version 2) and 9 second DEM for the Australian Geofabric were used to apply the ANAE Classification Scheme and map lacustrine, palustrine, estuarine and riverine aquatic systems. This information provided the base-level mapped aquatic ecosystems for the study area at a scale of 1:250 000.

Aquatic systems were then assigned ecologically relevant environmental data and statistical classifications, including perenniality and inundation frequency attributes, to define aquatic habitats. The environmental data assigned to aquatic systems comprised the broad themes of climate, catchment water balance, substrate,

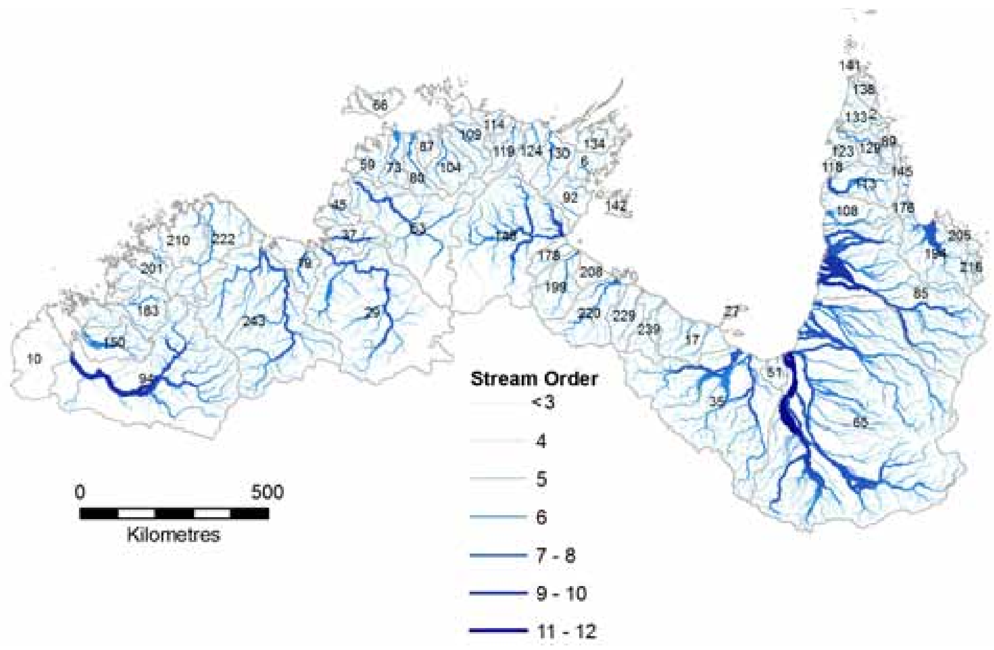


**Figure 1** Distribution of riverine aquatic systems of northern Australia showing Strahler stream order

terrain and vegetation. The data were compiled as a series of rasters of consistent spatial extent, gridded at a resolution of 9 seconds of latitude and longitude, or as an integer multiplier consistent with the scale of the source data mapping.

Aquatic systems and habitats were successfully mapped and classified for the HEVAE trial area. Example results are shown in Figures 1 to 5. Refer to Chapter 4 of Kennard (2010)[1] for more detailed descriptions of attribute themes and results.

1 http://www.environment.gov.au/water/publications/policy-programs/nawfa-hcvae-trial-report.html

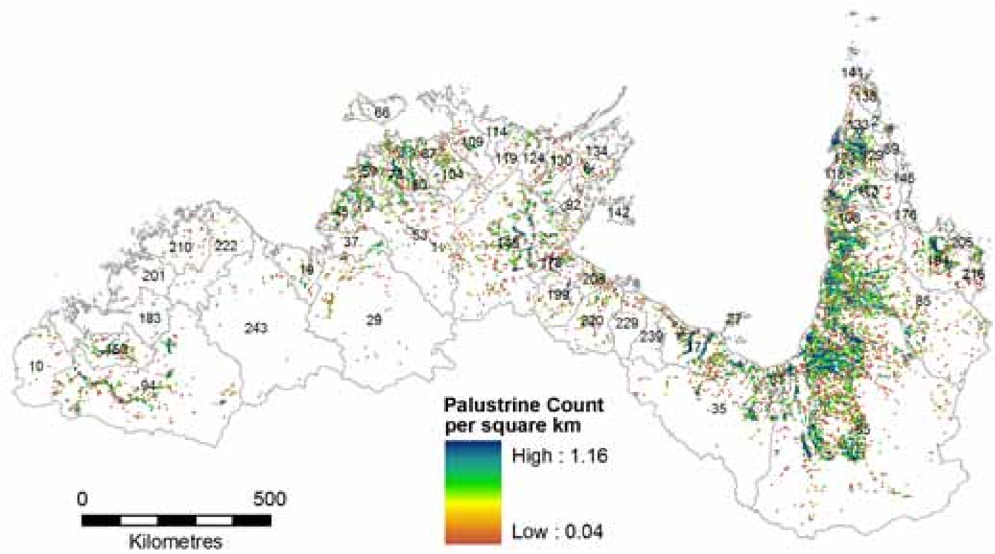


**Figure 2** **The number of palustrine aquatic systems per km² across northern Australia**

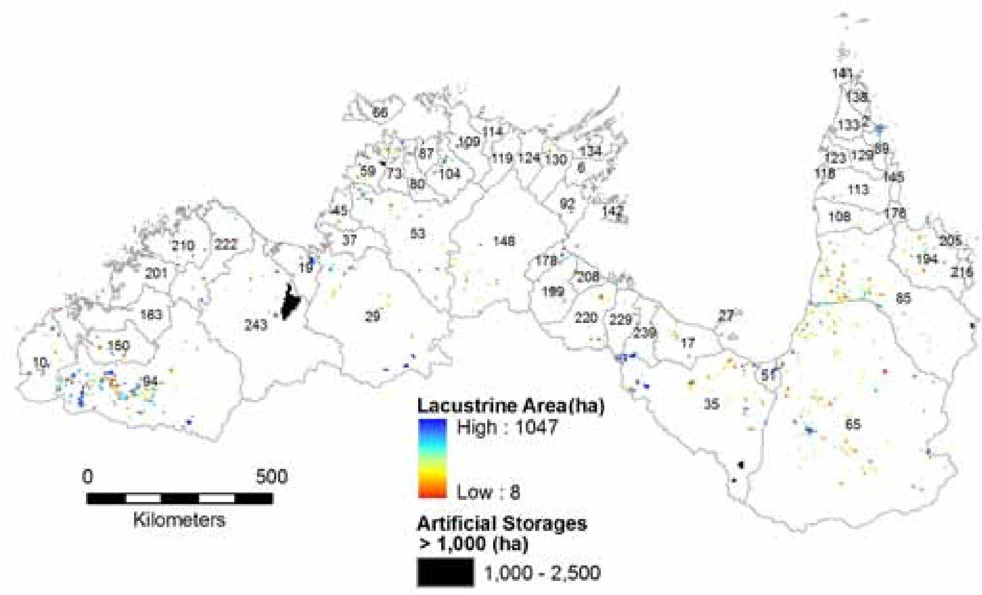


**Figure 3** **The area in hectares of lacustrine aquatic systems in 5 km² grids across northern Australia**

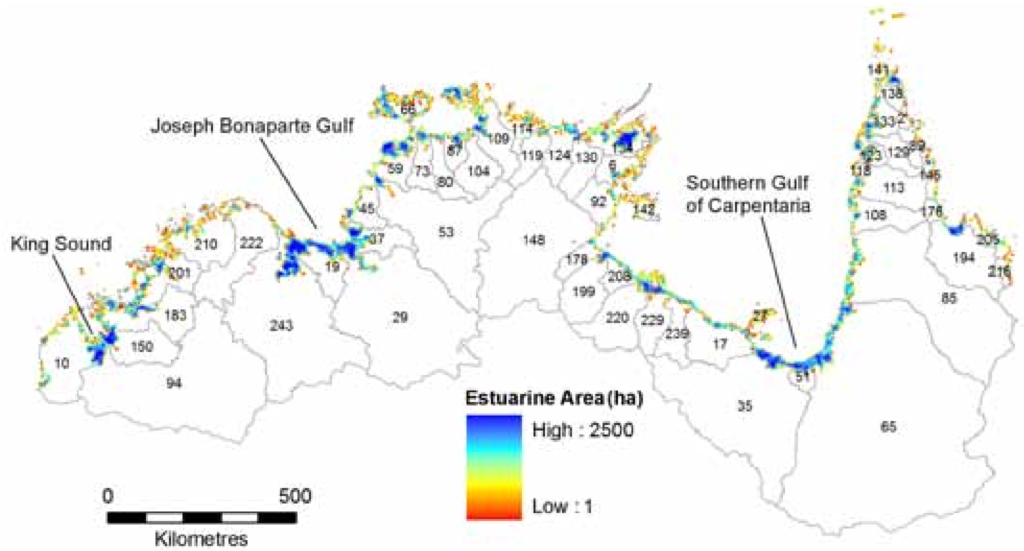


Figure 4 The area in hectares of estuarine aquatic systems in 5 km² grids across northern Australia

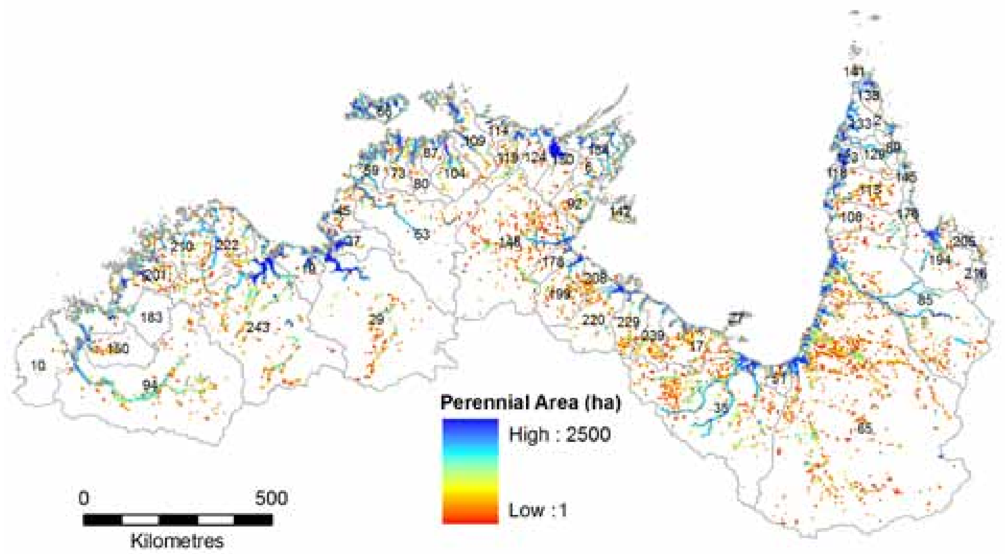


Figure 5 The area in hectares of perennial aquatic systems in 5 km² grids across northern Australia

## Step 3 Determine scale, regionalisation, and spatial units

***a. Determine scale and regionalisation***

The hierarchy of spatial units used to identify potential HEVAE in northern Australia is presented in Table 1. HEVAE were assessed and reported at three spatial scales (Figure 6):

1. referential to the study region
2. Gulf of Carpentaria and Timor Sea drainage divisions (Australian Water Resources Council 1976)
3. regions defined in the Northern Australia Sustainable Yields (NASY) project (CSIRO 2009).

**Table 1 Hierarchy of spatial units used in the assessment of HEVAE**

| NAME | N | SPATIAL EXTENT (KM$^2$) | DATA SOURCE/TYPE | PURPOSE |
|---|---|---|---|---|
| **Sampling unit** | 333 471 (birds: 16 597) | 0.07–4953, mean = 3.58 (birds: 0.07–9650, mean = 72) | National Catchment Boundaries (NCB) | • Attribution of raw species records and environmental data<br>• Basic unit for predictive modelling of species distributions |
| **Planning unit** | 5803 | 0.07–14 458, mean = 204 | Aggregated spatial units | • Attribution of predicted species distribution data and environmental ecotopes<br>• Calculation of biodiversity attributes<br>• Assessment and prioritisation of HEVAEs according to the HEVAE criteria |
| **River basin** | 24 820 | 0.07–230 618, mean = 49.4 | National Catchment Boundaries (NCB) | • Attribution of species distribution data and environmental data for assessment of bioregions |
| **Region** | 7 | 46 312–257 809, mean = 166 548 | Aggregated river basins (approximating NASY reporting regions) | • Assessment and reporting of HEVAEs according to the HEVAE criteria |
| **Drainage division** | 2 | 547 664 and 621 855 | National Catchment Boundaries (NCB) | • Assessment and reporting of HEVAEs according to the HEVAE criteria |
| **Entire study region** | 1 | 1 169 519 | National Catchment Boundaries (NCB) | • Assessment and reporting of HEVAEs according to the HEVAE criteria |

A new spatial framework, the National Catchment Boundaries (NCB), is an important component of the Bureau of Meteorology's Australian Hydrological Geospatial Fabric (Geofrabric), and was under development at the time of the study. It uses the analysis of a 9 second Digital Elevation Model (DEM). An interim version of the NCB was used as an appropriate basis for delineating stream networks, and nested sub-catchments in this project.

The NASY regions were aggregated based on extant (e.g. present-day flooding patterns) or recent past (e.g. late Pleistocene lowered sea levels) hydrological connectivity. The applicability of 'surrogate' regionalisations in distinguishing evolutionary cohesive units of freshwater biodiversity was tested using statistical analyses of available data and expert judgement. As a result of the analysis, two aggregated NASY regions were combined because they did not show substantial division in freshwater biodiversity.

(a)

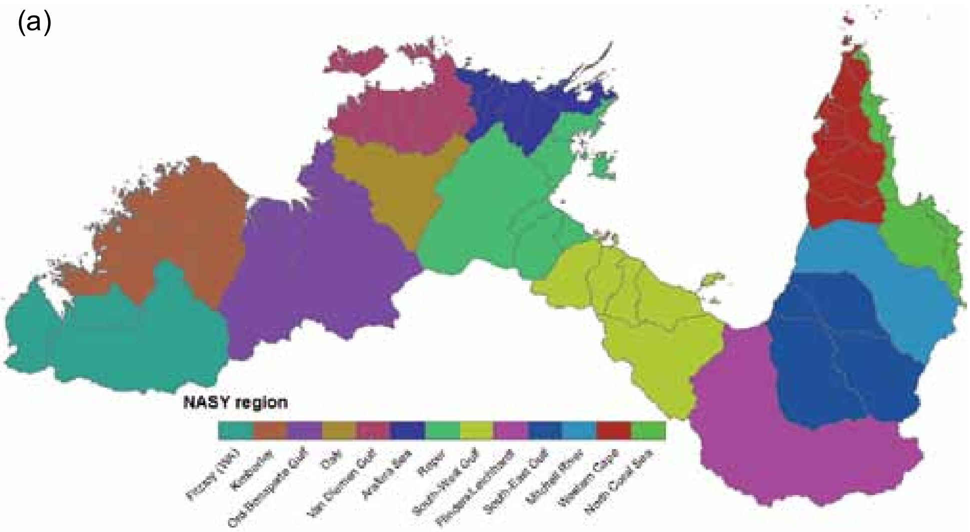


**Figure 6a** **Location of NASY regions using AWRC (1976) river basins as the basic sampling unit**

(b)

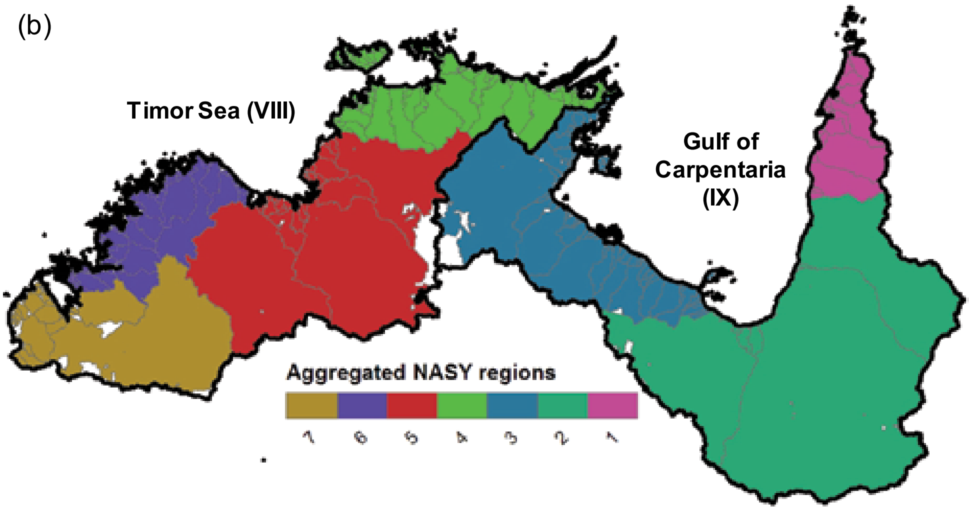


**Figure 6b** **Location of the aggregated NASY regions defined using the new topographically-defined river basins as the basic sampling unit. Also shown are the boundaries of the drainage divisions VII and IX. Areas in white are separate inland draining basins.**

*b.* Select spatial units

Planning units (hydrologically defined sub-catchments) were used in the trial to assess and prioritise HEVAE according to the criteria. Planning units were derived from the 9 second Digital Elevation Model using ARC Hydro (Maidment 2002) within ArcGIS 9. The planning units were attributed with environmental and biodiversity data (derived at the sampling unit scale) and formed the basic spatial unit for calculation and reporting of attributes for each HEVAE criterion.

Stream segments and their sub-catchments, delineated using the 9 second DEM (Fenner School of Environment and Society, Australian National University, and Geoscience Australia 2008) (Figures 7 and 8a and b), supplied the basic spatial units (sampling units) that were assigned environmental data and species records for use in predictive modelling of species distributions. Because waterbirds potentially range over larger spatial scales than other faunal groups, a coarser spatial grain was used for the analysis and prediction of waterbird distributions, using the NCB Pfafstetter labelled sub-catchments to aggregate spatial units.

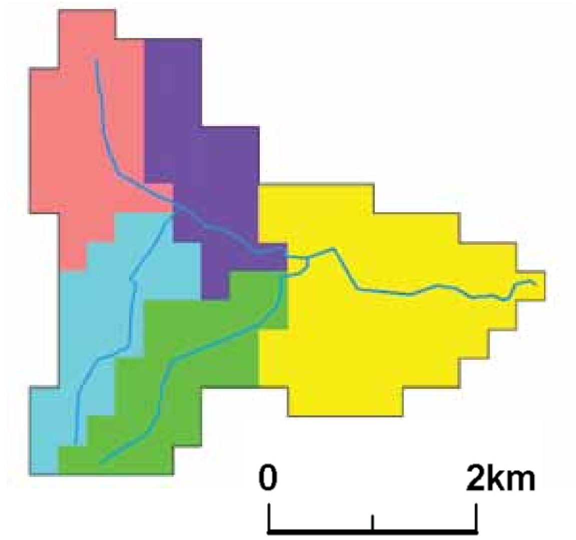


**Figure 7** Catchments, sub-catchments and streams. Each of the coloured areas is a sub-catchment (i.e. the area contributing directly to a stream segment. The catchment is the entire area draining to a pour-point and thus also includes all of the sub-catchments upstream.

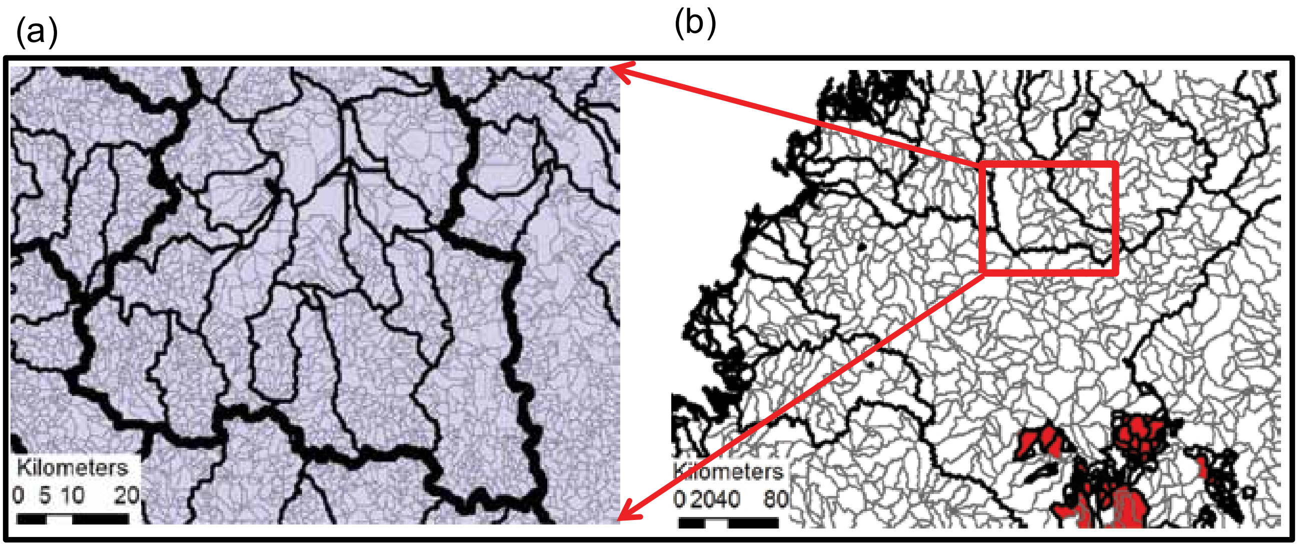


**Figure 8a** Example of the finest-scale spatial units (grey polygons), planning units (intermediate-sized dark polygons) and river basins (thick dark lines).

**Figure 8b** Example of planning units (grey polygons) within river basins (thick dark lines). Internally draining basins and planning units are highlighted with red polygons, all others drain to the coast.

**Expert knowledge input**

Rather than an expert panel approach, different components of the HEVAE identification trial were undertaken by relevant experts. The trial was lead by the TRaCK consortium, which brings together leading expert researchers and managers from a range of research organisations and government agencies.

Expert knowledge and judgement was used to consider the applicability of surrogate regionalisations (i.e. the AWRC Drainage Divisions and the North Australia Sustainable Yields reporting regions) in distinguishing evolutionary cohesive units of freshwater biodiversity. Expert knowledge was also used to inform the choice of predictor variables for each faunal group used in the development and application of predictive models.

**Lake Gregory, Paruka Indigenous Protected Area, Western Australia (Bruce Rose & DSEWPaC)**

## 1.2 Identification of HEVAE

### Step 4 Assign attributes to chosen spatial unit

***a. Selection of criteria***

At the time the trial was undertaken, there were six HEVAE criteria: diversity, distinctiveness, vital habitat, evolutionary history, naturalness and representativeness. Because the purpose of the assessment was to trial the draft guidelines for identifying HEVAE, this trial applied all six core criteria.

***b. Selection of attributes***

The overall philosophy was to only apply attributes that could be calculated from the biodiversity surrogates datasets with (nearly) complete coverage, rather than applying attributes based on other data which was of variable quality and spatial extent.

A total of 65 raw attributes were calculated from the biodiversity surrogate data sets and integrated into 22 attribute types that shared similar properties. The attributes used to characterise each of the six criteria are listed in Table 2, along with a brief description of the method of calculation, rationale for their inclusion and key references for further information.

***c. Development of metrics***

The rationale and data requirements for the selected metrics are detailed in Table 2.

***d. Compile and assign data***

A comprehensive database was assembled with spatially explicit information on species occurrences for a range of freshwater-dependent taxonomic groups (macroinvertebrates, freshwater fish, turtles and waterbirds). Datasets were also considered for other water-dependent fauna, including frogs, crocodiles, lizards, snakes and riparian birds; and aquatic, semi-aquatic and riparian flora. However, datasets were not collated for these species because of time, budget and/or data constraints.

Environmental surrogates for biodiversity included the riverine, lacustrine and palustrine habitats. The use of an existing estuarine classification scheme (OzCoasts Geomorphic Habitat Mapping) was considered to define estuarine habitats, but was rejected because it was not considered to be of sufficient spatial resolution, ecological relevance (particularly with reference to the catchment processes that influence estuarine structure and function) or be sufficiently validated with respect to the spatial accuracy of habitat boundaries.

Individual datasets for macroinvertebrates, freshwater fish, turtles, and waterbirds were sourced from government agencies, scientific literature, research scientists and online databases. Substantial time and effort was expended checking the accuracy of the locality records and taxonomic identifications. The species records collated were used to develop biodiversity surrogates for the ecological assessments.

Substantial spatial biases were found to exist in the availability of species distribution records. The use of such patchy data to derive biodiversity attributes can have potentially major implications for accurate and objective identification and prioritisation of high-ecological-value areas. To address this problem, predictive models were developed of the distributions of macroinvertebrates, freshwater fish, turtles and waterbirds (Kennard 2010—see Chapter 7 for full details). These predictive models were successfully calibrated and considered appropriate for making predictions of species distributions that could be extrapolated to the study entire area, including unsurveyed areas.

**Table 2 Attributes (n = 65) used to characterise each of the draft HEVAE Framework Criteria**

| CRITERION, ATTRIBUTE TYPE AND CODE | BIODIVERSITY SURROGATE SET | | | | | | | | METHOD, RATIONALE AND KEY REFERENCE |
|---|---|---|---|---|---|---|---|---|---|
| | BUG | FISH | TURT | BIRD | RIV | LAC | PAL | PU | |
| **1. DIVERSITY** | | | | | | | | | |
| Richness (S) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | Number of taxa in a planning unit (also referred to as alpha diversity). |
| Diversity (H’) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | Shannon Diversity. An index that incorporates the number of species and the evenness of the distribution of individuals across species (area of occurrences in a planning unit was used as the measure of abundance). The index can increase either by having additional unique species or by having greater species evenness (Shannon 1948). |
| Richness Index ($I_i$) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | An index of species richness which is weighted by individual species’ frequencies of occurrence. Planning units with high $I_i$ values contain many widespread species (Minns 1987; Chu, Minns & Mandrak 2003) |
| Phylogenetic diversity (PD) | ■ | ■ | ■ | ■ | | | | | A measure of diversity based on units of phylogenetic variation (instead of species) (Faith 1992; Faith, Reid & Hunter 2004). For a given faunal group, PD is calculated as the sum of those branch lengths of the phylogenetic tree representing the species occurring in a planning unit. Areas with high PD may represent centres of current speciation and may be important areas to protect for maintenance of evolutionary processes. High PD could arise by having a high number of closely related species or by having few species that are phylogenetically divergent from one another. PD incorporates complementarity in that the score contributed by a given taxon in a planning unit depends on how closely it is related to other species present. Molecular phylogenies are not available for most faunal groups and taxa considered in this report, so published phylogenies and assumed equal branch lengths were used. The level of taxonomic resolution used to calculate PD varied among faunal groups (order for macroinvertebrates, family-level for fish and waterbirds, and species-level for turtles). |
| **2. DISTINCTIVENESS** | | | | | | | | | |
| Rarity Index ($Q_i$) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | An index of species rarity based on the mean frequency of occurrences of individual species/ecotopes. Planning units with high $Q_i$ values are dominated by rare species with narrow distributions (Minns 1987; Chu, Minns & Mandrak 2003). |
| Rare & Threatened species score (R&T) | | ■ | ■ | ■ | | | | | The number of species listed on the IUCN Red List and/or the EPBC Act as endangered, vulnerable or conservation-dependent multiplied by an arbitrary ranking of 3, 2 or 1, respectively. Note that this attribute was not calculated for macroinvertebrates as available data contained taxa identified to family level only (not species). |
| **3. VITAL HABITAT** | | | | | | | | | |
| Number/area permanent/perennial dry season refugia (P) | | | | | ■ | ■ | ■ | | Hydrosystem areas that are permanent/perennial provide important dry-season refugia for many species of flora and fauna in northern Australia (Pusey & Kennard 2009). This attribute was calculated as the length of perennial streams/rivers (riverine) or area of permanent lacustrine or palustrine areas in each planning unit. See Chapter 4 (Kennard 2010) for more details. |
| Degree of natural longitudinal connectivity (con) | | | | | | | | ■ | Natural longitudinal connectivity facilitates movement of biota and materials along river networks and is critical to long-term persistence of biodiversity and ecosystem processes. This attribute was calculated as the proportional stream length within each planning unit that was unaffected by artificial barriers (dams, reservoirs and large weirs) downstream, within or upstream of each planning unit. Artificial barriers data was sourced from AusHydro version 1.1.6, (Geoscience Australia and the Fenner School of Environment and Society, ANU, unpublished) and Dams and Water Storages 1990 data (Geoscience Australia 2004). |
| Number of migratory bird species (Mbird_S) | | | | ■ | | | | | Planning units containing vital habit for international migratory waterbirds may be considered to be of high ecological value. This attribute was calculated simply as the number of migratory waterbird species recorded from a planning unit. Migratory waterbirds species were sourced from the national list of migratory species <http://www.environment.gov.au/biodiversity/migratory/list.html>. |

| CRITERION, ATTRIBUTE TYPE AND CODE | BIODIVERSITY SURROGATE SET | | | | | | | | METHOD, RATIONALE AND KEY REFERENCE |
|---|---|---|---|---|---|---|---|---|---|
| | BUG | FISH | TURT | BIRD | RIV | LAC | PAL | PU | |
| **4. EVOLUTIONARY HISTORY** | | | | | | | | | |
| Number of monospecific genera (monG) | | ■ | ■ | ■ | | | | | Genera (or families) of taxa that contain only a single species may be considered to be of high ecological significance as they often represent faunal groups with ancient evolutionary origins. Planning units containing one or more such species may therefore also be of high ecological value. This attribute was calculated simply as the number of monospecific genera recorded from a planning unit. Note that this attribute could not be calculated for macroinvertebrates as taxa within this faunal group were identified to family level only. |
| Number of species endemic to each NASYagg region (SES) | | ■ | ■ | | | | | | A simple index of endemism calculated as the number of species present in a single region (NASYagg). A limitation of this attribute is that it requires an a priori definition of the area of endemism, rather than letting the data define the areas of interest. Note that no macroinvertebrate families or waterbird species were endemic to a single region. |
| Taxonomic endemism index (TE) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | An index of endemism identifying areas where species with restricted ranges are concentrated. Based on the number of species within a planning unit weighted by the inverse of each species' distribution range (also known as weighted endemism). This index ranges from one, where all species in a planning unit have broad geographical ranges, to infinity, with large values indicating the presence of species with range-size rarity (i.e. areas with high endemism) (Rebelo & Siegfried 1992). |
| Phylogenetic endemism index (PE) | ■ | ■ | ■ | ■ | | | | | Phylogenetic endemism (PE) is a measure of the degree to which elements of evolutionary history are spatially restricted in space. PE combines the phylogenetic diversity (PD) and taxonomic endemism (TE ) measures to identify areas where substantial components of phylogenetic diversity are restricted (Rosauer et al. 2009). To estimate the degree of PE represented by the taxa in a given area, the range size of each branch of the phylogenetic tree (rather than the range of each taxon) is quantified. PE is therefore the sum of branch length/clade range for each branch on the tree (where a clade is a single branch on the tree consisting of an organism and all its descendants). |
| **5. NATURALNESS** | | | | | | | | | |
| Catchment Disturbance Index (CDI) | | | | | | | | ■ | The Catchment Disturbance Index (CDI) is a catchment summary of human settlements, infrastructure, land use and point sources of pollution that are expected to impact on aquatic ecosystem health (Stein, Stein & Nix 2002). The method uses geographical data recording the extent and intensity of human activities known to impact upon river condition to quantify disturbance along a continuum from near-pristine to severely disturbed. The index is calculated as a runoff contribution-weighted summary of these impacts in the catchment upstream and within each planning unit. This index was calculated using the data on human activities detailed in Stein, Stein & Nix (1998, 2002) with recent (2009) Land Use Mapping data for Australia (BRS 2009), clearing information (BRS Integrated Vegetation dataset, 2009) and infrastructure data from the Geodata TOPO 250K series 2 database (Geoscience Australia 2003). |
| Flow Regime Disturbance Index (FRDI) | | | | | | | | ■ | The Flow Regime Disturbance Index (Stein, Stein & Nix 2002) is a catchment summary of impoundments, flow diversions and levee banks within and upstream of each planning unit (calculated using data sources as per CDI). |
| **6. REPRESENTATIVENESS** | | | | | | | | | |
| Representativeness (R) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | Bray-Curtis similarity of each planning unit to the group centroid, where group is defined for the entire study region, each drainage division, and each NASY aggregated region. Those planning units with higher Bray-Curtis similarity to group centroid are more representative of the group (Belbin 1993). This attribute was calculated separately for each set of biodiversity surrogates. |

Note: Attributes for each criterion were calculated for each of the biodiversity surrogate sets where suitable data was available (depicted with dark shading). Abbreviations used for biodiversity surrogates are: macroinvertebrates (Bug), fish (Fish), turtles (Turt), waterbirds (Bird), riverine ecotopes (Riv), lacustrine ecotopes (Lac) and palustrine ecotopes (Pal). Attributes for criterion 5 (naturalness) were summarised for the planning unit (PU) (i.e. were not based on the biodiversity surrogate data).

The spatially explicit biodiversity surrogate datasets derived from the predictive modelling and aquatic systems classification were assigned to 5803 hydrologically-defined planning units (sub-catchments) to assess the relative ecological values for the Timor Sea and Gulf of Carpentaria drainage divisions.

## Step 5 Apply the assessment process and identify units of high ecological value

### *a. Apply the criteria*

The draft guidelines for identifying HEVAE were implemented to identify and prioritise aquatic ecosystems in the study region.

### Scoring

The raw data were standardised by converting them to indices ranging from 0 to 1, to overcome inconsistencies in the scale and type of attribute data, and to allow equal influence in the analysis (if desired).

Two stages of attribute integration were used for this trial, which are highlighted using criterion 1 (diversity) and its attribute types and indices (metrics) in Figure 9. Seven potential methods for integrating scores from the indices to attribute types and then from attribute types to the HEVAE criteria were applied. A method of simple averaging is recommended to integrate scores for each attribute into attribute types. Euclidean distance is the recommended method to then integrate scores within each criterion, giving a final criterion score for each planning unit (Figure 10).

The data for each planning unit were successfully combined into 49 HEVAE criteria scores for each of the six criteria at three spatial scales: referential to the entire study region, for each drainage division, and for each bioregion, respectively. Those criteria with higher scores are considered to have higher ecological value. Maps were used to show spatial variation in each of the attribute types and criteria.

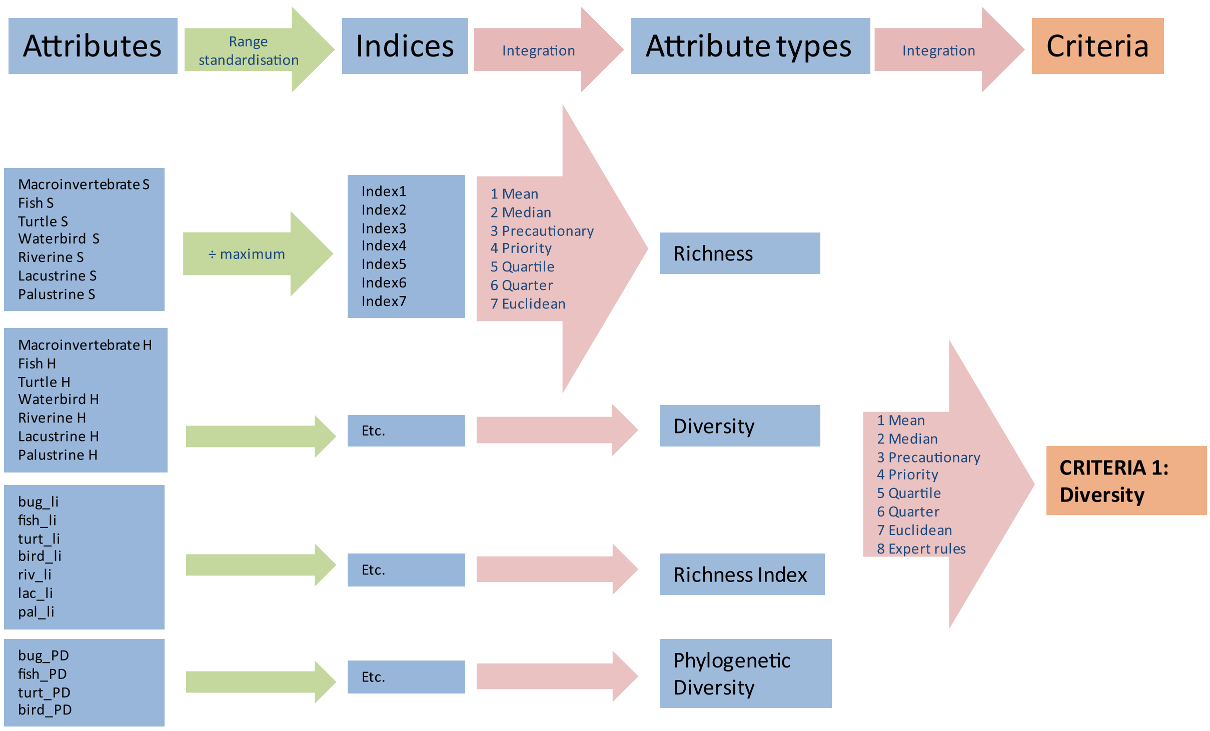


**Figure 9** **Standardising and integrating attributes to criteria using Criteria 1 as an example. The pink arrows list some of the potential integration methods available.**

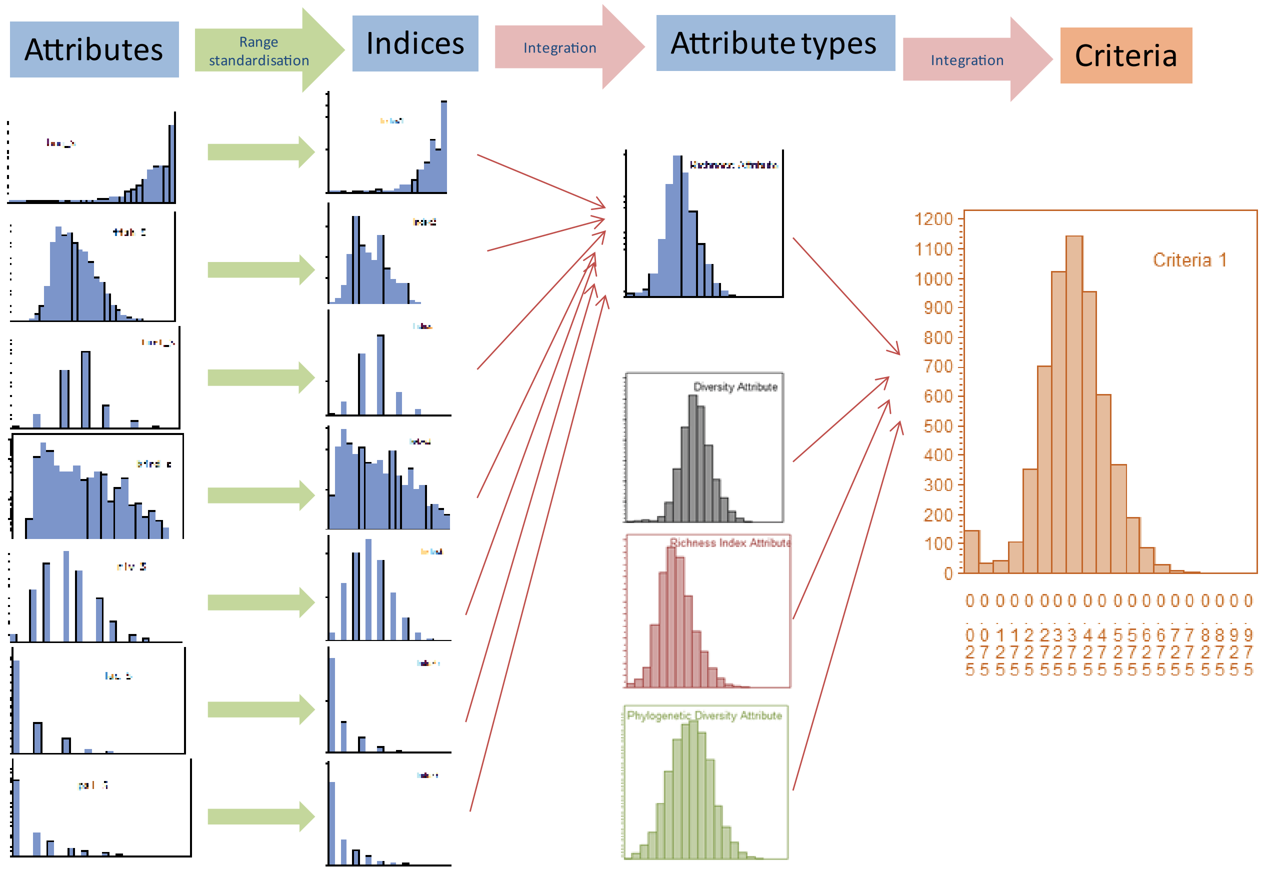


**Figure 10** **The complete data set showing the distributions of the raw data, the standardised indices, an integrated attribute, and Criterion 1 for all planning units using simple averaging**

Planning units that exceeded the upper 99th, 95th and 90th percentiles were identified for each criterion, respective of the distribution of criterion scores for all planning units. Those planning units identified in this process were considered to meet each criterion. The percentile method complements the integration methods because the highest-value sites are identified according to position in the distribution relative to other spatial units.

### Weighting

It is unlikely that all of the indices or attributes used would be considered to have the same weight (i.e. equal contribution) in the final criterion score for each spatial unit. However, the use of any weighting method requires considerably more time than was available in this trial as it demands sound expert opinion and statistical reasoning. Therefore, neither manual nor automatic weightings were attempted in the project.

It is unclear whether some criteria should be considered more important than others for identifying HEVAEs and whether particular planning units that meet a greater number of criteria are concordantly of higher ecological value. However, an assumption was made that ecological value increased with the number of criteria met.

### Sensitivity and redundancy

For the sensitivity analysis the correlation between every index and its attribute type and/or criteria were reported. The complete analysis was re-run with every index omitted and the average percent change in its associated attribute type and/or criteria recorded. The extent of redundancy among indices within attributes, and attributes within each criterion was evaluated by examining cross-correlation matrices (using Spearman's rank correlations). Correlations were also used to look at how the criteria were related.

*b. Identify HEVAE*

Twenty two attribute types were calculated from the 65 raw attributes and used to characterise the six criteria for each of the 5803 planning units. These calculations were repeated for each of the three reporting scales. Results of scoring and integrating to final scores for each criterion are presented in Figures 11 to 16. Planning units are coloured according to their respective percentile scores for each criterion, with higher percentile scores having greater ecological value.

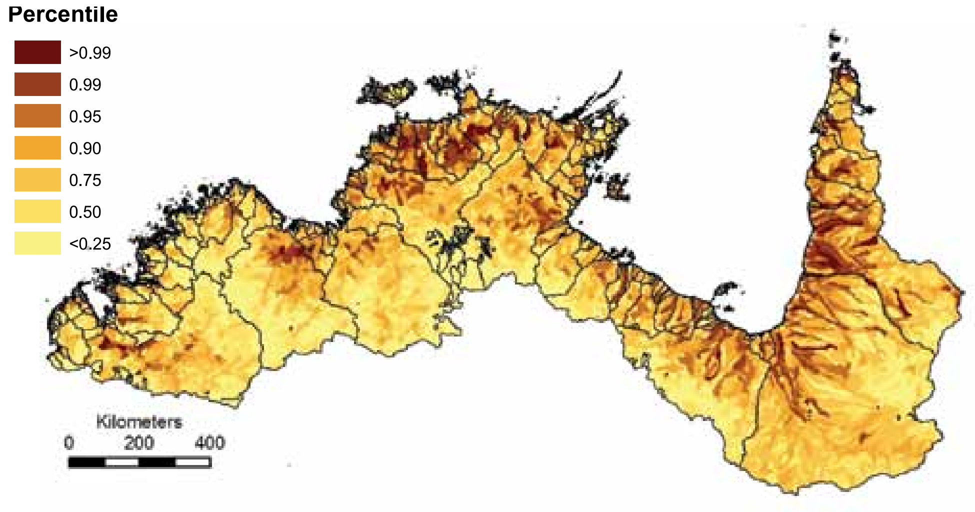


**Figure 11 Spatial distribution of planning unit scores for Criterion 1 (diversity), calculated using the four integrated attribute types (richness, diversity, richness index and phylogentetic diversity)**

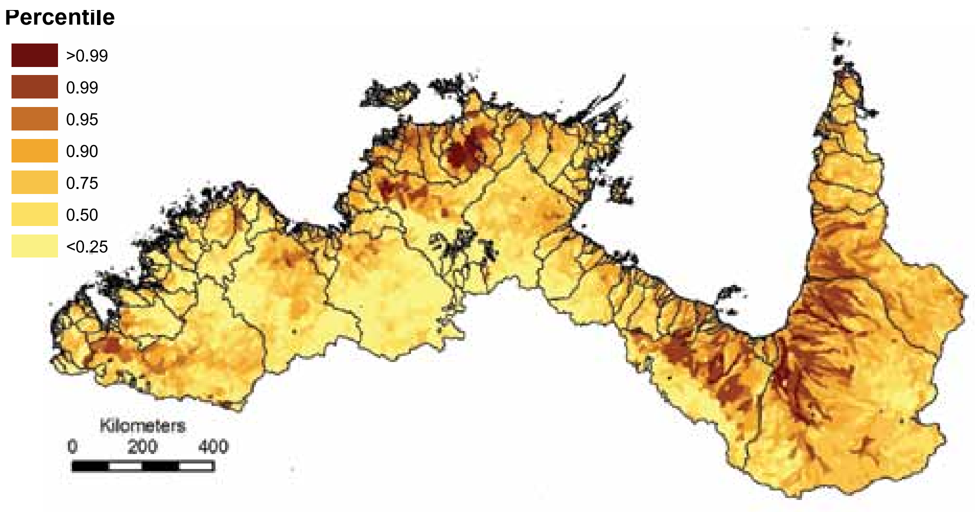


**Figure 12 Spatial distribution of planning unit scores for Criterion 2 (distinctiveness), calculated using the two integrated attribute types (Rarity Index and Rare and Threatened Species)**

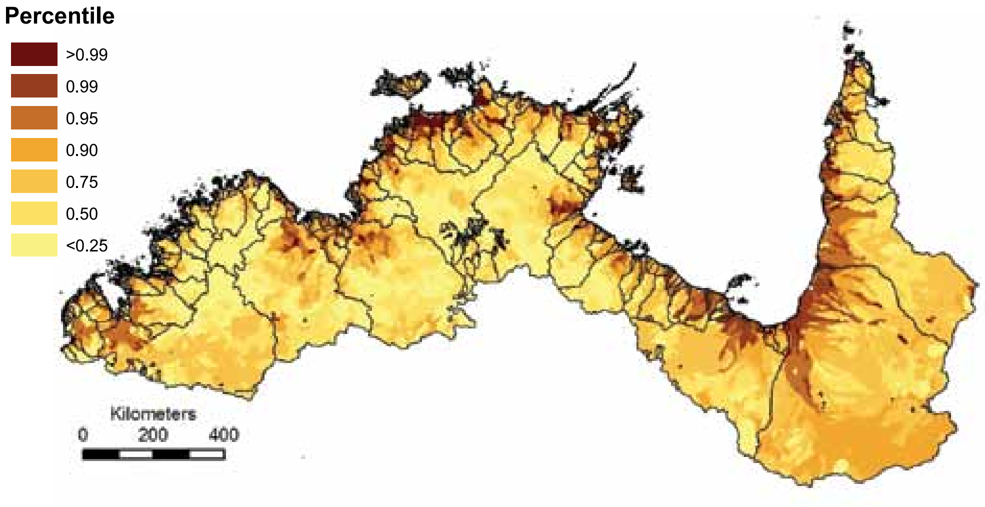


**Figure 13** Spatial distribution of planning unit scores for Criterion 3 (vital habitat), calculated using the three integrated attribute types (permanent refugia, natural connectivity and number of migratory birds)

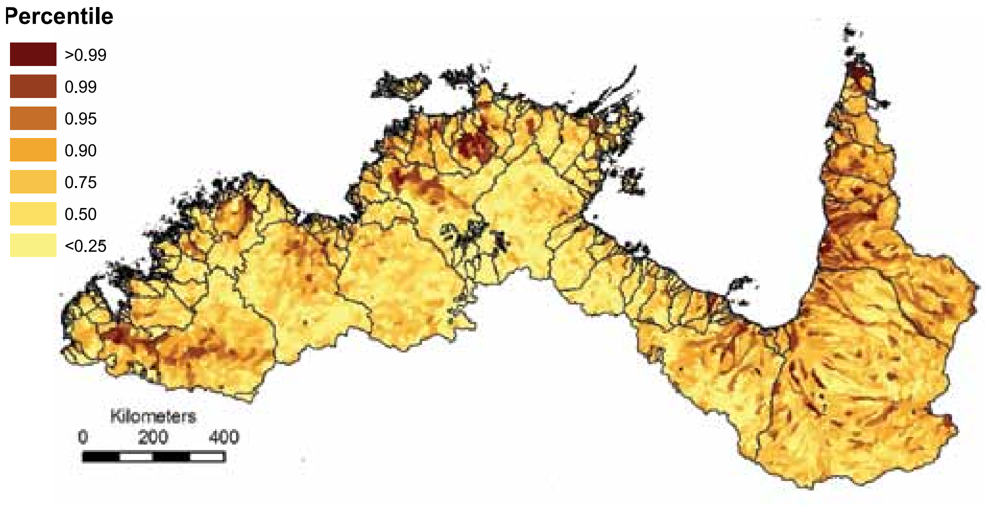


**Figure 14** Spatial distribution of planning unit scores for Criterion 4 (evolutionary history), calculated using the four integrated attribute types (monospecific genera, endemic species, taxonomic endemism and phylogenetic endemism)

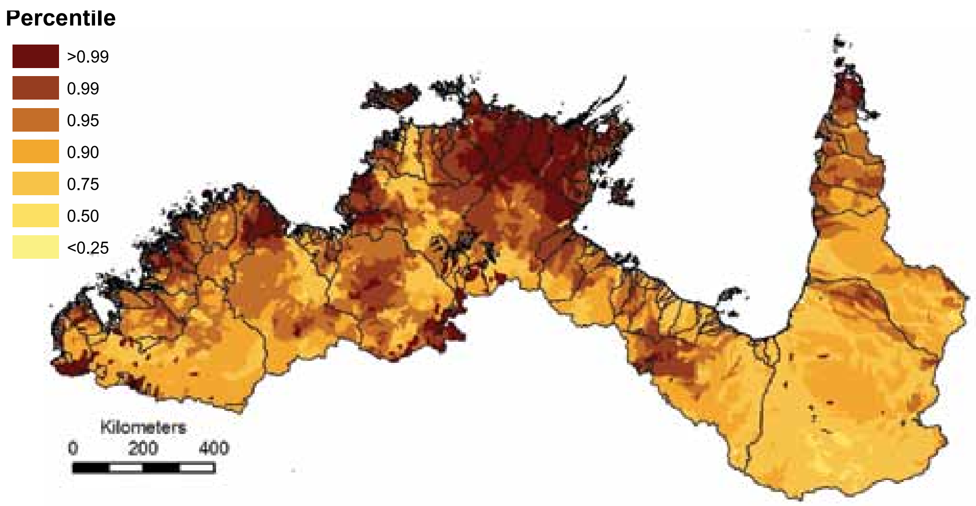


**Figure 15** Spatial distribution of planning unit scores for Criterion 5 (naturalness), calculated using the two integrated attribute types (Catchment Disturbance Index and Flow Regime Disturbance Index)

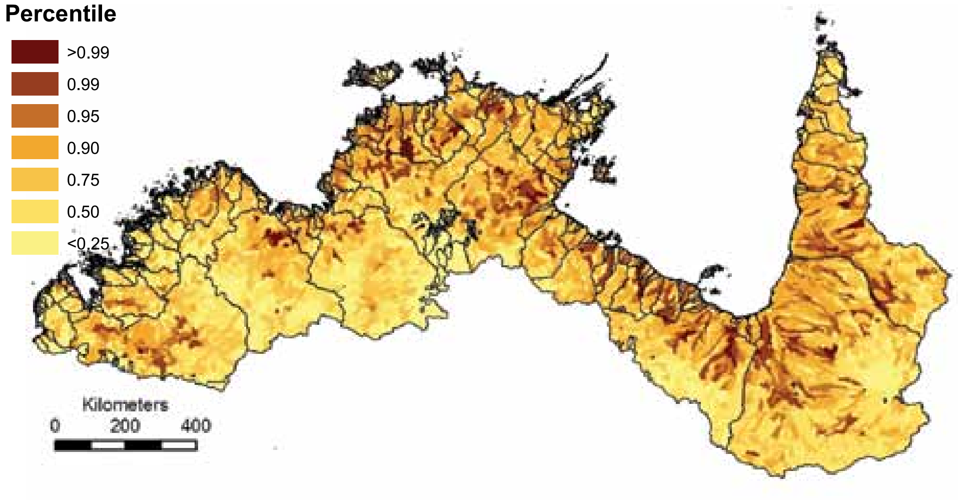


Figure 16 Spatial distribution of planning unit scores for Criterion 6 (representativeness), using the representativeness of the seven biodiversity surrogate sets (bug, fish, turtle, waterbird, riverine, lacustrine and palustrine)

**Yellow Water Lagoon, Kakadu National Park (John Baker & DSEWPaC)**

A total of 275 planning units met one or more criteria at the strictest threshold (99th percentile), but few of these met more than one criteria (maximum of four) and no planning units met all six criteria. As the threshold was relaxed, the number of planning units meeting one or more criteria increased rapidly (Figure 17a to c).

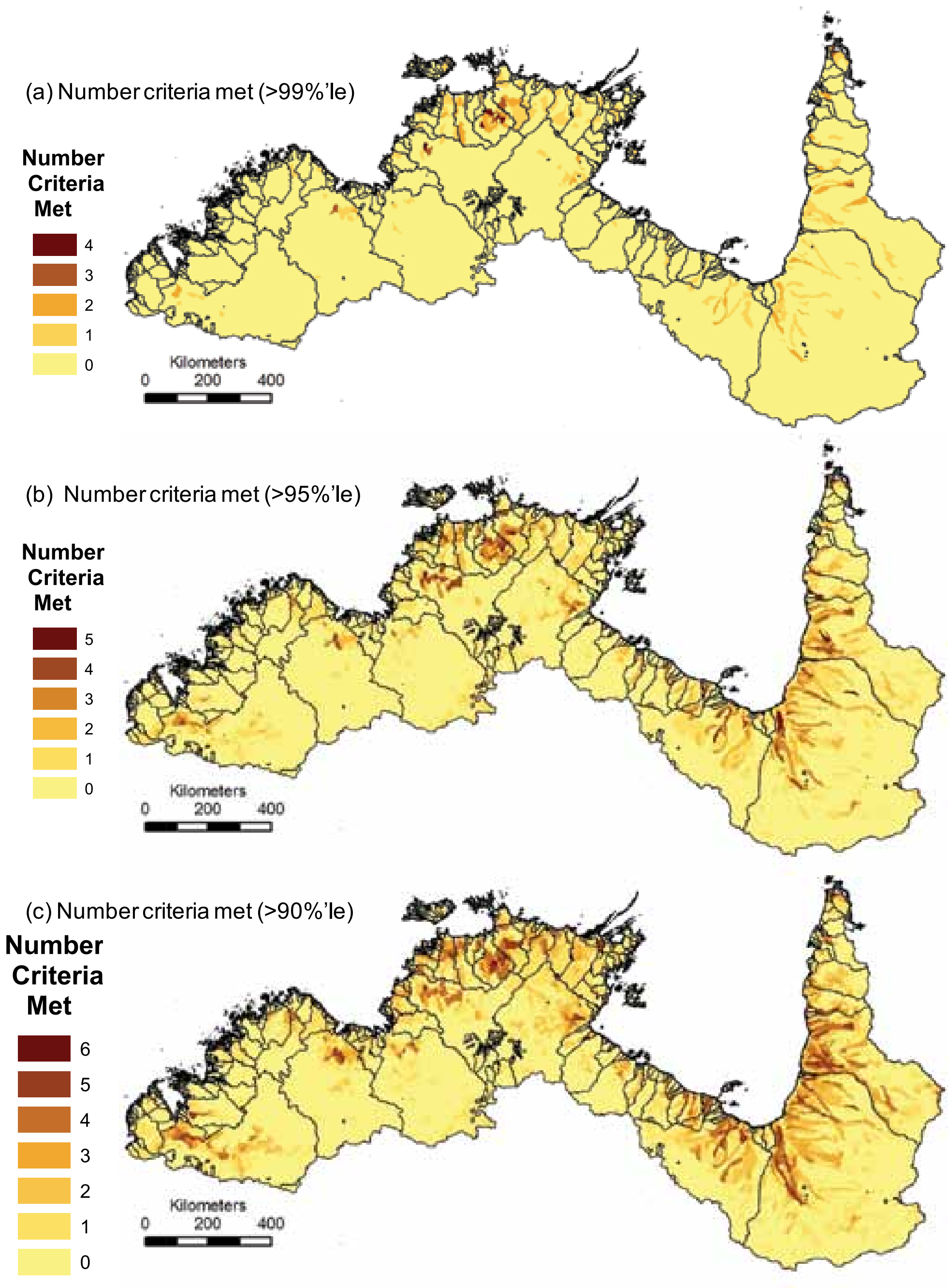


**Figure 17** **The number of criteria met for each planning unit defined using 99th, 95th and 90th percentile thresholds (a, b and c, respectively)**

Based on these results, it is suggested that the most robust and transparent approach to identifying the subset of planning units that are likely to contain aquatic ecosystems of the highest ecological value is simply to identify those that meet the threshold for one or more criteria and that the total number of candidate planning units can be restricted by simply using a strict threshold (e.g. 99th percentile). Following this approach, we have identified the set of planning units potentially containing HEVAEs for each of three reporting scales: (1) the entire study region, (2) each drainage division, and (3) each NASY region (Figure 18a to c).

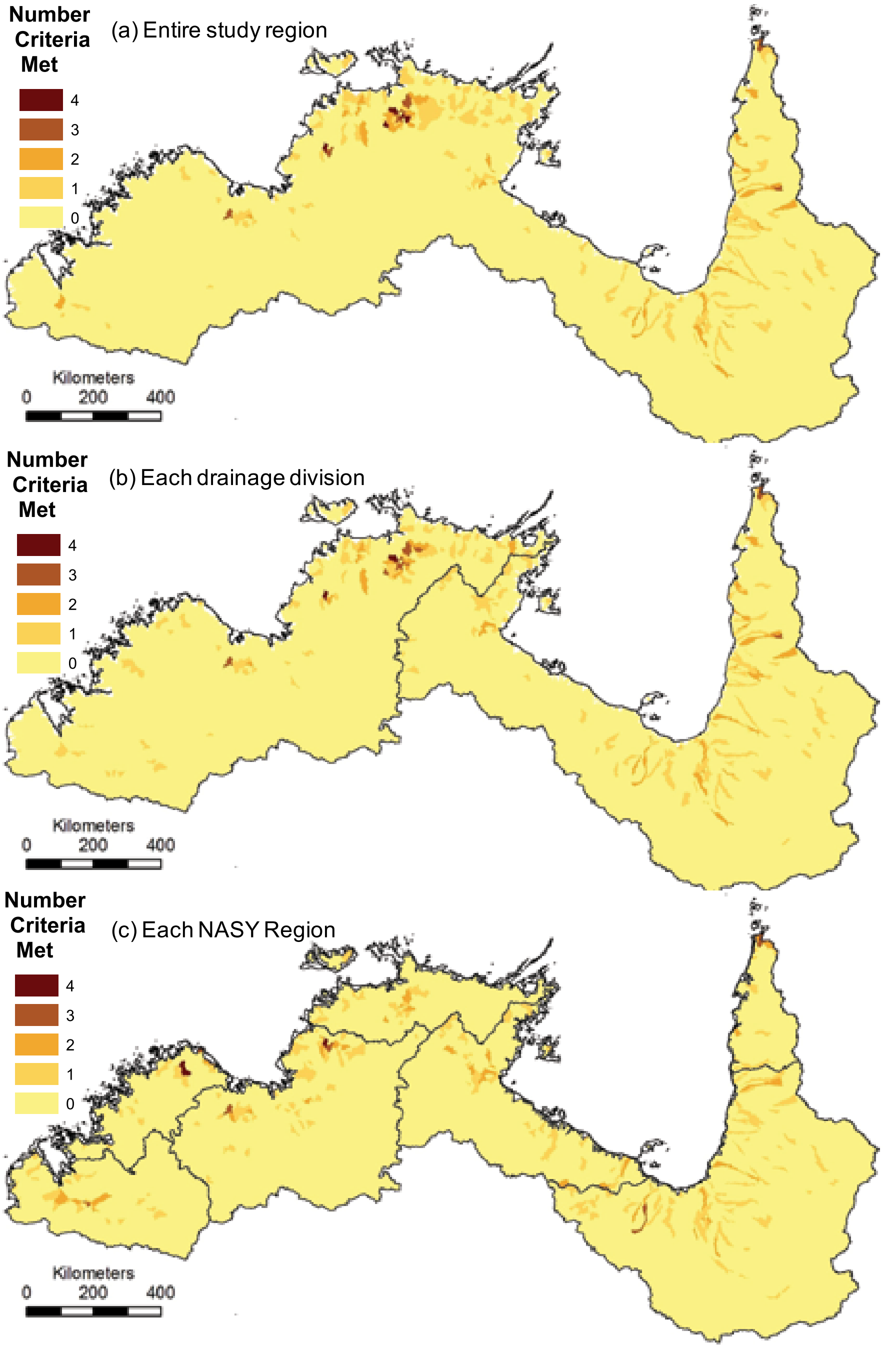


**Figure 18** **The number of criteria met for each planning unit defined using the 99th percentile threshold and referential to (a) the entire study region, (b) each drainage division, and (c) each NASY region**

### Step 6 Validate identified HEVAE

Planning units identified as containing a HEVAE were not validated through expert opinion or field observations ('ground-truthing') as part of this trial.

**Cadjeput Waterhole, Fitzroy River in the Kimberley (Nick Rains)**

Waterlilies, Yellow Water Lagoon, Kakadu National Park (Sarah Stuart-Smith & DSEWPaC)

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